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SHELL CANADA LIMITED

Quest Carbon Capture and Storage Project

2019 ANNUAL STATUS REPORT

Prepared By:
Shell Canada Limited
Calgary, Alberta

March 31, 2020

The 2019 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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LIST OF ACRONYMNS USED

AOR.........................Area of Review
BCS ....Basal Cambrian Sands
CBL-VDL-USIT............Cement Bond Log
DHP ....Downhole Pressure
DTS ....Distributed Temperature Sensing
DMW ....Deep Monitoring Well
EMIT.........................Electromagnetic Inspection Tool
GM ....Gas Migration
GWW ....Groundwater well
HMP ....Hydrosphere Monitoring Plan
InSAR ....Interferometric synthetic aperture radar
IW ....Injection Well
LELs ....Lower Explosive Limits
LMV ....Lower Master Valve
MMV........................Measurement, monitoring and verification
MSM ....Microseismic Monitoring
PNx..........................Schlumberger Pulsed Neutron Extreme
RST...........................Reservoir saturation tool
SCVF ....Surface Casing Vent Flow
TVDSS ....True Vertical Depth sub sea
VSP ....Vertical Seismic Profile

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 4.5
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 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 4.1
iii) summary of operations and maintenance activities conducted,	4.1
iv) details of any performance or Measurement, Monitoring, and Verification (MMV) Plan issues that require attention,	4.5

Requirement as listed in the AER Quest Project Approval No 11837C	Section
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.	5.1
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
iii) estimated or measured average reservoir pressure in the Basal Cambrian Sandstone (BCS) formation.	3.1

Requirement as listed in the AER Quest Project Approval No 11837C	Section
i) the potential need for installing additional monitoring towards the periphery of the pressure build up area later in the project life,	5.2
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	5.2
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,	5.2
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,	5.2
h) updated geology, and	3.4.1
i) potential need for additional monitoring wells towards the periphery of the pressure build up area.	5.2

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 [4], and on 29th September 2015, the commercial operations certificate for Quest was issued.

2.2. Project Wells / SCVF

Shell completed drilling all the wells 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 of AER approval 11837C [1].

Post drilling, surface casing vent flows (SCVF) were identified in all deep monitoring and injection wells, and gas migrations (GM) were identified in IW 7-11 and IW 5-35. As required, annual testing was completed in 2019 for surface casing vent flow and gas migration at the injection pads. Reports were sent to the AER in July 2019.

The SCVF flow test results for IW 5-35 and IW 7-11 are summarized in Figure 2-1. Measurements at the IW 5-35 well are at similar levels to those observed historically. The IW 7-11 SCVF declined to zero in 2019. The IW 8-19 SCVF tested at zero for a fourth consecutive year.

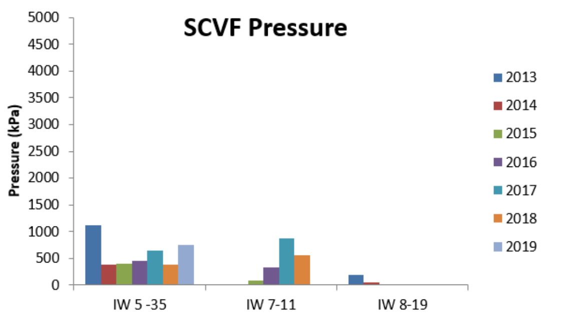
Gas Migration testing, as per the suggested method in AER Directive 20 - Appendix 2, was performed on both wells. Previously, the gas migrations observed on IW 5-35 and IW 7-11 occurred as bubbles in the well cellars.

The gas migration measurements at 30 cm from the wellhead are inside the well cellar which is typically water filled. In 2019 and 2018 the gas concentration measurements at 30 cm were whole air measurements collected via methane meter suspended over the well cellar. Consistent with 2018 results, the 2019 gas migration detections were limited to the well cellar. Measurements taken from soil gas sampling core holes did not detect any hydrocarbon Lower Explosive Limits (LELs).

On April 8, 2019 the IW 5-35 wellsite was flooded with freshwater (a combination of meltwater and rainwater) and bubbles were observed by Shell operators in two locations near the wellhead but outside the standard gas migration testing area. The locations were marked and the GPS coordinates recorded; they are referred to as locations "WEST - Latitude N

5408.6052 - Longitude W 11302.7268" and "EAST - Latitude N 5408.6041 - Longitude W 11302.7167" on the IW 5-35 wellsite. In June 2019, gas migration testing was also performed on these two marked locations as a precaution. Each of the soil gas testing core holes were tested for LELs and CO_2. No LELs were detected at either of the "EAST" or "WEST" test location core holes. A soil gas sample was acquired at both locations and submitted for analysis despite field observations. The gas isotopic analysis results indicate that the CO_2 present in the sample is atmospheric. No methane or other hydrocarbons were identified in the samples. Therefore, the observed bubbles at IW 5-35 are unlikely indicative of additional or further migrated gas.

Overall, while gas migration remains at IW 5-35 and IW 7-11; it remains consistent in composition and isotopic signature and has very limited impact and no potential for concern beyond the lease.



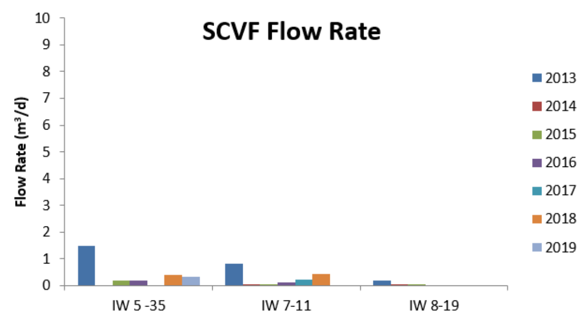


Figure 2-1: SCVF Pressure and Flow rate summary graphs for IW 5-35, IW 7-11, and IW 8-19.

Table 2-1: 2018 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
103113205521W402	Appraisal (Abandoned in PCMB)	Redwater 11-32	10/11/2008	02/01/2009	2240.6	Precambrian
103030405720W400	Observation (in CKLK)	Redwater 3-4	23/01/2009	18/03/2009	2190.0	Precambrian
100081905920W400	Injection	IW 8-19	01/08/2010	08/09/2010	2132.0	Precambrian
102081905920W400	Deep Monitoring	DMW 8-19	30/09/2012	15/10/2012	1696.0	Ernestina Lake
102053505921W400	Injection	IW 5-35	21/10/2012	20/11/2012	2143.0	Precambrian
100053505921W400	Deep Monitoring	DMW 5-35	24/11/2012	06/12/2012	1710.0	Ernestina Lake
103071105920W400	Injection	IW 7-11	14/12/2012	20/01/2013	2105.0	Precambrian
102071105920W400	Deep Monitoring	DMW 7-11	23/01/2013	05/02/2013	1664.5	Ernestina Lake
1F1081905920W400	Groundwater	GW 1F1/8-19	08/12/2010	08/01/2011	201	Lea Park
110000911151UL00*	Groundwater	GW UL1/8-19	14/01/2011	17/01/2011	101.0	Foremost
110000911152UL00*	Groundwater	GW UL2/8-19	12/01/2011	13/01/2011	62.8	Foremost
110000911153UL00*	Groundwater	GW UL3/8-19	09/01/2011	10/01/2011	37.5	Foremost
110000911154UL00*	Groundwater	GW UL4/8-19	11/01/2011	11/01/2011	20.0	Oldman
1F1053505921W400	Groundwater	GW 1F1/5-35	08/02/2013	17/02/2013	200	Lea Park
UL1053505921W401*	Groundwater	GW UL1/5-35	17/02/2013	18/02/2013	23	Foremost
1F1071105920W400	Groundwater	GW 1F1/7-11	19/02/2013	26/02/2013	180	Lea Park
UL1071105920W400*	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. Well Workovers and Treatments

2.3.1. *Injection Wells*

No new wells have been drilled since the completion of the 2012-2013 drilling campaign. During 2019, the following activities were executed in the Injector wells:

IW 8-19:

- Wellhead Integrity Test and Packer Isolation Test: passed.
- Packer Isolation Test: Performed fluid shot to confirm annulus Drillsol level at ~200m below WH and topped up N_2 in annulus.
- SCVF Test

IW 7-11:

- Wellhead Integrity Test and Packer Isolation Test: all components passed except for the Lower Master Valve (LMV). The LMV will be replaced in 2020.
- Packer Isolation Test: Performed fluid shot to confirm annulus Drillsol level at ~200m below WH and topped up N2 in annulus.
- SCVF and Gas Migration Test

IW 5-35:

- Wellhead Integrity Test and Packer Isolation test: passed.
- Packer Isolation Test: Performed fluid shot to confirm annulus Drillsol level at ~200m below WH and topped up N2 in annulus.
- Tubing integrity logging (caliper) and hydraulic isolation logging (PNx).
- SCVF and Gas Migration Test

2.3.2. *Deep Monitoring Wells*

SCVF testing was performed on the Quest Deep Monitoring Wells DMW 5-35 and DMW 8-19. The SCVF for DMW 5-35 tested non-serious which is consistent with historical results. The SCVF for DMW 8-19 tested at zero with no bubbles during the SCVF bubble test. The DMW 8-19 SCVF has completely died out.

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 wells integrity.

Well integrity assurance is supported by, but not limited to, activities 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 [7]. As of 2019 there is no indication of integrity issues in the CO_2 injection wells. Well integrity logging activities are detailed in Table 2-3.

The following is a summary of the evidence of the integrity of the Quest injection wells:

The SCVF and GM testing that was conducted in 2019 (Section 2.2) continues to indicate low flow levels. DTS data continue to behave in the expected manner for injection wells that convey a cold fluid relative to the sequestration reservoir. No trends indicative of a leak have been identified in the data (refer to Section 4.3).

During wellhead integrity testing in 2019 on the IW 7-11 well the lower master valve was found to be leaking internally across the valve gate. A lower master valve replacement is planned for this well. This valve failure is the only wellhead valve failure that has occurred on the Quest injection wells.

In late February 2019 a very small leak of CO_2 was detected from the ring gasket seal for the top of the IW 5-35 wellhead flow cross. The leak was detected during operator walk arounds, and could be seen and heard by a person standing beside the wellhead. The leak was resolved by replacing the wellhead flow cross, top, and corresponding ring gaskets.

During September 2019 very small leaks of CO_2 were detected from the valve stems of the Lower Master Valve, Upper Master Valve and Flow Wing Valve on the IW 5-35 wellhead. These leaks were also detected during operator walk arounds where ice was observed to have started building up around the valve stems. The leaks were remediated by shutting in the well and greasing the respective valves along with the injection of stem packing. Following the greasing and injection of stem packing, all respective valves were successfully pressure tested to confirm valve integrity.

Tubing integrity logging (caliper) on the IW 5-35 well does not show any indication of corrosion in the tubing string. Hydraulic isolation logging (PNx) in the IW 5-35 injection well demonstrates 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. The injection wells have a production casing by tubing annulus containing Drillsol with an N_2 cushion above the Drillsol. The annulus pressure, also known as casing head pressure, is monitored continuously. In addition to the continuous pressure monitoring, the annular Drillsol liquid level is measured annually and before/after service rig workovers. Both the continuous pressure monitoring data and the annular Drillsol liquid level are incorporated into the assessment of the annulus integrity.

Injection well monitoring occurs continuously using tubing head pressure (THP), casing head pressure (CHP), injection rate, tubing head temperature (THT), bottom hole pressure (BHP) and bottom hole temperature (BHT). This data is summarized in Section 3.

Table 2-2: Well integrity activities (from the 2017 MMV Plan [6], 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 EMIT	CBL-VDL-USIT EMIT
2015	RST	RST	RST
2016	PNx Tubing Caliper	PNx Tubing Caliper	
2017	PNx Tubing Caliper	PNx Tubing Caliper	
2018		Downhole Video Log	
2019			PNx Tubing Caliper

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).

Table 3-1: 2019 Quest CO_2 Injection Summary.

Mass of Injected CO2 (thousand-tonnes) in 2019					
Month	**05-35**	**08-19**	**07-11**	**Total**	**Cum Total for 2019**
Jan-19	14	33	39	86	86
Feb-19	32	35	21	89	174
Mar-19	14	42	49	104	279
Apr-19	1	34	42	77	356
May-19	37	0	31	67	423
Jun-19	35	1	29	65	488
Jul-19	35	25	46	106	594
Aug-19	36	37	36	109	703
Sep-19	36	39	29	104	807
Oct-19	26	44	41	111	918
Nov-19	36	35	37	107	1025
Dec-19	39	28	36	103	1128

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
2017	-	589	549	1138	2617
2018	91	511	464	1066	3683
2019	340	352	436	1128	4811

3.2. Injectivity

Overall the Quest project has demonstrated sufficient injectivity. Additional operational flexibility has been gained since IW 5-35 was brought on in October 2018.

Injectivity reductions have been observed following short well shut in periods; however, as the initial injectivity was very high, these injectivity reductions currently do not form an operational constraint. At this time the cause of the injectivity reductions is unknown, and if the trend continues, this may develop into an operational limit for the Quest CCS operation. Understanding how to reduce or even reverse these injectivity reductions may be important for maintaining reliable CO_2 injection at Quest and other CCS wells.

Injection flow rates for the injection wells are show in Figure 3-1, Figure 3-2, and Figure 3-3.

The injectivity is illustrated in the plots shown in Figure 3-4, Figure 3-5 and Figure 3-6.

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.

2019 monthly data summaries for injected mass, rates and pressures and temperatures are reported in Table 3-4, Table 3-5, Table 3-6, and Table 3-7.

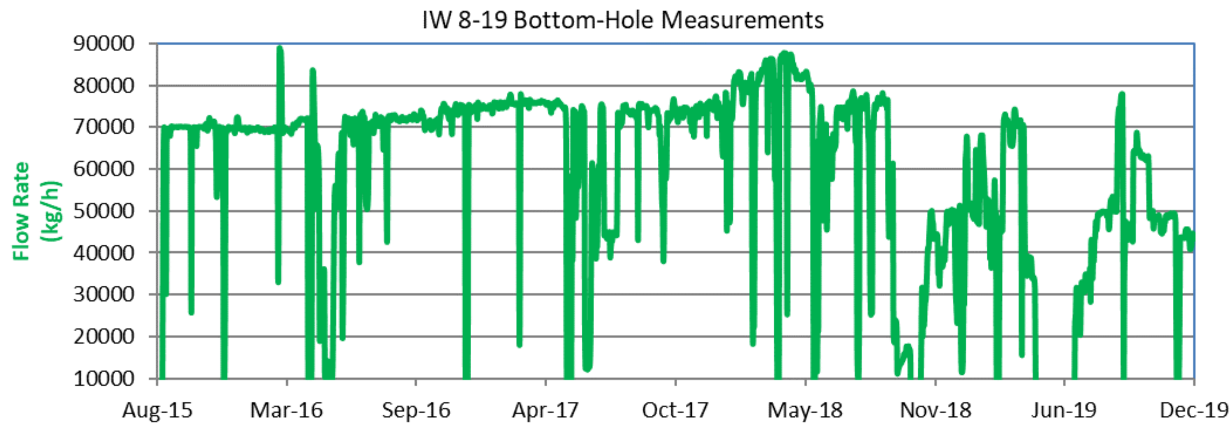


Figure 3-1: Rate History for IW 8-19.

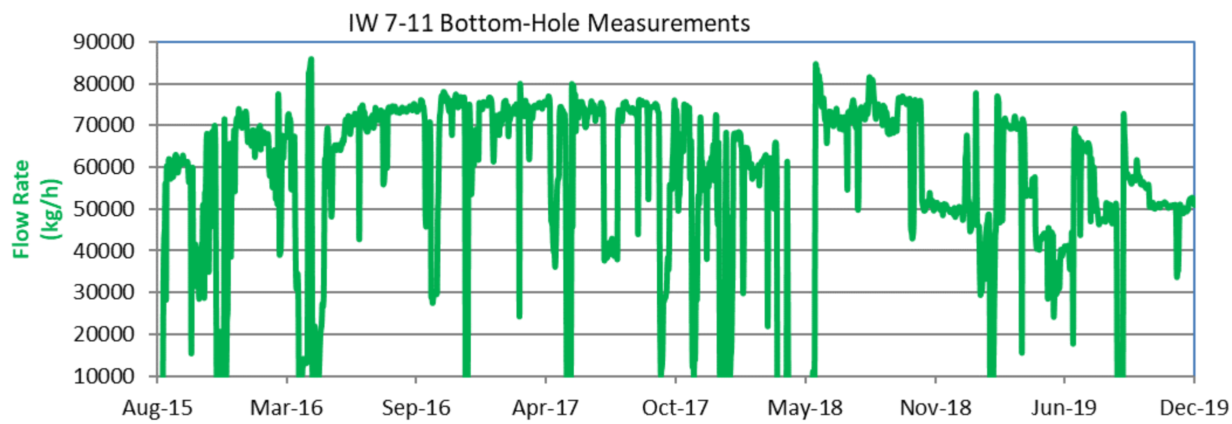


Figure 3-2: Rate History for IW 7-11.

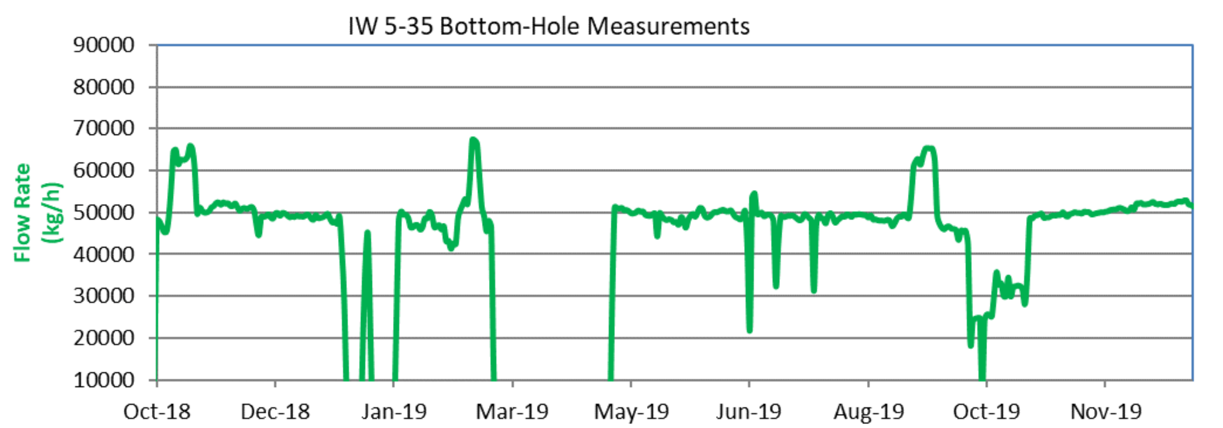


Figure 3-3: Rate History for IW 5-35.

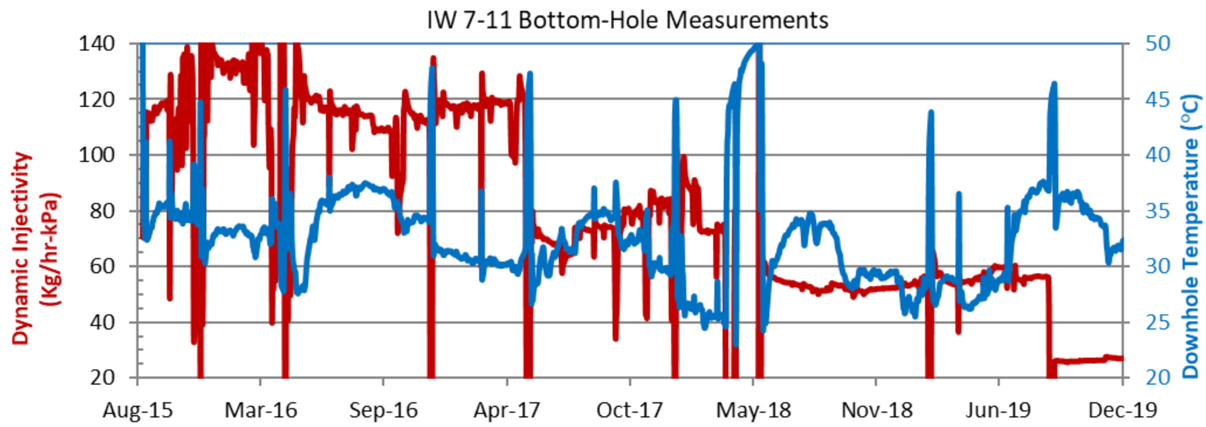


Figure 3-4: Injectivity Index and BHT for 7-11 over time.

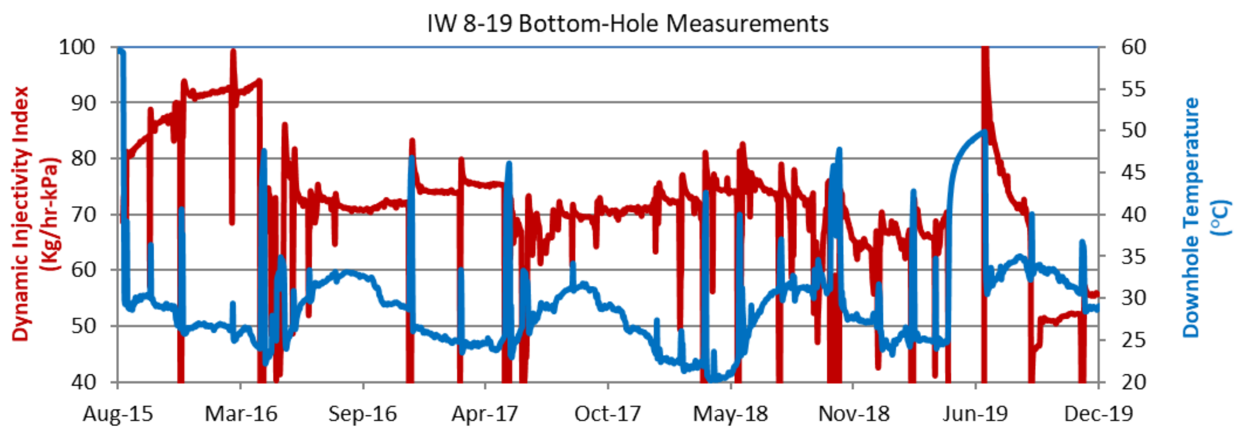


Figure 3-5: Injectivity Index and BHT for 8-19 over time.

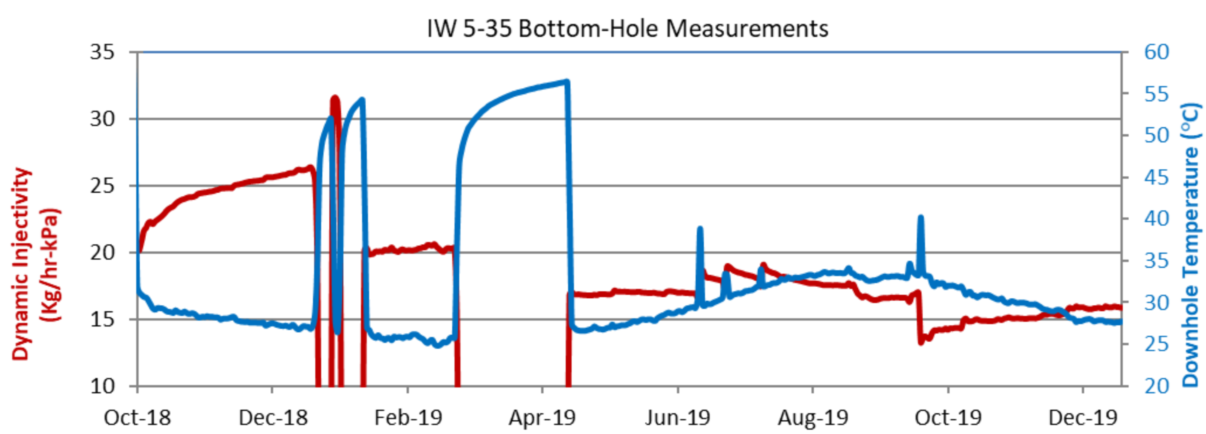


Figure 3-6: Injectivity Index and BHT for 5-35 over time.

Table 3-3: 2019 Quest CO_2 Injection Summary: Injection Stream

MONTHLY DATA	Injection Stream Content (Volume %)				
	CO_2	H_2	CH_4	CO	H_2O
Jan-19	99.45	0.47	0.05	0.01	0.004
Feb-19	99.44	0.49	0.06	0.02	0.004
Mar-19	99.47	0.47	0.05	0.05	0.004
Apr-19	99.41	0.50	0.06	0.01	0.005
May-19	99.44	0.49	0.06	0.01	0.005
Jun-19	99.41	0.51	0.06	0.01	0.005
Jul-19	99.46	0.48	0.05	0.01	0.004
Aug-19	99.40	0.47	0.04	0.01	0.004
Sep-19	99.53	0.46	0.05	0.01	0.004
Oct-19	99.46	0.46	0.05	0.01	0.004
Nov-19	99.41	0.46	0.05	0.01	0.004
Dec-19	99.41	0.48	0.05	0.01	0.004

Table 3-4: 2019 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-19	39	33	14
Feb-19	21	35	32
Mar-19	49	42	14
Apr-19	42	34	1
May-19	31	0	37
Jun-19	29	1	35
Jul-19	46	25	35
Aug-19	36	37	36
Sep-19	29	39	36
Oct-19	41	44	26
Nov-19	37	35	36
Dec-19	36	28	39
Cumulative Mass of CO_2 Injected [1] (kt)			
2018	1831	1761	91
Jan-19	1870	1794	105
Feb-19	1891	1829	136
Mar-19	1940	1871	150
Apr-19	1983	1905	151
May-19	2013	1905	188
Jun-19	2042	1906	223
Jul-19	2088	1930	258
Aug-19	2124	1967	294
Sep-19	2153	2007	330
Oct-19	2194	2051	356
Nov-19	2231	2085	392
Dec-19	2267	2113	431

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

Table 3-5: 2019 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-19	768	768	347
Feb-19	549	671	672
Mar-19	744	643	246
Apr-19	698	684	14
May-19	744	0	744
Jun-19	702	30	702
Jul-19	733	732	730
Aug-19	744	744	744
Sep-19	498	697	720
Oct-19	744	744	731
Nov-19	720	720	720
Dec-19	744	744	744
Maximum Daily Injection Rate [1] (t/h)			
Jan-19	77	68	52
Feb-19	49	68	53
Mar-19	77	74	67
Apr-19	71	72	30
May-19	45	0	51
Jun-19	69	23	55
Jul-19	67	44	50
Aug-19	52	53	50
Sep-19	72	78	65
Oct-19	62	69	50
Nov-19	52	49	51
Dec-19	53	49	53
Average Daily Injection Rate (t/h)			
Jan-19	52	45	19
Feb-19	32	53	47
Mar-19	66	56	18
Apr-19	59	47	1
May-19	41	0	49
Jun-19	40	1	49
Jul-19	62	33	48
Aug-19	49	49	49
Sep-19	40	55	50
Oct-19	55	59	35
Nov-19	51	48	50
Dec-19	49	38	52

[1]Maximum of the daily averages.

Table 3-6: 2019 Quest CO_2 Injection Summary: Well Head Pressures and Temperatures.

MONTHLY DATA	IW 7-11		IW 8-19		IW 5-35	
Maximum WHIP and WHIT	**WHIP (kPa-g)**	**WHIT (°C)**	**WHIP (kPa-g)**	**WHIT (°C)**	**WHIP (kPa-g)**	**WHIT (°C)**
Jan-19	9490	14	7906	9	7987	6
Feb-19	5937	9	8048	7	7052	3
Mar-19	9430	13	9055	9	9203	6
Apr-19	8855	13	8634	8	6096	11
May-19	5436	9	4422	26	7253	6
Jun-19	8821	14	4466	24	8125	9
Jul-19	9036	19	6009	14	7743	11
Aug-19	7443	19	7324	17	7964	12
Sep-19	10751	19	10619	18	10580	13
Oct-19	9496	19	9390	16	8188	10
Nov-19	7847	17	6608	13	8176	9
Dec-19	7697	15	6398	11	8177	7
	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-19	6261	8	5390	4	4413	-5
Feb-19	4778	2	6109	5	6266	1
Mar-19	8234	11	7209	4	5098	2
Apr-19	7252	10	5864	5	3991	5
May-19	5098	8	4357	13	7098	4
Jun-19	5272	9	4404	16	7384	7
Jul-19	8508	18	4876	10	7357	10
Aug-19	7077	19	6806	16	7769	12
Sep-19	7204	17	7645	15	8215	12
Oct-19	8521	18	8067	15	6280	8
Nov-19	7756	16	6416	12	8100	8
Dec-19	7156	13	5286	7	8079	6

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

Table 3-7: 2018 Quest CO_2 Injection Summary: Bottom Hole Pressures and Temperatures.

MONTHLY DATA	IW 7-11		IW 8-19		IW 5-35	
Maximum BHIP and BHIT	**BHIP (kPa-g)**	**BHIT (°C)**	**BHIP (kPa-g)**	**BHIT (°C)**	**BHIP (kPa-g)**	**BHIT (°C)**
Jan-19	22099	32	21153	32	23864	54
Feb-19	20965	44	21192	26	23089	26
Mar-19	21451	29	21313	43	23818	54
Apr-19	21435	37	21283	35	22273	56
May-19	20917	30	20299	48	23552	28
Jun-19	21343	35	20440	50	23546	39
Jul-19	21352	36	20807	34	23309	34
Aug-19	21092	38	20996	35	23397	34
Sep-19	22936	46	21514	40	24537	35
Oct-19	22584	37	21596	34	23906	40
Nov-19	22160	35	21227	33	23928	31
Dec-19	22164	34	21216	37	23932	29
	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-19	21100	27	20850	26	21342	41
Feb-19	20684	31	20978	25	22838	26
Mar-19	21293	28	21037	27	21473	43
Apr-19	21205	28	20917	25	20627	55
May-19	20860	27	20233	46	23435	27
Jun-19	20814	29	20210	49	23387	29
Jul-19	21264	34	20631	32	23146	31
Aug-19	21025	37	20924	34	23302	33
Sep-19	21656	39	21242	34	23549	33
Oct-19	22297	36	21422	33	22972	32
Nov-19	22129	34	21196	31	23904	30
Dec-19	22002	32	20982	30	23895	28

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

3.3. Model to Performance Conformance

In 2018 and 2019 a few time-significant pressure fall-offs were recorded and this enabled a calibration of conformance to shut-in stabilized pressures. Figure 3-7 illustrates the measured Bottom Hole Pressures (BHP) that were recorded when the wells are shut-in (discrete data points). The modelled BHP (solid lines) show that the reservoir model pressure fall-off response is similar to those observed in the longer more stabilized pressure fall-offs. With this additional calibration it is reasonable to use the model for pressure prediction forecasting for injection rates similar to those observed to date (Section 3.4).

The operational flexibility afforded by having all three wells on injection means that pressure fall-offs can become a more habitual form of data collection for reservoir pressure conformance.

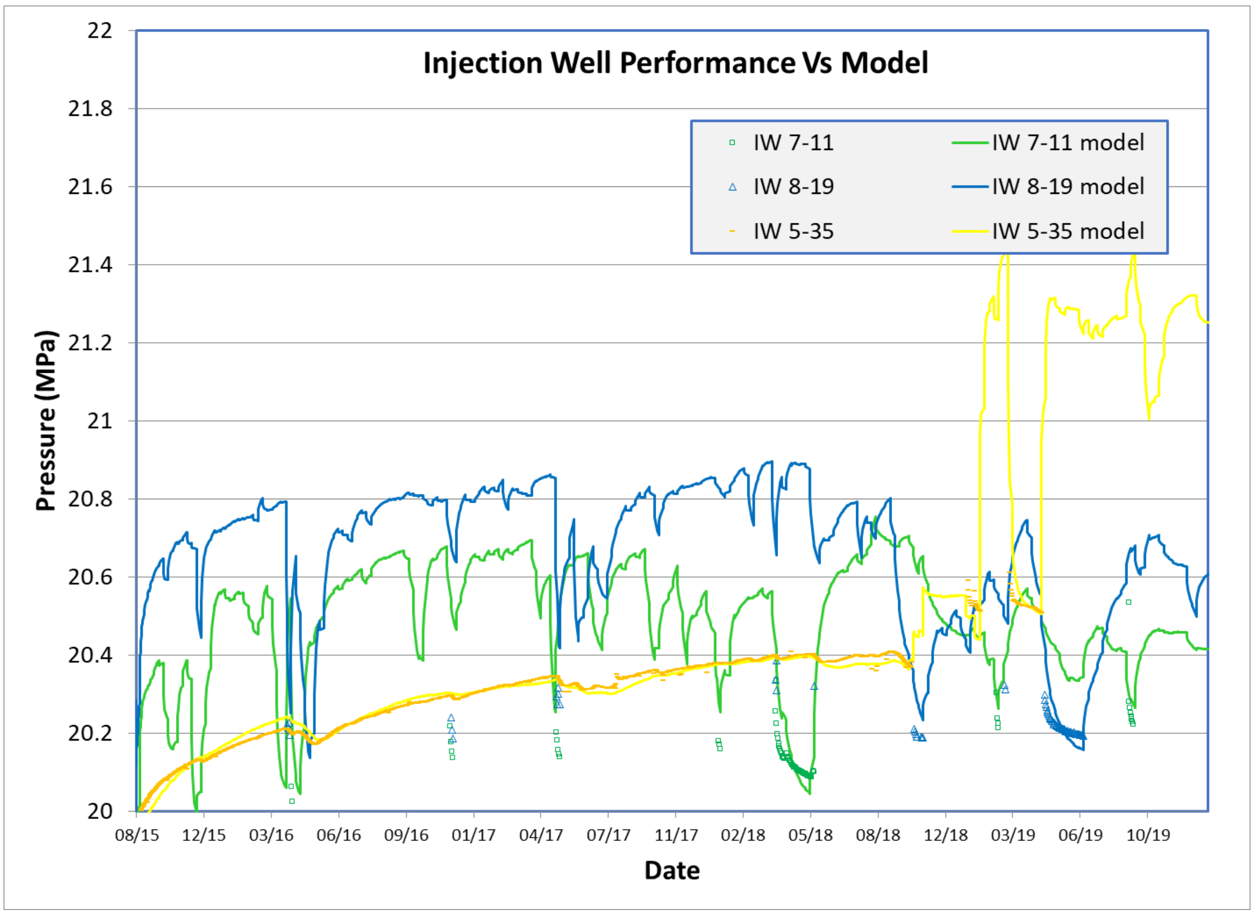


Figure 3-7: Actual Shut-in BH Gauge Response vs Modelled Pressure Response.

3.4. Reservoir Modelling

3.4.1. *Modelling Updates*

No significant update to the reservoir models occurred as no new wells were drilled, and the performance is close to the expectation case. The weekly well rate history has been incorporated into the model controls as illustrated in Figure 3-7. As described in Section 3.3, pressure fall-offs will likely be the primary data collection for calibrating the modelled pressure response.

3.4.2. *Pressure Prediction*

The forecast in Figure 3-8 assumes that 1/3 of the CO_2 will be injected into each of the three injection wells for the remainder of the life of the project. Intermittent shut-ins have been included in the pressure forecast to illustrate the slow rise of stabilized reservoir pressure both being predicted and observed.

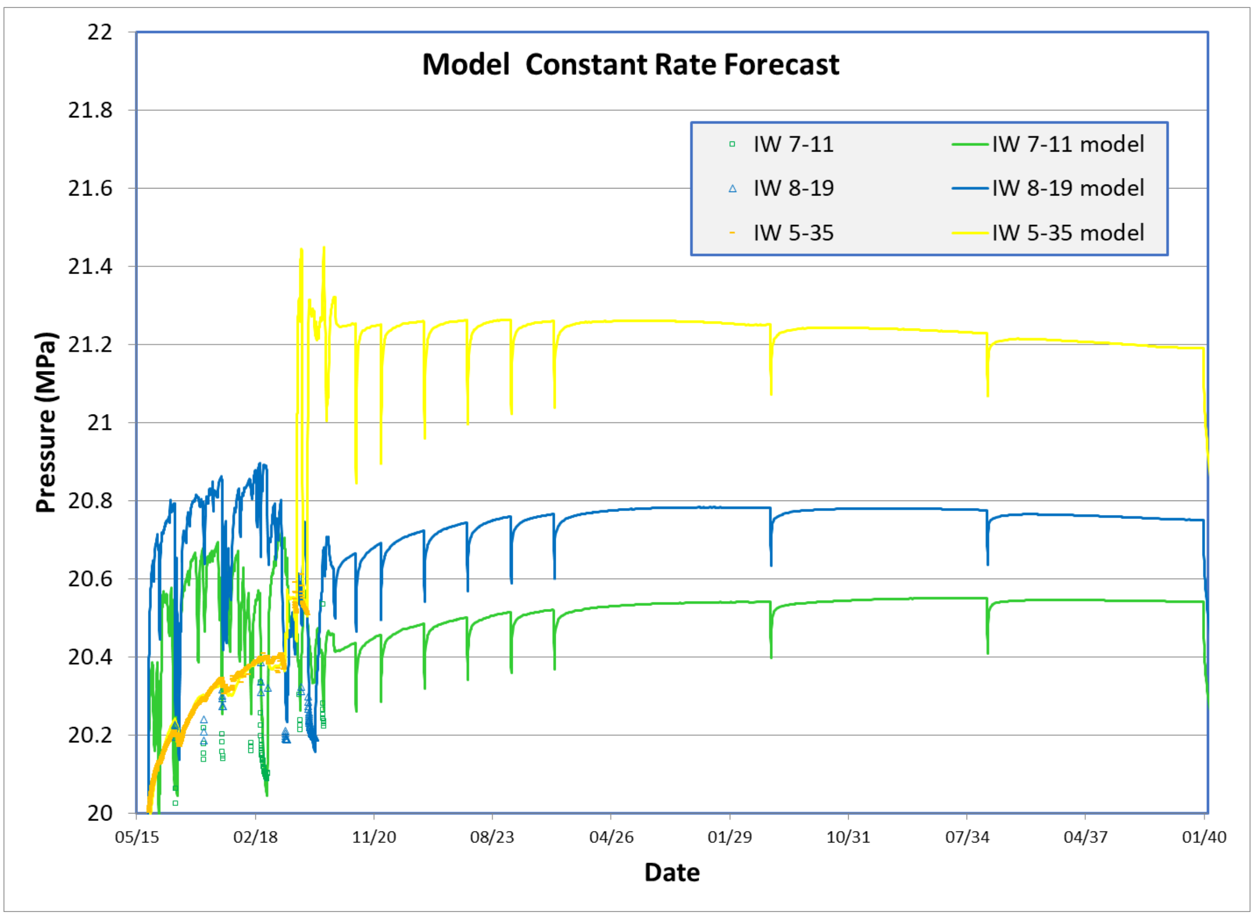


Figure 3-8: Well by well expected pressure build forecast.

In April and May there was reduced CO_2 available during a plant turn-around and the opportunity was taken to monitor long term pressure fall-off by shutting in IW 5-35 and IW 8-19 to collect pressure fall-off data. In September a smaller window allowed for the acquisition of pressure fall-off data at IW 7-11. Figure 3-9, Figure 3-10, and Figure 3-11 each show injection well BHP over the shut-in period, and illustrate that a representative stabilized reservoir pressure is in line with previous expectations.

The average stabilized reservoir pressure as measured in the injection wells is less than 20.2 MPa near IW7-11 and IW8-19. The initial average reservoir pressure from these two wells was 19.7 MPa, indicating a pressure escalation of 0.5 MPa since the start of injection. IW5-35 had an initial gauge pressure of 20 MPa which also supports an observed pressure increase of about 0.5 MPa. This also validates the model conclusion that the current rate of injection is insufficient to cause significant escalation of reservoir pressure.

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 3-8). 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]. Continued trending of low end-of-life reservoir pressures increases confidence that it is extremely improbable for CO_2 leakage to occur via fracturing or fault reactivation.

3.4.3. *Plume Prediction*

The plume sensitivity modelling documented in the Gen-4 report shows maximum plume radii in 2040 of 2 to 4 km. The pressure forecast model discussed in Section 3.4.2 illustrates a conservative, non-unique scenario for the end-of-life plumes in Figure 3-12 that support that being within that range of uncertainty.

The CO_2 plume size at IW 5-35 is slightly smaller than the other two as it will have lower injection volumes associated with it. Thus far, the VSP2D data have only imaged CO_2 plumes that are smaller than predicted by the model. This provides additional assurance that the range of uncertainty we are modeling is practicable and not exceeding the maximum. Uncertainties will continue to be reduced in in time as significantly additional well performance data become available.

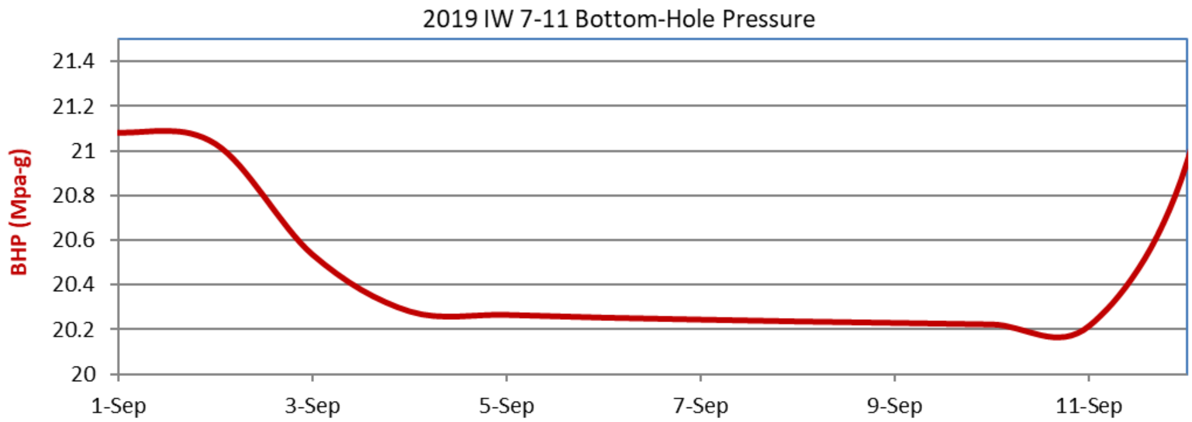


Figure 3-9: IW 7-11 pressure fall-off and stabilization in 2019.

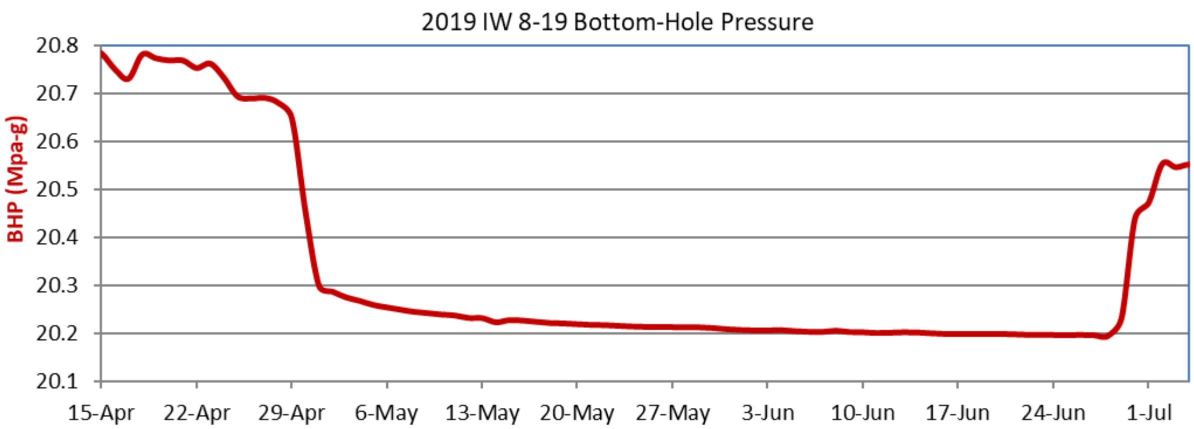


Figure 3-10: IW 8-19 pressure fall-off and stabilization in 2019.

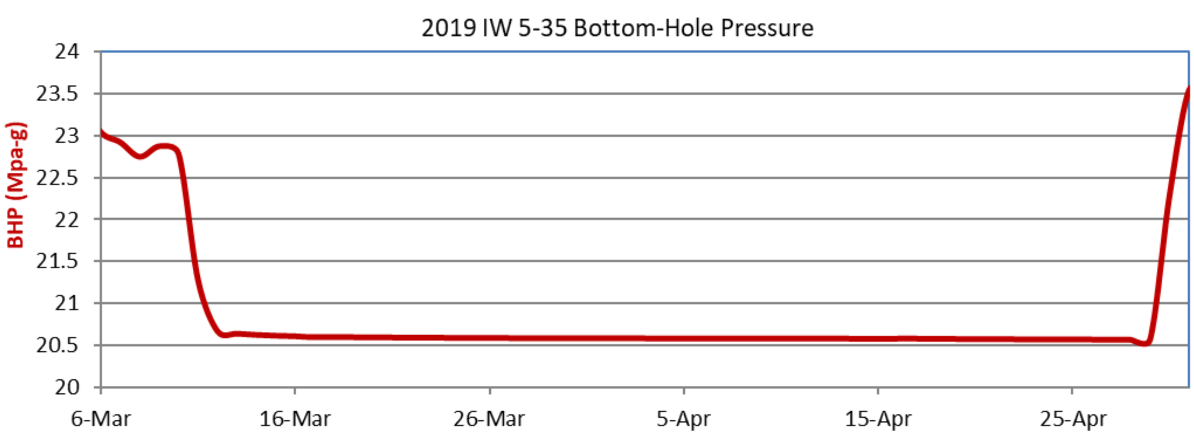


Figure 3-11: IW 5-35 pressure fall-off and stabilization in 2019.

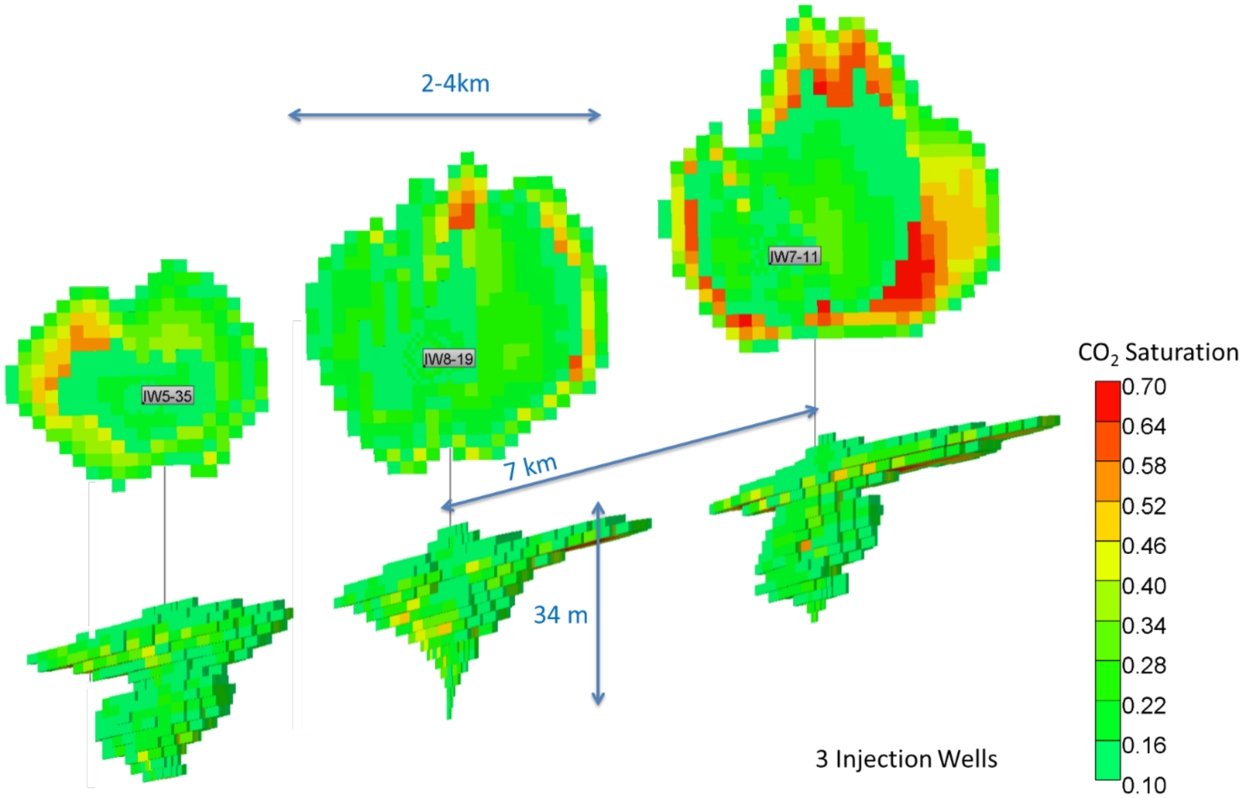


Figure 3-12: Schematic map view and 3D views of the predicted CO_2 plume in 2040. The plumes as displayed utilize the Gen-4 property model.

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 [8]. 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).

The full 27 Mt of CO_2 is still expected to be sequestered without ever approaching the pressure 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 bottom hole 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 3-8, as per the data from Table 3-1.

Table 3-8: Remaining capacity in the Sequestration Lease Area as of end 2019.

Year	Yearly Injection Total	Remaining Capacity
Pre-injection	-	27 Mt CO_2
2015	0.371Mt	26.629 Mt CO_2
2016	1.108 Mt	25.521 Mt CO_2
2017	1.138 Mt	24.383 Mt CO_2
2018	1.066 Mt	23.317 Mt CO_2
2019	1.128 Mt	22.189 Mt CO_2

4. OPERATIONAL MMV PLAN ACTIVITIES AND PERFOMANCE

4.1. Summary of Operational MMV Activities in 2019

In 2019 MMV activities included: atmosphere, hydrosphere, geosphere, and well-based monitoring.

In addition to Table 4-1, the following is a summary of these activities:

Atmosphere Domain: Monitoring of CO_2 levels in the atmosphere at the injection well sites continued using the Light Source technology. Operator rounds daily at the injection well sites.

Hydrosphere Domain: Discrete sampling at select Landowner water wells before and after the Q1 2019 VSP program in the vicinity of IW 5-35 and IW 8-19. Further details on the hydrosphere monitoring activities can be found in Appendix A.

Biosphere Domain: No activities took place regarding soil gas and soil surface CO_2 flux measurements.

Geosphere Domain: Monthly satellite image collection for InSAR continued. Since September 2017, a single frame centered over the 3 injection well pads has been used for image collection. 2D VSP and 2D SEIS data were acquired at IW5-25 and IW8-19 well in Q1 2019.

Well based Monitoring: ongoing data collection via wellhead gauges, downhole gauges, downhole microseismic geophone array, and DTS lightboxes. Routine well maintenance and integrity activities (Section 2.4).

4.2. MMV Infrastructure

Minimal infrastructure work was conducted in 2019.

- MMV servers at the well sites were remediated to remove a ransom worm (virus) called WannaCry in 2018. Work in 2019 continued to maintain the integrity of the network and firewalls.
- In Q3 2019, maintenance of the 9 Project GWW Troll gauges resulted in the installation of new sensors in the gauges for pH, ORP, EC and temperature.

Table 4-1: Summary of MMV activities planned and executed in 2019.

Domain	Activity planned for 2019 ^	Executed	Comment
Atmopshere			
	LightSource measurements at pads 8-19, 7-11, & 5-35	✓	Data not collected at 8-19 from June-December
Biosphere			
	not applicable		conducted on an as needed basis, as per 2017 MMV plan
Hydrosphere			
	Downhole pH & EC monitoring at Project groundwater wells	✓	
	Discrete Sampling at Landowner wells associated with VSP surveys	✓	VSP executed in 2019 at 8-19 and 5-35
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	✓	Packer isolation tests performed. Tubing caliper in 5-35.
	Routine well maintenance, including Temperature & RST logs and measurement of hold-up depths (HUD) of IWs at which injection started	✓	Performed temperature and pulsed utron log on 5-35, as per AER Approval No. 11837C condition 5c and associated logging extension request granted on January 24, 2018
	MSM at DMW 8-19	✓	
	DTS monitoring at IWs	✓	
	DAS monitoring at IWs	✓	VSP acquired at 8-19 and 5-35
	Surface Seismic monitoring	✓	2D surface seismic data acquired at 8-19 and 5-35
	InSAR: monthly satellite image collection	✓	
corrosion probes	at injection skids	✓	Executed in 2019
SCVF/GM	annually by June 30th	✓	Performed in 2019
Injected CO_2	analysis of captured CO_2 at Scotford Upgrader	✓	
Notes:	^ list of MMV activities as per 2017 MMV plans		

4.3. Assessment of MMV objective 'Containment'

One of the primary objectives of the MMV plan is to verify containment: that the injected CO_2 and the native BCS brine remain inside the storage complex. The 2017 MMV plan includes a tiered system to review and assess the MMV data. Tier 1 technologies form the basis for assessing whether or not there is an indication of loss of containment. Depending on the outcome of that assessment, further analysis or investigation of the Tier 2 technologies will be undertaken and then, if needed, Tier 3 technologies will be assessed.

No trigger events were identified during 2019 that would indicate a loss of containment (Table 4-2). As a result, the focus of this report will be on Tier 1 technologies.

Table 4-2: Overall assessment of trigger events used to assess loss of containment in 2019.

Tier	Technology ^	Trigger	2019
Tier 1	IW DHP	Measuring greater than 26 Mpa	
	DMW DHP	Anomalous pressure increase above background levels	
	MSM	Sustained clustering of events with a spatial pattern indicative of fracturing upwards	
	DTS	Sustained temperature anomaly outside casing	
Tier 1 - when available	Pulsed Neutron log	Indication of CO_2 out of zone	
	SCVF	Change in geochemical composition indicating presence of project CO_2	
	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
	SEIS2D	Identification of a coherent and continuous amplitude anomaly above the storage complex	Monitor survey executed in Q1/2019

^ based on Table 4-3 of the 2017 MMV Plan

Legend	
	no trigger event
	trigger event
	not evaluated

4.3.1. *IW DHP (Pressure monitoring Basal Cambrian Sand Formation)*

Continuous pressure data in the Basal Cambrian Sand via three injection wells, IW 7-11, IW 8-19, and IW 5-35 are plotted in Figure 4-1. The pressure data has remained far below the 28 MPa maximum operating pressure [1].

4.3.2. *DMW DHP (Pressure monitoring with Cooking Lake Formation)*

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 4-2. A discussion of why the Cooking Lake was selected as a deep pressure monitoring formation in the DMWs can be found in the First Annual Status Report, Section 5 [2].

A pressure fluctuation greater than 200 kPa is the threshold for indication of a leak in the 2017 MMV Plan. Thus far, pressure data has not given any behavior to warrant further investigation. The slow increasing pressure response shown in Figure 4-2 is likely due to regional aquifer response to the production in the Redwater Leduc field. The trend is also consistently gradual over all three wells, indicating a far-field response.

Pressure data in the Cooking Lake Formation (Figure 4-3) is also collected at DMW 3-4, in order to monitor far-field pressures responses to non-Quest activities in the Leduc Formation.

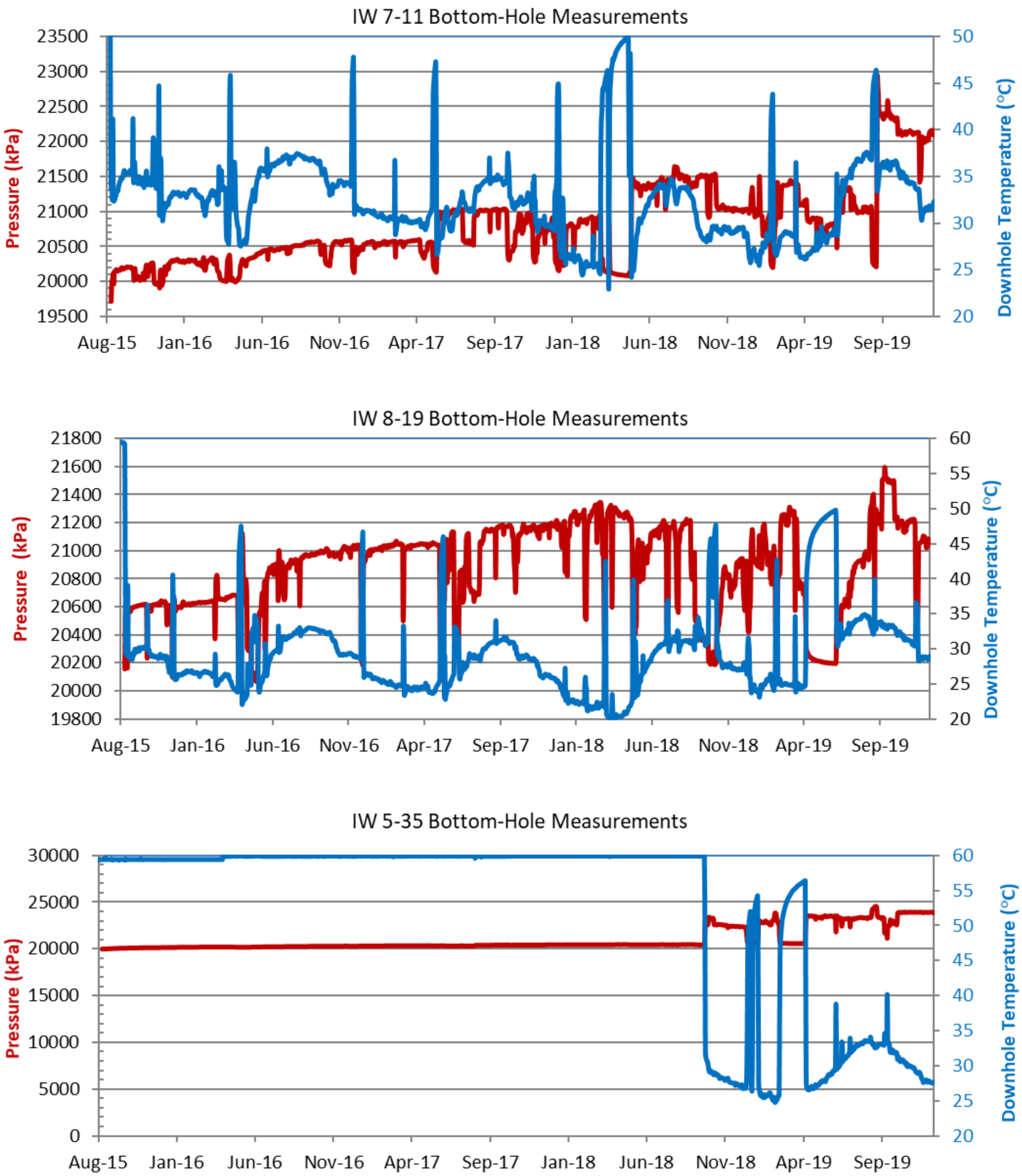


Figure 4-1: Quest injection wells downhole pressure and temperature trends.

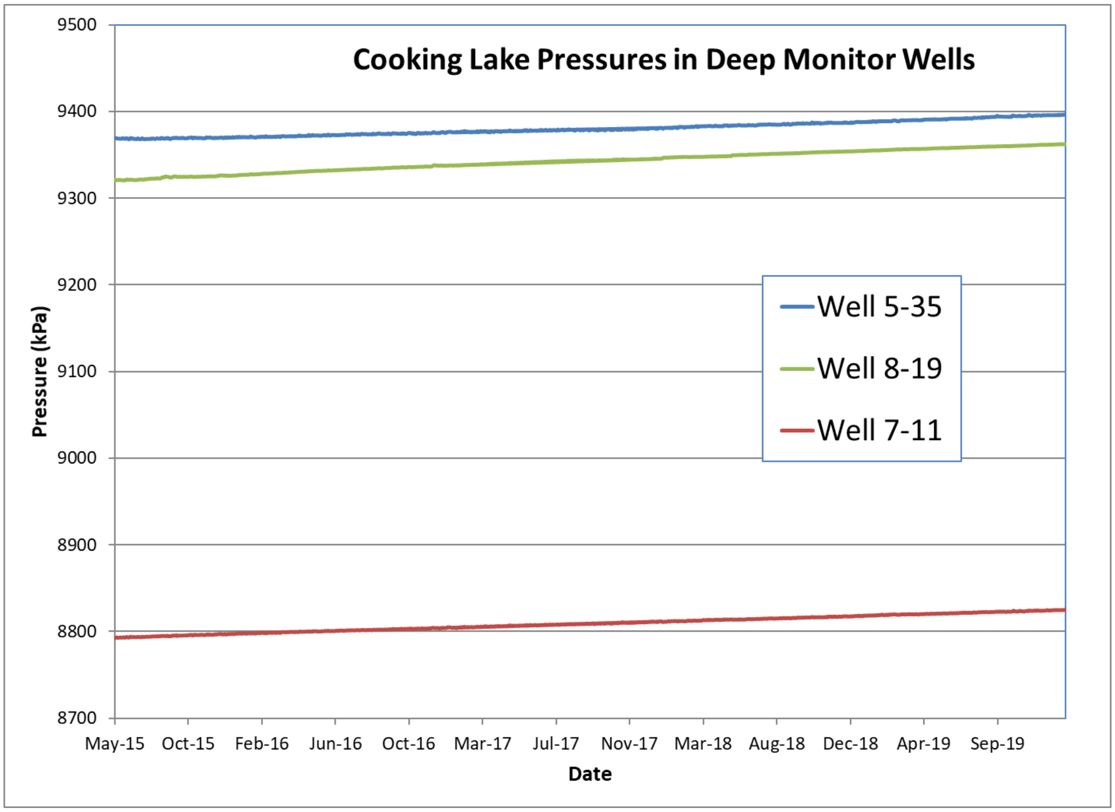


Figure 4-2: Quest deep monitoring well pressure history before and after injection.

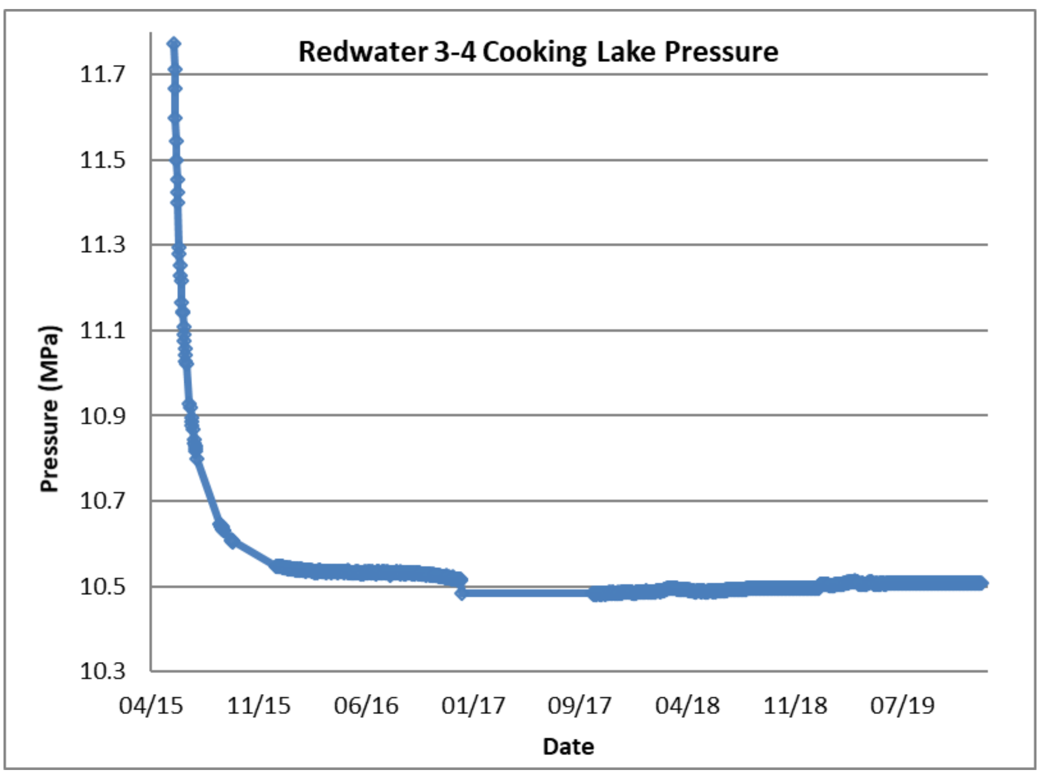


Figure 4-3: Quest DMW 3-4 pressure history.

4.3.3. *MSM*

The microseismic array has been functioning continuously since the start of injection. In 2019 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 4-4 shows the daily statistics for major categorized events in 2019. Appendix B documents the location, time, magnitude information for all locatable events to date and located within the Quest area of review (AOR). Figure 4-5 and Figure 4-6 are plan and depth views respectively of all event locations in reference to DMW 8-19.

Table 4-3: Trigger classifications used for the Quest Project and trigger totals from January 1st, 2019 to December 31st, 2019

Trigger Type	Description	Total
Automatic	Hourly triggering intended to ensure health of the system	8627
High Frequency Noise	Caused by elevated, high frequency background noise	6042
Acoustic	Caused by energy travelling up and down the wellbore	499
Hammer Tap Test	Tap test on the wellhead to test geophone functionality	0
Locatable Events	Events in the AOR with clear P- and S-wave arrivals exhibiting waveform characteristics typical of microseismic events	136
Single-Phase Events	Seismic signals that lack significant P- and S-wave arrivals and cannot be located	135
Surface	Events that originate at the surface	3338
Electrical	Caused by electrical interference	0
Vibes	Vibroseis shots	7177
Potential Regional Events	Far offset earthquake events that occur beyond the AOR	425
Total		26379

Since January 2017 sustained low-level magnitude microseismic activity has been observed within the Quest AOR . All of these events have been located within the Precambrian basement (Figure 4-5, Figure 4-6). The events show a normal distribution (Figure 4-7), have an average magnitude of -0.7, a maximum magnitude of 0.8, and have a typical occurrence rate of 1-2 events per week.

136 locatable events were detected in 2019 which is more than the 105 detected in 2018. The event timing shows no correlation to injection pressure variations and none of these events present a risk to CO_2 containment.

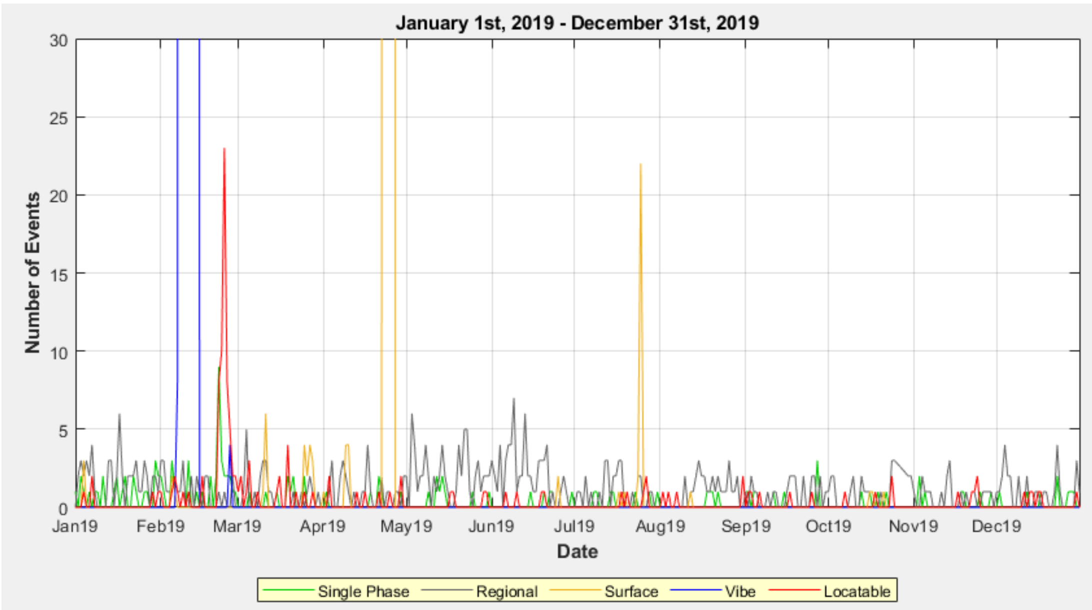


Figure 4-4: Daily event counts of microseismic categorized events in 2019.

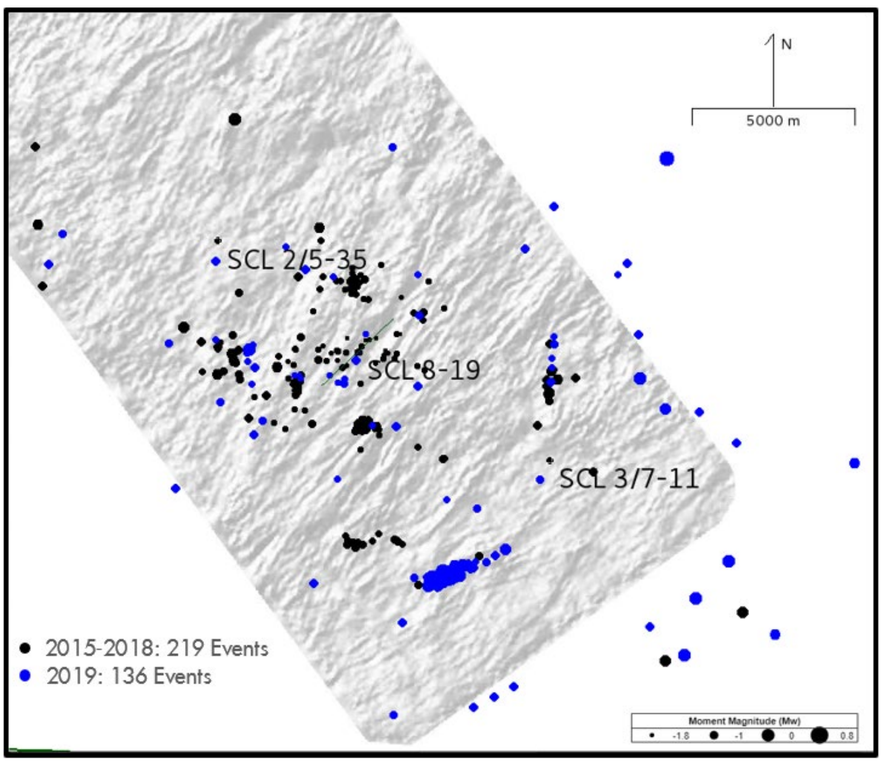


Figure 4-5: Plan view of the 355 locatable events recorded 2015-2019. Events recorded prior to January 1st 2019 are coloured black while 2019 events are coloured blue.

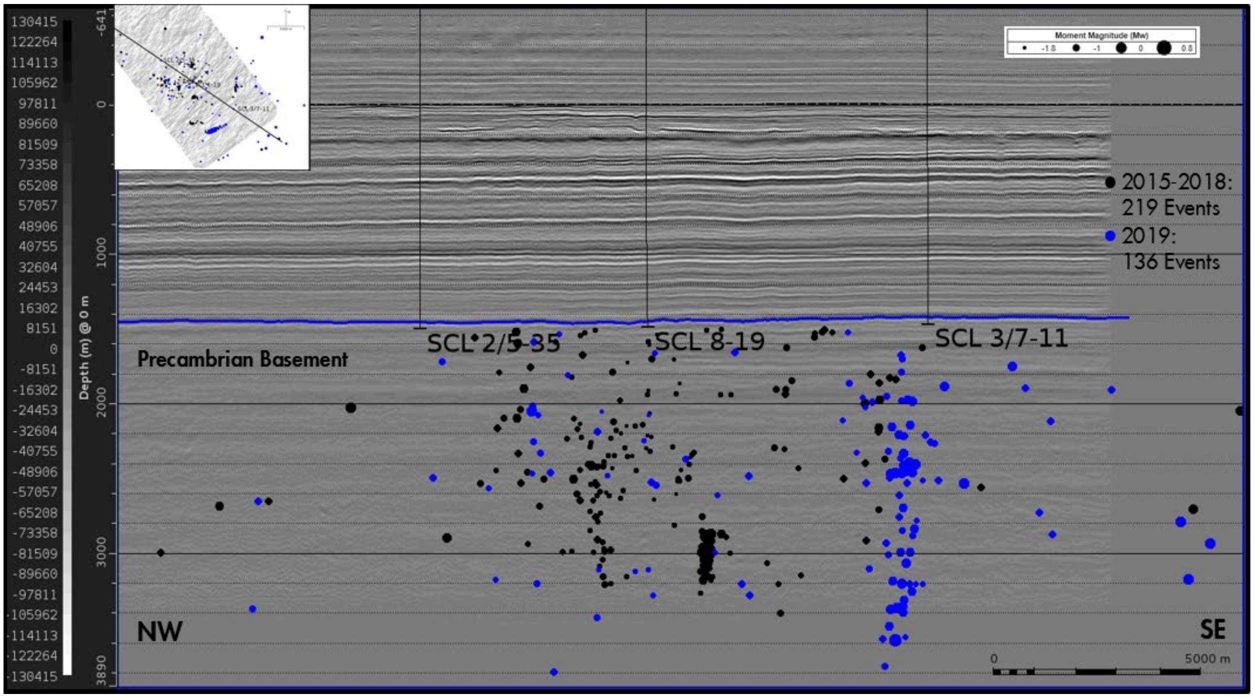


Figure 4-6: Depth view of all 355 locatable events recorded 2015-2019. Events recorded prior to January 1st 2019 are coloured black while 2019 events are coloured blue.

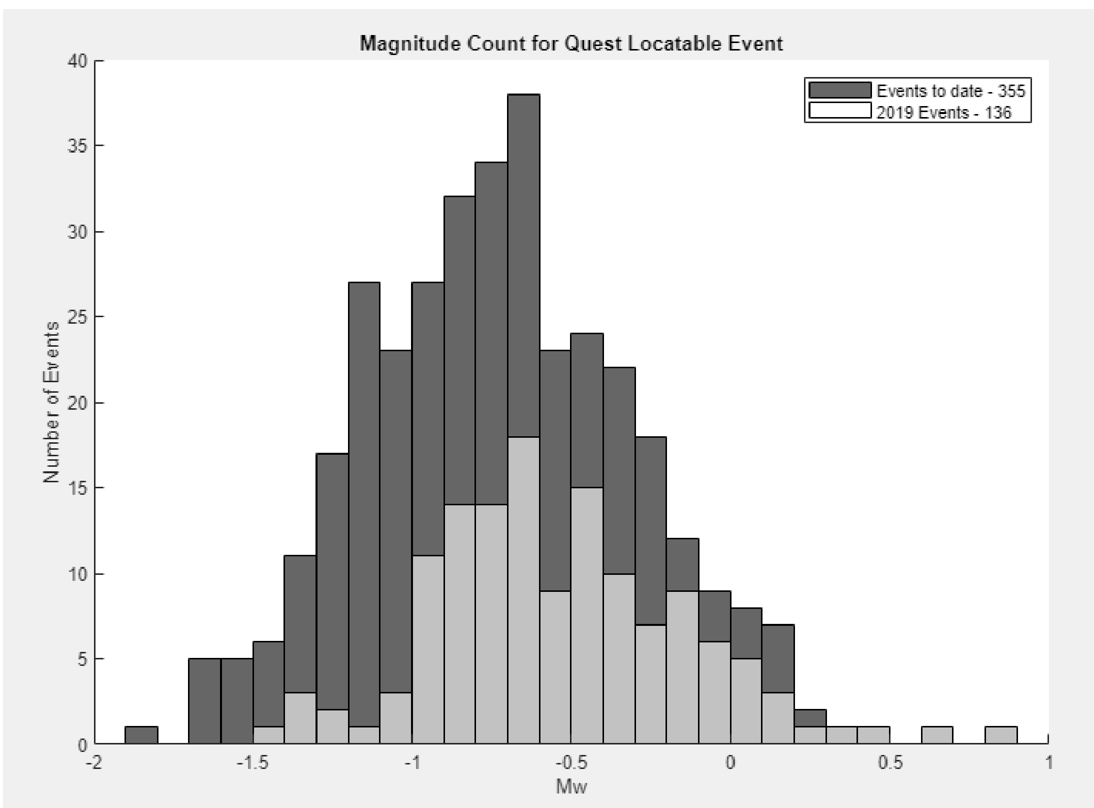


Figure 4-7: Histogram of magnitude of Quest locatable microseismic events 2015-2019; 355 locatable events. Overlay of 2019 locatable microseismic events; 136 locatable events.

The magnitudes of the locatable microseismic events have had a consistent distribution since 2017 (Figure 4-8). Two clusters of locatable events in 2017 and 2019 represent about 30% of all locatable events. Two locatable events of magnitude greater than 0.5 Mo were detected in 2019. These two events were located at distances greater than 8000m from the down-hole microseismic array (Figure 4-9).

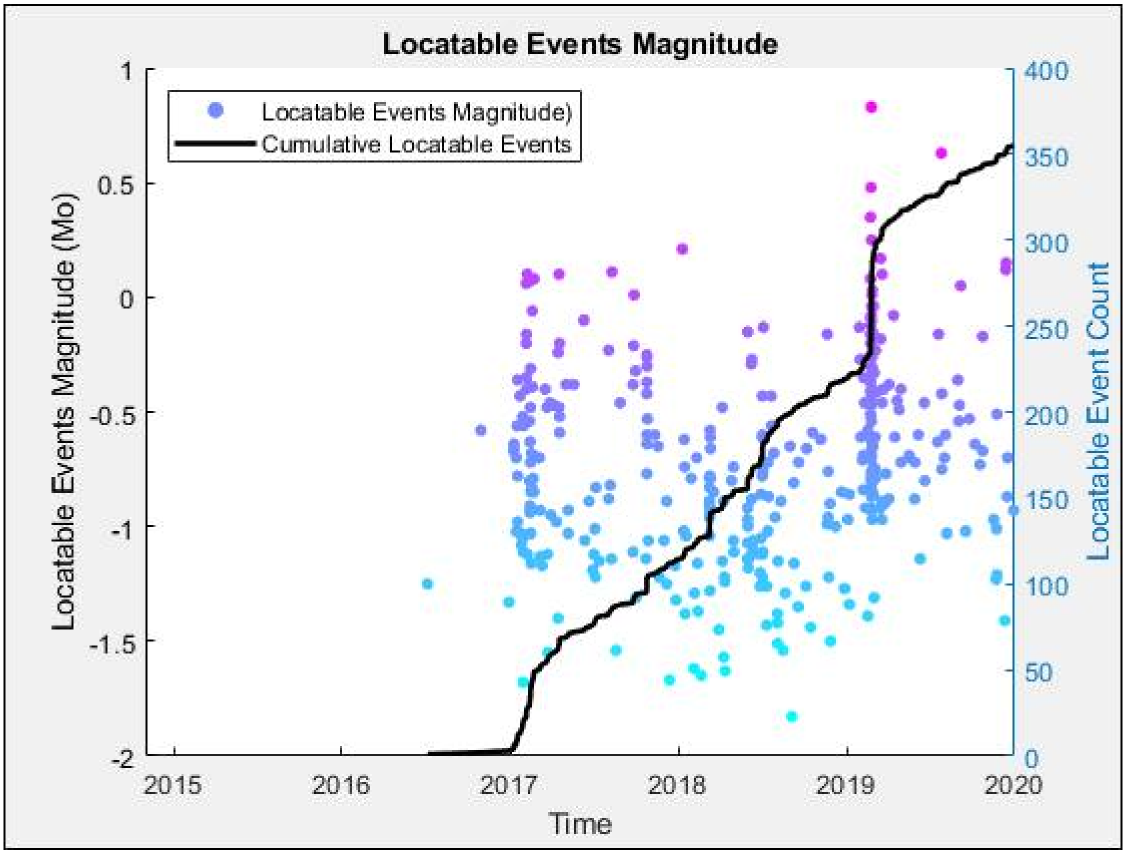


Figure 4-8: All locatable events recorded from November 2014 to December 2019 are plotted by magnitude (Mo). These locatable events are coloured by magnitude with hot colours representing the highest magnitude events. The black curve represents the cumulative count of locatable events.

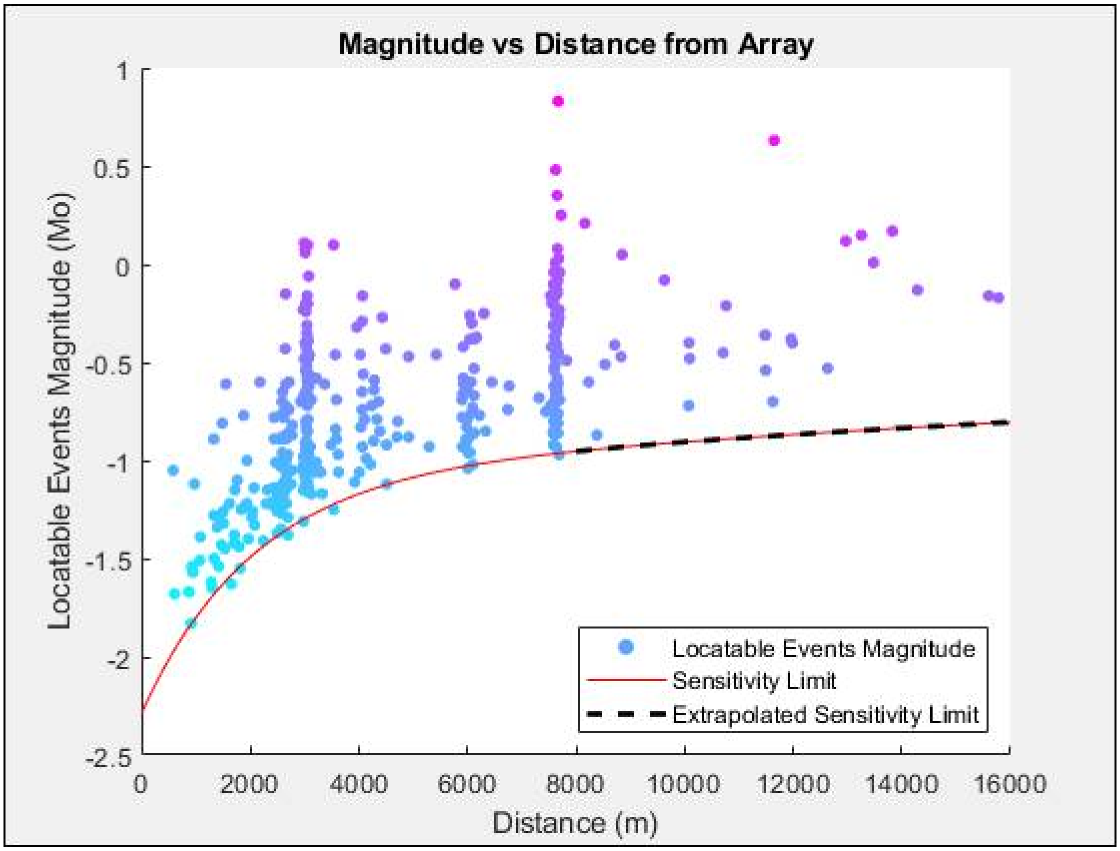


Figure 4-9: Locatable events magnitudes vs distance from array, recorded from November 2014 to December 2019. All locatable events are coloured by magnitude (Mo). The sensitivity limit is plotted in red and represents the smallest observed magnitude at each distance. The extrapolated sensitivity limit is plotted by the black dashed line.

4.3.4. *DTS*

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 4-10 which provides an example of heatmaps for downhole temperature measured within IW 8-19, along with the temperature profile and injection flow rates.

Figure 4-11, Figure 4-12, and Figure 4-13 are overviews of all the DTS data collected during 2019 at IW 8-19, IW 7-11 and IW 5-35, respectively.

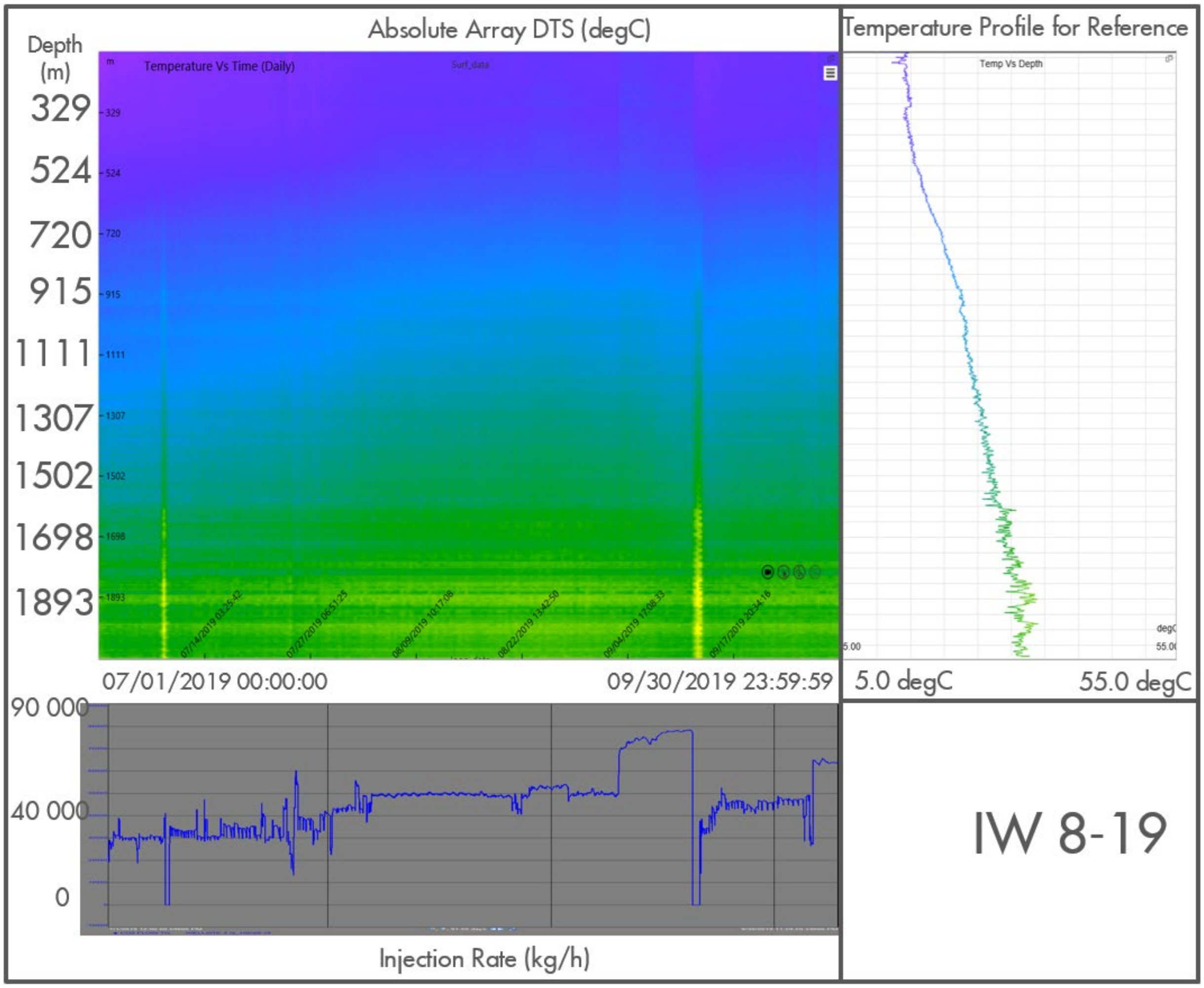


Figure 4-10: Heatmap for IW 8-19 DTS data recorded from July to September (top left plot), and corresponding temperature profile and flow (kh/hr) into the well.

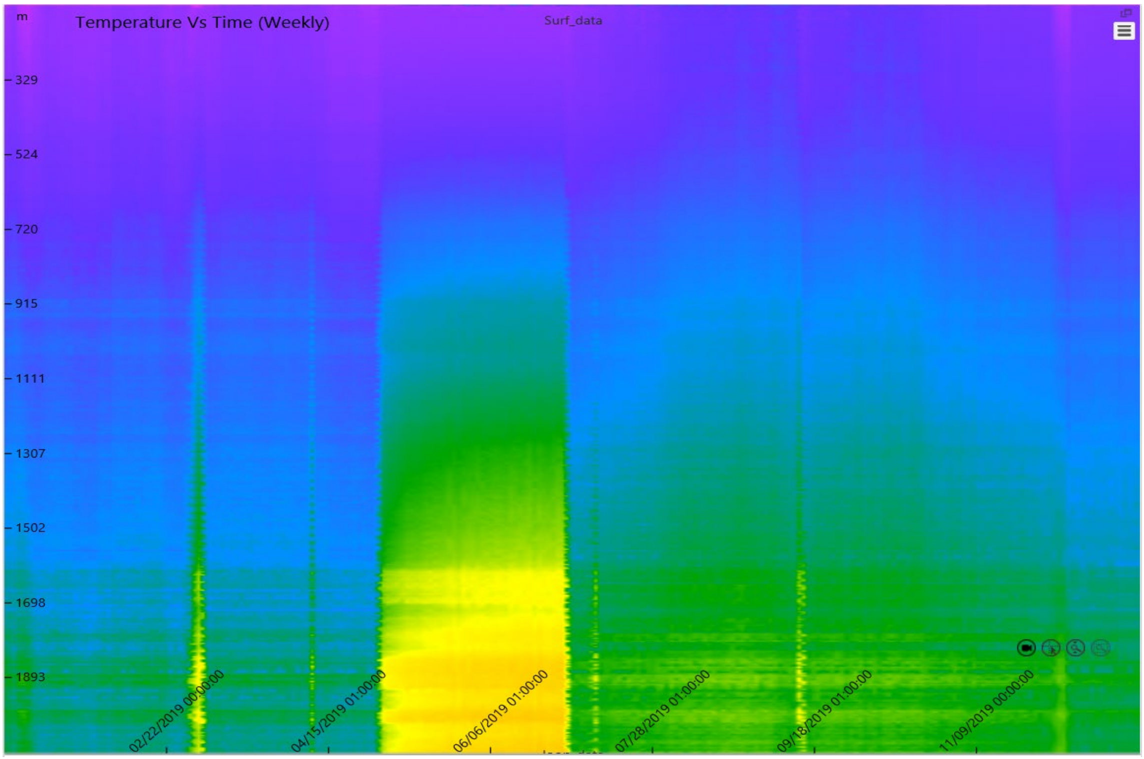


Figure 4-11: Injection well 8-19: heatmap of DTS data collected during 2019. Temperature heatmap scale is 5 to 55 degree Celsius.

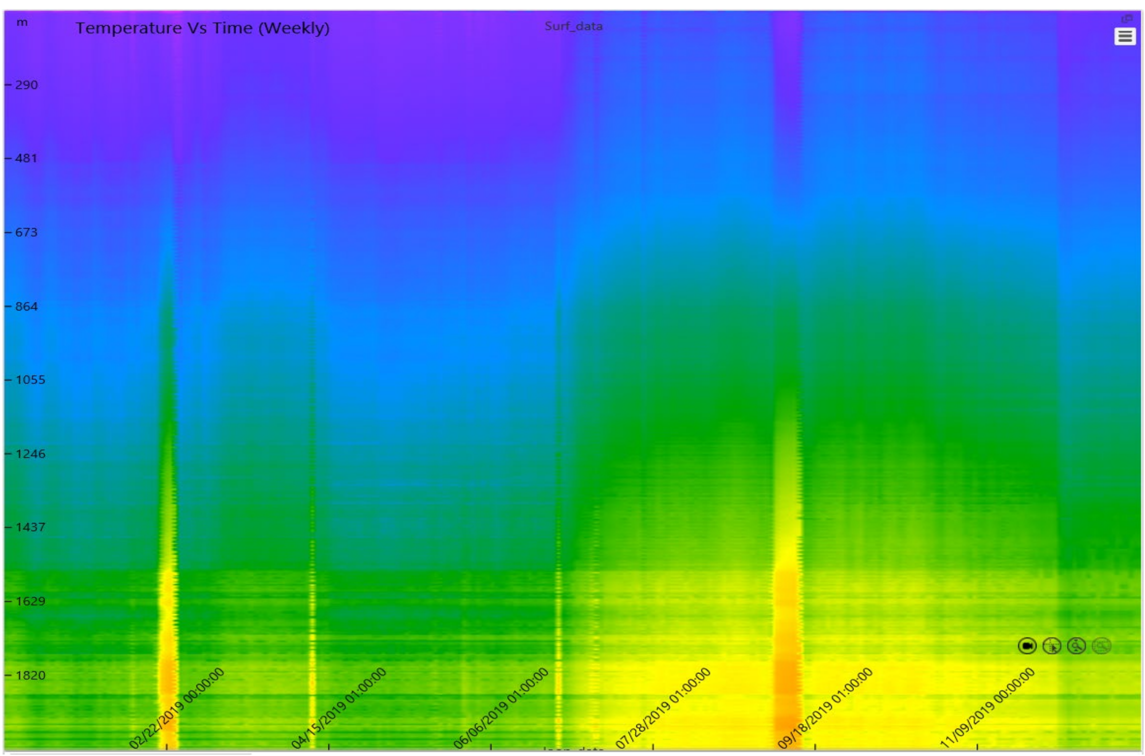


Figure 4-12: Injection well 7-11: heatmap of DTS data collected during 2019. Temperature heatmap scale is 5 to 55 degree Celsius.

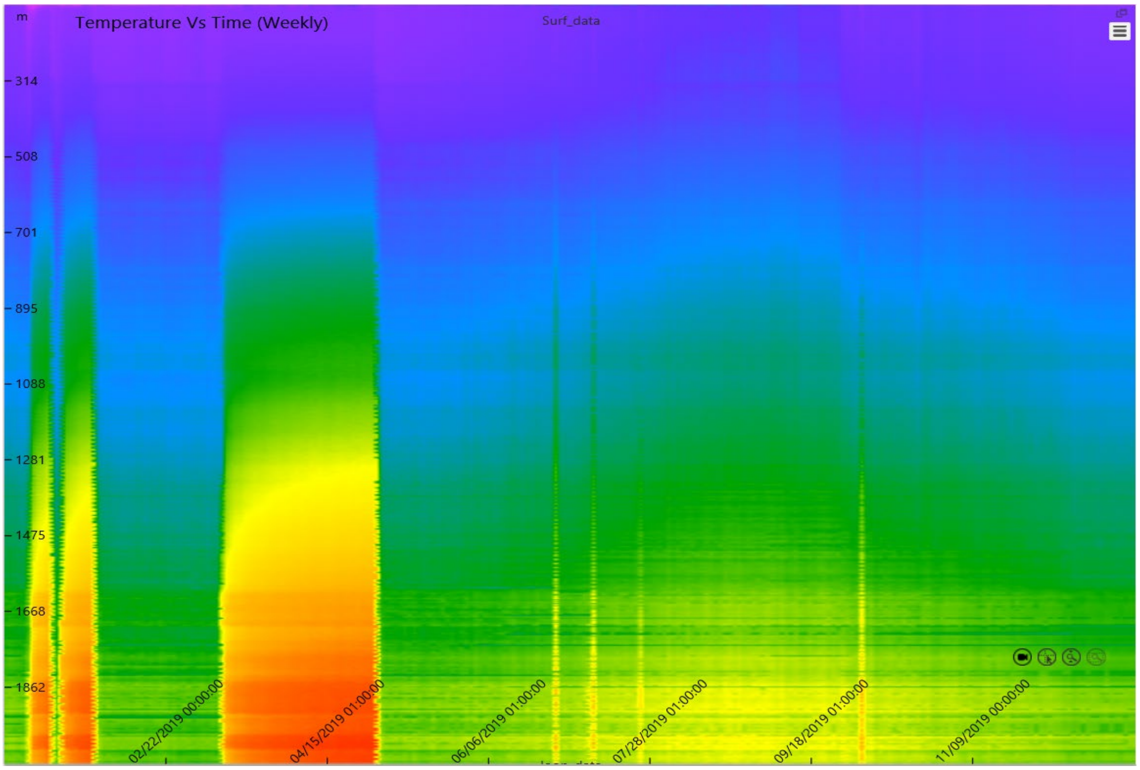


Figure 4-13: Injection well 5-35: heatmap of DTS data collected during 2019. Temperature heatmap scale is 5 to 55 degree Celsius.

4.3.5. *Pulsed Neutron log*

The first post initial CO_2 injection pulsed neutron log (PNX) hydraulic isolation log was performed on the IW 5-35 well January 21-22, 2019.

Figure 4-14 shows the interpretation for the log. The findings indicate that the BCS is hydraulically isolated from over- and under-laying units and thus the CO_2 injection is confined to the BCS unit. The following observations can be made:

- Baseline 2015 RST log plotted in green
- Red shading indicates the change in reservoir saturation with injection
- Changes are confined to perforated intervals (2061.50 – 2098.00 mKB)

Further details on the PNX logging can be found in Appendix C.

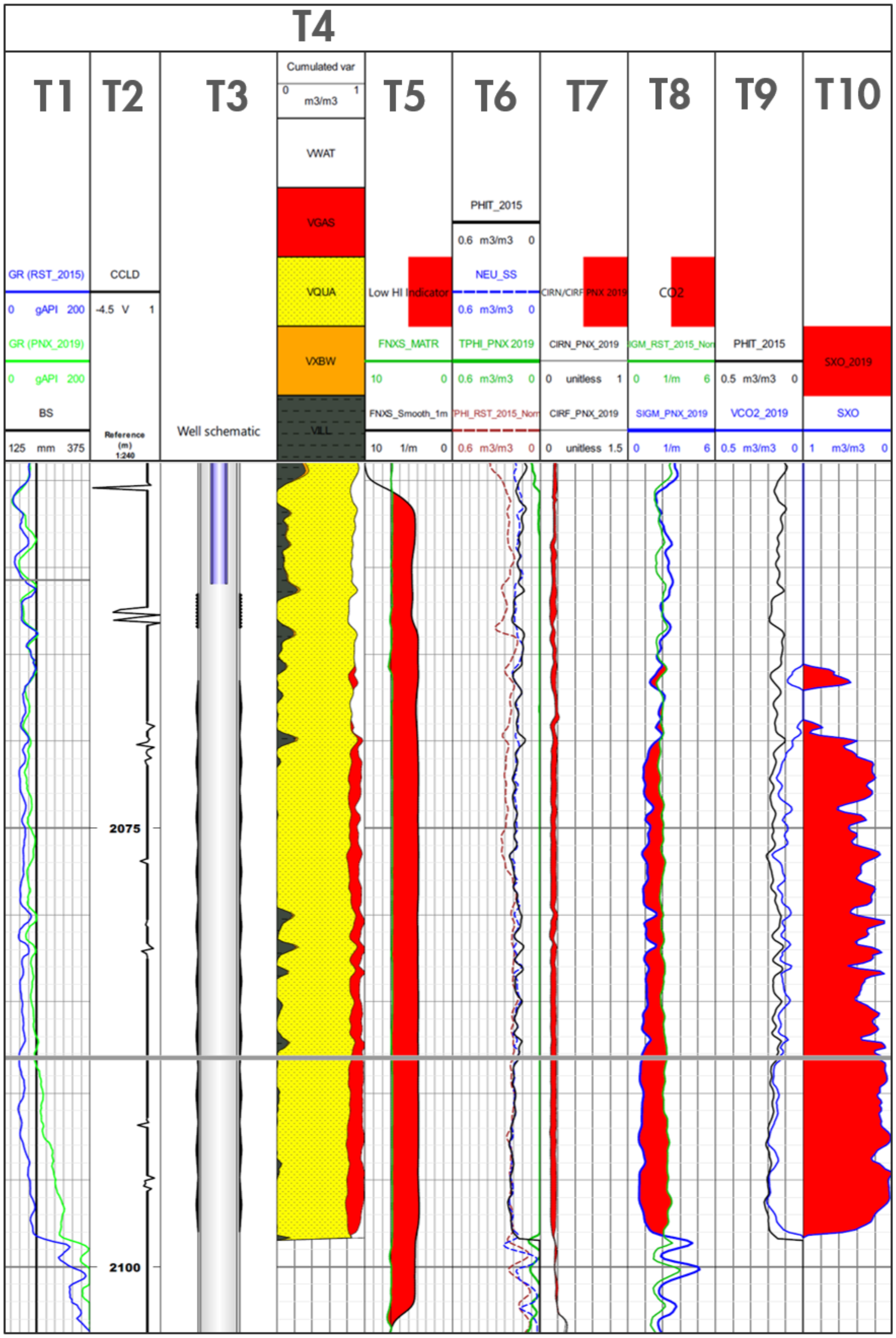


Figure 4-14: PNX logging for injection well IW 5-35. Track T8 shows three month formation sigma log overlay (Oct 2018 – Jan 2019) with the baseline 2015 RST log. Tracks T1 to T7 plus T9 and T10 show other logs, such as gamma ray (GR) or collar locator (CCLD) logs.

4.3.6. *VSP2D*

Please refer to Section 4.4 for details on 2D walk-away borehole DAS VSPs (VSP2D).

4.3.7. *SEIS3D, SEIS2D*

Not applicable yet for 3D surface seismic (SEIS3D).

In Q1 of 2017, 2D surface seismic (SEIS2D) was acquired alongside the VSP2D at IW 7-11 and IW 8-19. In Q1 of 2019, a second SEIS2D was acquired at IW 5-35 and IW 8-19.

Figure 4-15 shows one of the SEIS2D 2019 lines acquired and processed over IW 8-19 and overlain on the baseline SEIS3D. This line is representative of the overall data quality of 2DSEIS at each IW well. The feasibility of SEIS2D as a time-lapse seismic method will be assessed in 2020 using the IW 8-19 dataset.

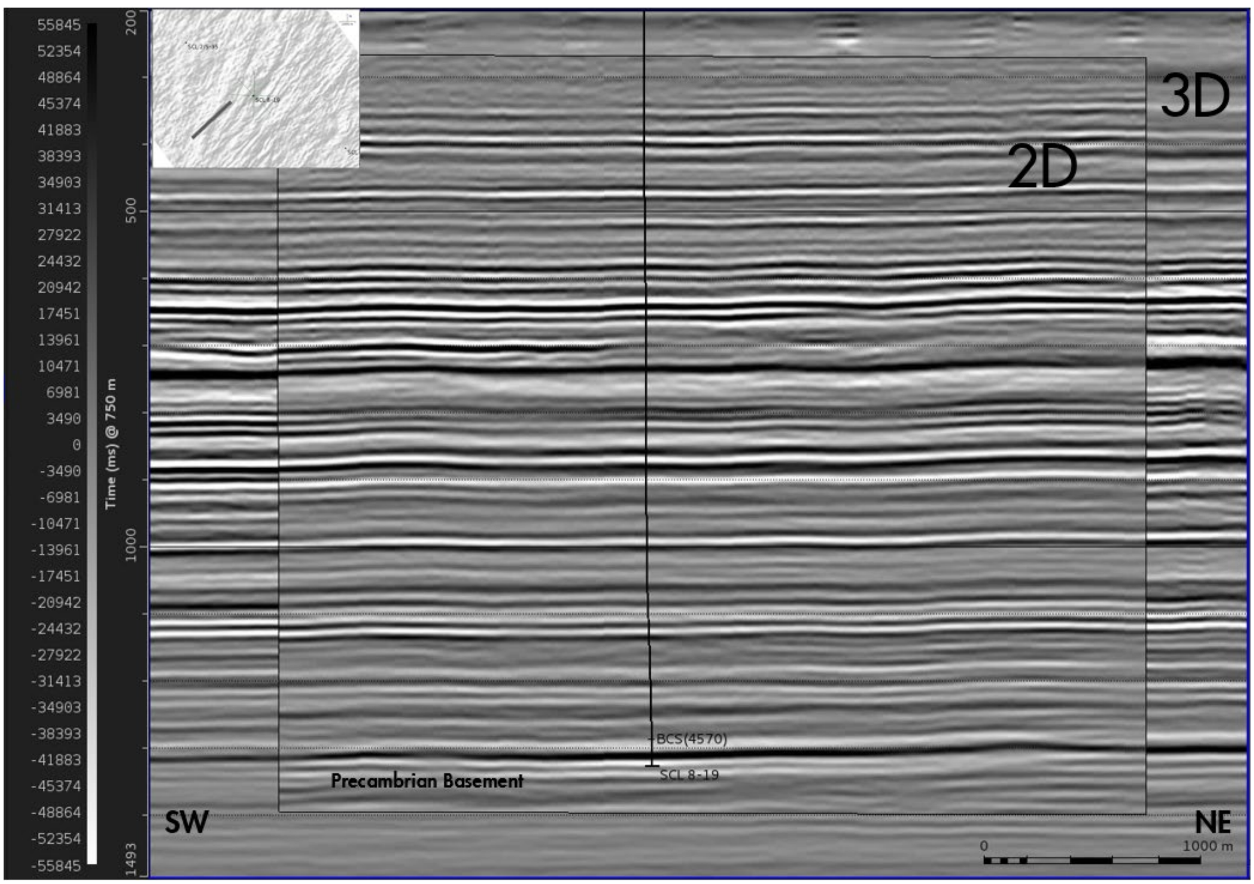


Figure 4-15: SEIS2D SW-NE line at IW 8-19 overlain on baseline 3D surface seismic.

4.3.8. *SCVF*

SCVF samples for laboratory analyses were collected from IW 5-35 in June 2019. Measurements at the IW 5-35 well are at similar levels to those observed historically. The IW 7-11 SCVF declined to zero in 2019. The IW 8-19 SCVF tested at zero for a fourth consecutive year.

The compositional results indicate that the SCVF and GM gas at the IW wells is predominately methane. For SCVF, CH_4 concentration was 98.6% for IW 5-35. For the GM, CH_4 concentration was 98.7% for IW 5-35, and 99.0% for IW 7-11. The isotopic results from the June 2019 SCVF – GM gas sampling campaign are comparable to findings from previous years. Figure 4-16 shows the data for IW 5-35, and Figure 4-17 for IW 7-11.

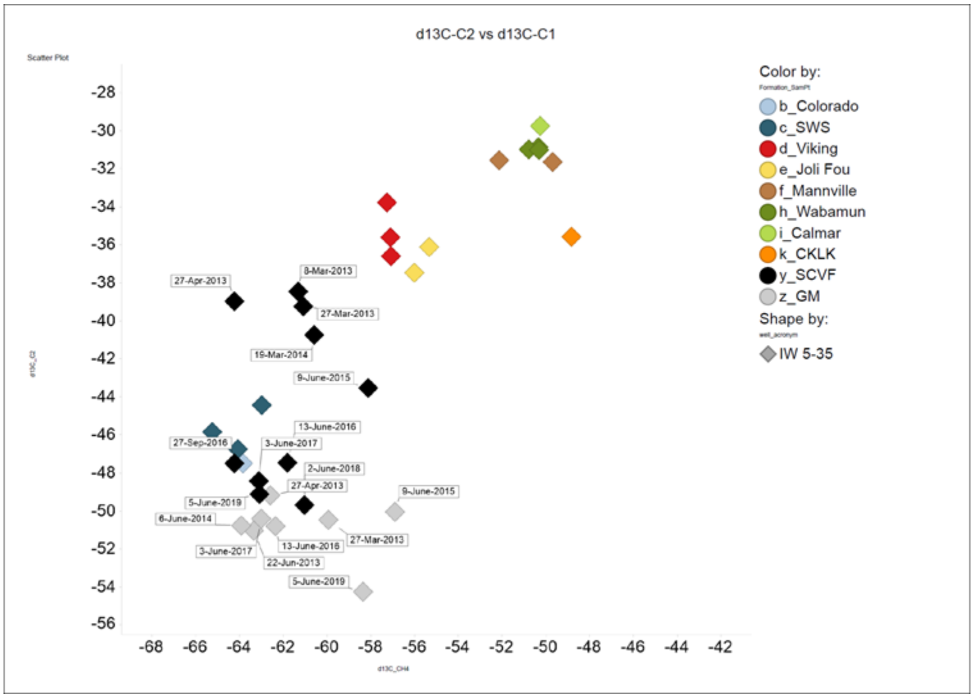


Figure 4-16: δ^{13}C-C2 versus δ^{13}C-CH_4 plot for SCVF (black diamonds) samples and gas migration (gray diamonds) collected at IW 5-35. Also shown are formation specific data based on isotube measurements collected during drilling of IW 5-35.

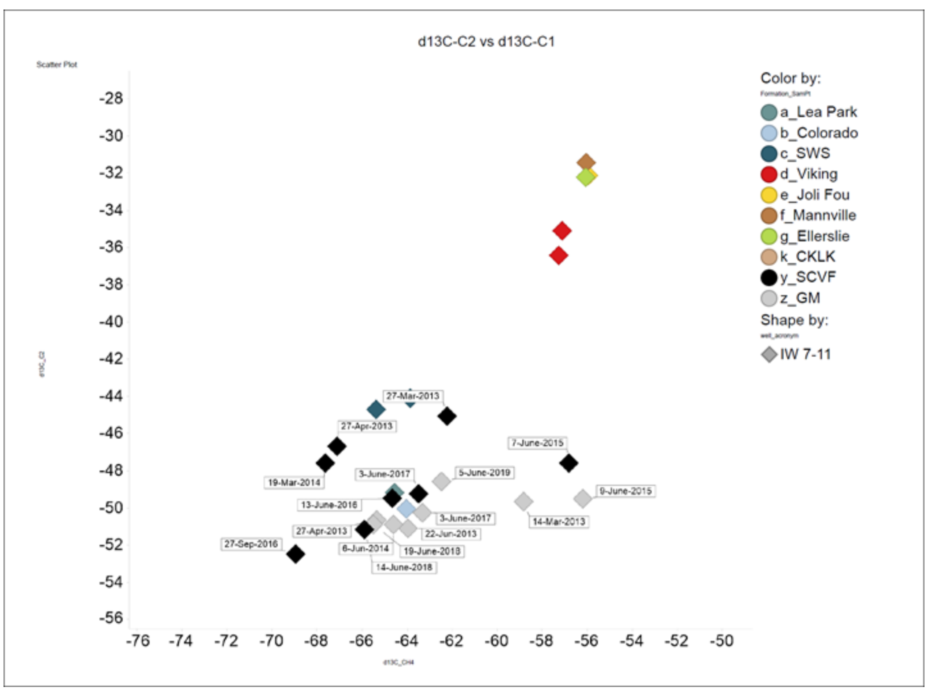


Figure 4-17: δ^{13}C-C2 versus δ^{13}C-CH_4 plot for SCVF (black diamonds) samples and gas migration (gray diamonds) collected at IW 7-11. Also shown are formation specific data based on isotube measurements collected during drilling of IW 7-11.

4.4. Assessment of MMV objective 'Conformance'

4.4.1. *Time-lapse seismic data*

Baseline VSP2D was acquired in 2015, and three monitorVSP2D campaigns were executed in 2016, 2017 and 2019. All campaigns have occurred over the winter season to facilitate surface access, minimize impact on the land and farming/harvest activities, and to ensure maximum repeatability. Eight VSP2D lines were acquired over each injection well location during the surveys.

In 2016 and 2017, both ODH4 and ODH4i light boxes were used to compare the repeatability back to the 2015 ODH4i. Results from 2017 demonstrated that data from the ODH4 light box is repeatable compared to ODH4i [9], and as such only the ODH4 light source box was used in 2019.

The 2019 campaign acquired data at IW 5-35 and IW 8-19; this is the first monitor dataset for IW 5-35 and the third for IW 8-19. The baseline VSP2D and subsequent monitor VSP2Ds were subject to the same processing workflow to optimize the time-lapse signal and to be consistent between datasets.

The 2019 results demonstrate a clear time-lapse anomaly present in the difference between the Baseline and Monitor data for each vintage (Figure 4-18, Figure 4-19, Figure 4-20, Figure 4-21). The maximum distance illuminated by the VSP2D continues to be approximately 800 meters away from each well. The "maximum reliable image" to interpret 4D differences is approximately 500 meters away from each well. The criteria for the "maximum reliable image" is qualitative and derived from synthetic modelling, the dimming of BCS amplitudes in the VSP2D, and variations in the interpretation pick of the base BCS reflector between the SEIS3D and VSP2D.

Using a similar interpretation workflow to 2016, the time-lapse anomaly is interpreted using the straight calculated difference [4]. Measurement uncertainty in the exact plume dimensions arises from several sources such as: geometrical positioning, processing, imaging and attribute cut-off values. Quantifying the measurement uncertainty will continue in 2020.

One key result of the 2019 acquisition, processing and imaging is that time-lapse techniques can be used to image an anomaly attributed to the displacement of brine by CO_2, and that this anomaly is interpreted to be growing in size. Further in-depth analysis will take place in 2020 to understand how the anomaly we interpret relates to the specifics of the CO_2 plume.

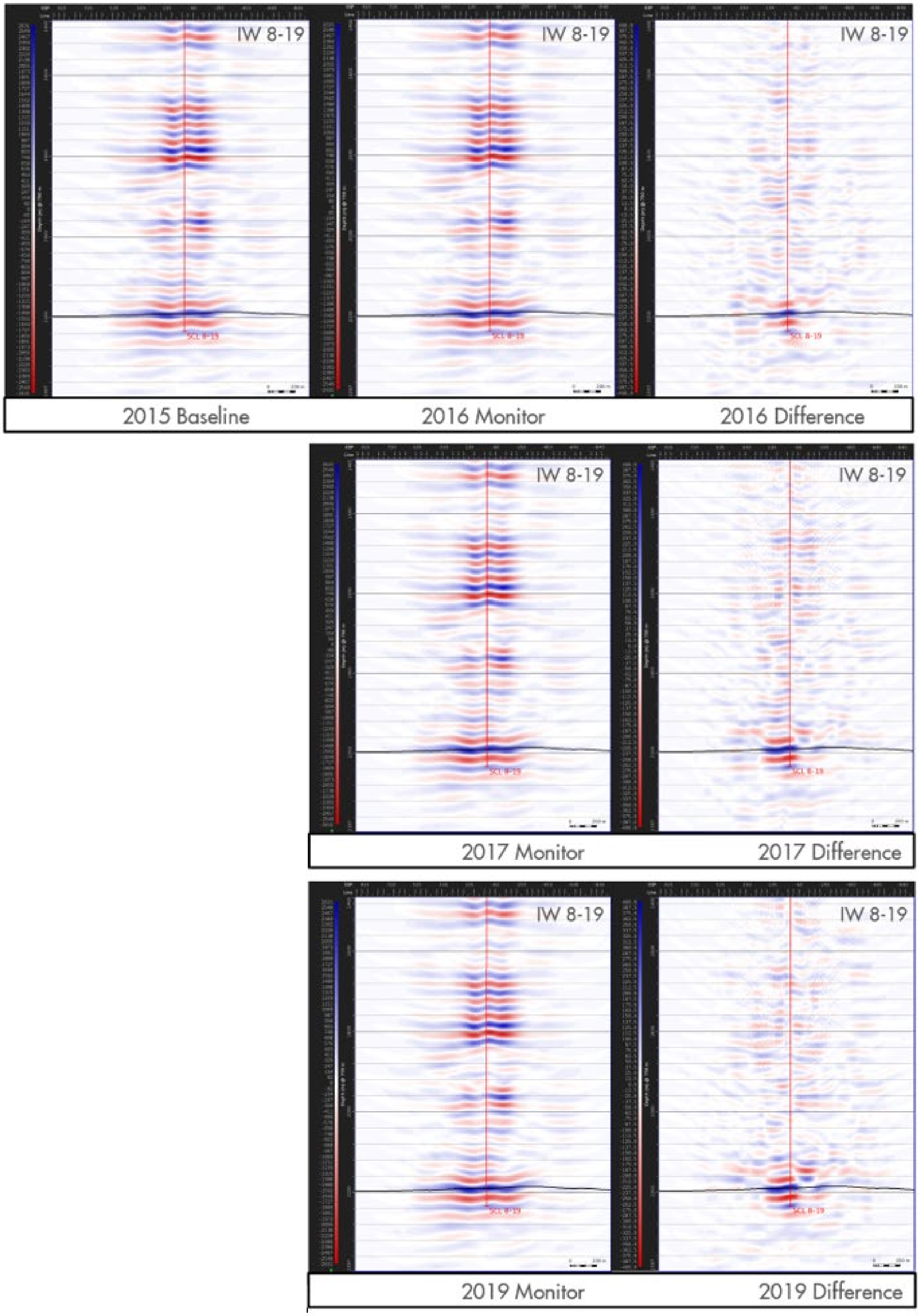


Figure 4-18: Baseline, 2016 Monitor, 2017 Monitor, 2019 Monitor and each difference for IW 8-19

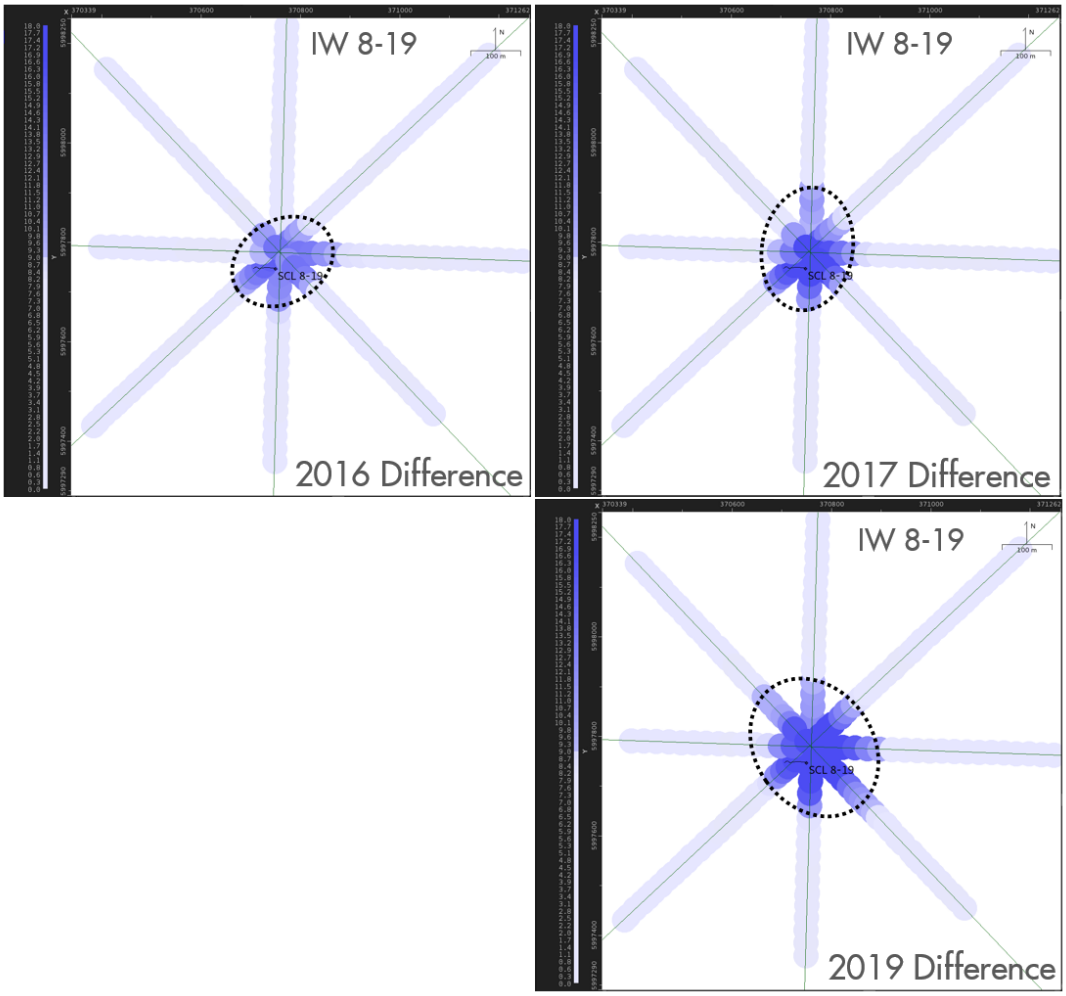


Figure 4-19: Amplitude extraction at the Precambrian Top Event at IW-8-19 showing the progression of the time-lapse anomaly for each vintage

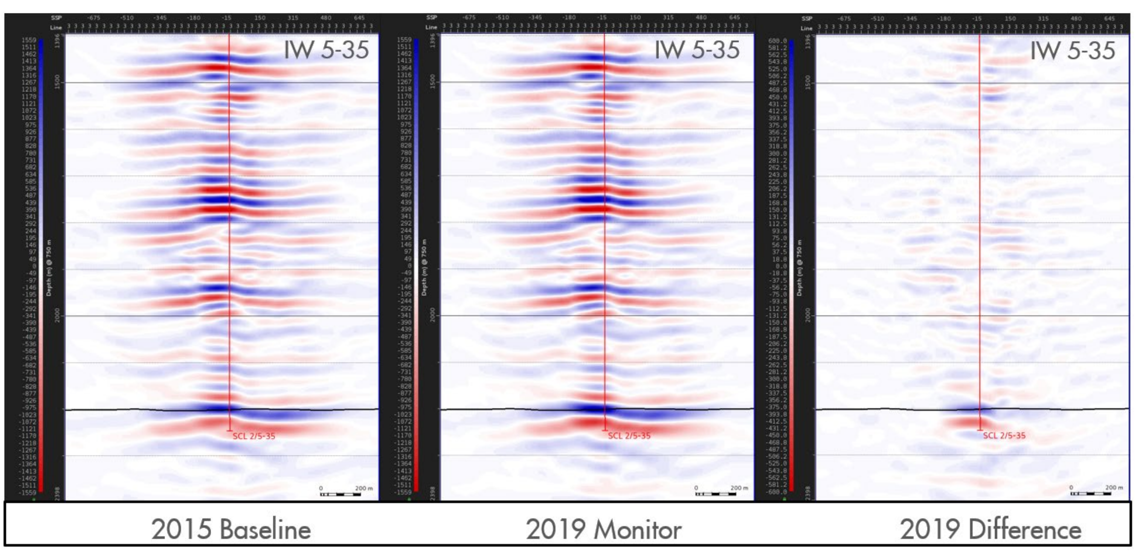


Figure 4-20: Baseline, 2019 Monitor and difference for IW 5-35

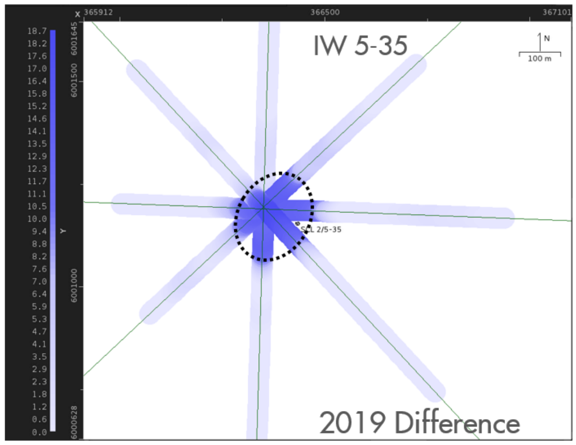


Figure 4-21: Amplitude extraction at the Precambrian Top Event at IW 5-35 showing the time-lapse anomaly.

4.4.2. *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 as discussed in Section 3: Injection Well Performance.

4.4.3. *InSAR*

Monthly collection of Radarsat-2 satellite images continued in 2019. As in 2018, the data were not processed. InSAR will only be analyzed in the event of another MMV technology or observation indicating the need for further investigation.

4.5. MMV Performance and Plan Issues

The current MMV plan was submitted for review in February 2017 and approved on 11 May, 2017. The 2017 MMV plan is in effect until 11 May, 2020. The 2020 MMV Plan has been submitted for review and approval in February 2020.

- The microseismic data transmission system encountered issues over a period in Q3. It was mitigated via manually downloading and transmitting the data while the IT solution was delivered.
- The Tier 2 LightSource laser system at the 8-19 well pad stopped functioning in June 2019. The LightSource system at the 5-35 and 7-11 well pads remain functional. The daily operator rounds, with visual, audible and personal CO_2 sensor checks, have been monitoring the atmosphere at the well pad while an assessment of the end to end system is occurring.
- The equipment failure identified at DMW 3-4 was remediated in Q1 2019.

5. FUTURE MMV ACTIVTIES

In 2020, there will be MMV activity in the following areas:

- A new MMV Plan will be submitted for review and approval in early 2020.
- Pursue opportunities to optimize the newly submitted 2020 MMV plan as they arise.
- Continue working on evaluating the utilization of SEIS2D, surface 2D seismic, as an assessment of conformance.
- Maintenance of the LightSource laser system.

5.1. Changes to approved 2017 MMV Plan

On 15 Jan 2018, Shell submitted a letter to the AER seeking to update Section 4.6.4 of the 2017 MMV Plan. Per communication received by Shell on July 24, 2018, the AER accepted the update to the MMV Plan, and approved the proposed groundwater sampling frequency for the wells subject to the following conditions:

a) Shell must complete an evaluation of why pH values exceeded 9.5 at certain times in Landowner wells 9 and 13, and Project wells 1F1-05-35, UL1-05-35, 1F1-07-11, and UL2-08-19. Shell must provide the results of the evaluation as part of the next annual report.
b) Shell must complete, as part of the next annual report, trend analyses on both field measured and downhole probe measured pH values and comment on the results in light of Shell's proposed changes in sampling schedule.

In response, Shell completed the evaluation of the above statements and the results were presented in the 2018 Annual Status Report [9].

In 2019, two discrete sampling events- pre and post VSP took place at landowner groundwater wells within1 km of IW8-19 and IW5-35. Continuous monitoring of pH and EC was done using downhole water quality probes at the project groundwater wells located on the 3 injection well pads.

5.2. Monitoring Wells

Need for Monitoring Wells Near Periphery of Pressure Build-up

Approval No. 11837C Condition 10(i), 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 [1]. 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

Currently, 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 was monitoring pressures in the BCS until the well was activated as an injection well in October 2018. The permanent downhole pressure gauges will opportunistically capture BCS Formation fall-off shut-in reservoir pressures when possible (refer to Section 3 for discussion).

Monitoring at Groundwater Wells

In 2018, Shell submitted an optimized 2018-2019 Groundwater Sampling Plan to the Alberta Energy Regulator (AER). In a letter dated July 24, 2018, the AER approved Shell's proposed changes to the HMP. As such, there is currently no discrete sampling as part of the MMV program. As per the 2017 MMV Plan and 2018 approved update, discrete groundwater well sampling is a Tier 3 technology that would be triggered by Tier 1 and/or 2 events, or, as per water well owner requests to participate in MMV program (Condition 20 of AER Approval No 11837C) [1].

No impact is expected from the reduced monitoring of landowner and project GWWs as no leaks or triggers have been observed at the IW locations thus far. The current program consists of continuous monitoring of pH and Electrical Conductivity (EC) using the existing AquaTROLL 600s (AT600s) Multi-Parameter Sondes and performing calibration and/or maintenance activities as needed at the project GWWs.

Past Annual reports have suggested that trends are generally stable at project GWWs, there have been well specific instances of either elevated or decreasing trends in pH that have required additional data review and discussion with AER historically.

Elevated pH at Project wells but not at Landowner Wells

Higher pH values have been measured at a few specific project GWWs but not necessarily Landowner wells. This observation is not interpreted to be indicative of an instrument issue or IW leakage, and supported by other MMV results. The Landowner well pH levels, for both field and laboratory measurements, have remained generally stable and below a pH of 9.5. The approach was used to compare the intra-well data (not between wells, or inter-well) in order to understand the impact of Quest CO_2 injection activities. The current data was compared to pre-injection data baseline data at the individual landowner and project GWWs.

The Mann-Kendall Trend Test is a statistical test used to analyze time-series of data to identify any consistently increasing or decreasing trends. Table 5-1 (from Table G3 in the Golder 2018 HMP Report [9]) provides concentration trend results for pH using a Mann-Kendall analysis. Individual wells with high pH (e.g. 1F1/08-19 – total well depth 201 m) are biasing high the combined pH of the project wells. When reviewing data on a well by well basis, project wells with a pH greater than 9 in 2018 (1F1/08-19, UL1/5-35 and UL1/7-11) also had elevated pH during pre-injection baseline monitoring and sampling.

Table 5-1: Summary of Mann-Kendall Trend for pH in Landowner and Project groundwater Wells

Location	Pre-Injection		Post-Injection	
	Field pH	Downhole pH	Field pH	Downhole pH
Landowner 1	S	-	NT	-
Landowner 2	NT	-	S	-
Landowner 3	NT	-	S	-
Landowner 4	NT	-	NT	-
Landowner 5	S	-	PD	-
Landowner 6	S	-	S	-
Landowner 7	-	-	D	-
Landowner 8	NT	-	S	-
Landowner 9	NT	-	S	-
Landowner 10	-	-	S	-
Landowner 11	-	-	PD	-
Landowner 12	S	-	S	-
Landowner 13	NT	-	S	-
Landowner 14	NT	-	S	-
Landowner 15	-	-	S	-
Landowner 16	-	-	NT	-

Location	Pre-Injection		Post-Injection	
	Field pH	Downhole pH	Field pH	Downhole pH
1F1-05-35	I	NT	PI	NT
UL1-05-35	S	I	PI	PI
1F1-07-11	NT	NT	S	S
UL1-07-11	PI	I	I	I
1F1-08-19	NT	D	NT	NT
UL1-08-19	D	NT	D	D
UL2-08-19	D	D	S	NT
UL3-08-19	D	D	D	D
UL4-08-19	S	S	S	S

Notes:

Highlighted - N	- no trend
Highlighted - S	- stable
Highlighted - I	- increasing or probably increasing
Highlighted - D	- decreasing or probably decreasing

"-" The concentration trend could not be determined because the number of samples is less than four or there is no sample

Decreasing or Possibly Decreasing Trends

Table 5-2 highlights the wells identified as having decreasing or possibly decreasing trends in Table 5-1. A review of the data used to develop the Mann-Kendall trends shows that the magnitude of the decreasing trend, the difference between mean, minimum and maximum pH pre- and post-injection is quite small. It is interpreted that a decrease in pH is related to a seasonal variation and/or may be within the measurement accuracy.

While a decreasing trend in pH is something that can occur as CO_2 is dissolved in water, it is noted that UL1-08-19 and UL3-08-19 both exhibited decreasing trends in pH pre-injection. The decrease in pH post-injection does not represent a change in trend as a result of injection, and the overall trend has generally remained below 9.5. This is similar to data presented in Tables G3, and pH trend analyses in Appendix B of the 2018 HMP Annual Report [9].

Landowner wells 7 and 11 did not have sufficient data to run Mann-Kendall analysis (less than four data points) pre-injection, and may also have been decreasing prior to injection.

Landowner well 5 is "probably decreasing", and therefore not a strong trend in the downward direction. These are the only wells with Decreasing or Potentially Decreasing Trends since 2013.

Shell will continue to collect data to ensure trending can be competed and changes evaluated for significance.

Table 5-2: Summary of Mann-Kendall Trend for Decreasing Trend in pH

Well Name	Mann-Kendall Trend*		Mean pH		Min pH		Max pH	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
UL1/8-19	D	D	8.03	7.45	7.81	7.17	8.20	8.08
UL3/8-19	D	D	9.06	8.00	8.71	7.28	9.46	8.76
Landowner Well 5	S	PD	7.19	7.31	6.84	7.05	7.48	7.59
Landowner Well 7	-	D	7.65	7.60	7.58	7.37	7.72	7.93
Landowner Well 11	-	PD	-	7.32	-	7.00	-	7.69

*Field measured pH

A trend analysis was completed for all wells on both downhole and field-measured pH levels. A comparison between the trend results indicated general consistency between the pre- and post-injection data for both the downhole and field-measured data. This indicates that there are no noticeable differences in pH levels between the downhole and field-measured data.

Overall, despite some initial challenges associated with sensor units (since replaced by newer models), the Groundwater program has successfully demonstrated that Shell is not having impact on local groundwater geochemistry. Measurements of pH, soil gas and dissolved gas in groundwater conducted from 2013 to 2018 have shown that intra-well and intra-pad trending is stable or has no trend for most wells pre and post injection.

Dissolved gas, if present, as well as SCVF and GM sampling does not indicate any isotopic change in source (Section 4.3.8). Shell continues to utilize pH, temperature, pressure and EC as real time indicators of potential groundwater impacts.

6. STAKEHOLDER ENGAGEMENTS

Community stakeholder engagement activities for Quest in 2019 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

Municipal Government Updates

Annual updates were offered to municipal governments at their council sessions to provide updates on Quest operations. Updates were provided to the following municipalities in 2019:

- February 12, 2019 – Thorhild County
- March 12, 2019 – Strathcona County

No major issues were raised specific to the Quest facility and questions were answered immediately at the council sessions.

Public Concerns

Shell has a comprehensive public concerns process that is designed to encourage community feedback. In 2019, Shell recorded eight concerns related to Quest operations.

Three concerns were related to crop loss. These concerns were associated with the weed management program and ongoing recovery of the soil following pipeline construction. Engagement with landowners continues as Shell works with impacted stakeholders to find the most appropriate actions to address these impacts.

Three concerns were related to the quarterly testing of water wells. These concerns were related to water well maintenance rather than the testing of the wells themselves (not related to Shell's activity).

One concern was related to the potential for a landowner's water well to be impacted by Shell MMV activities.

One concern was related to water pooling on the 5-35 well pad. While a project to deal with the water pooling issue was completed in the summer of 2019, heavy rainfall through the spring and summer made it was necessary to haul water off-site.

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 of local community members including educators, business owners, emergency responders, and medical professionals as well as academics, Thorhild County 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.

In 2019, the Quest MMV CAP met on June 12 to review the latest MMV data. New representatives were in attendance from Thorhild County and the Alberta Energy Regulator (AER). The Terms of Reference was updated to reflect the current state now that Quest has been operational for a few years.

Emergency Response

Groundtruthing – an activity to update contact information and to communicate information about the project for residents within the Emergency Response Zone – was conducted in 2019 for the bi-annual update of the Emergency Response Plan. During the groundtruthing process, stakeholders were invited to meet with Shell if they desired.

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 [4].

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: Fourth Annual Status Report. Submitted to AER March 31, 2016.
[5] Special report on InSAR efficacy as per Condition 16 of AER Approval 11837C, submitted to AER March 31, 2017.
[6] Shell Quest Carbon Capture and Storage Project, AER Approval No. 11837C, February, 2017 MMV Plan Update.
[7] Quest Carbon Capture and Storage Project Injection Well Integrity Study, Schlumberger, submitted to AER 2014.
[8] Shell Quest Carbon Capture and Storage Project: 2011 Carbon Capture and Storage Detailed Reports, Capacity Risk and Uncertainty Review. Submitted to Alberta Energy, 2011.
[9] Shell Quest Carbon Capture and Storage Project: 2018 Annual Status Report. Submitted to AER March 31, 2019.

APPENDIX A: REPORT ON 2019 HYDROSHPERE MONITORING PROGRAM

REPORT

Shell Quest Hydrosphere Monitoring Program

2019 HMP Annual Report

Submitted to:

Shell Canada Limited

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Calgary, AB
T2P 2H5

Submitted by:

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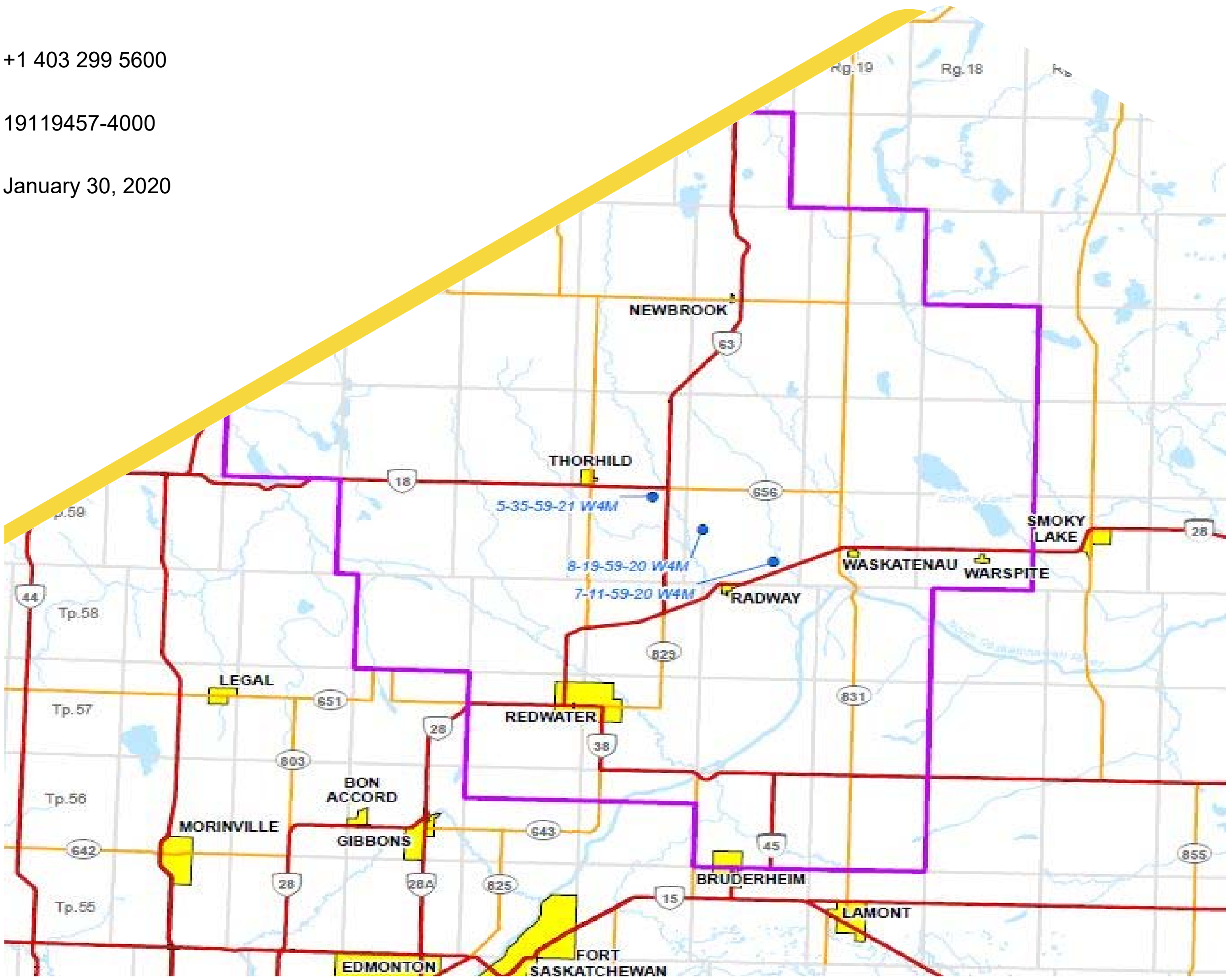
January 30, 2020



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Summary of Groundwater Analytical Results

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by Shell Canada Limited (Shell) to prepare the 2019 Annual Hydrosphere Monitoring Program (HMP) Report, which documents the results from the HMP activities and the Vertical Seismic Profile (VSP) sampling program completed in 2019.

The HMP and VSP sampling are part of Shell's Quest Carbon Capture and Storage (CCS) Measurement, Monitoring and Verification (MMV) plan.

In 2018, Shell submitted an optimized *2018-2019 Groundwater Sampling Plan* to the Alberta Energy Regulator (AER). In a letter dated July 24, 2018, the AER approved Shell's proposed changes to the HMP. The approved changes included the following:

- **Project Monitoring Wells**: continuous monitoring of pH and Electrical Conductivity (EC) using the existing AquaTROLL 600s (AT600s) Multi-Parameter Sondes and performing calibration and/or maintenance activities of the AT600s, as needed. No discrete groundwater and gas sampling, unless there is evidence of potential loss of CO_2 containment.
- **Landowner's water wells**: no discrete sampling, unless there is evidence of potential loss of CO_2 containment.

The VSP sampling involves:

- Flow-testing and groundwater sampling at select Landowner water wells before and after Shell's VSP program.

This report outlines the field activities, sampling methods and analytical results from the HMP and VSP program completed in 2019.

2.0 HYDROSPHERE MONITORING PROGRAM

The 2019 HMP and VSP program involved the following activities:

- Completing flow-testing and groundwater sampling at select Landowner water wells before and after Shell's 2019 VSP program, which took place in February 2019. Pre- and Post-VSP sampling, along with flow-testing, were completed in January and March 2019, respectively. Landowner water wells selected by Shell included 13 wells in the vicinity of the 05-35 and 08-19 well sites.
- Performing maintenance checks on In-Situ Multi-Parameter data loggers Aqua TROLL® 600 (AT600) and downloading pressure and basic water quality data.

The following sections provide a summary of field activities, sampling and testing methods, and analytical results from the 2019 activities.

2.1 Monitoring Well Network

The groundwater monitoring wells are within the Shell Quest sequestration lease area and includes Project wells and participating Landowner water wells identified within a radius of about 1 km of the three injection wellsites.

2.1.1 Project Wells

Project wells are nine (9) Shell-owned groundwater monitoring wells installed by Shell at the three injection wellsites:

- five (5) Project wells at 08-19-059-20 W4M (08-19);
- two (2) Project wells at 07-11-059-20 W4M (07-11); and
- two (2) Project wells at 05-35-059-21 W4M (05-35).

2.1.2 Landowner Wells

The Landowner wells selected by Shell for the 2019 VSP sampling included 13 privately-owned wells in the vicinity of the 05-35 and 08-19 well sites.

2.2 2019 Sampling Schedule

There were no quarterly HMP sampling programs in 2019, as per the optimized HMP approved by the AER. The pre- and post-VSP sampling schedule is presented in Table 1. Where possible, both groundwater and free gas samples from Landowner water wells were planned for sampling during each event.

Table 1: 2019 Planned Groundwater and Free-Gas Sampling Schedule

Sampling Event	Dates	Planned Sampling	Number of Planned Wells	
			Landowner Wells	Project Wells
Pre-VSP	January 2019	Groundwater and Gas	13	0
Post-VSP	March 2019	Groundwater and Gas	13	0

In most cases, groundwater samples were collected from all the water wells planned for sampling. However, in some circumstances, such as when a well was not accessible, it was not possible to collect every sample that was planned. A summary of accomplished sampling is included in Sections 2.4.2 and 2.4.3.

Golder personnel attempted dissolved gas sampling at all planned water well locations following the procedure described in Section 2.3.3. However, dissolved gas samples could not be collected in any of these locations. This was primarily due to the lack of gas separation from the groundwater after a minimum 30-minute purge period and the pressure differential being insufficient to allow gas to build up above the surface saturation levels (i.e. the groundwater contained a very low volume of dissolved gas).

2.3 Field Methodology

2.3.1 Data Loggers

A dedicated AT600 has been installed in each Project well to record daily pressure and basic water quality data (i.e., pH, temperature, conductivity and oxidation-reduction potential). Data recorded by the AT600s are remotely transmitted to Shell via a telemetry system, allowing for monitoring of the data in real time. If issues are identified (e.g., abnormal readings or the probe stops working between scheduled maintenance visits), action is taken to inspect and repair/replace the probes as required.

Since installation, field maintenance activities have been performed every quarter, where the AT600s and associated sensors are removed from the wells, cleaned, inspected, and calibrated according to the manufacturer's specifications. Calibration of pH sensors is completed using fresh standard solutions at pH values of 4.0, 7.0, and 10.0. If any issues with the probe sensors are identified during the maintenance work, the sensors may be replaced or the AT600 unit may be returned to the manufacturer for further checks and repair, in which case, a loan unit from the manufacturer may be temporarily deployed in the Project well.

Downloading of the data and on-site maintenance (i.e., calibration and sensor inspection) were performed by Golder personnel in January, June and August 2019. Maintenance activities were not performed in Q4 2019 as the AT600s were scheduled for complete checks and, if necessary, repairs by the manufacturer.

New sensors for pH, Oxidation Reduction Potential (ORP), Electrical Conductivity (EC) and temperature were purchased in Q3 2019 and subsequently installed in the nine AT600s.

2.3.2 Groundwater Sampling

2.3.2.1 Project Wells

There were no groundwater samples collected from Project wells, as per the optimized HMP approved by the AER.

2.3.2.2 Landowner Wells

At least one week prior to each VSP sampling event, Landowners were contacted for permission to access their property and conduct the sampling.

Groundwater samples from Landowner water wells were collected via a raw water sampling outlet (e.g., an outdoor spigot or kitchen tap), upstream of any known water treatment or softening systems.

- Clean tubing was attached from the sampling outlet to a flow-through (FT) gas separator. The FT gas separator captures gas bubbles that enter the separator or are released from solution within the separator.
- The water was run through the FT gas separator for approximately 25 to 30 minutes. Field parameters (pH, conductivity, temperature and dissolved oxygen) were monitored and recorded during the purging time. Once parameters stabilized, indicating representative groundwater conditions, water samples were collected directly into laboratory-supplied bottles using industry-standard sampling protocols, including, where appropriate, field filtration and the addition of chemical preservatives.
- Landowner water well samples were placed in an ice-filled cooler and submitted under chain-of-custody to AGAT in Edmonton, AB. As much as possible, samples were collected and delivered to the laboratory on the same day of sampling. In cases where same-day delivery was not possible (e.g., due to scheduling, availability of Edmonton staff and/or weather conditions), samples were submitted the following day.

2.3.3 Dissolved Gas Sampling

Concurrently with groundwater sampling, any gas accumulated in the FT gas separator was collected into two Tedlar® bags for laboratory analysis.

The FT gas separator operates by capturing free-phase gas bubbles that enter the separator or are released from solution within the separator. The detailed protocol adopted for flow-through sampling is described in "The Free Gas Sampling Standard Operating Procedure for Baseline Water Well Testing" prepared by Alberta Research Council (Jones et al. 2009).

Typically, gases are fully dissolved at depth and there is no free gas phase in the wells. However, as the sample is pumped to surface, gas bubbles may form in response to the reduced pressure. These bubbles are captured in the FT gas separator.

Although gas collection was attempted at all planned water wells, none of the wells produced sufficient gas for sampling.

2.3.4 Vertical Seismic Profile Testing

The Landowner water wells selected by Shell were flow tested before and after Shell's 2019 VSP program that took place in February. Pre-VSP flow testing was performed in January 2019 and post-VSP testing was performed in March 2019. The selected VSP Landowner water wells included 13 wells in the vicinity of the 05-35 and 08-19 well sites.

Flow testing was conducted to determine drawdown and recharge rates before and after the VSP program. Testing consisted of opening a tap or pumping the well at a constant rate for approximately 60 minutes, followed by a recovery period of 60 minutes. During pumping and recovery, water level data were recorded both manually and using a pressure transducer to log continuous data. Water quality parameters were also recorded during testing. Groundwater sampling (Section 2.3.2) was completed prior to flow testing.

2.3.5 Quality Assurance/Quality Control

The groundwater Quality Assurance/Quality Control (QA/QC) program consisted of collecting field duplicate groundwater and gas samples, and water equipment and field blanks during each sampling event.

Field duplicates were collected to assess the reliability of field sampling procedures. One duplicate was collected for every 10 to 12 regular samples and submitted with the regular samples for laboratory analysis. The measure of the reproducibility or precision of the groundwater and gas chemistry duplicate analyses was quantified by calculating the Relative Percent Difference (RPD) between parameter concentrations of select samples and the corresponding field duplicate samples submitted to the laboratory. RPD values have been calculated for the results that exceed five times the RDL given by the laboratory, as follows:

$$RPD = \frac{\mathrm{S} - \mathrm{D}}{\frac{1}{2}(\mathrm{S} + \mathrm{D})} \text{ x } 100$$

Where:

RPD = relative percent difference;

S = sample value of parameter; and

D = duplicate value of parameter.

Theoretically, the samples should have identical chemical concentrations (i.e., RPD = 0). However, due to factors such as sample matrix heterogeneity, natural variations or variations due to sample collection, handling or analysis, some variation in chemical concentration may occur (i.e., RPD greater or less than 0). Furthermore, reproducibility of duplicate analyses at concentrations near the laboratory Reportable Detection Limit (RDL) can be poor, resulting in RPD values outside the desirable limits. Therefore, for duplicate concentrations greater than five times the RDL, a value of ±25% was considered acceptable.

Because isotope analysis results are relative and not absolute concentrations, RPD comparisons were not performed on isotopic results.

Equipment blanks were collected by running laboratory-grade distilled deionized water over and through decontaminated collection equipment, including flow-through cells, tubing and multiparameter probes. This procedure serves as a check for proper decontamination techniques. If equipment is being decontaminated correctly, results from an equipment blank should be essentially identical to field blanks; ideally with all constituents below RDLs.

Field blanks were collected to assess potential contamination introduced in the field during the sampling process. Field blank samples were filled in the field using laboratory-supplied distilled water, exposing them to the sampling environment. Theoretically, sample concentrations in field blank samples should be below RDLs.

2.3.6 Laboratory Analysis

Laboratory analysis of groundwater samples collected in 2019 was conducted according to the analytical program listed in Table 2. Groundwater samples collected for isotope analysis were forwarded by AGAT to laboratories at the University of Calgary. There were no gas samples collected in 2019.

Table 2: 2019 Laboratory Analysis

Matrix	Analysis Type	Laboratory	Method
Groundwater	Routine water[(a)]	AGAT	Various
	Total iron, total and fecal coliforms	AGAT	Incubator
	Dissolved arsenic	AGAT	ICP-MS, ICP-OES, or CVAA[(d)]
	δ^{13}C-dissolved inorganic carbon	University of Calgary	Isotope-Ratio Mass Spectrometry

Notes:

[(a)] Routine parameters included: pH, alkalinity, bicarbonate, carbonate, hydroxide, electrical conductivity, chloride, fluoride, nitrate, nitrate-N, nitrite, Nitrite-N, nitrate+nitrite-N, sulphate, dissolved calcium, dissolved magnesium, dissolved sodium, dissolved potassium, dissolved iron, dissolved manganese, calculated total dissolved solids (TDS), sodium adsorption ratio (SAR), hardness, ion balance and dissolved inorganic carbon (DIC).

[(b)] Helium, hydrogen, nitrogen, carbon dioxide, hydrogen sulphide, methane (C1), ethane (C2), propane (C3), i-butane (iC4), n-butane (nC4), i-pentane (iC5), n pentane (nC5), hexanes (C6), heptanes (C7), Octanes (C8), Nonanes (C9) and Decanes+ (C10+).

[(c)] $\delta^{13}C_{CH4}$, $\delta^{13}C_{CO2}$, $\delta^{13}C_{C2}$, $\delta^{13}C_{C3}$, $\delta^{13}C_{iC4}$, $\delta^{13}C_{nC4}$

[(f)] Frequency as per Enhance's MMV Plan.

[(d)] Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) or Cold Vapour Atomic Absorption (CVAA) depending upon analyte.

2.4 Results

2.4.1 AT600s Data Download and Maintenance Results

Downloading of the data and on-site maintenance (i.e., calibration and sensor inspection) were performed by Golder personnel in January, June and August 2019. Maintenance activities were not performed in Q4 2019 as the AT600s were scheduled for a complete service and, if necessary, repairs by the manufacturer.

New sensors for pH, ORP, EC and temperature installed in the nine AT600s during the Q3 2019 maintenance activities.

Data currently available for 2019 extends from January 1 to August 23, 2019, with the exception of three Project wells (1F1/08-19, UL1/05-35 and UL1/05-35), where the data extends up to June. This is because the well caps (flange) of these three Project wells were temporarily removed (on June 10 & 11, 2019) for fabrications, and the associated AT600 could not be suspended/deployed in the Project wells until the fabrication was complete.

The total number of water pressure data points collected during this period are summarized in Table 3. Data from the remainder of 2019 will be downloaded during the 2020 Q1 event. A summary of the data downloaded from each AT600 in 2019 (as minimum, maximum, average, standard deviation and count) is included in Appendix A.

Table 3: 2019 AT600s Data Summary

Project Well ID	2019 Date Range	2019 Data Points Collected[(a)]
8195920400 (1F1/08-19)	January 1 to June 11	162
8195920401 (UL1/08-19)	January 1 to August 23	235
8195920402 (UL2/08-19)	January 1 to August 23	235
8195920403 (UL3/08-19)	January 1 to August 2	214
8195920404 (UL4/08-19)	January 1 to August 23	235
5355921400 (1F1/05-35)	January 1 to August 23	205
5355921401 (UL1/05-35)	January 1 to June 6	162
7115920400 (1F1/07-11)	January 1 to August 23	235
7115920401 (UL1/07-11)	January 1 to June 10	161

Note: [(a)] Represents number of water pressure data points collected for the specified date range. Number of data points for remaining water quality parameters (temperature, pH, ORP, conductivity) may vary.

2.4.2 Groundwater Sampling and Analytical Results

The number of wells sampled in 2019 are summarized in Table 4. Of the 13 planned Landowner water wells, one well could not be sampled as per Landowner's request (integrity of well is questionable).

Table 4: 2019 Accomplished Groundwater Sampling

Sampling Event	Groundwater Analysis[(a)]	Number of Wells Sampled/Tested		
		Landowners Well	Project Wells	Flow Testing[(b)]
VSP sampling	Pre-VSP Chemistry	12	0	10
	Post-VSP Chemistry	12	0	10

Notes:
[(a)] Pre- and Post-VSP chemistry shown in Section 2.3.6.
[(b)] refer to Section 2.3.4 for details.

The analytical results from groundwater samples collected in 2019 are summarized in Appendix B. Sample blanks have not been included in the summary.

2.4.3 Gas Sampling and Analytical Results

None of the Landowner water wells selected for the VSP sampling in 2019 produced sufficient gas for sampling.

2.4.4 Vertical Seismic Profile

Landowner water wells selected for VSP flow testing included 13 wells in the vicinity of the 05-35 and 08-19 well sites. Of the 13 Landowner wells, three water wells (Wells #6, 12 and 13) could not be flow-tested as per Landowner request and/or accessibility.

2.4.5 Quality Assurance/Quality Control

Duplicate groundwater samples, along with groundwater equipment and field blanks, were collected during each sampling event to assess precision of field sampling procedures and the quality of reported analytical results. The QA/QC samples collected are summarized in Table 5.

Table 5: 2019 Quality Assurance/Quality Control Sampling

Sampling Event	Groundwater QA/QC Samples		Gas QA/QC Samples[a]	
	Duplicates	Water Blanks	Duplicates	Blanks
Pre-VSP	2	1	0	0
Post-VSP	2	1	0	0

Note:
[a] there were no gas samples collected in 2019.

The QA/QC results for samples collected as part of the pre- and post-VSP events were included in their respective quarterly report previously delivered to Shell (Golder 2019). All calculated RPDs for groundwater samples were within the ±25% criterion.

For water blanks samples, a QA/QC exceedance (i.e., results greater than the RDL) was noted for ion balance in the two field blank samples and for electrical conductivity in one field blank sample. Field and equipment blank samples were prepared using standard distilled water. This matrix is not filtered for specific metal/inorganic parameters; therefore, the concentrations are likely naturally occurring within these blank samples. Under these circumstances, the data reported can be considered reliable.

3.0 SUMMARY

The following is a summary of the Hydrosphere Monitoring Program completed in 2019:

- Flow-testing and groundwater sampling of Landowner water wells before and after Shell's 2019 VSP program. Of the 13 water wells selected for sampling, one well (Well #13) could not be sampled as per Landowner's request and three wells (Wells #6, 12 and 13) were not flow tested as per Landowner's request.
- Three quarterly (Q1 to Q3) maintenance checks on In-Situ Multi-Parameter data loggers Aqua TROLL® 600 and downloading pressure and basic water quality data.
- Golder personnel attempted gas sampling at all planned water well locations; however, gas samples could not be collected due to either low pressures or volumes of dissolved gas.

4.0 REFERENCES

Golder (Golder Associates Ltd.). 2019. *Shell Quest Hydrosphere Monitoring Program, 2019 Q1 Hydrosphere Data Report*. May 17, 2019.

Jones, D., S. Gordon, B. Mayer, M. Hitz, and A. Blyth. 2009. *The Free Gas Sampling Standard Operating Procedure for Baseline Water Well Testing*. Prepared by Alberta Research Council Inc. for Alberta Environment and Sustainable Resource Development, March 31, 2009, 13 p.

Signature Page

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APEGA Permit to Practice P5122

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APPENDIX A

Summary of AT600 Downaloaded Data

AT600s 2019 Summary Data
Shell Quest Carbon Capture and Storage Hydrosphere Monitoring Program
Shell Canada Limited

Parameter	Water Pressure (kPa)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	878.75	180.92	853.30	243.28	1247.51	753.24	514.64	304.93	113.97
Max	885.01	182.11	859.73	246.42	1270.39	757.20	529.11	306.18	114.92
Average	881.77	181.40	856.05	245.17	1255.59	756.01	528.49	305.59	114.39
STDV	1.65	0.24	1.90	0.93	8.63	0.70	1.01	0.24	0.20
Count	205	162	235	161	162	235	235	214	235

Parameter	Water Level (mbgs)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	27.51	2.25	37.87	4.90	37.48	20.06	6.08	4.60	5.24
Max	27.82	2.64	38.42	5.35	40.00	20.43	7.56	5.03	5.32
Average	27.61	2.37	38.13	5.05	39.34	20.22	6.15	4.69	5.29
STDV	0.06	0.12	0.13	0.14	0.64	0.07	0.10	0.13	0.02
Count	205	162	235	161	162	235	235	214	235

Parameter	Water Level (masl)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	613.56	638.74	597.87	630.76	598.65	618.22	631.07	633.57	633.38
Max	613.87	639.13	598.42	631.21	601.17	618.59	632.55	634.00	633.46
Average	613.77	639.01	598.16	631.06	599.31	618.43	632.48	633.91	633.41
STDV	0.06	0.12	0.13	0.14	0.64	0.07	0.10	0.13	0.02
Count	205	162	235	161	162	235	235	214	235

Parameter	Barometric Pressure (kPa)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	93.21	92.25	92.96	92.38	94.15	92.76	92.37	92.08	91.96
Max	97.70	96.92	97.64	97.02	94.49	98.01	96.98	96.66	96.55
Average	95.31	94.47	95.30	94.60	94.37	95.58	94.68	94.38	94.27
STDV	0.71	0.83	0.74	0.82	0.16	0.78	0.73	0.75	0.72
Count	205	162	235	161	162	235	235	214	235

Parameter	Temperature (°C)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	6.43	5.01	7.07	5.12	8.16	6.37	5.46	5.20	5.30
Max	6.48	5.05	7.18	5.20	8.30	6.57	5.52	5.21	5.43
Average	6.47	5.03	7.11	5.18	8.22	6.40	5.50	5.21	5.38
STDV	0.01	0.01	0.02	0.01	0.05	0.05	0.01	0.00	0.04
Count	205	162	235	161	162	235	235	214	235

Parameter	Oxidation Reduction Potential (V)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	-0.38	-0.54	-0.54	-1.40	-0.78	-0.45	-0.45	-0.52	-0.52
Max	-0.20	-0.36	-0.18	-0.26	-0.22	-0.19	-0.02	-0.10	0.00
Average	-0.33	-0.51	-0.44	-1.04	-0.64	-0.33	-0.34	-0.43	-0.43
STDV	0.04	0.05	0.09	0.43	0.17	0.05	0.13	0.07	0.10
Count	205	162	235	161	162	235	235	214	235

Parameter	pH								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	8.16	9.41	7.65	0.00	10.76	6.95	7.45	7.56	8.11
Max	8.68	9.63	8.48	10.12	12.02	7.57	7.71	8.08	8.74
Average	8.36	9.52	8.08	3.80	11.10	7.20	7.58	7.79	8.39
STDV	0.14	0.07	0.33	4.88	0.37	0.22	0.10	0.21	0.26
Count	205	162	235	161	162	235	235	214	235

AT600s 2019 Summary Data
Shell Quest Carbon Capture and Storage Hydrosphere Monitoring Program
Shell Canada Limited

Parameter	Specific Conductivity (µS/cm)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	20,854.47	1,838.85	12,990.77	1,508.42	29,182.91	20,403.26	11,951.60	4,947.89	1,813.33
Max	21,918.19	1,877.81	13,684.47	1,717.41	30,127.90	23,513.87	15,444.07	6,419.53	2,001.86
Average	21,698.40	1,862.17	13,116.95	1,627.49	29,514.63	21,736.03	12,960.21	5,320.93	1,839.16
STDV	229.62	9.59	149.15	85.35	406.35	997.87	1,421.96	610.94	49.23
Count	205	162	235	161	162	235	235	214	235

Parameter	Actual Conductivity (µS/cm)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	15,455.04	1,137.82	8,546.03	1,043.39	22,585.49	13,152.49	8,642.51	3,549.61	1,135.24
Max	16,256.39	1,161.17	9,011.63	1,086.31	23,385.05	15,982.95	9,689.50	3,992.51	1,252.88
Average	16,091.16	1,151.74	8,635.27	1,062.61	22,872.91	15,187.84	8,931.77	3,671.49	1,149.81
STDV	174.38	5.66	99.85	16.63	345.31	1,051.80	395.80	176.87	31.13
Count	205	162	235	161	162	235	235	214	235

Parameter	Salinity (PSU)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	14.18	0.92	7.35	0.83	20.46	11.92	7.77	3.03	0.91
Max	14.97	0.94	7.77	0.87	21.19	14.72	8.79	3.43	1.00
Average	14.81	0.93	7.43	0.85	20.72	13.93	8.05	3.14	0.92
STDV	0.17	0.01	0.09	0.01	0.31	1.05	0.39	0.16	0.03
Count	205	162	235	161	162	235	235	214	235

Parameter	TDS (ppm)								
Project Well	1F1/05-35	UL1/05-35	1F1/07-11	UL1/07-11	1F1/08-19	UL1/08-19	UL2/08-19	UL3/08-19	UL4/08-19
Min	13,555.41	1,195.25	8,444.00	980.47	18,968.89	13,262.12	7,768.54	3,216.13	1,178.67
Max	14,246.82	1,220.58	8,894.91	1,116.32	19,583.14	15,284.01	10,038.65	4,172.69	1,301.21
Average	14,103.96	1,210.38	8,526.02	1,057.87	19,184.51	14,128.42	8,424.13	3,458.60	1,195.46
STDV	149.25	6.25	96.95	55.48	264.13	648.61	924.28	397.11	32.00
Count	205	162	235	161	162	235	235	214	235

Notes:
STDV - Standard Deviation
kPa - kilopascal
m - metres
masl - metres above sea level
mbgs - metres below ground surface
V - volts
ppm - parts per million
PSU - practical salinity unit
TDS - Total Dissolved Solids
uS/cm - microsiemens per centimeter
°C - degree Celsius

APPENDIX B

Summary of Groundwater Analytical Results

Table B1
Pre-VSP 2019 Groundwater Analytical Results Summary
Shell Quest Carbon Capture and Storage Hydrosphere Monitoring Program
Shell Canada Limited

Parameter	Unit	Well 1	Well 2	Well 3	Well 4	Well 4 (duplicate)	Well 5	Well 6	Well 7	Well 7 (duplicate)	Well 8	Well 9	Well 10	Well 11	Well 12
		25-Jan-19	23-Jan-19	23-Jan-19	24-Jan-19	24-Jan-19	24-Jan-19	25-Jan-19	28-Jan-19	28-Jan-19	31-Jan-19	31-Jan-19	22-Jan-19	22-Jan-19	30-Jan-19
Field Parameters															
pH	-	7.23	7.38	7.49	7.27	7.27	7.34	7.24	7.35	7.35	8.35	8.17	7.63	8.29	7.76
Temperature of Water	degC	4.90	3.3	4.3	5.4	5.4	3.1	4.1	7	7.0	5.7	4.8	4.9	4.5	4.3
Dissolved Oxygen (O_2)	mg/L	1.70	3.17	0.49	0.4	0.4	1.14	3.63	0.74	0.74	0.9	0.5	0.61	0.62	0.6
Oxidation Reduction Potential	mV	15	-15.2	-23.4	142.9	142.9	120	33.6	100.6	101	-87.5	-71.3	-248.5	-98	129.2
Turbidity	NTU	9.50	5.2	21	3.6	3.6	8.2	33.3	38.9	38.9	1,399	1,089	178.5	20.5	299
Electrical Conductivity	uS/cm	1,770	1,694	2,095	1,331	1,331	1,925	1,339	817	817	1,217	1,164	1,791	2,226	1,117
Conventional Parameters															
pH	-	8.19	8.13	8.11	8.1	8.12	8.03	8.09	8.13	8.12	8.45	8.44	8.33	8.57	8.2
Hardness	mg/L	162.0	250	195	225	226	946	251	31	31	16	12	152	56	218
Total Dissolved Solids	mg/L	1,740	1,920	2,260	1,340	1,330	2,100	1,370	784	784	1,190	1,180	1,920	2,550	1,220
Electrical Conductivity	uS/cm	2,920	2,830	3,390	2,120	2,160	3,240	2,260	1,350	1,360	2,080	2,070	3,160	4,010	2,030
Alkalinity, total (as $CaCO_3$)	mg/L	902	826	928	755	743	728	758	581	581	721	781	1,040	887	605
Alkalinity, phenolphthalein ($CaCO_3$)	mg/L	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	14	13	6	25	< 5
Dissolved Inorganic Carbon	mg/L	156.0	146	163	130	130	126	130	96	102	14	17	205	190	16
SAR	-	18.30	16.7	23	10.2	10.3	4.34	10	23.3	23.2	48.6	53.3	22.6	48.8	9.96
Major Ions															
Dissolved Calcium (Ca)	mg/L	49.50	61.8	54.7	63.8	63.3	199	74.6	8.3	8.3	5.1	4	38.6	18.8	61.8
Dissolved Magnesium (Mg)	mg/L	9.30	23.2	14.3	15.9	16.4	109	15.6	2.5	2.5	0.9	0.6	13.6	2.3	15.4
Dissolved Potassium (K)	mg/L	7.0	6.1	7.2	5.3	5.2	4.7	8.4	2	2.0	2.4	2.1	3.8	4.2	4.4
Dissolved Sodium (Na)	mg/L	536	608	738	350	355	307	364	298	297	453	433	641	843	338
Bicarbonate (HCO_3)	mg/L	1,100	1,010	1,130	921	906	888	924	708	709	880	953	1,260	1,020	738
Carbonate (CO_3)	mg/L	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	27	27	8	30	< 5
Chloride (Cl)	mg/L	38.0	25	16	4	4	283	30	28	29	233	241	59	12	296
Fluoride (F)	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.16	0.14	< 0.05	< 0.05	0.65	0.24	< 0.05
Sulphate (SO_4)	mg/L	555	694	871	439	434	534	422	97	97	34	< 1	537	1,140	117
Hydroxide (OH)	mg/L	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Ion Balance	%	87.0	100	98	81	83	87	85	95	94.0	89	82	92	91	83
Nutrients															
Nitrate-N (NO_3-N)	mg/L	0.50	0.75	< 0.02	2.35	2.28	51.3	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	4.86
Nitrate (NO_3)	mg/L	2.20	3.3	< 0.5	10.4	10.1	227	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.2	< 0.2	21.5
Nitrite-N (NO_2-N)	mg/L	< 0.01	< 0.01	< 0.01	0.09	0.09	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Nitrite (NO_2)	mg/L	< 0.05	< 0.05	< 0.05	0.29	0.28	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.10	< 0.10	< 0.05
Dissolved Metals															
Dissolved Arsenic (As)	mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.0020
Dissolved Iron (Fe)	mg/L	0.40	< 0.1	0.3	< 0.1	< 0.1	< 0.1	0.5	< 0.1	< 0.1	0.1	< 0.1	0.6	< 0.1	< 0.1
Dissolved Manganese (Mn)	mg/L	0.077	0.052	0.071	0.043	0.045	0.056	0.174	0.022	0.022	0.117	0.008	0.048	0.048	0.04
Total Metals															
Total Iron (Fe)	mg/L	1.10	0.2	0.7	< 0.1	< 0.1	0.2	2.8	0.1	< 0.1	0.2	0.1	1.6	< 0.1	0.4
Biological Parameters															
Total Coliform	MPN/100 mL	< 1	< 1	< 1	< 1	< 1	< 1	2	20	23.0	< 1	< 1	345	< 1	< 1
Fecal Coliform	MPN/100 mL	< 1	< 1	< 1	< 1	< 1	< 1	2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Carbon Isotope in Water															
$\delta^{13}C_{-DIC}$	‰	-13.70	-14.67	-14.86	-12.19	-13.8	-10.36	-13.6	-10.54	-11.19	-13.76	-16.38	-15.03	-18.5	-14.40

Notes:
degC - degree Celsius
mL - millilitres
mg/L - milligrams per litre
MPN - most probable number
mV - millivolts
nd - not detected; no concentrations observed above RDL
NTU - nephelometric turbidity unit
RDL - reportable detection limit
‰ - per mil
\> - greater than
< - less than
'-' - no data

Table B2
Post-VSP 2019 Groundwater Analytical Results Summary
Shell Quest Carbon Capture and Storage Hydrosphere Monitoring Program
Shell Canada Limited

Parameter	Unit	Well 1	Well 2	Well 2 (duplicate)	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 9 (duplicate)	Well 10	Well 11	Well 12
		11-Mar-19	28-Feb-19	28-Feb-19	4-Mar-19	1-Mar-19	1-Mar-19	1-Mar-19	7-Mar-19	5-Mar-19	5-Mar-19	5-Mar-19	8-Mar-19	8-Mar-19	7-Mar-19
Field Parameters															
pH	-	7.26	7.38	7.38	7.3	7.32	6.94	7.35	7.3	8.32	8.23	8.23	7.75	8.39	7.52
Temperature of Water	degC	5.10	4.5	4.5	4	4.3	2.7	4.4	17.4	5.8	4.1	4.1	5.1	4.3	4.4
Dissolved Oxygen (O_2)	mg/L	1.12	2.29	2.29	0.7	1.19	0.68	2.94	0.75	0.5	0.72	0.72	0.53	0.8	0.730
Oxidation Reduction Potential	mV	7.4	-72.3	-72.3	24.8	163.7	163.7	18.9	124.9	-92.4	-66.6	-66.6	-179	61	145.5
Turbidity	NTU	6.8	-0.2	-0.2	10.1	-0.9	26	14.7	117	126.1	187	187	24.9	177.2	123.1
Electrical Conductivity	uS/cm	1,590	1,723	1,723	1,937	1,292	1,863	1,316	1,046	1,275	1,189	1,189	1,640	1,934	1,082
Conventional Parameters															
pH	-	8.01	7.93	8.07	8.07	7.97	7.89	8.02	8.02	8.4	8.38	8.39	8.13	8.41	8.06
Hardness	mg/L	182	227	231	175	234	868	235	35	14	13	13	143	52	243
Total Dissolved Solids	mg/L	1,910	1,860	1,910	2,180	1,290	2,090	1,290	810	1,130	1,110	1,100	1,940	2,470	1,140
Electrical Conductivity	uS/cm	2,900	2,900	2,880	3,320	2,090	3,140	2,130	1,460	2,040	2,010	2,010	2,930	3,610	2,030
Alkalinity, total (as $CaCO_3$)	mg/L	886	832	813	910	729	712	748	579	703	758	759	883	771	611
Alkalinity, phenolphthalein ($CaCO_3$)	mg/L	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	10	10	10	< 5	12	< 5
Dissolved Inorganic Carbon	mg/L	164	210	194	224	170	166	175	131	168	179	182	48	142	119.0
SAR	-	19.3	16.8	17.3	24.4	11	5.48	10.8	23.8	49.9	52.5	51.1	25.2	51.7	10
Major Ions															
Dissolved Calcium (Ca)	mg/L	54.3	58.6	59.7	50.2	63.8	191	66.6	9.1	4.6	4.2	4.3	34.9	17.2	68.8
Dissolved Magnesium (Mg)	mg/L	11.30	19.5	19.8	12.1	18.1	94.9	16.6	2.9	0.6	0.6	0.6	13.5	2.2	17.20
Dissolved Potassium (K)	mg/L	7.9	5.4	5.5	6.9	5.9	7.1	8.6	2.2	2.2	2.1	2.2	4	4.3	5
Dissolved Sodium (Na)	mg/L	600	583	603	744	385	371	382	322	429	435	427	693	858	358
Bicarbonate (HCO_3)	mg/L	1,080	1,020	992	1,110	889	869	912	707	858	925	926	1,080	941	746
Carbonate (CO_3)	mg/L	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	21	19	21	< 5	24	< 5
Chloride (Cl)	mg/L	7	22	20	14	3	217	18	27	236	194	194	51	16	216.0
Fluoride (F)	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.15	0.2	0.23	0.2	< 0.05	< 0.05	< 0.05
Sulphate (SO_4)	mg/L	696	674	708	804	373	681	348	99	10	< 1	< 1	617	1,090	84.0
Hydroxide (OH)	mg/L	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Ion Balance	%	93.0	96	98	102	96	93	95	102	88	90	88	104	98	101
Nutrients															
Nitrate-N (NO_3-N)	mg/L	< 0.02	< 0.02	0.7	< 0.02	1.58	22	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	4.41
Nitrate (NO_3)	mg/L	< 0.5	< 0.5	3.1	< 0.5	7	97.3	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	19.5
Nitrite-N (NO_2-N)	mg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Nitrite (NO_2)	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Dissolved Metals															
Dissolved Arsenic (As)	mg/L	0.0020	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.0010
Dissolved Iron (Fe)	mg/L	0.30	< 0.1	< 0.1	0.3	< 0.1	< 0.1	0.4	0.1	0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1
Dissolved Manganese (Mn)	mg/L	0.06	0.051	0.054	0.068	0.049	0.102	0.162	0.025	0.07	0.006	0.006	0.05	0.053	0.032
Total Metals															
Total Iron (Fe)	mg/L	1.1	0.4	0.2	0.9	< 0.1	0.1	2.6	0.1	0.1	< 0.1	< 0.1	2.2	0.1	0.40
Biological Parameters															
Total Coliform	MPN/100 mL	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	45	< 1	3.0
Fecal Coliform	MPN/100 mL	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1	< 1
Carbon Isotope in Water															
$\delta^{13}C_{-DIC}$	‰	-14.51	-14.86	-15.07	-15.1	-13.13	-10.9	-13.11	-11.02	-13.04	-16.61	-16.54	-14.25	-17.71	-14.69

Notes:
degC - degree Celsius
mL - millilitres
mg/L - milligrams per litre
MPN - most probable number
mV - millivolts
nd - not detected; no concentrations observed above RDL

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APPENDIX B: 2019 MICROSEISMIC LOCATABLE EVENTS

Locations, times, and magnitudes for all locatable events detected to date. None of the locatable events constitute an MMV trigger, all are located <10km from an injection well (AOR), and all have small measured moment magnitudes less than 0.8.

For reference, the BCS injection zone is located at approximately 1430m TVDSS.

Event	Date	Time	TVDss (m)	Northing (m)	Easting (m)	Moment Magnitude	Distance to Deep Geophone (m)	Formation
1	7/5/2016	23:21:56	3200	6000406	371492	-1.3	3533	Precambrian
2	10/29/2016	2:36:17	1671	5996421	367929	-0.6	3211	Precambrian
3	12/29/2016	9:26:57	1938	5997314	372578	-1.3	2076	Precambrian
4	1/8/2017	0:01:06	2753	5995322	370696	-0.7	2991	Precambrian
5	1/9/2017	14:57:57	3121	5995558	370794	-0.7	3047	Precambrian
6	1/9/2017	18:21:41	3038	5995488	370960	-0.6	3046	Precambrian
7	1/14/2017	6:17:30	3108	5995470	370777	-1.0	3101	Precambrian
8	1/14/2017	20:01:45	2853	5995307	370676	-0.7	3063	Precambrian
9	1/16/2017	14:13:57	3071	5995482	370970	-0.6	3073	Precambrian
10	1/17/2017	15:46:12	3003	5995457	370832	-1.0	3041	Precambrian
11	1/17/2017	17:01:08	2601	5998196	369001	-0.8	2438	Precambrian
12	1/17/2017	21:00:46	2953	5995410	370716	-0.4	3044	Precambrian
13	1/22/2017	4:22:30	3047	5995506	370834	-0.4	3034	Precambrian
14	1/24/2017	16:26:59	3113	5995521	370937	-1.0	3072	Precambrian
15	1/25/2017	22:36:47	3100	5995606	370925	-1.1	3001	Precambrian
16	1/27/2017	19:07:11	3268	5995545	370798	-1.1	3160	Precambrian
17	1/28/2017	1:28:50	2897	5995384	370968	-0.5	3034	Precambrian
18	1/28/2017	23:02:49	1581	5997734	370764	-1.1	586	Precambrian
19	1/29/2017	0:18:30	1607	5997738	370792	-1.7	612	Precambrian
20	1/29/2017	13:34:18	3088	5995548	370885	-1.1	3033	Precambrian
21	1/30/2017	13:18:09	2980	5995445	370926	-0.6	3038	Precambrian
22	2/5/2017	0:24:26	2992	5995489	370811	0.1	3009	Precambrian
23	2/5/2017	1:01:46	2999	5995480	370786	-0.2	3021	Precambrian
24	2/5/2017	1:02:08	2863	5995377	370842	-0.4	3013	Precambrian
25	2/5/2017	1:04:21	2889	5995359	370762	-0.4	3042	Precambrian
26	2/5/2017	23:32:27	3079	5995523	370880	-0.2	3044	Precambrian
27	2/7/2017	1:29:53	3020	5995498	370890	0.1	3023	Precambrian
28	2/7/2017	13:49:45	2850	5997346	368787	-1.1	2750	Precambrian
29	2/12/2017	0:33:14	3005	5995501	370968	-0.5	3015	Precambrian
30	2/12/2017	17:13:42	2869	5995398	370985	0.1	3007	Precambrian

31	2/12/2017	17:15:35	2987	5995483	370983	-0.8	3017	Precambrian
32	2/13/2017	8:04:57	2989	5995488	370963	-0.9	3014	Precambrian
33	2/13/2017	8:23:39	2950	5995444	370842	-0.9	3016	Precambrian
34	2/13/2017	18:52:53	2980	5995443	371004	-0.6	3044	Precambrian
35	2/14/2017	1:14:58	2946	5995456	370981	-0.5	3011	Precambrian
36	2/14/2017	7:01:27	2956	5995413	370974	-0.7	3049	Precambrian
37	2/14/2017	7:43:12	3169	5995615	370906	-1.0	3043	Precambrian
38	2/14/2017	21:34:33	3031	5995492	370978	-0.3	3040	Precambrian
39	2/15/2017	6:29:05	2968	5995419	370764	-1.2	3046	Precambrian
40	2/15/2017	17:44:52	2987	5995458	371003	-0.9	3037	Precambrian
41	2/16/2017	11:30:38	2878	5995368	371000	-0.7	3037	Precambrian
42	2/17/2017	11:33:07	2961	5995441	370965	-0.8	3031	Precambrian
43	2/18/2017	19:36:08	2968	5995391	370964	-0.1	3073	Precambrian
44	2/18/2017	19:42:37	3009	5995441	370982	-0.4	3063	Precambrian
45	2/20/2017	13:15:39	3014	5995365	370958	-0.7	3122	Precambrian
46	2/20/2017	13:15:43	3013	5995451	370978	-0.8	3058	Precambrian
47	2/21/2017	10:17:11	2919	5995388	371011	-0.7	3048	Precambrian
48	2/21/2017	21:18:10	3014	5995458	370963	-0.9	3053	Precambrian
49	2/22/2017	19:30:15	2940	5995445	370960	0.1	3014	Precambrian
50	3/5/2017	14:22:54	2992	5995499	370989	-0.7	3009	Precambrian
51	3/7/2017	1:44:41	2941	5995455	370974	-1.1	3008	Precambrian
52	3/7/2017	8:19:57	3200	5994843	372584	-0.9	4064	Precambrian
53	3/11/2017	8:54:00	3177	5995527	371085	-1.2	3123	Precambrian
54	3/18/2017	17:54:29	3148	5995661	371069	-0.4	3007	Precambrian
55	3/22/2017	8:31:44	2648	5999780	361029	-0.5	10096	Precambrian
56	3/23/2017	3:38:19	1504	5994748	370848	-1.1	3036	Precambrian
57	3/24/2017	16:27:12	2605	5997779	371601	-1.6	1809	Precambrian
58	3/28/2017	10:22:50	3017	5995471	370918	-0.5	3042	Precambrian
59	3/30/2017	21:16:16	3042	5995487	370912	-1.0	3047	Precambrian
60	4/6/2017	15:58:04	1552	5998070	365907	-0.5	4914	Precambrian
61	4/11/2017	1:35:50	2915	5995475	371042	-1.0	2981	Precambrian
62	4/15/2017	12:45:33	2869	5995436	371327	-0.2	3020	Precambrian
63	4/15/2017	18:05:51	2594	5997955	369672	-1.4	1956	Precambrian
64	4/17/2017	7:35:19	3045	5995475	371002	-0.5	3063	Precambrian
65	4/17/2017	18:24:44	2953	5995399	370883	0.1	3054	Precambrian
66	4/18/2017	0:14:46	3181	5995613	370911	-0.2	3053	Precambrian
67	4/18/2017	3:32:06	3009	5995476	370929	-0.5	3034	Precambrian
68	4/18/2017	12:39:32	3130	5995577	370900	-0.6	3042	Precambrian
69	5/2/2017	23:05:52	2995	6004059	360815	-0.4	11966	Precambrian
70	5/7/2017	0:32:49	2888	5995365	371391	-0.9	3098	Precambrian
71	5/7/2017	18:00:15	2164	5999939	370197	-1.0	2557	Precambrian
72	5/19/2017	8:08:40	2914	5996897	376547	-0.4	6138	Precambrian

73	6/10/2017	13:12:04	2896	5998512	365385	-0.1	5770	Precambrian
74	6/12/2017	0:06:02	3155	5995408	371049	-1.1	3190	Precambrian
75	6/21/2017	2:01:16	2441	5997833	368821	-0.9	2435	Precambrian
76	6/29/2017	1:42:45	2616	5999699	370610	-1.2	2548	Precambrian
77	7/2/2017	22:19:02	1941	5997919	370872	-1.1	967	Precambrian
78	7/4/2017	22:42:12	3096	5995310	370889	-1.0	3214	Precambrian
79	7/5/2017	4:19:55	2631	5997477	369784	-1.2	1932	Precambrian
80	7/6/2017	15:35:45	2501	5996886	367136	-0.8	4033	Precambrian
81	7/13/2017	21:44:08	1937	5997191	372822	-1.2	2317	Precambrian
82	8/3/2017	0:49:20	2501	5997267	368263	-0.2	2969	Precambrian
83	8/3/2017	7:01:02	2500	5998961	372477	-0.9	2577	Precambrian
84	8/6/2017	8:12:58	2500	5998944	372768	-0.8	2770	Precambrian
85	8/9/2017	16:59:55	2812	5996764	370858	-1.1	2064	Precambrian
86	8/10/2017	20:35:57	2893	5995430	370873	0.1	2991	Precambrian
87	8/19/2017	0:45:19	1702	5997405	371276	-1.5	927	Precambrian
88	8/28/2017	16:21:14	2527	5997804	367059	-0.5	4023	Precambrian
89	9/25/2017	2:54:21	2996	5996942	368611	-1.1	3056	Precambrian
90	9/25/2017	13:39:56	2500	5998006	376660	-0.4	6077	Precambrian
91	9/26/2017	20:29:04	2686	6001652	360891	-0.2	10766	Precambrian
92	9/27/2017	9:03:53	2704	5988267	380218	0.0	13482	Precambrian
93	9/30/2017	19:41:14	1897	5997466	366935	-0.3	3957	Precambrian
94	10/1/2017	11:58:18	2292	5997783	370114	-1.3	1458	Precambrian
95	10/23/2017	2:20:33	2581	5995986	368814	-1.1	3074	Precambrian
96	10/25/2017	20:59:14	1800	5996710	376553	-0.4	5921	Precambrian
97	10/25/2017	21:54:48	1976	5996438	376637	-0.3	6082	Precambrian
98	10/25/2017	21:57:08	2394	5997216	376758	-0.4	6164	Precambrian
99	10/25/2017	22:00:10	1997	5997138	376706	-0.3	6042	Precambrian
100	10/25/2017	22:23:45	1856	5996465	376645	-0.6	6065	Precambrian
101	10/25/2017	22:27:57	1824	5995488	376270	-0.6	5993	Precambrian
102	10/25/2017	22:30:37	2372	5996239	376658	-0.8	6223	Precambrian
103	10/25/2017	22:55:59	2159	5996882	376913	-0.3	6303	Precambrian
104	10/26/2017	22:24:59	2185	5996532	376659	-0.5	6121	Precambrian
105	10/28/2017	18:48:16	2233	5995549	368173	-1.1	3622	Precambrian
106	11/11/2017	19:53:14	2555	5994078	377987	-0.6	8235	Precambrian
107	11/18/2017	19:27:40	2121	5996426	368847	-0.7	2593	Precambrian
108	11/21/2017	7:30:19	2346	5996522	368949	-1.2	2580	Precambrian
109	12/1/2017	6:51:35	3000	5995196	371405	-1.1	3299	Precambrian
110	12/7/2017	0:56:41	2402	5997697	371943	-1.3	1827	Precambrian
111	12/7/2017	17:04:18	2094	5999947	370091	-0.9	2559	Precambrian
112	12/13/2017	4:47:44	1538	5998169	371309	-1.7	872	Precambrian
113	12/25/2017	7:25:37	2288	5999897	372950	-1.2	3323	Precambrian
114	12/27/2017	14:36:47	2446	5997735	370396	-1.3	1500	Precambrian

115	1/10/2018	11:19:25	2024	6004886	366962	0.2	8166	Precambrian
116	1/13/2018	10:46:54	3038	5996843	368794	-1.0	2986	Precambrian
117	1/14/2018	22:29:28	1835	5996947	377446	-0.6	6767	Precambrian
118	1/15/2018	5:17:33	1703	5995538	369367	-0.7	2709	Precambrian
119	1/16/2018	7:13:36	2635	5999428	372079	-1.4	2689	Precambrian
120	1/18/2018	16:43:04	2923	5996767	368762	-1.0	2954	Precambrian
121	1/29/2018	20:23:46	2685	5997040	367108	-0.8	4101	Precambrian
122	2/4/2018	12:58:24	2147	5998166	370431	-1.6	1276	Precambrian
123	2/5/2018	11:51:26	2148	5995940	369143	-1.3	2691	Precambrian
124	2/10/2018	13:23:38	3210	5997032	368997	-0.7	2929	Precambrian
125	2/12/2018	17:25:56	2345	5996743	368923	-1.2	2502	Precambrian
126	2/13/2018	4:07:46	2130	5997467	368578	-1.4	2491	Precambrian
127	2/20/2018	19:37:51	2215	5998115	370992	-1.7	1294	Precambrian
128	3/10/2018	13:27:23	2037	5997158	366615	-0.8	4331	Precambrian
129	3/10/2018	22:55:14	2301	5991908	370735	-0.9	5977	Precambrian
130	3/10/2018	22:55:19	3061	5992110	370360	-1.0	6012	Precambrian
131	3/10/2018	22:56:26	2293	5991908	370452	-0.8	5984	Precambrian
132	3/10/2018	23:34:38	2426	5991956	371183	-0.9	5972	Precambrian
133	3/10/2018	23:35:44	3143	5992164	371397	-1.0	6007	Precambrian
134	3/11/2018	12:30:14	1503	5991956	371952	-0.6	5924	Precambrian
135	3/11/2018	13:51:50	1508	5991964	371908	-0.9	5908	Precambrian
136	3/11/2018	15:03:36	1520	5991970	371906	-0.8	5903	Precambrian
137	3/11/2018	15:04:52	1846	5991830	370908	-0.8	5972	Precambrian
138	3/11/2018	21:04:33	2318	5997734	370808	-1.3	1323	Precambrian
139	3/12/2018	0:10:13	1625	5991861	370786	-0.7	5913	Precambrian
140	3/12/2018	5:13:39	1936	5991885	370756	-0.6	5930	Precambrian
141	3/12/2018	22:15:41	1903	5991833	370444	-0.8	5986	Precambrian
142	3/19/2018	1:10:58	3403	5991883	370630	-0.9	6334	Precambrian
143	3/30/2018	10:25:21	2345	5997494	370109	-1.5	1527	Precambrian
144	4/7/2018	1:07:57	2978	5996588	368857	-0.5	2992	Precambrian
145	4/7/2018	15:30:20	2972	5996743	368786	-1.2	2978	Precambrian
146	4/10/2018	16:31:48	1726	5997793	370183	-1.6	944	Precambrian
147	4/10/2018	22:25:22	1581	6000083	369660	-0.9	2661	Precambrian
148	4/12/2018	11:13:08	2386	5997819	369534	-1.2	1868	Precambrian
149	4/12/2018	14:01:35	1931	5998295	371970	-1.2	1614	Precambrian
150	4/13/2018	9:22:15	1863	5998306	372060	-1.6	1648	Precambrian
151	4/27/2018	11:39:56	2705	5990575	372606	-0.8	7590	Precambrian
152	5/1/2018	13:13:02	2989	5996367	367585	-1.1	4007	Precambrian
153	5/1/2018	19:21:58	2459	5997403	367008	-0.7	4058	Precambrian
154	5/2/2018	4:32:32	3156	5995375	368517	-1.1	3921	Precambrian
155	6/1/2018	16:54:48	2408	5999972	370612	-0.2	2647	Precambrian
156	6/1/2018	17:09:36	2729	5999767	370747	-1.1	2668	Precambrian

157	6/1/2018	17:21:00	2643	5999853	370600	-1.0	2686	Precambrian
158	6/1/2018	17:45:57	2541	5999907	370567	-1.1	2670	Precambrian
159	6/1/2018	21:36:50	2160	5997857	366425	-0.9	4508	Precambrian
160	6/2/2018	0:47:52	2584	5999867	370795	-1.0	2655	Precambrian
161	6/2/2018	2:21:47	2409	5999928	370673	-1.2	2607	Precambrian
162	6/3/2018	23:47:48	1508	6000111	370835	-1.1	2427	Precambrian
163	6/9/2018	10:15:11	2095	5997678	366871	-0.3	4059	Precambrian
164	6/10/2018	9:36:54	1785	5997139	365963	-0.9	4916	Precambrian
165	6/10/2018	15:18:44	1521	5997057	366431	-0.3	4432	Precambrian
166	6/10/2018	17:09:19	2445	5998041	366517	-1.1	4511	Precambrian
167	6/12/2018	10:27:08	2343	5997516	371885	-1.1	1759	Precambrian
168	6/14/2018	3:07:38	1507	5999081	373405	-1.1	2994	Precambrian
169	6/28/2018	17:20:07	2260	6000004	370651	-1.1	2597	Precambrian
170	6/28/2018	21:42:01	1528	6000168	370575	-1.3	2494	Precambrian
171	6/28/2018	23:49:39	2789	5999625	370582	-1.2	2610	Precambrian
172	6/30/2018	5:47:47	2989	5999542	370700	-0.9	2689	Precambrian
173	6/30/2018	6:39:36	3085	5999538	370563	-1.1	2765	Precambrian
174	7/3/2018	14:39:18	2537	5999883	370712	-0.4	2641	Precambrian
175	7/3/2018	14:43:46	2403	5999925	370514	-0.8	2613	Precambrian
176	7/3/2018	15:19:02	2753	5999714	370573	-0.6	2651	Precambrian
177	7/3/2018	17:22:16	2286	6000051	370639	-1.1	2651	Precambrian
178	7/3/2018	18:46:41	2908	5999654	370578	-0.6	2713	Precambrian
179	7/3/2018	18:47:00	1545	6000340	370576	-1.2	2665	Precambrian
180	7/4/2018	5:18:41	2721	5999671	370378	-1.1	2621	Precambrian
181	7/4/2018	14:00:16	2422	5999895	370741	-0.8	2585	Precambrian
182	7/5/2018	20:02:11	2042	5989752	382587	-0.1	14295	Precambrian
183	7/12/2018	20:36:56	2193	5997724	369932	-1.4	1467	Precambrian
184	7/13/2018	1:10:39	2354	5997743	370151	-1.3	1497	Precambrian
185	7/15/2018	3:56:11	1553	5994444	373372	-0.7	4231	Precambrian
186	7/15/2018	4:09:08	1527	5994497	373416	-1.0	4214	Precambrian
187	7/16/2018	22:37:54	2231	5997630	368309	-0.9	2763	Precambrian
188	7/22/2018	1:20:01	2159	5997905	366439	-0.4	4495	Precambrian
189	7/23/2018	22:39:07	2329	5997706	366923	-0.6	4079	Precambrian
190	7/28/2018	9:37:21	1626	5991468	374494	-0.7	7317	Precambrian
191	7/31/2018	8:42:40	2321	5998729	372764	-1.0	2585	Precambrian
192	8/5/2018	1:15:34	2061	5997759	370815	-1.5	1067	Precambrian
193	8/5/2018	15:25:42	2442	5997710	371680	-1.4	1705	Precambrian
194	8/5/2018	19:22:58	2515	5997647	371548	-1.4	1706	Precambrian
195	8/6/2018	14:48:13	2515	5997516	371532	-1.2	1711	Precambrian
196	8/12/2018	11:03:59	2137	5997287	370285	-0.9	1324	Precambrian
197	8/17/2018	10:20:09	2296	5997339	370406	-1.5	1411	Precambrian
198	8/22/2018	23:55:51	2177	5999374	370939	-1.3	2023	Precambrian

199	9/1/2018	12:35:38	2098	5998273	366912	-0.7	4055	Precambrian
200	9/5/2018	6:12:30	1907	5997792	370796	-1.8	914	Precambrian
201	9/9/2018	16:59:40	1787	5997484	369555	-0.8	1479	Precambrian
202	9/10/2018	13:38:17	2520	5999871	370674	-1.2	2623	Precambrian
203	9/19/2018	18:54:39	2431	5996657	368951	-1.4	2564	Precambrian
204	9/20/2018	9:18:13	2414	5999962	370975	-0.7	2644	Precambrian
205	10/6/2018	7:27:17	1825	5998980	369387	-1.3	2040	Precambrian
206	10/7/2018	22:36:40	3155	5996899	368878	-0.7	2997	Precambrian
207	10/16/2018	12:02:37	2351	5997677	371940	-1.4	1787	Precambrian
208	10/20/2018	16:31:48	2644	5995730	367375	-0.6	4282	Precambrian
209	11/7/2018	13:22:58	1755	6000065	368908	-0.6	3079	Precambrian
210	11/21/2018	12:05:46	1596	6001575	369569	-0.2	4066	Precambrian
211	11/21/2018	15:42:45	2935	6001190	369593	-1.0	4132	Precambrian
212	11/23/2018	20:50:35	1518	5991863	372105	-1.0	6048	Precambrian
213	11/23/2018	22:13:24	1906	5991732	370675	-0.8	6078	Precambrian
214	11/24/2018	11:59:06	2224	5997801	368846	-1.2	2291	Precambrian
215	11/27/2018	5:22:12	2985	5999678	369579	-0.9	3025	Precambrian
216	11/28/2018	12:23:39	2218	5998138	371112	-1.5	1329	Precambrian
217	12/9/2018	13:07:20	1976	5999385	371062	-1.0	1936	Precambrian
218	12/22/2018	7:33:06	2535	5999547	367094	-0.9	4383	Precambrian
219	12/28/2018	20:32:22	2617	5996840	368995	-1.3	2573	Precambrian
220	1/4/2019	18:43:40	2991	5995503	371178	-1.0	3025	Precambrian
221	1/7/2019	14:21:46	2109	5998224	376779	-0.9	6123	Precambrian
222	1/7/2019	20:43:53	2247	5998289	371007	-1.3	1386	Precambrian
223	1/29/2019	23:41:12	2463	5990541	372907	-0.1	7649	Precambrian
224	1/31/2019	12:51:22	2838	5990958	373896	-0.3	7689	Precambrian
225	2/1/2019	3:39:03	2522	5997513	370680	-0.6	1547	Precambrian
226	2/5/2019	15:50:40	1786	5990583	373260	-0.7	7616	Precambrian
227	2/6/2019	7:10:21	2252	5997759	367419	-0.7	3587	Precambrian
228	2/6/2019	22:26:49	2013	5997706	367356	-0.8	3570	Precambrian
229	2/7/2019	4:13:29	2467	5990613	373099	-0.4	7639	Precambrian
230	2/9/2019	15:18:55	1585	6000288	369143	-0.5	3084	Precambrian
231	2/11/2019	2:54:51	1532	5996768	367474	-0.9	3486	Precambrian
232	2/16/2019	14:03:46	2071	5997751	370777	-1.4	1076	Precambrian
233	2/16/2019	23:39:55	1673	5990511	373190	-0.6	7651	Precambrian
234	2/22/2019	13:33:52	2453	5990828	373576	-0.4	7598	Precambrian
235	2/22/2019	13:39:48	2214	5990634	373320	-0.4	7645	Precambrian
236	2/22/2019	20:34:05	2394	5990783	373641	0.4	7652	Precambrian
237	2/22/2019	21:37:42	2406	5990722	373390	-0.5	7620	Precambrian
238	2/22/2019	21:50:42	2404	5990879	373876	0.1	7659	Precambrian
239	2/22/2019	21:51:21	2404	5990783	373639	-0.1	7653	Precambrian
240	2/22/2019	21:55:46	2207	5990744	373298	-0.2	7534	Precambrian

241	2/22/2019	23:06:47	2331	5990732	373417	-0.1	7607	Precambrian
242	2/23/2019	4:30:35	2611	5990752	373309	-0.6	7606	Precambrian
243	2/23/2019	6:47:30	2212	5990711	373431	-0.5	7611	Precambrian
244	2/23/2019	6:51:08	2699	5990786	373453	-0.3	7643	Precambrian
245	2/23/2019	8:19:37	2525	5990837	373582	-0.5	7606	Precambrian
246	2/23/2019	8:42:54	2430	5990774	373484	-0.8	7610	Precambrian
247	2/23/2019	11:06:06	2456	5990729	373199	-0.2	7560	Precambrian
248	2/23/2019	15:00:49	2457	5990719	373453	-0.4	7654	Precambrian
249	2/23/2019	18:16:54	2460	5990797	373598	-0.8	7636	Precambrian
250	2/23/2019	23:52:56	2455	5990720	373371	0.5	7625	Precambrian
251	2/23/2019	23:58:41	2444	5990862	373626	-0.9	7584	Precambrian
252	2/24/2019	0:20:43	3372	5990836	373104	-0.1	7663	Precambrian
253	2/24/2019	0:26:28	3558	5991206	373800	-0.9	7642	Precambrian
254	2/24/2019	1:29:38	3200	5991280	374150	-0.9	7613	Precambrian
255	2/24/2019	1:29:48	3192	5990971	373527	-0.9	7629	Precambrian
256	2/24/2019	1:30:30	3355	5991030	373597	0.0	7651	Precambrian
257	2/24/2019	1:32:36	2363	5990689	373309	-0.8	7615	Precambrian
258	2/24/2019	2:42:23	3312	5991001	373618	-0.3	7671	Precambrian
259	2/24/2019	2:48:21	3581	5990998	373371	0.8	7672	Precambrian
260	2/24/2019	2:54:07	2402	5990804	373610	-0.8	7623	Precambrian
261	2/24/2019	2:57:00	2850	5990791	373433	-0.8	7667	Precambrian
262	2/24/2019	3:03:55	2454	5990891	373774	-0.4	7617	Precambrian
263	2/24/2019	3:23:56	2315	5990564	372880	-0.7	7593	Precambrian
264	2/24/2019	3:50:33	3569	5990822	372880	-0.5	7675	Precambrian
265	2/24/2019	4:09:47	3013	5990734	372980	-0.8	7616	Precambrian
266	2/24/2019	4:54:50	3368	5990840	373315	0.3	7725	Precambrian
267	2/24/2019	5:45:27	2928	5990709	372900	-0.5	7594	Precambrian
268	2/24/2019	5:57:06	3255	5991212	374002	-0.3	7623	Precambrian
269	2/24/2019	12:09:01	2411	5990767	373387	-0.9	7579	Precambrian
270	2/24/2019	12:42:11	3200	5991182	373911	-0.6	7595	Precambrian
271	2/24/2019	13:12:21	3489	5990880	373110	-0.3	7663	Precambrian
272	2/24/2019	13:59:03	2842	5991118	374021	-0.8	7601	Precambrian
273	2/24/2019	14:04:58	3396	5991182	373728	-0.3	7581	Precambrian
274	2/24/2019	20:03:49	3754	5990911	373012	-0.7	7697	Precambrian
275	2/25/2019	4:04:16	2992	5991039	373843	-0.3	7635	Precambrian
276	2/25/2019	4:14:50	2142	5990818	373678	-0.2	7592	Precambrian
277	2/25/2019	5:03:46	1980	5990830	373748	-0.1	7585	Precambrian
278	2/25/2019	5:05:46	3199	5990981	373535	0.0	7625	Precambrian
279	2/25/2019	11:10:47	2779	5991130	374066	-0.9	7595	Precambrian
280	2/25/2019	12:19:21	2206	5991109	374310	-0.6	7610	Precambrian
281	2/25/2019	19:44:22	2880	5991041	373902	-0.7	7628	Precambrian
282	2/25/2019	23:08:45	2757	5990777	373331	-0.4	7623	Precambrian

283	2/26/2019	4:24:44	2458	5990832	373730	-0.2	7653	Precambrian
284	2/26/2019	7:23:53	3200	5990907	373497	0.0	7678	Precambrian
285	2/26/2019	9:21:08	3186	5990793	373165	-0.3	7665	Precambrian
286	2/26/2019	21:07:29	2266	5991288	374715	-0.8	7664	Precambrian
287	2/26/2019	21:31:47	3200	5991317	374378	-1.0	7686	Precambrian
288	2/27/2019	15:15:09	1878	5991700	375291	0.0	7591	Precambrian
289	2/27/2019	15:52:54	1703	5990531	373251	-0.7	7654	Precambrian
290	2/28/2019	12:31:29	3200	6004025	371820	-0.7	6742	Precambrian
291	2/28/2019	21:34:37	2508	5991050	374203	-0.9	7667	Precambrian
292	3/1/2019	12:53:41	3061	5990879	373587	0.0	7696	Precambrian
293	3/2/2019	1:06:59	3108	5997015	368812	-1.3	2976	Precambrian
294	3/2/2019	22:58:16	1973	5990692	373528	-0.3	7628	Precambrian
295	3/4/2019	13:43:42	2508	5991499	374968	-0.6	7668	Precambrian
296	3/5/2019	3:21:43	1980	5990665	373313	-0.8	7580	Precambrian
297	3/5/2019	3:21:51	3198	5990978	373533	-0.8	7627	Precambrian
298	3/5/2019	16:05:35	2991	5990785	373380	-0.2	7689	Precambrian
299	3/8/2019	13:34:25	2254	5998280	379383	-0.4	8713	Precambrian
300	3/15/2019	16:22:57	3174	6000978	368518	-0.9	4510	Precambrian
301	3/16/2019	5:11:41	2152	5990560	372957	-0.2	7592	Precambrian
302	3/16/2019	6:00:45	2936	5988407	380802	0.2	13833	Precambrian
303	3/19/2019	5:22:51	2050	5997812	367408	0.1	3532	Precambrian
304	3/19/2019	5:23:00	2460	5997279	367563	-0.5	3563	Precambrian
305	3/19/2019	6:05:29	2461	5997984	367515	-0.9	3586	Precambrian
306	3/19/2019	9:20:52	2072	5997461	367339	-1.0	3614	Precambrian
307	3/22/2019	11:02:32	1904	5994965	382406	-0.4	11989	Precambrian
308	3/25/2019	9:10:32	2608	5993842	370109	-0.9	4271	Precambrian
309	3/28/2019	3:22:40	2544	5996783	370340	-0.8	1873	Precambrian
310	4/3/2019	0:02:02	1984	5996817	376671	-0.4	6046	Precambrian
311	4/3/2019	21:25:23	1957	5997275	376712	-0.9	6029	Precambrian
312	4/13/2019	2:12:58	1749	5995997	380218	-0.1	9629	Precambrian
313	4/16/2019	13:57:19	3200	5995474	371936	-0.6	3367	Precambrian
314	4/21/2019	22:04:44	2115	5995910	381273	-0.5	10712	Precambrian
315	4/25/2019	14:56:37	3987	5990644	369377	-0.5	7827	Precambrian
316	4/29/2019	6:10:37	2647	6000467	361210	-0.4	10085	Precambrian
317	4/29/2019	6:14:47	3370	6001360	361677	-0.7	10078	Precambrian
318	5/17/2019	2:31:24	1715	5998021	364928	-0.7	5901	Precambrian
319	5/18/2019	13:42:09	3427	5995638	367832	-0.7	4360	Precambrian
320	5/29/2019	0:24:35	2564	5998145	366365	-0.9	4701	Precambrian
321	5/30/2019	14:04:55	4200	5993814	376355	-0.7	7536	Precambrian
322	6/6/2019	2:39:43	1654	5996714	372577	-0.6	2173	Precambrian
323	6/10/2019	8:13:32	2478	5996929	369010	-1.1	2446	Precambrian
324	6/19/2019	6:24:54	2492	6000533	366373	-0.5	5426	Precambrian

325	6/20/2019	1:14:20	2328	5996187	366533	-0.8	4713	Precambrian
326	7/18/2019	10:36:14	2480	6002234	376781	-0.6	7644	Precambrian
327	7/20/2019	20:15:40	2757	5989043	383607	-0.2	15599	Precambrian
328	7/26/2019	22:39:20	4200	6003686	380273	0.6	11653	Precambrian
329	7/27/2019	14:23:24	3790	5993567	365138	-0.4	7552	Precambrian
330	7/27/2019	16:33:30	3101	5990805	372483	-0.8	7446	Precambrian
331	8/2/2019	20:39:24	4099	5986584	371847	-0.7	11629	Precambrian
332	8/4/2019	12:07:22	3278	6000925	375899	-0.6	6448	Precambrian
333	8/7/2019	16:12:46	1806	6000076	370000	-1.0	2592	Precambrian
334	8/31/2019	23:18:15	1890	5986834	374301	-0.4	11496	Precambrian
335	8/31/2019	23:49:29	2869	5987457	375534	-0.4	11484	Precambrian
336	9/2/2019	5:13:25	2723	5987167	374950	-0.5	11497	Precambrian
337	9/3/2019	13:53:31	2529	6000484	379027	-0.5	8828	Precambrian
338	9/6/2019	16:56:12	2532	5996939	379458	0.1	8851	Precambrian
339	9/17/2019	1:41:15	2322	5997572	376727	-1.0	6098	Precambrian
340	9/25/2019	18:19:29	3938	5989310	379720	-0.5	12637	Precambrian
341	10/7/2019	5:03:29	2185	5995216	367538	-0.6	4276	Precambrian
342	10/18/2019	21:57:24	1861	5997979	376803	-0.7	6092	Precambrian
343	10/24/2019	11:12:49	1949	5992924	374432	-0.7	6120	Precambrian
344	10/24/2019	20:29:32	2961	5994322	386054	-0.2	15777	Precambrian
345	11/17/2019	17:40:13	1658	6000132	372596	-1.0	3077	Precambrian
346	11/22/2019	4:57:03	3124	5997029	369896	-1.2	2412	Precambrian
347	11/23/2019	6:50:22	3278	5996927	370338	-1.0	2463	Precambrian
348	11/24/2019	2:24:21	2494	5989445	372126	-0.5	8536	Precambrian
349	11/24/2019	6:54:11	3110	5996797	370132	-1.2	2404	Precambrian
350	12/11/2019	0:55:39	2049	5997044	368927	-1.4	2241	Precambrian
351	12/13/2019	18:53:14	2791	5990156	381149	0.1	12973	Precambrian
352	12/14/2019	11:34:02	3172	5991313	382172	0.2	13262	Precambrian
353	12/16/2019	20:44:13	2019	6000129	378752	-0.9	8387	Precambrian
354	12/17/2019	11:14:27	2368	5998880	372645	-0.7	2583	Precambrian
355	12/30/2019	19:24:00	1520	5993224	373490	-0.9	5294	Precambrian

APPENDIX C: RESULTS OF 2019 PNX LOGGING (HYDRAULIC ISOLATION LOG)

Schlumberger

*Techlog Processed Interpretation

Analysis Behind Casing Pulsed Neutron eXtreme Tool (PNX)

* A Mark of Schlumberger

COMPANY:	SHELL CANADA LIMITED
WELL:	SCL THORH 5-35-59-21
FIELD:	THORHILD
PROVINCE:	ALBERTA
COUNTRY:	CANADA

Date Logged: 21-Jan-2019	Run No. RUN 1	API Number: 0448520
Location: 5-35-59-21W4		UWI: 102053505921W400
Borehole Fluid Type: Air		Borehole Fluid Weight:
Elevations:	KB: 646.84 m	DF: 641.54 m	GL: 641.54 m
Top Log Interval: 5.3 m	Bottom Log Interval: -999.25 m	TD Logger: 2143 m
Casing Size: 177.8 mm @ 2115 m	Casing Weight: 36.84 kg/m	Casing Grade: L80
Bit Size: 222 mm		

FOLD HERE: The well name, location and borehole reference data were furnished by the customer.

Svc. Order #: DVJQ-00127 Location: NISKU PS	Interpretation Center: Calgary Techlog Vers: 2018.1	Analyst: Sarvenaz MOAZAMI Email: SMoazami@slb.com	Process Date: 12 February 2019

Remarks:

The PNX outputs from 2019 are used to estimate CO_2 volume and saturation in combination with the OH and RST petrophysical results from 2015.

The RST TPHI and Sigma are not calibrated for double casings and tubing. Therefore these measurements from RST 2015 are normalized over these sections, to have better match with PNX 2019 readings (Which is calibrated for double casings and tubing)

FNXS, is the fast neutron elastic cross section for hydrogen index detection (Low FNXS indicates low HI). In this well the low FNXS mainly responded to the CO_2 in the borehole.

The CO_2 volume (VCO2) was calculated from Sigma_PNX_2019. The interpretation results showed high CO_2 saturation over the intervals 2070 to 2098m which also matched the injection intervals. Further confirmation of CO_2 was established using RST baseline Sigma (2015 prior to CO_2 Injection) compared to post CO_2 injection measurement in 2019.

There were several CO_2 indications from the PNX measurements:

- A drop in Sigma_PNX_2019 from the 2015 baseline which is indicative of CO2
- The TPHI_PNX_2019 reading very low due to low CO2 hydrogen index
- Temperature decrease over the CO2 injection interval

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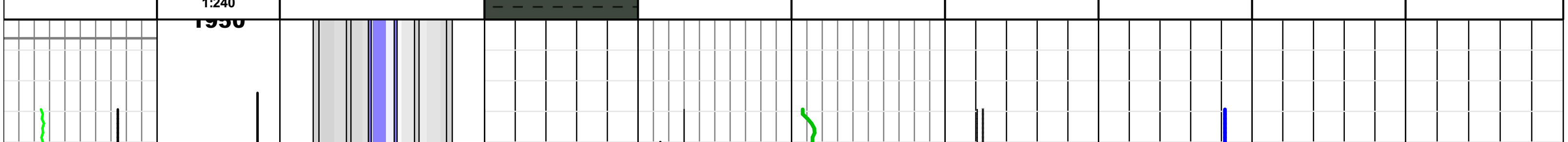
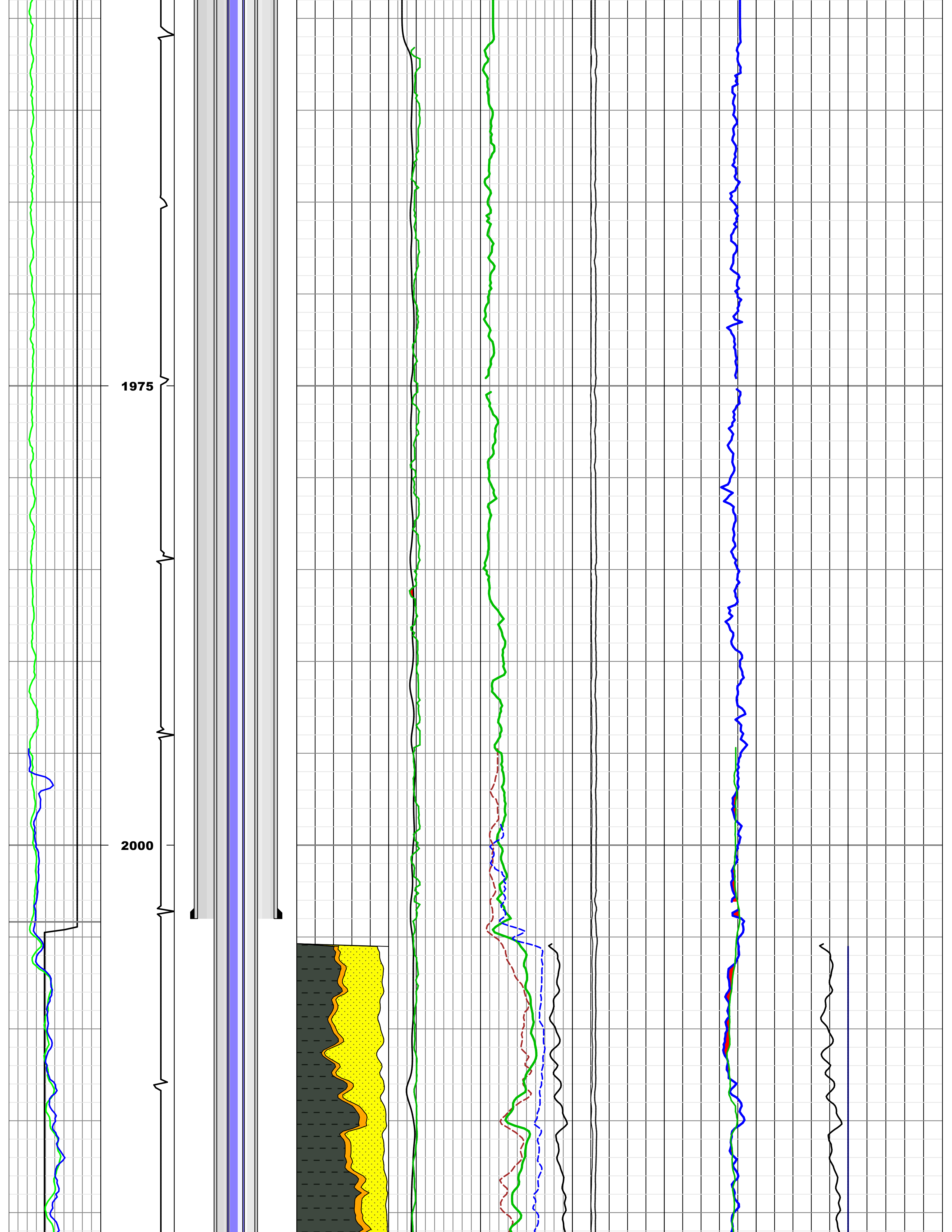
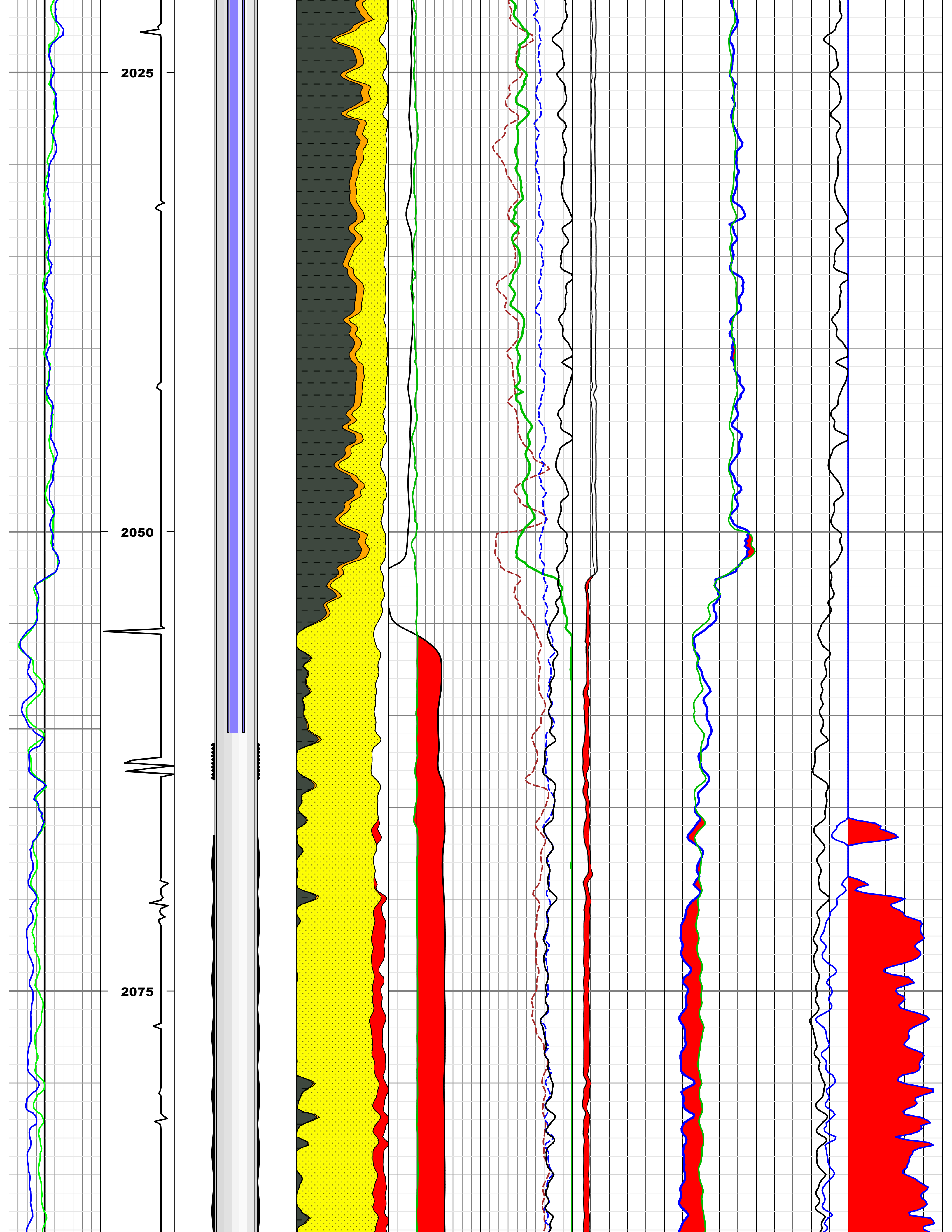
Gamma Ray RST 2015(blue) & GR PNX 2019(Green)	GR (RST_2015): 0 gAPI 200; GR (PNX_2019): 0 gAPI 200; BS: 125 mm 375
MD, Collar Locator	CCLD: -4.5 V 1; Reference (m) 1:240
Well Completion	Well schematic
OH Petrophysics Results with CO2 volume PNX results	Cumulated var: 0 m3/m3 1; VWAT; VGAS; VQUA; VXBW; VILL
Fast Neutron Ratios	Low HI Indicator; FNXS_MATR: 10 0; FNXS_Smooth_1m: 10 1/m 0
TPHI, OH Thermal Neutron (Sand Stone), Total porosity	PHIT_2015: 0.6 m3/m3 0; NEU_SS: 0.6 m3/m3 0; TPHI_PNX 2019: 0.6 m3/m3 0; PHI_RST_2015_Norm: 0.6 m3/m3 0
Near & Far Count Rates,Gross Inelastic Count Rate	CIRN/CIRF PNX 2019; CIRN_PNX_2019: 0 unitless 1; CIRF_PNX_2019: 0 unitless 1.5
Formation Sigma	CO2; SIGM_RST_2015_Norm: 0 1/m 6; SIGM_PNX_2019: 0 1/m 6
C02 Volumes	PHIT_2015: 0.5 m3/m3 0; VCO2_2019: 0.5 m3/m3 0
Water Saturation	SXO_2019; SXO: 1 m3/m3 0

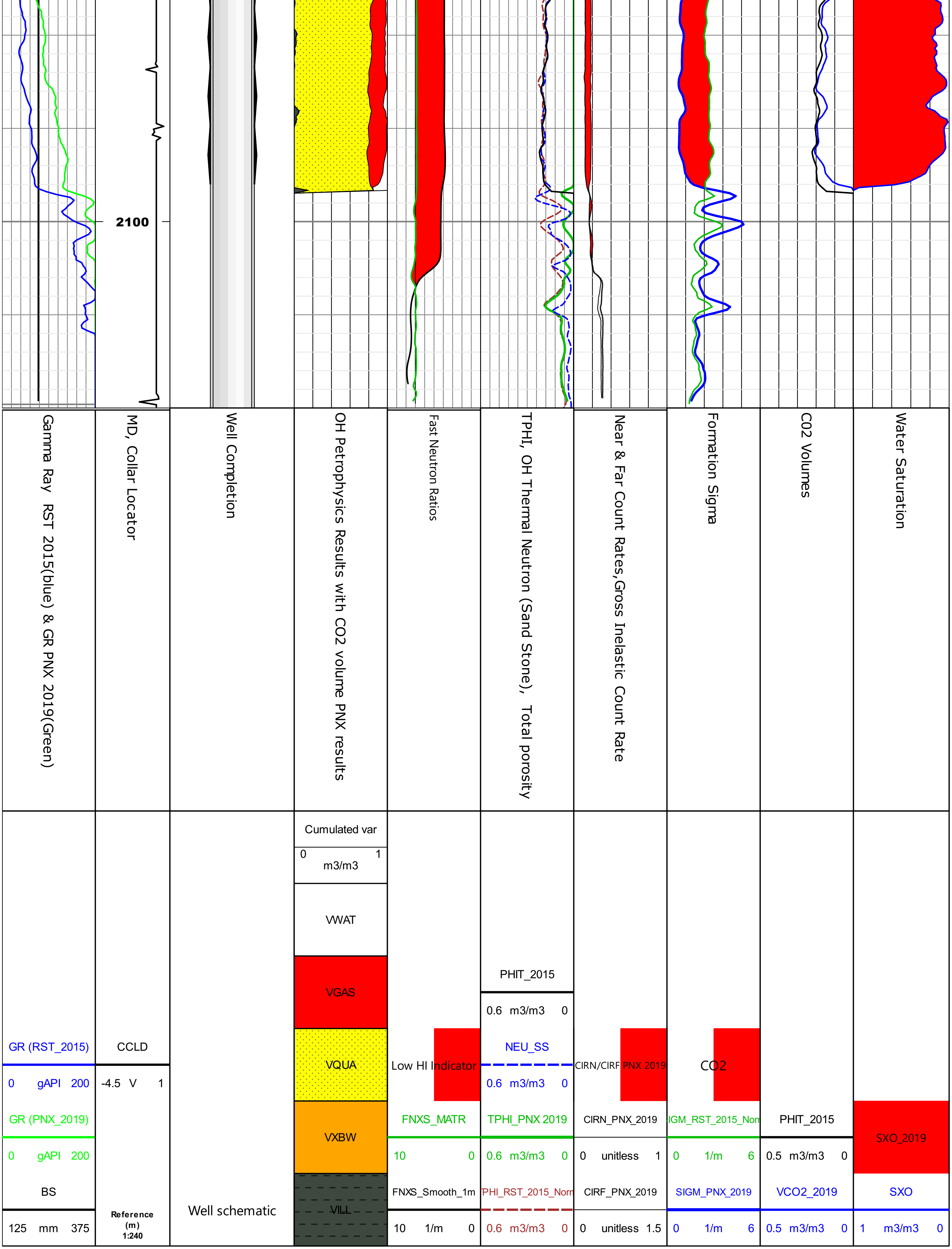
1950




1975
2000

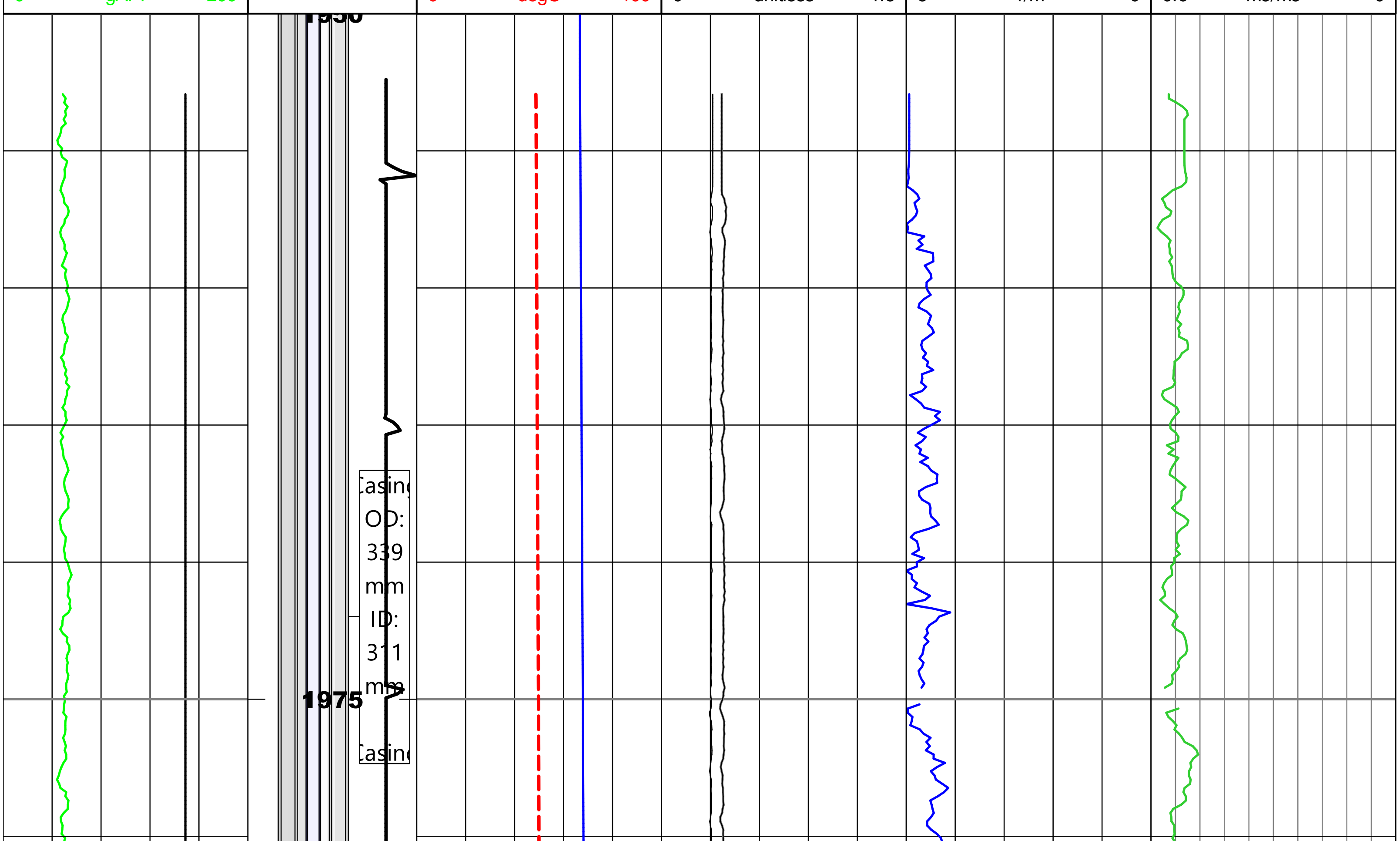


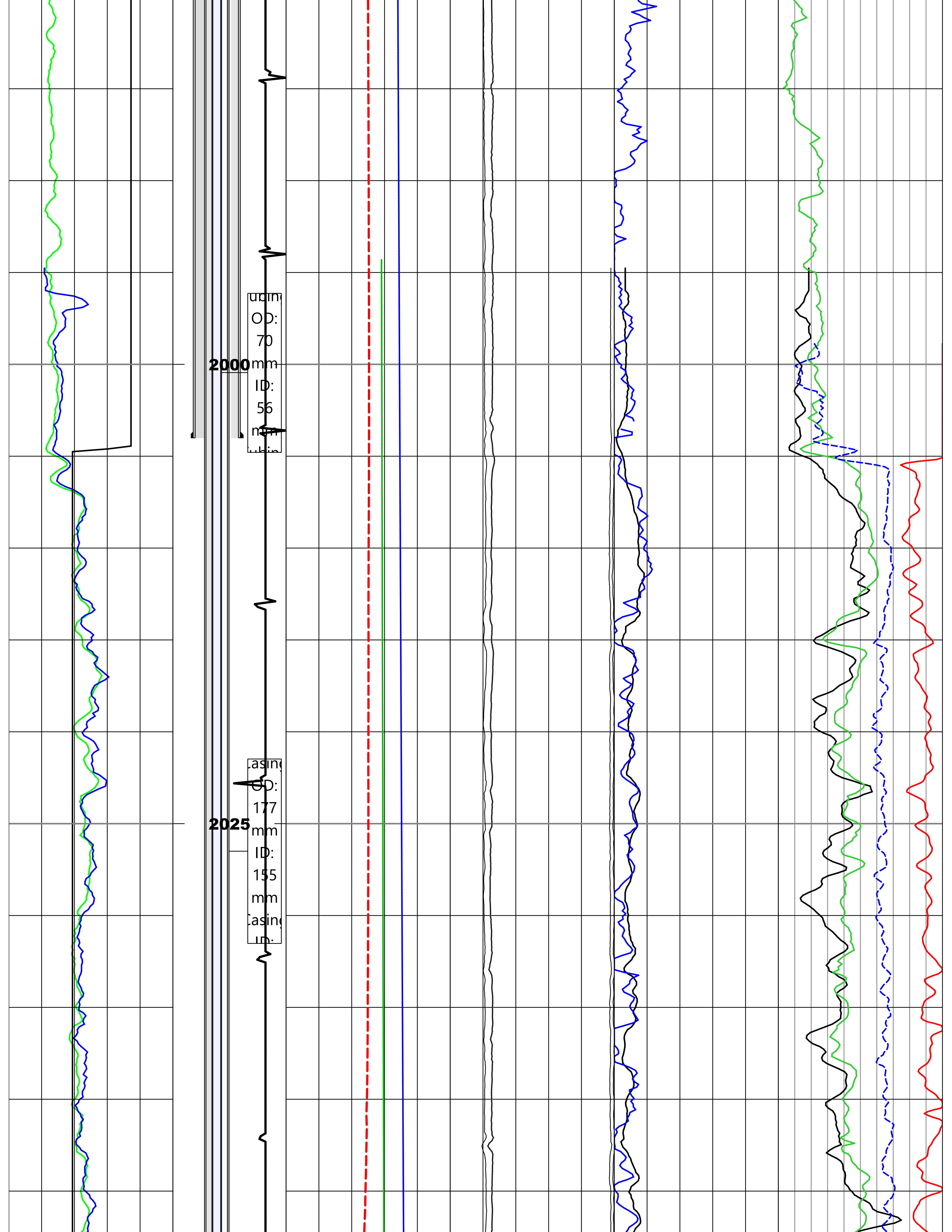
2025
2050
2075


2100
Gamma Ray RST 2015(blue) & GR PNX 2019(Green)
MD, Collar Locator
Well Completion
OH Petrophysics Results with CO2 volume PNX results
Fast Neutron Ratios
TPHI, OH Thermal Neutron (Sand Stone), Total porosity
Near & Far Count Rates,Gross Inelastic Count Rate
Formation Sigma
CO2 Volumes
Water Saturation
GR (RST_2015)
0 gAPI 200
GR (PNX_2019)
0 gAPI 200
BS
125 mm 375
CCLD
-4.5 V 1
Reference (m) 1:240
Well schematic
Cumulated var
0 1
m3/m3
VWAT
VGAS
VQUA
VXBW
VILL
Low HI Indicator
FNXS_MATR
10 0
FNXS_Smooth_1m
10 1/m 0
PHIT_2015
0.6 m3/m3 0
NEU_SS
0.6 m3/m3 0
TPHI_PNX 2019
0.6 m3/m3 0
TPHI_RST_2015_Norm
0.6 m3/m3 0
CIRN/CIRF PNX 2019
CIRN_PNX_2019
0 unitless 1
CIRF_PNX_2019
0 unitless 1.5
CO2
SIGM_RST_2015_Norm
0 1/m 6
SIGM_PNX_2019
0 1/m 6
PHIT_2015
0.5 m3/m3 0
VCO2_2019
0.5 m3/m3 0
SXO_2019
SXO
1 m3/m3 0

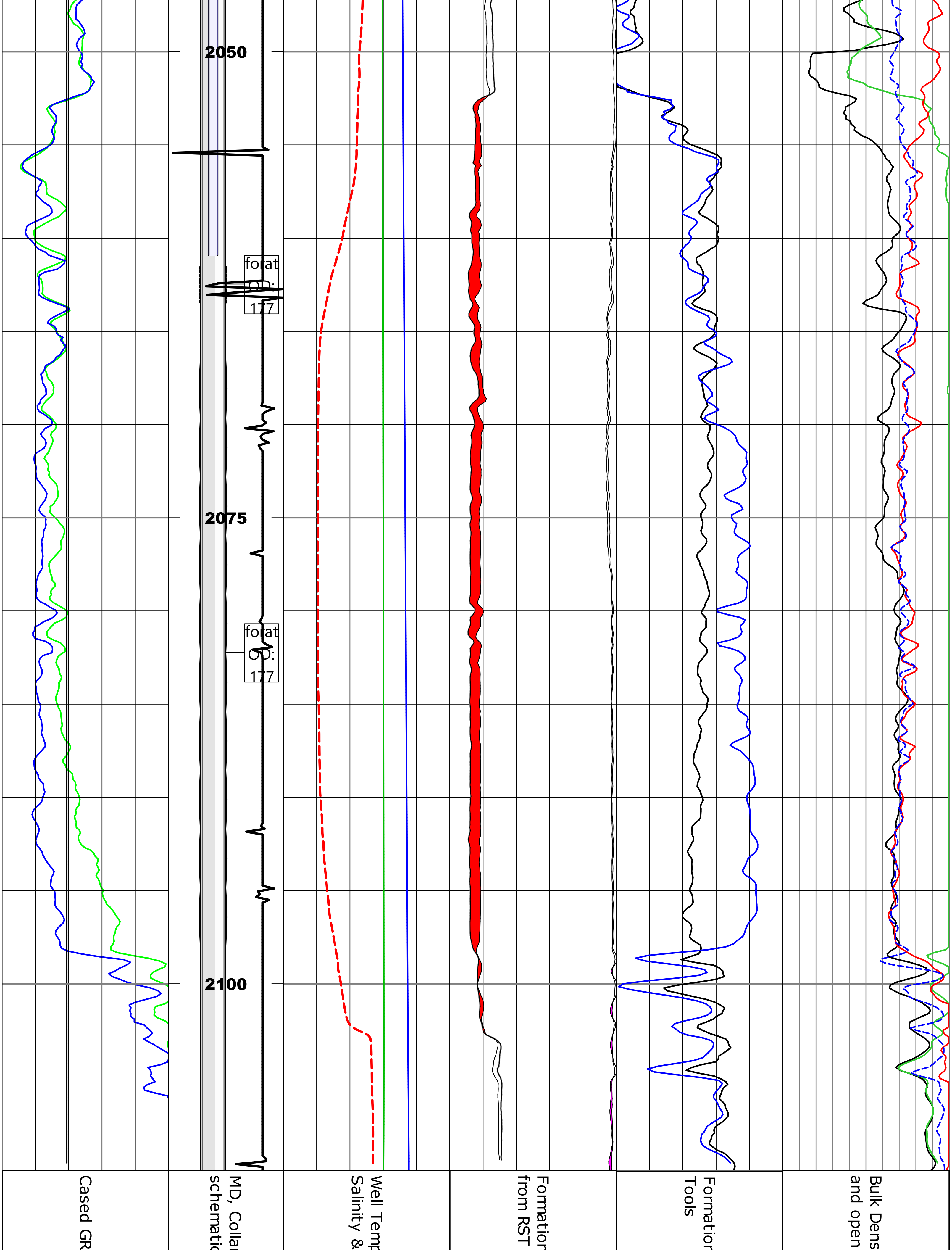
SCL THORH 5-35-59-21

Cased GR (RST and PNX), BS	MD, Collar locator, well schematics	Well Tempt, Pressure,Borehole Salinity & Borehole Sigma	Formation Sigma count rates from RST & PNX	Formation Sigma from RST & PNX Tools	Bulk Density, Cased hole Neutron and open hole neutron
	Well schematic		RSCN/RSCF RST 2015 CIRN/CIRF PNX_2019 RSCF_RST 2015 200 3		NEU_SS 0.6 m3/m3 0
BS 125 mm 375	CCLD -4.5 V 1	WTEP_2015 0 degC 100	RSCN_RST 2015 201 0		DEN 1650 kg/m3 2650
GR (RST_2015) 0 gAPI 200		WPRE_2019 10000 kPa 25000	CIRN_PNX_2019 0 unitless 1	SIGM_PNX_2019 5 1/m 0	TPHI_PNX_2019 0.6 m3/m3 0
GR (PNX_2019) 0 gAPI 200	**Reference (m)** **1:240**	WTEP_2019 0 degC 100	CIRF_PNX_2019 0 unitless 1.5	SIGM_RST_2015_Norm 5 1/m 0	TPHI_RST_2015_Norm 0.6 m3/m3 0





2000
OD:
70
mm
ID:
56
2025
OD:
177
mm
ID:
155
mm


2050
2075
2100
forat
OD:
177
forat
OD:
177
Cased GR
MD, Colla
schemati
Well Temp
Salinity &
Formation
from RST
Formation
Tools
Bulk Dens
and open

(RST and PNX), BS	r locator, well cs	ot, Pressure,Borehole Borehole Sigma	n Sigma count rates & PNX	n Sigma from RST & PNX	ity, Cased hole Neutron hole neutron
			RSCN/RSCF RST 2015		
			CIRN/CIRF PNX_2019		
	Well schematic		RSCF_RST 2015		NEU_SS
			200 3		0.6 m3/m3 0
BS	CCLD	WTEP_2015	RSCN_RST 2015		DEN
125 mm 375	-4.5 V 1	0 degC 100	201 0		1650 kg/m3 2650
GR (RST_2015)		WPRE_2019	CIRN_PNX_2019	SIGM_PNX_2019	TPHI_PNX_2019
0 gAPI 200	**Reference (m) 1:240**	10000 kPa 25000	0 unitless 1	5 1/m 0	0.6 m3/m3 0
GR (PNX_2019)		WTEP_2019	CIRF_PNX_2019	SIGM_RST_2015_Norm	TPHI_RST_2015_Norm
0 gAPI 200		0 degC 100	0 unitless 1.5	5 1/m 0	0.6 m3/m3 0

Schlumberger

COMPANY: SHELL CANADA LIMITED

WELL: SCL THORH 5-35-59-21

PROVINCE: ALBERTA

FIELD: THORHILD

Analysis Behind Casing
Pulsed Neutron eXtreme Tool (PNX)