PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING, IGNACE AREA

WP06 Data Report - Hydraulic Testing for IG_BH01

APM-REP-01332-0235 **July 2019**

Golder Associates Ltd.

NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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REPORT

PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING, IGNACE AREA

WP6 Data Report - Hydraulic Testing for IG_BH01

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1671632 (1600)

NWMO Report: APM-REP-01332-0235

July 2019

Distribution List

eCopy - NWMO

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WP6 DATA REPORT – HYDRAULIC TESTING FOR IG_BH01

CLIENT INFORMATION

Project Name: Phase 2 Initial Borehole Drilling and Testing, Ignace Area

Project Number: 1671632

Client PO Number: 01559 A-TGS

Document Name: 1671632 (1600) IG_BH01_WP6_Report_15July2019_R2b.docx

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ISSUE/REVISION INDEX

Issue Code	Revision					Revision Details
	No.	By	Rev'd.	App.	Date	
RR	0	ML	JW	-	May 7, 2018	Draft released for review and comment
RR	1	ML	JW	JC	October 16, 2018	Revised draft addressing NWMO review comments
RR	2a	ML	JW	JC	January 11, 2019	Final for NWMO review and comments
RI	2b	ML	JW	JC	July 15, 2019	Final based on NWMO review and comments

Issue Codes: RR = Released for Review and Comments, RI = Released for Information

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1.0 INTRODUCTION

The Initial Borehole Drilling and Testing project in the Wabigoon and Ignace Area, Ontario is part of Phase 2 Geoscientific Preliminary Field Investigations of the NWMO's Adaptive Phased Management (APM) Site Selection Phase.

This project involves the drilling and testing of the first of three deep boreholes within the northern portion of the Revell batholith. The first drilled borehole, IG_BH01, is located a direct distance of approximately 21 km southeast of the Wabigoon Lake Ojibway Nation and a direct distance of 43 km northwest of the Town of Ignace. Access to the IG_BH01 drill site is via Highway 17 and primary logging roads, as shown on Figure 1.

The project was carried out by a team led by Golder Associates Ltd. (Golder) on behalf of the NWMO. The overall program is described in the Initial Borehole Characterization Plan (Golder 2017). This report describes the methodology, activities and results for Work Package 6 (WP6): Hydraulic Testing for IG_BH01.

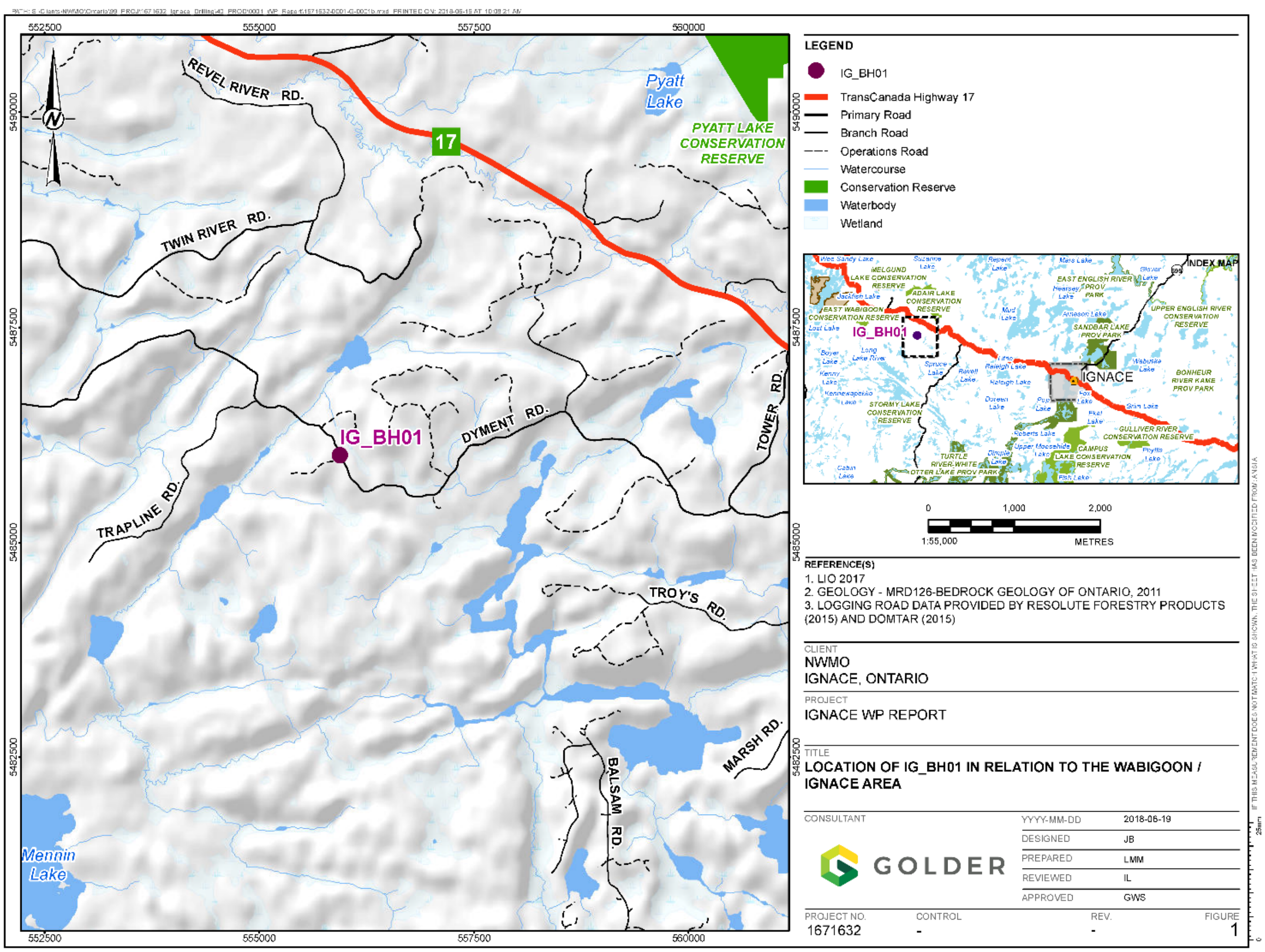

Figure 1: Location of IG_BH01 in relation to the Wabigoon / Ignace Area.

2.0 BACKGROUND INFORMATION

2.1 Geological Setting

The approximately 2.7 billion year old Revell batholith is located in the western part of the Wabigoon Subprovince of the Archean Superior Province. The batholith is roughly elliptical in shape trending northwest, is approximately 40 km in length, 15 km in width, and covers an area of approximately 455 km^2. It is likely that the batholith is approximately 2 km to 3 km thick through the center of the northern portion (SGL, 2015). The Revell batholith is surrounded by the Raleigh Lake (to the north and east) and Bending Lake (to the southwest) greenstone belts (Figure 2).

Borehole IG_BH01 is within an investigation area of approximately 19 km^2 in size situated in the northern portion of the Revell batholith. Bedrock exposure in this area is very good due to minimal overburden, few water bodies, and relatively recent logging activities. Ground elevations generally range from 400 to 450 m above sea level. The ground surface broadly slopes towards the northwest as indicated by the flow direction of the main rivers in the area (Revell and Mennin rivers). Local water courses within the investigation area tend to flow to the southwest towards Mennin Lake.

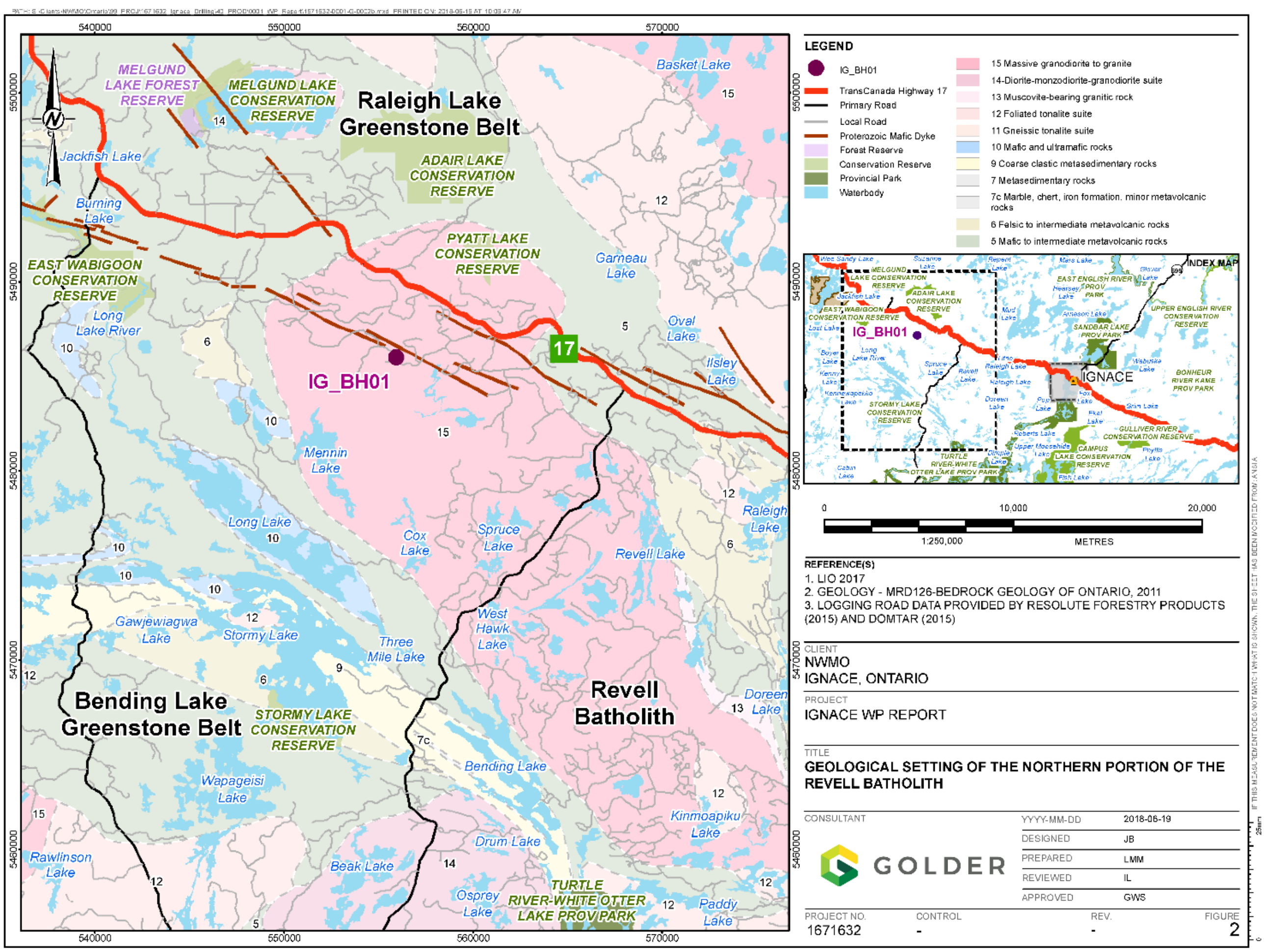

Figure 2: Geological setting of the northern portion of the Revell batholith.

The northern portion of the Revell batholith is composed mainly of granodiorite and tonalite, which together form a relatively homogeneous intrusive granitoid complex. The granodiorite and tonalite are massive to weakly foliated. Overall, the tonalite transitions gradationally into granodiorite and no distinct contact relationships between these two rock types are typically observed. There is also a younger granite intrusion, which is observed southeast of the investigation area and primarily in the central portion of the Revell batholith. The granite, which is massive to weakly foliated, post-dates and intrudes into the granodiorite-tonalite intrusive complex (Golder and PGW, 2017). In the centre of the investigation area, a west-northwest trending mafic dyke is interpreted from aeromagnetic data and observed during detailed mapping to be approximately 15-20 m wide (Figure 2). This dyke is associated with a similarly-orientated mafic dyke that stretches along the entire northern limit of the investigation area. Both dykes, along with others in the northern portion of the Revell batholith, have a similar character and are interpreted to be part of the Wabigoon dyke swarm. It is assumed based on surface measurements that these mafic dykes are sub-vertical (Golder and PGW, 2017).

Long, narrow valleys are located along the western and southern limits of the investigation area (Figure 1). These local valleys host creeks and small lakes that drain to the southwest and may represent the surface expression of structural features that extend into the bedrock. A broad valley is located along the eastern limits of the investigation area and hosts a more continuous, un-named water body that flows to the south. The linear and segmented nature of this waterbody's shorelines may also represent the surface expression of structural features that extend into the bedrock.

Details of the lithological units and structures found within the investigation area are provided in Golder and PGW, 2017.

2.2 Purpose

The purpose of WP6 is to estimate the hydraulic properties of the crystalline rock units at selected depths in IG_BH01. Borehole IG_BH01 was drilled vertically to a total depth of 1001.27 mbgs with a diameter of 96 mm (HQ). Additional borehole details are presented in the report WP2 – Borehole Drilling and Coring for IG_BH01 (Golder 2018a). Testing occurred after the completion of drilling and logging. Selection of test intervals considered potential water conductive zones based on review of the earlier stages of work that included the following:

- WP2 – Borehole Drilling and Coring;
- WP3 – Geological and Geotechnical Core Logging, Photography, and Sampling;
- WP7 – Opportunistic Groundwater Sampling; and
- WP5 - Geophysical Logging and Interpretation was available to help select appropriate test interval locations and anticipate hydraulic conductivities to aid in test design.

The scientific objective was the collection of high quality and reliable test data that will support the derivation of high-confidence hydraulic properties including:

- Bulk hydraulic conductivity (i.e. transmissivity divided by thickness);
- Inferred hydraulic pressure in the rock;
- Total test zone compressibility, comprising the rock within the isolated interval, water within the test zone and the test tool;

- Borehole skin factor; and
- Specific storage (storativity / thickness).

The procedures for the collection, analyses and reporting of the test data were developed by Golder and reviewed by the NWMO. These procedures for data collection are summarized in the following sections.

It should be noted that static formation pressure was estimated from extrapolation of the test interval pressure response for the purpose of test analysis. More reliable static formation pressure will be measured with the long-term monitoring installation in the borehole completed under WP9.

2.3 Roles and Responsibilities

Testing was carried out by a team of testing specialists from Golder. Drill rig operation support was provided by Rodren Drilling Ltd., based in Winnipeg, Manitoba. Work was performed under direction and review from Golder's WP6 lead, Mike Lemon. Golder's WP6 lead communicated with NWMO's WP6 lead, Andre Vorauer, regarding the development of the test plan and decisions during field testing based on preliminary test results.

3.0 TESTING EQUIPMENT

The testing tool consisted of a straddle packer with integrated shut-in tool (SIT) and multi-zone (i.e. above, between and below the packers) real-time pressure and temperature monitoring. Real-time pressure was monitored at surface using pressure transducers manufactured by Aquitronic. A separate pressure transducer with internal memory, manufactured by Pioneer Petrotech Services (PPS), was positioned within the interval and used to analyze the tests. A list of equipment used downhole is provided in Table 1. A list of equipment used at surface is provided in Table 2. Photos of the test equipment are provided in Appendix A. Pressure transducers were calibrated following manufacturers' instructions. Calibration certificates are provided in Appendix B.

Table 1: List of Downhole Equipment

Item Name	Manufacturer and Model	Item Description
Packers x 2	Baski MD3.4	Inflatable packers for isolating test zone
Test Tubing within interval and below shut-in tool	AWIK Aluminum tubing	API threaded pipe with o-ring sealed joints OD = 60.25mm ID = 48 mm Length = 2.9 m length
Test Tubing above shut-in tool	Boart Longyear NQ drill rods	Flush-threaded drill rods for lowering tool to test depth OD = 69.9 mm ID = 60.3 mm Length = 3 m

Item Name	Manufacturer and Model	Item Description
Multi-zone pressure transducers x 4	Aquitronic, model PDCR 1830-2236	Absolute pressure monitoring in test interval between packers, bottom zone below bottom packer, annulus above top packer and test tubing above SIT. Max operating pressure rating = 6.0 MPa Accuracy = 0.015% FS
Submersible pump	Grundfos Redi-flo 2	Lowering water level in test tubing for slug and pulse withdrawal Outer diameter = 46 mm
Interval pressure transducer	PPS25 pressure transducer	Absolute pressure monitoring at interval for data analyses Max operating pressure rating= 41.3 MPa Accuracy = 0.03% FS
Shut-in tool (SIT)	Baski APV 2.375-1.05 (SIT),	Hydraulically actuated OD = 60mm Mandrel diameter = 19.05 mm NPT
Transducer Protective Casing	LTG	Protective metal casing for the shut-in valve and for the pressure transducers
Flatpack	Baski, BKM	800 m length, 3 x 6.35 mm poly inflation lines, 1 x electrical cable for communication to transducers, 220 V electric drive

Table 2: Surface Equipment

Item Name	Manufacturer and Model	Item Description
Inflation Pressure Vessel	Misc.	20-liter capacity with 8.0 MPa pressure rating. Filled with glycol for testing during freezing conditions. Glycol pressurized using nitrogen to inflate packers and operate SIT.
Flow board and hoses	Misc.	Flow board to operate shut-in valve and packer inflation, 8.0 MPa pressure rating

Item Name	Manufacturer and Model	Item Description
Nitrogen Pressure regulator	Omega	Pressure regulator for controlling pressure outflow from nitrogen cylinder
Nitrogen cylinders	Praxair Canada Inc., Dryden, Ontario	Compressed nitrogen gas cylinder for packer inflation and activation of shut-in tool by pressurizing the inflation pressure vessel.
Barometric Pressure transducer x 2	Baro-diver manufactured by Van Essen Leveltroll 700, manufactured by In-situ Inc.	Barometric pressure monitoring for correcting downhole gauges Baro-diver: Max operating pressure = 0.015 MPa Accuracy = 0.33% FS Leveltroll: Max operating pressure = 6.89 MPa Accuracy = 0.05% FS
Data Acquisition System	ATL11 datalogger manufactured by Aquitronic	Data logger operated with AquiPro data acquisition software provided by Aquitronic. This software is exempt from the NWMO’s Technical Computing Software Procedure.

The straddle packer consisted of two hydraulically inflated packers connected using the aluminum tubing to provide an interval length of 19.78 m. The testing tool included a hydraulically operated SIT for isolating the test interval from the test tubing to reduce well-bore storage. The standard configuration of the Baski shut-in tool consists of two nylon activation lines, 6.35 mm diameter, integrated into the flat pack. One shut-in tool activation line was plumbed into the open port of the shut-in tool with the other connected to the closed port of the shut-in tool. The Baski shut-in tool operates by pressurizing the corresponding line to push a metal sleeve to expose (open) or cover (close) a perforated pipe that allows water to flow from inside the testing rods to the test interval.

3.1 Packer Inflation

At the surface, a pressure vessel filled with glycol was pressurized using compressed nitrogen to achieve the desired packer inflation pressure. While packer inflation is typically performed using water, glycol was used to inflate packers in IG_BH01 to prevent freezing. To reduce the compressibility of the packers and inflation lines, which contributes to the test interval compressibility, fluid is used for inflation instead of gas (typically nitrogen) for packer inflation.

Glycol has a freezing temperature of -25°C, specific gravity of 1.03 at 20°C and viscosity of 21 mPa*s at 20°C (versus water viscosity of 1.002 mPa*s). The additional density produces higher pressure at the packer element relative to water. This increased density provides an advantage by reducing the necessary pressure to be applied from the surface to achieve the desired packer pressure. However, the use of glycol is a disadvantage when deflating the packers. Deflation of the packers is achieved through the elasticity of the packers, as well as pressure equilibration between the fluid pressure in the packers and the annulus. Typically, the differential pressure between the packer pressure and the annulus pressure is sufficient to push the inflation fluid from the packers when the external borehole hydraulic pressure is within 0.3 MPa of the static inflation fluid hydraulic column pressure within the packers. The elasticity of the packers was not sufficient to fully overcome the density differential and increased friction losses due to viscosity produced by the glycol. This required additional deflation time and the evacuation of glycol from the inflation line to allow the packers to return to their pre-inflation diameter. Evacuating glycol from the flatpack took several hours for each deflation, adding significant time to the testing program.

Packer inflation pressure is calculated following the manufacturer's recommendations and recorded in the Field Data tab of the Data Quality Confirmation workbook. The inflation pressure at surface was set at 2.0 MPa, which is the summation of several criteria:

a) *Hydrostatic Pressure* – Pressure exerted on the external surface of the packers. When inflating with fluid, the external pressure on the packer is balanced by the equivalent internal hydrostatic pressure in the inflation line.

b) *Packer stretch (or packer seating pressure)* – Pressure required to expand and seat the packer to the borehole wall. This pressure is dependent on the borehole diameter and provided in the manufacturer's user manual (equals 0.7 MPa for HQ borehole).

c) *Test Differential Pressure (or packer sealing pressure)* – Packer pressure required to prevent leakage across the packer when maximum differential pressure is exerted at the test interval during the test execution. A maximum test pressure of 0.95 MPa was applied for the inflation pressure calculation.

d) *Factor of Safety* – Extra applied pressure to ensure the required packer inflation pressure is maintained through the entire test. The factor of safety accounts for any slow leakage in the system and temperature variations at surface. A factor of safety of 0.35 MPa was applied for all tests.

The required packer inflation pressure is first set at the nitrogen cylinder by the pressure regulator. This pressure is then led to the flow board, where a more precise adjustment of the required inflation pressure can be achieved. The pressure from the flow board is then diverted to the pressure vessel and pressurizes the glycol within it. The packer inflation pressure can also be observed at the vessel. The pressurized glycol within the vessel is then diverted into the flatpack and will start to inflate the packers.

3.2 Data Acquisition

In order to collect accurate pressure and temperature data, the following data measurement instruments were used:

- **Multi-zone Packer Tool Pressure Measurements –** Multi-zone pressure was monitored with four transducers manufactured by Aquitronic, model PDCR 1830-2236. Pressure readings were communicated, in real-time, to the surface via dedicated cabling in the flatpack. Data were recorded with an ATL11 datalogger manufactured by Aquitronic and operated with AquiPro data acquisition software provided by Aquitronic. Pressure readings were used to monitor the test progress, verify packer seal of the test zone and allow for estimation of preliminary transmissivity values during testing. The Aquitronic transducers were housed within the shut-in tool protective casing above the test zone as shown in Figure 3. The zones monitored during testing include:

- Test interval below the shut-in tool;
- Open borehole below the packer tool to confirm adequate seal at the bottom of the test interval;
- Annular space above the packer tool and between the test tubing and borehole wall to confirm adequate seal at the top of the test interval; and
- Test tubing to measure the magnitude of the induced slug or pulse. The measured tubing pressure is the hydrostatic pressure above the shut-in tool.

- **Interval Test Pressure for analyses –** Interval test pressure and temperature were obtained with a single pressure transducer Model PPS25, manufactured by Pioneer Petrotech Services Inc. (PPS). The PPS transducer is self-contained with integrated internal memory and battery. The transducer was positioned within the test interval inside a perforated pipe below the upper packer. The test pressures recorded from this transducer were used for the formal test analyses since it measured pressures at the test interval and provided a complete borehole pressure history from the start of testing.
- **Packer pressure -** Packer pressures were monitored at surface with an analog pressure gauge plumbed into the packer inflation vessel. Packer pressures were monitored during the testing to ensure no change in packer pressure occurred. Packer pressures at the start and end of each test were recorded in Field Data tab of the Data Quality Confirmation (DQC) workbook included in the electronic deliverable under separate cover.
- **Barometric pressure** – Barometric pressure trends were recorded at the drill rig during testing using a LevelTroll 700 manufactured by In-Situ Inc. For higher barometric resolution, a Baro-Diver manufactured by Van Essen was used. Barometric pressure and air temperature were recorded every minute for the entire duration of the testing program. Barometric pressure was used to compensate the downhole transducer pressures by subtracting the barometric pressure from the downhole transducer absolute pressure reading to provide gauge pressure at depth. Barometric pressure range over each test was included in the Field Data tab of the DQC workbook.

All electronic instrumentation was calibrated prior to arrival on site following the manufacturer's instructions. Calibration checks of the Aquitronic transducers using a digital pressure gauge, model DPG4000-2k manufactured by Omega, were performed prior to lowering the tool downhole. Calibration checks are recorded in the Tool Assembly tab of the DQC workbook. Calibration certificates are provided in Appendix B.

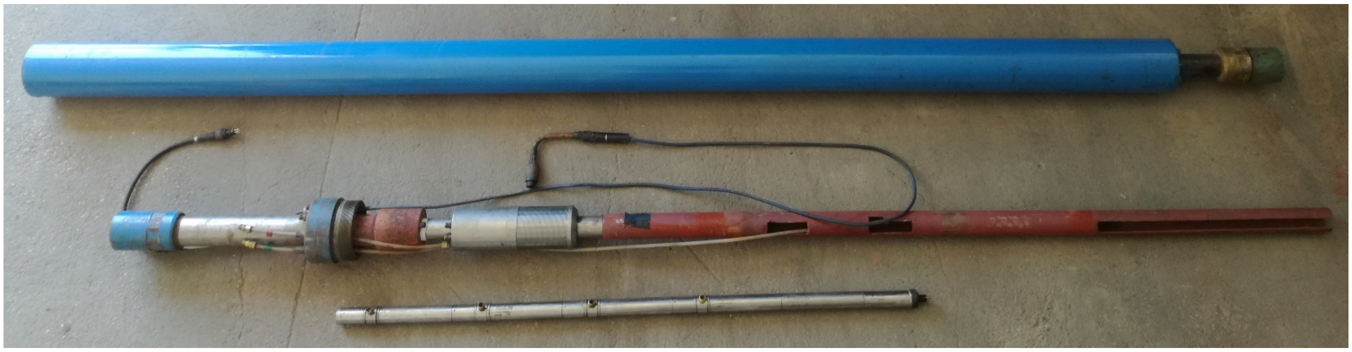

Figure 3: Shut-in tool casing (blue pipe), showing shut-in tool (stainless steel cylinder in center) and Aquitronic transducers (bottom of image).

3.3 Tool Assembly

For all test intervals, the testing tool was configured for a test interval length of 19.78 m between two inflatable packers. The testing depth of the tool is limited by the differential rating of the packers and the pressure rating of the pressure transducers. The packers (Baski model MD3.4), are rated to a differential pressure of 7000 kPa in a 100 mm diameter borehole. The interval pressure transducer (PPS25) was rated to 41.3 MPa. However, for real-time pressure readout at surface, the pressure rating of the Aquitronic transducers wired to the surface through the flat pack limits the depth that the transducers can be placed. The pressure rating of the real-time readout transducers (Aquitronic PDCR 1830-2236) was 6,000 kPa. Therefore, for test depths deeper than 600 m, the testing tool was reconfigured to prevent the Aquitronic transducers from over-pressuring.

On-site assembly of the testing equipment was from bottom-up, while the tool was lowered down the borehole. Prior to lowering the testing equipment down the borehole, the packers and the inflation lines were filled with glycol due to the sub-freezing air temperatures.

The bottom packer was threaded to the aluminum interval test tubing which was threaded to the perforated transducer carrier. The pre-programmed, battery powered, interval pressure transducer (PPS) with internal memory was threaded inside the perforated transducer carrier. The recording frequency was set to 5 second intervals allowing for several days of data recording and storage. The perforated transducer carrier was then threaded to the bottom of the top packer. The shut-in tool protective casing, which contains the real-time pressure and temperature transducers and shut-in tool, was positioned above the upper packer in two different configurations. Tool configuration 1 was used for test interval depths less than 600 m. Tool configuration 2 was used for test interval depths greater than 600 m. The tool configurations are described in the subsections below.

Regardless of the tool configuration, the connection end of the flatpack was positioned directly above the shut-in tool protective casing. The flatpack contains three poly lines: one to inflate/deflate the packers and two to operate the shut-in valve. An electrical cable connecting the tool instrumentation to the real-time data acquisition system is also included in the flatpack. All lines are sealed in a hardened rubber sleeve. The flatpack was secured to the outside of the NQ test tubing using duct tape every 3 m to surface, which was sufficient to prevent the flatpack from separating from the NQ test tubing.

Above the shut-in tool protective casing, NQ test tubing was used to position the testing tool at the testing depths. The threads of the NQ test tubing were sealed with Teflon tape and paste. However, leakage of varying magnitudes from the NQ test tubing was observed during testing. Leakage in tubing does not impact pulse tests as the pressure recovery is occurring with the shut-in tool closed that isolates the fluid in the tubing from the test interval. Leakage is discussed further in Sections 3.4 and 6.2.

At surface, the pressure required to inflate the packers and to operate the shut-in tool was supplied from a compressed nitrogen gas cylinder. A pressure regulator was directly attached to the cylinder and controlled the inlet pressure and flow to the flow board. The flow board was located inside the testing trailer and enabled the operation of the shut-in tool and packer inflation by pressurizing the glycol-filled inflation pressure vessel located within in a heated trailer (Figure 4).

Figure 4: Heated trailer (flow board at upper left, inflation pressure vessel at lower right).

3.3.1 Tool Configuration 1 - Depths Less than 600 m

Testing depths less than 600 m allow for the 'typical' testing configuration. This configuration, as shown on Figure 5, positions the shut-in tool directly above the upper packer. The Aquitronic transducers are not lowered deeper than 600 m (or equivalent fresh water head). This configuration minimizes the wellbore storage and tool compressibility below the shut-in tool with the shut-in tool as close to the upper packer as possible. Tool Configuration 1 was used for tests HT001 – HT008 and HT013.

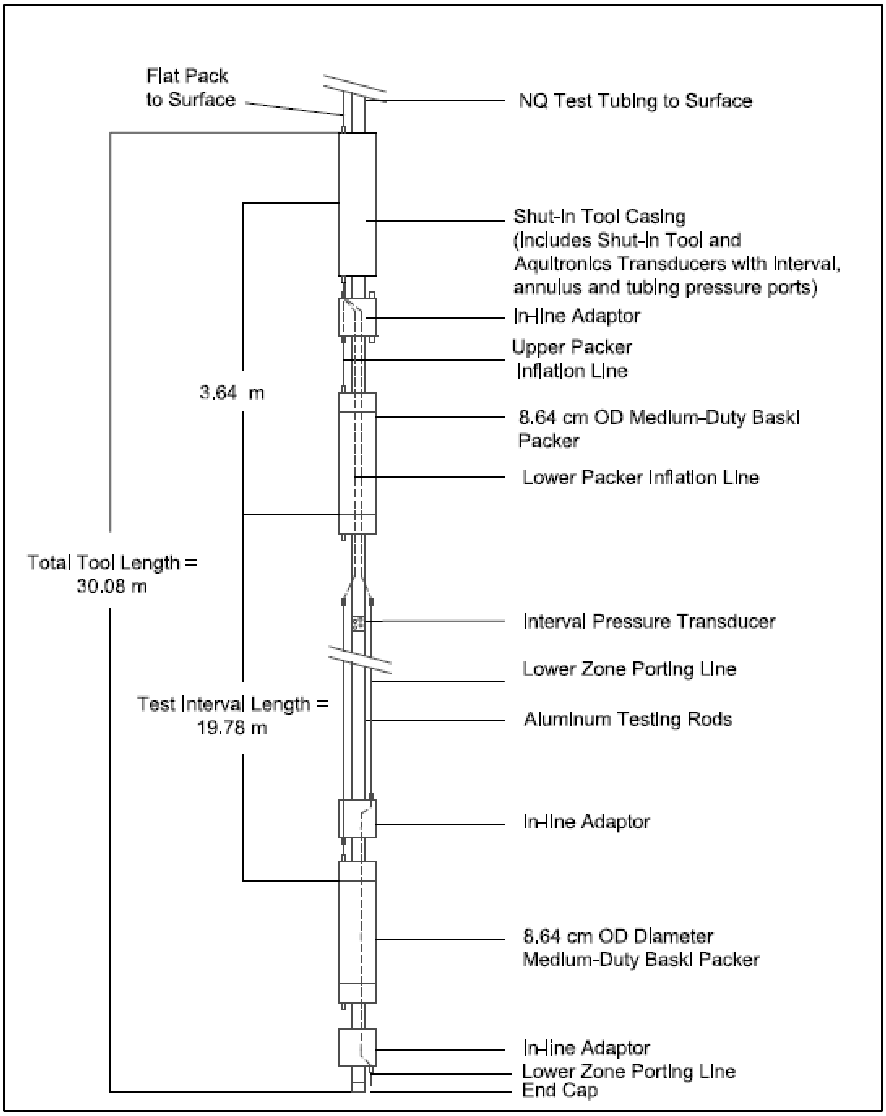

Figure 5: Tool Configuration 1 Schematic.

3.3.2 Tool Configuration 2 - Depths Greater than 600 m

Multi-zone, real-time pressure readout at surface for depths greater than 600 m (or equivalent fresh-water head) was achieved by positioning the shut-in tool casing, which includes the Aquitronic transducers, such that it is not lowered deeper than 600 m. Inside the shut-in tool casing, the Aquitronic transducers are ported into the test interval below the shut-in tool, the annular space above the shut-in tool, and into the test tubing. For real-time monitoring below the packers, a porting line consisting of nylon line (6.35 mm diameter), was extended to below the lower packer. The upper packer was positioned below the shut-in tool casing using approximately 313.74 m of aluminum testing rods to reach the deepest test interval for the testing program (HT010 – 906.6 – 1001.5 m). The advantage of this configuration is that allows testing to any depth, but with the disadvantage that wellbore storage increases with depth below 600 m. Wellbore storage increases at the compressibility of water as related to the volume of the inside of the aluminum testing rods. Wellbore storage increases by 3.7E-10 m/Pa (3E-13 m/Pa per m that is extended below 600 metres), or by 1.3 times the wellbore storage of Tool Configuration 1, by extending the tool to 1000 m. Packer inflation was relayed from the flatpack to the upper packer using nylon inflation line (6.35 mm diameter). This configuration is shown in Figure 6.

Tool Configuration 2 was used for tests HT009 – HT012 and HT0013a.

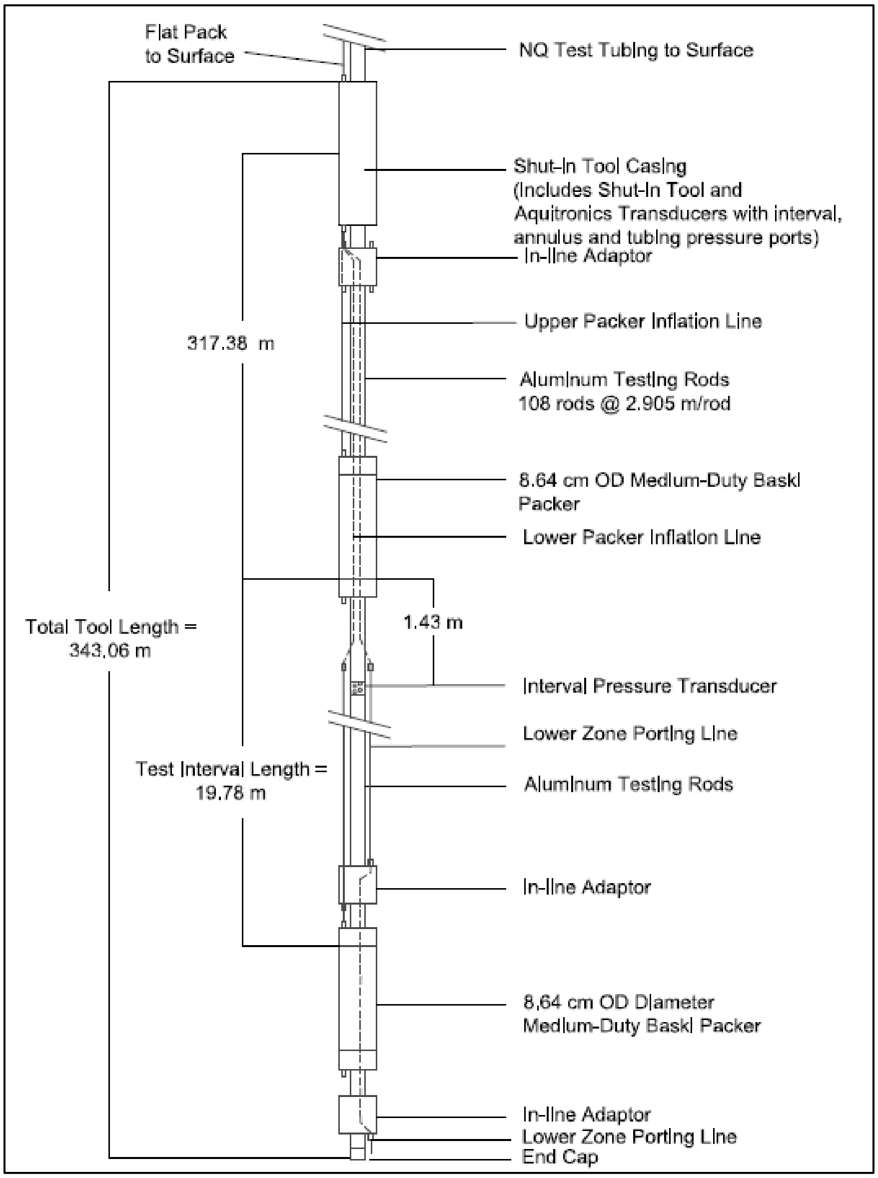

Figure 6: Tool Configuration 2 Schematic.

3.4 Tool Function Checks

Tool quality assurance testing was performed on the packer inflation lines and SIT activation lines to ensure the tool would function properly at test depths. Leak testing was performed inside the core shack prior to lowering the tool down hole for the casing tests. The flatpack lines were pressurized to 20 MPa and monitored for leakage for 30 minutes. Data from the quality assurance testing is documented in the DQC workbook.

Three tests were performed inside the surface casing (i.e. Casing Test) with Tool Configuration 1 prior to lowering the tool to test depths and also at the end of the testing program. The casing test measured the leakage of the testing tool exceeding the maximum test differential pressures (max test differential pressure = 0.498 MPa) and allowed for the estimation of an equivalent transmissivity of the cased interval. This transmissivity was considered the lower testing limit of the tool. Total test zone compressibility was not measurable as the volume change from the instantaneous pressure change induced for a pulse phase was below the measurement resolution of the downhole Aquitronic pressure transducers.

Casing tests with Tool Configuration 2 were not possible due to the long length of aluminium test rods added between the top packer and the shut-in tool, which resulted in the re-configured tool not being fully contained within the surface casing. However, the packers were inflated within the casing to confirm the packer inflation line and packers were not leaking. Data specific to the leak testing on Tool Configuration 2 are provided in the DQC workbook.

For all casing tests associated with Tool Configuration 1, the tool was assembled within the surface casing following the tool assembly description in Section 3.3. The tool was positioned to seal with the surface casing approximately 43 m to 63 m below ground surface so that the shut-in tool was below the water level.

The casing tests performed on Tool Configuration 1 are summarized in the following subsections. Details are provided in the DQC workbook.

3.4.1 Casing Test 1 – Start of Testing

Casing Test 1 was performed on February 1-2, 2018. The testing tool with a test interval length of 19.78 m using Tool Configuration 1 was lowered into the surface casing and inflated below the groundwater level, which was near surface (approximately 40 mbgs). The packers were inflated to the highest anticipated inflation pressure during testing. For Casing Test 1, the packers were inflated to 2.55 MPa surface pressure and monitored for leakage. As the test tubing was pressurized, a leak occurred within the packer inflation line at the pressure vessel causing the packers to partially deflate. After repairing the leakage, the packers were repressurized to 2.05 MPa. After packer reinflation, the test rods were pressurized with water to create a differential pressure of 0.896 MPa, which is higher than the anticipated test differential pressures to ensure a tight seal with the rods. The shut-in tool was then closed, and the interval pressure was monitored for approximately 4.5 hours with no observable hydraulic connection above and below the test interval.

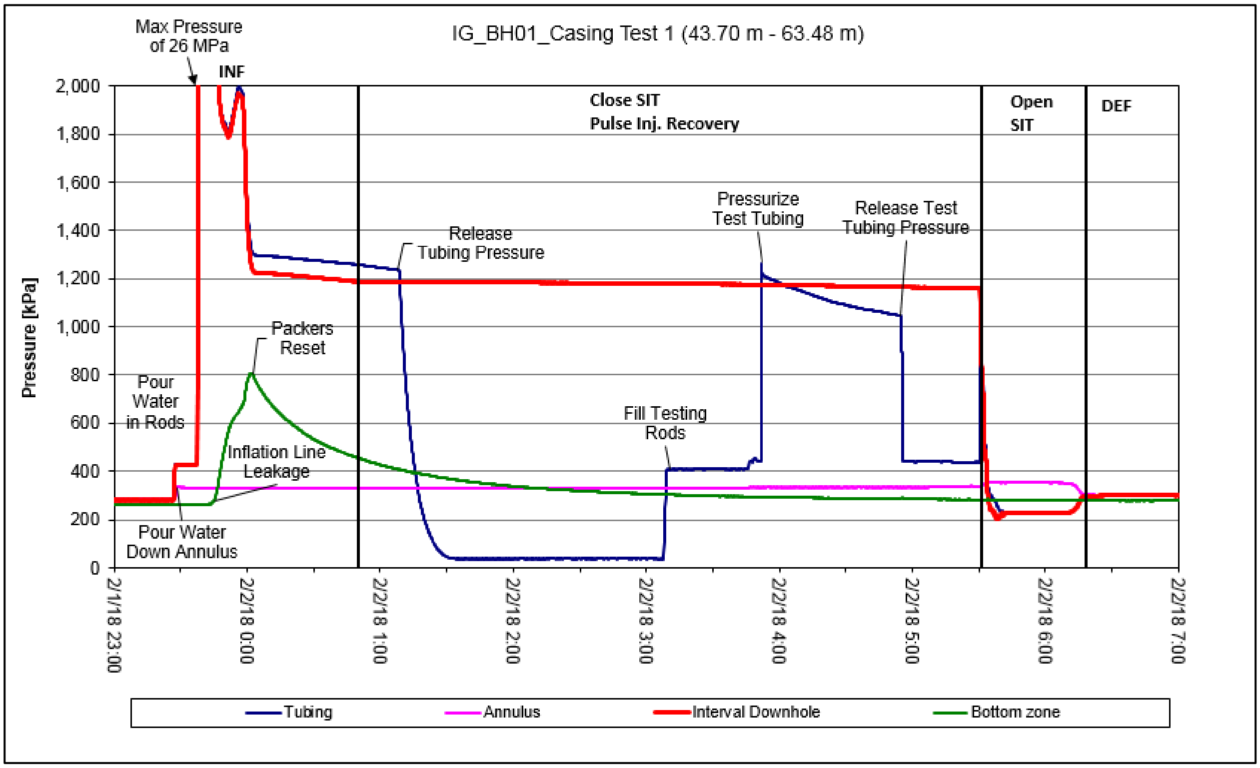

Figure 7: Casing Test 1 Pressure plot.

Casing tests were analyzed using HydroBench (see Section 6.2 for a description of HydroBench). The interval pressure from the PPS25 pressure transducer was analyzed by HydroBench during the shut-in phase after releasing the tubing pressure. The resulting transmissivity (T) of the testing tool with the shut-in tool closed was 3E-13 m^2/sec or an equivalent hydraulic conductivity of 2E-14 m/sec over the 19.78 m test interval. This is considered to be the lower limit for pulse tests (HT001 to HT008).

3.4.2 Casing Test 2 – Tool Reconfiguration

Casing Test 2 was performed on February 27, 2018 after completing test HT013a and removing the tool from the borehole for confirming the repair of the upper packer bypass and reconfiguration to reattempt the test HT013a. The testing tool with a test interval length of 19.78 m using Tool Configuration 1 was lowered into the surface casing and inflated below the groundwater level, which was near surface. The packers were inflated to 2 MPa surface pressure and monitored for leakage. No leakage was observed from the packer inflation system. With the packers inflated the shut-in tool was closed and then the water level in the test tubing was lowered while adding water to the annulus. No hydraulic connection was observed between the annulus, tubing and test interval for two hours and 15 minutes. The increase in the interval pressure after packer inflation is likely due to the confined pressure response to the expanding packers, closing of the SIT, and the additional hydrostatic load exerted above the upper packer when adding water to the annulus. The shut-in tool was then opened, introducing a slug withdrawal. The interval pressure was monitored for approximately 2 hours with no observable hydraulic connection above and below the test interval.

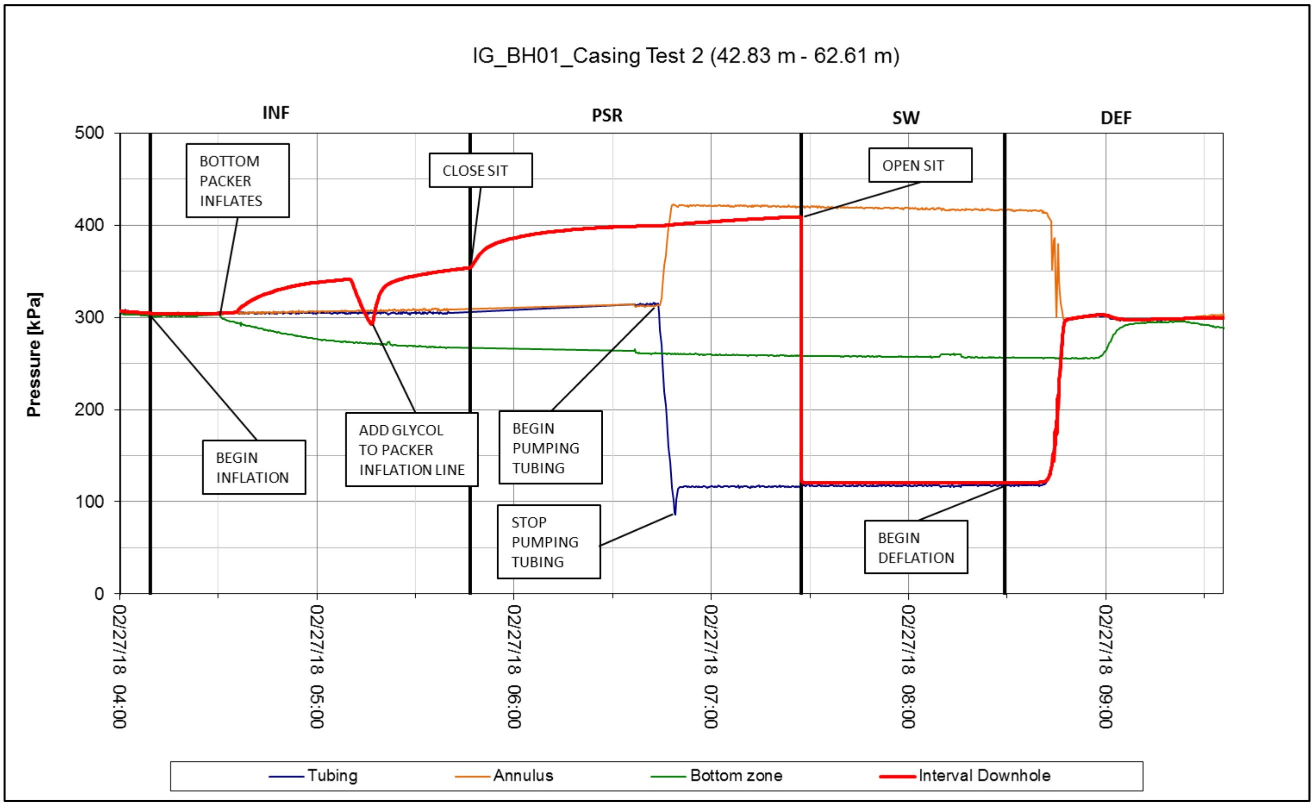

Figure 8: Casing Test 2 Pressure Plot.

From the HydroBench analysis, the slug withdrawal phase (SW) was analyzed resulting in a measured transmissivity of the testing tool with the shut-in tool open was 6E-10 m^2/sec or an equivalent hydraulic conductivity of 3E-11 m/sec over the 19.78 m test interval length. This can be considered the lower limit for slug test HT013.

3.4.3 Casing Test 3 – End of Testing

Casing Test 3 was performed on March 2, 2018 after completing test HT013b to confirm the tool performance. The testing tool with a test interval length of 19.78 m using Tool Configuration 1 was positioned within the surface casing prior to removing the tool from the borehole and inflated below the groundwater level, which was near surface. The packers were inflated to 2.50 MPa surface pressure and monitored for leakage. No leakage was observed from the packer inflation system. With the packers inflated, the shut-in tool was closed while the water level in the test tubing was lowered. The shut-in tool was then opened, introducing a slug withdrawal. After 2.5 hours of slug withdrawal recovery, the shut-in tool was closed for a shut-in recovery phase. The interval pressure was monitored for approximately 2.5 hours with no observable hydraulic connection above and below the test interval.

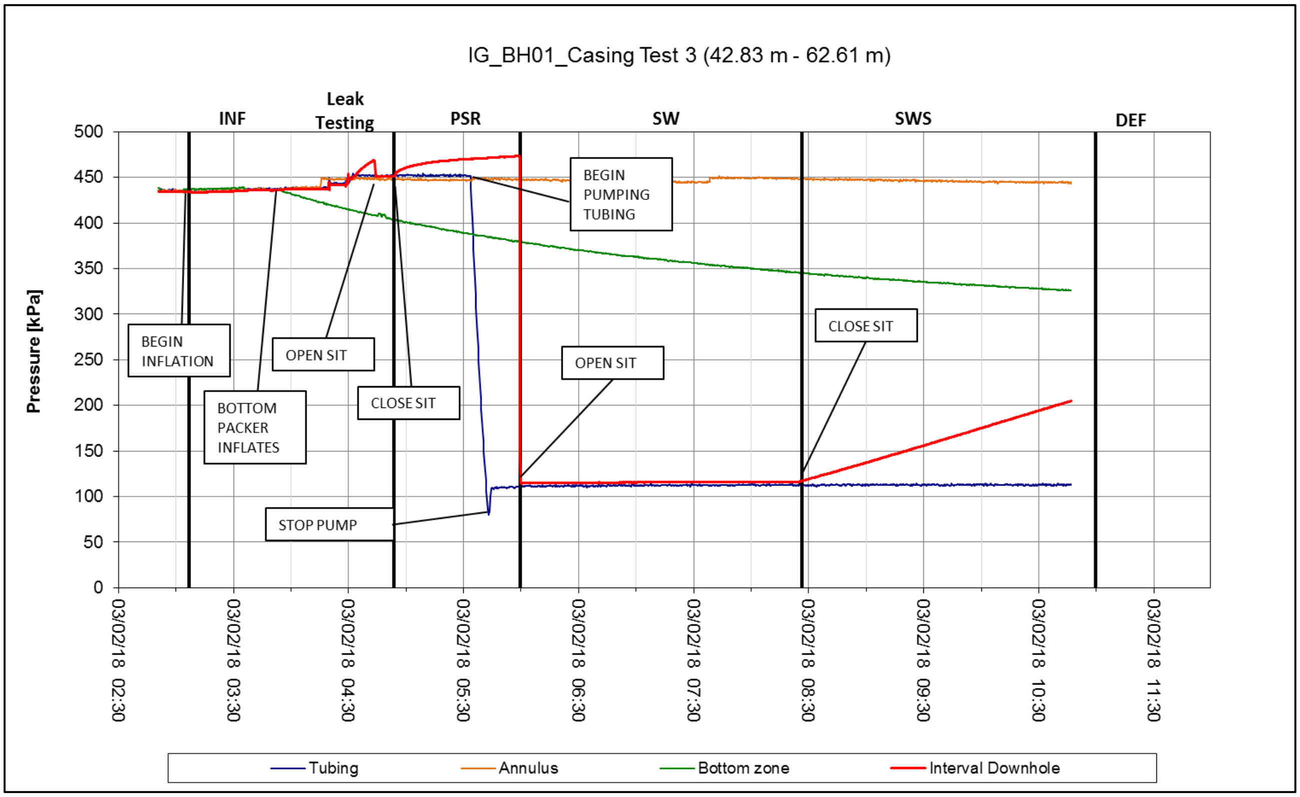

Figure 9: Casing Test 3 Pressure Plot

From the HydroBench analysis, the measured transmissivity of the testing tool with the shut-in tool open was 9E-10 m^2/sec resulting from a 2.5 kPa pressure change during the SW phase. The transmissivity with the shut-in tool closed was measured at 5E-11 m^2/sec. The increased transmissivity measured with the shut-in tool open was likely due to rod leakage above the shut-in tool. This rod leakage was observed during Test HT013b.

4.0 TEST INTERVAL SELECTION

The test interval selection was determined in a collaborative workshop with NWMO and Golder technical leads to review the findings from drilling, core logging, and geophysical logging. The objectives for test interval selection consisted of:

1) Confirm low bulk hydraulic conductivity in a potential repository horizon (500 m – 600 m depth) and directly above the repository horizon (400 m – 500 m);

2) Determine hydraulic conductivity of selected fractured intervals if present within and in proximity to the repository horizon while attempting to collect groundwater samples if possible; and

3) Assess bulk hydraulic conductivity of shallow (<200 m) bedrock.

The final selection of the test intervals considered the following criteria:

- **Acceptable packer element placement**. Packer element placement was governed by the borehole condition. Geophysical caliper logs (WP5) were reviewed to confirm the borehole was a consistent diameter to ensure the differential pressure rating of the packers would apply. Acoustic televiewer imagery (WP5) and core photos (WP3) were reviewed to ensure the packers were seated in sections free of fractures to ensure no packer bypass.

- **Location of hydrogeologic features.** The presence of broken joints, zones of increased porosity or weathering can influence the hydraulic response of the bulk rock mass. These features were identified and incorporated into the test interval selection decision to ensure that variably fractured intervals were tested to assess the range of hydraulic conductivities within the borehole. Also, as only a small percent of open fractures tends to be conductive, flow logging was performed under non-pumping and pumping conditions to identify the more water conductive fractures. These features were identified during Drilling and Coring (WP2), Geological and Geotechnical Core Logging, Photography and Sampling (WP3), Opportunistic Groundwater Sampling (WP7), and Fluid Temperature and Resistivity Log and Flowing Fluid Electrical Conductivity Log (WP5).

Observations from these data are summarized in the Cover Page of the DQC workbook.

Fifteen (15) intervals were identified applying the testing objectives and the test interval selection criteria. The project schedule allowed 20 days of hydraulic testing. In order to complete the highest priority test intervals in the allotted time, the test intervals were grouped into series of priority (1, 2 and 3) based on the test objectives listed above including test intervals that could potentially yield water samples based on the flow logging responses observed during WP5. The testing sequence was developed to complete the highest priority test intervals (series 1) while reducing the time moving the testing tool between test intervals. This sequence of test intervals is reflected in the test identification (HT001, HT002, HT003, etc.). Thirteen intervals were tested from February 2, 2018 to March 2, 2018 over 27 days. The extension of the testing program was the result of packer tool reconfiguration and subsequent leak testing within the casing and slow deflation times resulting from a combination of the sub-freezing temperatures (-20° to -30° C) and the use of glycol as the inflation fluid.

5.0 TESTING METHODOLOGY

The planned hydraulic testing workflow illustrated in Figure 10 was followed for most tests and further described below. Due to the overall low to very low hydraulic conductivity of the test intervals, only pulse and slug type tests were completed for hydraulic testing in borehole IG_BH01. Appendix D includes a legend of abbreviations used for the test presentations and analysis.

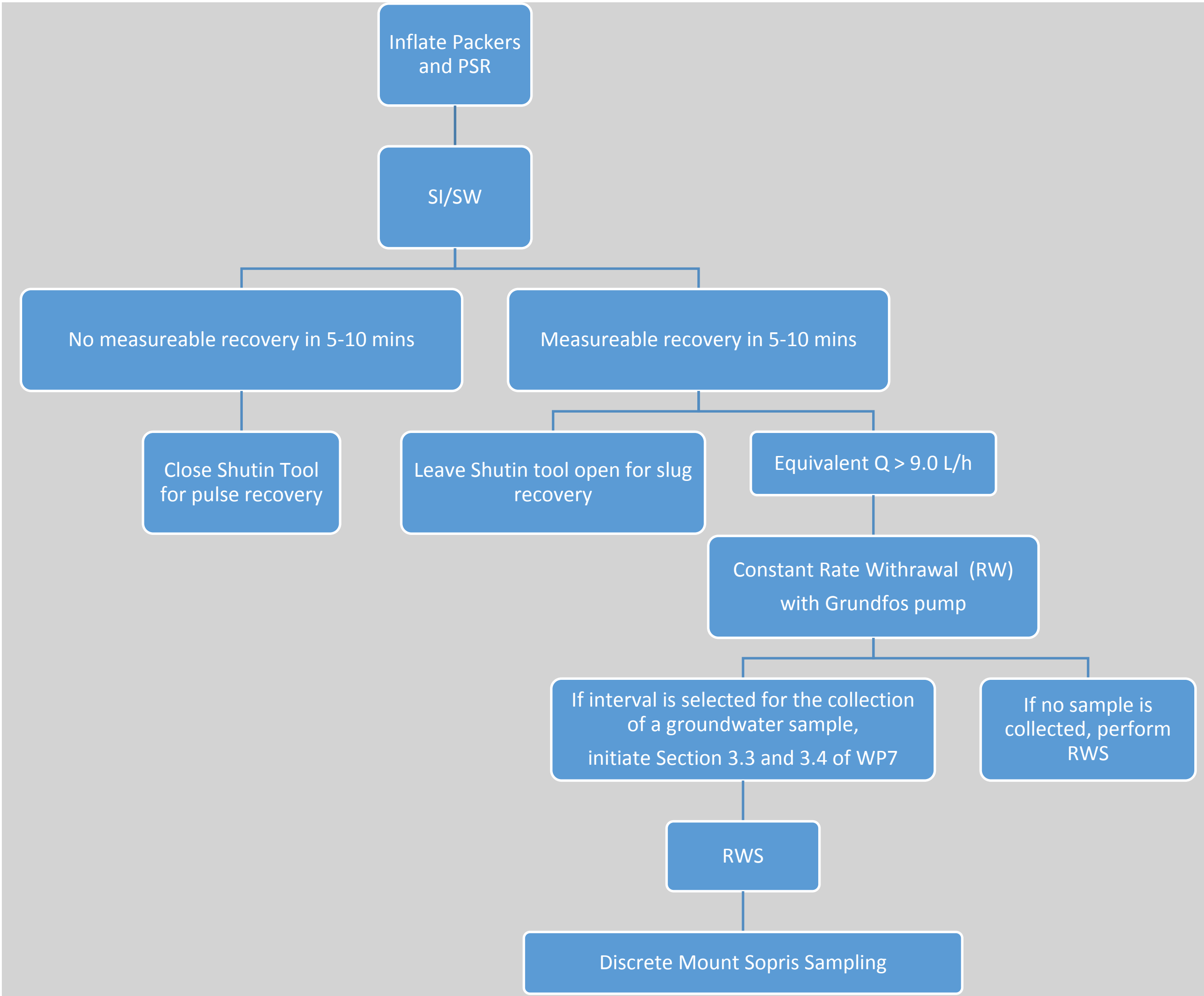

Figure 10: Flow chart showing planned test type decision from WP6 Test Plan.

Test HT001 is shown in Figure 11 as a typical pulse test performed in the program.

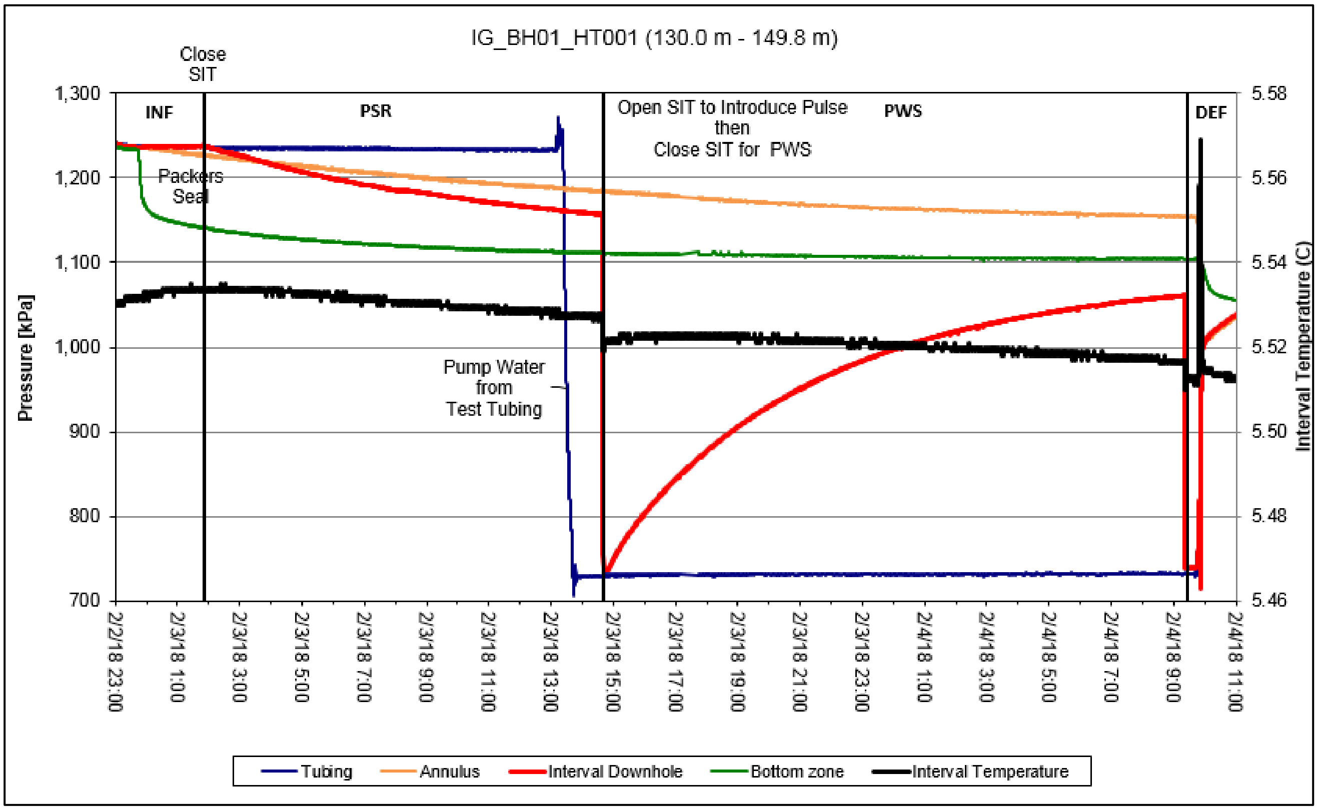

Figure 11: Typical pulse test procedure, HT001.

Packer Inflation

The required packer inflation pressure was first set at the nitrogen cylinder using a pressure regulator. This pressure is then directed through the flow board to the pressure vessel, pressurizing the glycol within. The packer inflation pressure was monitored at the pressure vessel with an analog dial pressure gauge. The pressurized glycol within the vessel is diverted into the flatpack, which was also filled with glycol, to inflate the packers. Pressure was applied with nitrogen to the pressure vessel until the glycol level in the vessel remained stable, indicating the packers have inflated to their full size against the borehole wall. The typical duration of the packer inflation was approximately 2 hours.

After the packers were inflated, the packer seals were confirmed by monitoring the real-time pressure responses in the bottom zone and annulus (see zone pressure responses during the INF phase in Figure 12). If the expected pressure responses were not discernable, several litres (i.e. enough to raise the water column at least one meter) of drilling supply water were poured between the annulus of the surface casing and the test tubing while monitoring for any change in pressure at the interval transducer. The interval temperature was monitored until stable before initiating the pressure static recovery phase. The packer pressure (start and end of test) was recorded in the Field Data tab in the DQC workbook.

Pressure Static Recovery (PSR) Phase

The PSR phase is intended to assess the initial test interval pressure prior to testing. After the packers were inflated at the selected depth interval, the PSR phase was initiated by closing the shut-in valve. The shut-in valve was operated by nitrogen gas supplied from the cylinder via the glycol-filled inflation pressure vessel. The required pressure value to operate (open and close) the valve was 2.0 MPa. The shut-in valve pressure is adjusted and controlled by the flow board, and from there diverted with glycol from the inflation pressure vessel to the shut-in valve via the flatpack. Closing and opening the shut-in valve was completed within a relatively short period of time (a few seconds). With the shut-in valve closed, the hydrostatic pressure within the test section is effectively separated from the rest of the test tubing while the pressure in the test interval starts equilibrating. The PSR phase was monitored in real-time and continued until the rate of pressure change stabilized relative to the transducer resolution or could be extrapolated with confidence by examining the semi-log Horner plot in Golder's analysis software HydroBench. The semi-log Horner plot for HT008 is shown below as an example.

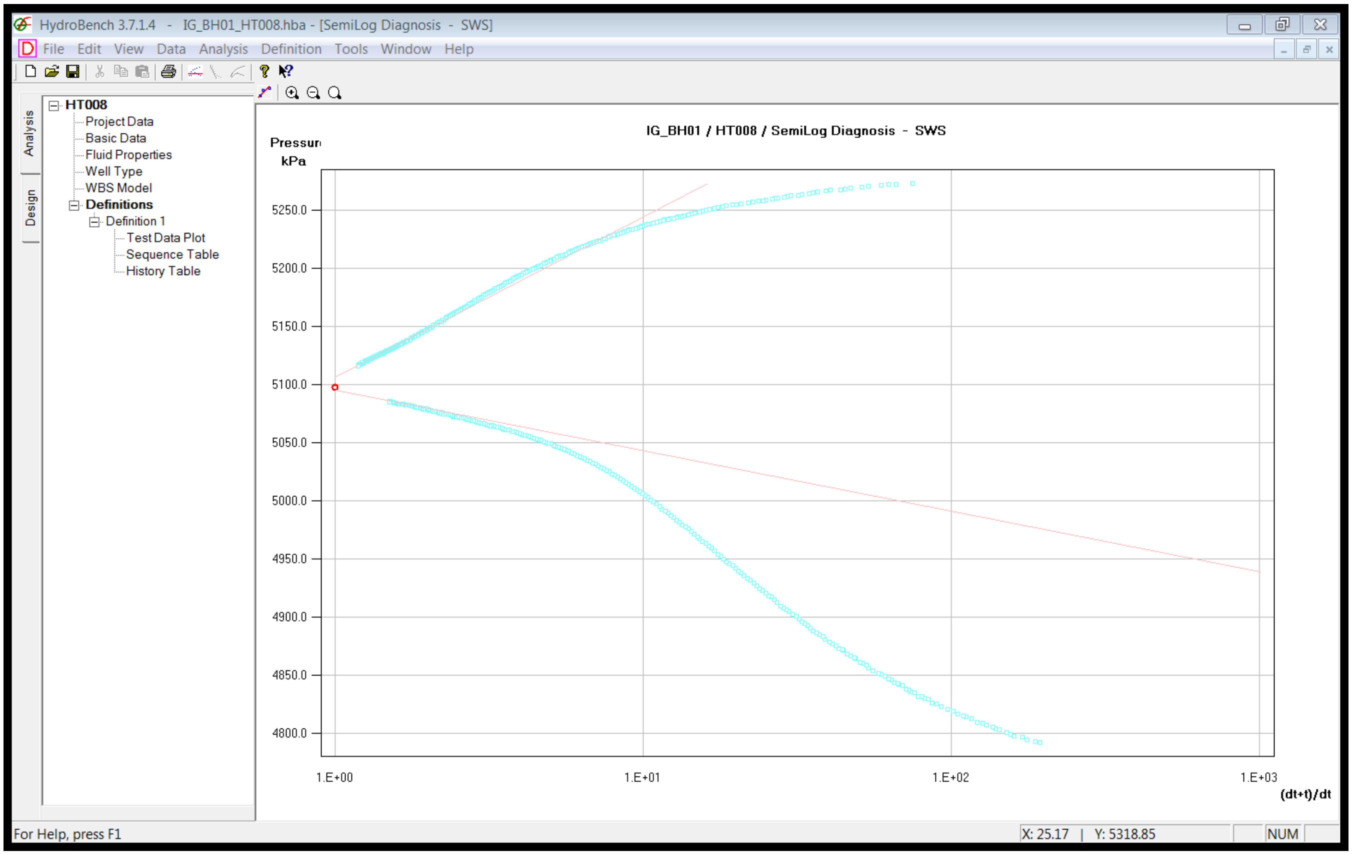

Figure 12: HydroBench semi-log plot from HT008 showing the pressure recoveries of the PSR (upper curve) and SWS (lower curve) phases.

The PSR phase details including start time, end time and stabilized pressure were recorded in the Field Data tab of the DQC workbook. In addition to assessing the initial test interval pressure prior to testing, the PSR Phase served to dissipate a portion of the borehole pressure and temperature history effects to minimize their influence on the derivation of hydraulic parameters.

Creating Test Differential Pressure

The water level within the test tubing was typically within 20 m of the ground surface therefore a withdrawal test was performed for every test. The water column in the test tubing was lowered using a submersible Grundfos Redi-Flo 2 pump while the shut-in valve was still closed. Head differentials achieved for the tests ranged from approximately 0.285 MPa to 0.490 MPa, based on the lifting capacity of the submersible pump. After pumping water from the test tubing, the submersible pump was removed for the test phases. The shut-in tool was then opened, introducing the pressure change to the test interval. The interval pressure was monitored for a short period of time (typically 5-10 minutes) to assess the relative magnitude of the interval transmissivity before deciding whether to close the shut-in tool to begin the pulse recovery phase (PWS) in very low conductivity intervals or to leave the shut-in tool open to continue the slug withdrawal recovery phase (SW) for low conductivity intervals.

Test Pressure Recovery for Very Low Conductivity Test Intervals

For those intervals with very low transmissivity (i.e. $< 10^{-9}$ m^2/s) with minimal recovery within 5-10 minutes, the interval pressure was shut-in by closing the shut-in tool for the PWS. The interval pressure recovery was monitored in real-time with the interval pressure transducer and assessed in the field using Golder's analysis software HydroBench. This field assessment of real-time data was used to determine the duration of the PWS to ensure a high level of confidence has been achieved for the derived formation parameters prior to terminating each interval test.

Test Pressure Recovery for Low Conductivity Test Intervals

Three test intervals (HT002, HT008 and HT009) had transmissivity sufficiently high to observe a measured slug recovery phase with the shut-in tool open. The length of the slug recovery phase depends on formation transmissivity. For intervals HT002 and HT008, the shut-in tool was then closed for a Slug Withdrawal Shut-in (SWS) phase due to the slow slug withdrawal recovery.

For tests HT008 and HT009, the shut-in tool was reopened after the completion of the SWS allowing the recovery to serve as part of a purging phase prior to the collection of groundwater samples. Groundwater sampling is discussed in the WP7 – Opportunistic Groundwater Sampling technical report (Golder 2018b).

The interval pressure recovery was monitored in real-time with the interval pressure transducer and assessed in the field using Golder's analysis software HydroBench. This field assessment of real-time data was used to determine the duration of the interval pressure recovery phases (SW or SWS) to ensure a high level of confidence has been achieved for the derived formation parameters prior to terminating each interval test.

Packer Deflation

At the termination of each test, the packers were deflated by releasing the nitrogen pressure from the pressure vessel. The pressures in each zone (i.e. bottom, interval and annulus) were monitored in real-time for pressure equilibration to confirm the packers had unseated from the borehole wall. The level of glycol in the pressure vessel was monitored to determine when the packers had fully deflated. However, most tests encountered difficulty achieving full deflation due in part to the excessive time required to evacuate the glycol from the inflation line. The specific gravity of glycol is 1.03, which acts to increase the pressure in the packers compared to the standing fluid column in the borehole. Packer elasticity was insufficient to overcome this extra pressure, contributing to poor deflation performance. Attempts were made to improve deflation performance by increasing the water level in the borehole, but freezing conditions near surface limited the use of this method. Attempts were also made to draw a vacuum on the pressure vessel and lower the pressure in the packers. While this approach partially decreased the deflation times, it still did not achieve full deflation as indicated by the packers initially dragging on the borehole wall during moving to the next test interval. During the reconfiguration of the tool between tests HT008 and HT009, the shut-in tool closed activation line was joined to the packer inflation line at the top of the shut-in tool. This allowed the complete evacuation of glycol from the inflation line using nitrogen. This process allowed for the full deflation of the packer, but did not reduce the time required for deflation.

6.0 TEST ANALYSIS

In fractured crystalline rock settings, it is expected that rock mass would have low bulk hydraulic conductivity, except in the presence of localized conductive fractures. The main contribution to hydraulic conductivity and total porosity in crystalline rocks comes from the fractures, with minimal contribution from the matrix. Under these conditions, the volume of rock actually influenced during a borehole hydraulic test can be quite limited. For relatively short test durations that were completed for this program, it is expected that near borehole conditions dominate the test response with only limited transition to the undisturbed formation response. Two flow models are commonly applied to try and match the test interval responses:

- Wellbore storage and skin with a homogeneous formation model
- Wellbore storage with composite flow model (i.e. a two-zone model)

Wellbore storage and skin are discussed further in Section 6.1. The skin derived with the homogeneous model is essentially equivalent to the inner zone parameters derived with the composite model. In both cases, only transitional data to the undisturbed formation response (i.e. radial flow regime on log-log plot) is observed during the test and it would require unrealistic test duration to reach the undisturbed formation response. In most cases, the approach was to apply wellbore storage and skin with a homogeneous model as test response was dominated by transition between near wellbore effects and undisturbed formation response.

The analysis approach is knowledge-based versus automated or statistical that follows a systematic, hierarchical workflow to minimize uncertainty:

- Test is performed to minimize factors that increase uncertainty such as borehole history and temperature effects.
- Select input parameters.
- Input borehole pressure history.
- Review data in transmissivity normalized plots for consistency between phases and for order of magnitude transmissivity.
- The flow model is diagnosed using high resolution of the changes in the interval pressure response visible with the semi-log pressure derivative in log-log plots. The flow model is selected based on the shapes and slopes of the semi-log derivative, geologic setting, and experience at other sites in similar hydrogeologic settings.

- Parameters are derived by matching on the log-log plot to both the pressure change and semi-log pressure derivative knowing, for example, that transmissivity is derived from the pressure match to the derivative data radial flow period or to the extrapolated radial flow period, distances to discontinuity boundaries are derived from time match to transitional data from upward deflection of the derivative data from the near well or inner zone radial flow period to the outer zone radial flow period and dependent on the assumed storativity.
- The match to parameters is optimized by iterating between log-log match to a single phase and match on the entire simulation plot.

The input parameters applied to the test analysis have different degrees of uncertainty. The uncertainty of the input parameters impacts the uncertainty of the transmissivity estimates from the test analyses. This robust and hierarchal workflow progressing from field performance to optimizing estimated parameters constrains and minimizes uncertainty.

Input parameters used for each test analysis are listed in Appendix C. Some parameters are measured while others rely on assumptions to be estimated. The parameters are defined in the following subsections.

6.1 Input Parameters

6.1.1 Borehole Pressure History

Borehole pressure history effects are pressure transients in the formation caused by drilling activities, geophysical logging, and previous WP6 testing activities in the borehole prior to the start of the test. Test intervals with low transmissivity compound the effects of borehole pressure history with pressure transients superimposed on the test data. These transients are difficult to represent accurately in the analysis due to the long and complicated borehole fluid history, introducing uncertainty into the estimation of the initial formation pressure.

HydroBench incorporates borehole pressure history in the analyses by allowing the user to sequence periods of various induced pressures by pumping or injection prior to the start of the test and including these periods in the simulation matches.

Due to the inherent uncertainties of a complex borehole pressure history, a simplified borehole pressure history was applied to each test. The borehole pressure history applied to each test consisted of a single constant head phase over a defined historical period. The constant head was estimated at ground surface to take into account periods of borehole flushing and lowering tools downhole. The borehole pressure history duration was defined as the elapsed time from the drilling through the mid-point of each test to the start of each respective test. The uncertainties in the representation of the borehole pressure history in the analysis are most sensitive to the estimation of the initial formation pressure. Post-drilling, long-term pressure monitoring in the instrumented borehole, as implemented in WP9, will help to assess the validity of the static formation pressures used in the analysis.

6.1.2 Wellbore Storage

Wellbore storage is the response of the test zone to the change in pressure as a result of the compressibility of the fluid in the system (test interval + test tubing), the packer tool and the rock formation within the interval. For test interval sections of low hydraulic conductivity, the phase of the pressure response dominated by wellbore storage can mask the pressure response of the rock. Wellbore storage is identified with an early unit slope of the pressure change derivative plotted on the log-log plot. HydroBench produces this graph for assessing the wellbore storage phase during testing.

Wellbore storage is a sensitive parameter in the estimation of hydraulic parameters in low transmissivity rock. There are two types; open tubing wellbore storage where the fluid level is changing in the tubing with the shut-in tool open and shut-in wellbore storage where pressure is recovering within the test interval with the shut-in tool closed. For slug tests, the open tubing wellbore storage coefficient is determined by the test tubing radius where the fluid column change is measured.

For pulse tests, the shut-in wellbore storage coefficient is determined by the total test zone compressibility. Typically, multiple methods are used to estimate total test zone compressibility for corroboration. The test zone compressibility can be estimated based on literature values, measured during the test, estimated from wellbore storage matching if there is a constant rate phase, or derived from wellbore storage normalization between a constant rate, shut-in phase with a pulse phase.

Open Tubing Wellbore Storage

For slug tests, wellbore storage C (m^3/Pa) is calculated by the equation below

$$C(SI\ open) = \frac{\pi * r_u^2}{\rho * g}$$

where:

- r_u is the test tubing radius = 0.03015 m
- ρ is the density of water at 10°C = 999.7 kg/m^3
- g is the earth gravity acceleration = 9.81 m/s^2

Applying these values, C (SI open) = 3E-07 m^3/Pa, which was applied for all slug test analyses.

Shut-in Wellbore Storage

Shut-in wellbore storage is defined as follows:

- Test interval volume * total test zone compressibility.

Total test zone compressibility is the sum of compressibility of water, borehole walls and test tool (including packers). Casing tests carried out for the Swiss National Cooperative for the Disposal of Radioactive Waste (NAGRA) report water and test tool compressibility values that typically approach 6E-10 1/Pa to 2E-09 1/Pa (Kennedy and Davidson 1989). Total test zone compressibility has been reported to be 2E-09 1/Pa (Ostrowski et al. 1992). The lower limit is the compressibility of water that approaches 5E-10 1/Pa for typical near surface temperature and pressure conditions (i.e. upper 1000 m).

The method applied for determining wellbore storage for a pulse test was to compare a slug recovery phase and pulse recovery phase performed on the same test interval. The slug recovery pressure response was plotted with the pulse recovery on the same log-log transmissivity normalized plot. Given the slug test has a well-defined wellbore storage, the wellbore storage of the pulse test can be adjusted to match the pressure response of the slug test. This value was then compared to literature values for corroboration.

The wellbore storage derived from the normalization was 3E-10 m^3/Pa and by dividing by the test interval volume, a total test zone compressibility of 2E-09 1/Pa was derived. This value compares with literature values and provides confidence in the order of magnitude wellbore storage applied to tests HT001 through HT008.

This method was not applicable for Tool Configuration 2 used for test HT009. Instead the same tool compressibility derived from the slug and pulse test comparison method was applied to the larger system volume of HT009.

6.1.3 Skin Zone

Skin is a dimensionless term that is used to quantify the hydraulic properties of the rock around a borehole which may be enhanced by an increased fracturing during drilling or reduced by drilling debris and/or mud invasion. The skin magnitude correlates to the ratio of the change in permeability as a factor to the thickness of the skin relative to the borehole diameter. Diagnostic tools are used to identify the hydraulic properties (transmissivity and radial thickness) of the "skin zone" based on the shape and the slopes of the semi-log derivative of the specific drawdown on the log-log plot produced in HydroBench. A negative skin value corresponds to an increase in transmissivity within the skin zone. A positive skin value corresponds to a decrease in transmissivity within the skin zone. The effects of the skin are then separated from the portion of the data that is primarily influenced by the undisturbed rock properties. Hydrobench applies skin thickness and magnitude as fitting parameters to the simulation match which influences the shape of the pressure derivative.

Skin magnitudes, where detected, are included in the analysis summary in Appendix C.

6.1.4 Storativity

Storativity is an input parameter in HydroBench, which is directly correlated with skin effect and cannot be uniquely determined from a single hole test. While storativity directly impacts skin, it has less of an impact on the determination of transmissivity.

Storativity is calculated using the following equation:

$$S = \rho * g * \emptyset * c_t * h$$

Where

- ρ is the density of water
- g is the acceleration of gravity
- $\emptyset$ is the formation effectivity porosity
- c_t is the total compressibility in 1/Pa
- h is the length of the test interval in m

Estimates of the formation compressibility and effective porosity can be applied to constrain the storativity parameter. Total porosity laboratory testing was completed on selected core samples as part of WP4 Core Testing and presented in detail in the WP4A Petrophysical Technical Report (Golder 2018c). Total porosity lab results ranged from 0.001 to 0.011 with an average value of 0.007. This average value of total porosity was applied as an approximation of the upper bound of the effective porosity.

Total compressibility is the compressibility of the formation on a pore volume basis plus the formation water based on the definition above. Total compressibility was assumed at 2E-09 1/Pa. Laboratory testing as part of WP4B Geomechanical Technical Report (Golder 2018d) can be applied to estimate a total compressibility when available.

6.2 Analyses

Analyses of packer tests were carried out based on the type of test and resulting formation response with Golder's internally developed software program HydroBench.

HydroBench allows the analyses of pulse, slug, and constant rate/pressure injection and recovery tests. HydroBench is based on a numerical borehole simulator using an automated matching procedure (nonlinear regression algorithms). Both homogeneous and composite flow models with flow geometry matching may be used to interpret the data and to infer the local connectivity of a fracture network if present. HydroBench also includes the derivative of pressure (i.e., rate of pressure change) with respect to the natural logarithm of time that has shown to significantly improve the diagnostic and quantitative analysis of slug tests and constant-rate pumping tests. Transmissivity normalised plots are included in the software package that allow comparing different phases of a hydrogeological test by normalising the pressure response. The software also includes the deconvolution approach to analyze slug and pulse test data, which was used for the analyses of all tests in borehole IG_BH01.

The applied analysis produces the test interval transmissivity. Hydraulic conductivity is derived from transmissivity by applying the measured transmissivity over the length of the test interval contributing to that transmissivity. It was assumed for all tests that the test interval is homogeneous (i.e. the entire test interval contributes equally to the measured transmissivity). Hydraulic conductivity was calculated by dividing the measured transmissivity by the interval length.

In borehole IG_BH01, three test types were performed:

1) Pulse tests for measured low transmissivities (less than 1E-10 m^2/sec) in intervals HT001, HT003 through HT007, and HT013.

2) Slug tests for moderately low transmissivity (greater than 1E-10 m^2/sec) in intervals HT002, HT008 and HT009.

3) Modified test at interval HT010 to estimate transmissivity below the testing tool when the tool performance was not adequate to produce high confidence result within the test interval. The pressure response below the testing tool to the packer inflation gave an indication of the magnitude of hydraulic conductivity by multiplying the measured transmissivity by the length of the bottom of the borehole below the test interval.

The basis for minimizing uncertainty and obtaining a 'high confidence' analysis result is a systematic workflow that starts with geology understanding and experience with low permeability testing along with a test design to minimize non-ideal effects and progresses to analysis. Analysis starts with reviewing data on high resolution plots to assist in flow model selection and progresses to manual matching on log-log plots for single phases and checking both flow model and parameters based on a visual closeness of fit on the entire simulation match. If the match to both plots are unacceptable either the flow model is revisited and/or parameters are adjusted until an optimized match is obtained on the log-log plot. Typically, the analysis starts with manual fitting and may be finished with automated matching to optimize the match. The work flow includes high resolution tools within HydroBench to assist in flow model selection with built-in internal checks for adequacy of flow model and parameters (i.e. iterations between log-log analysis of individual phases to matching on entire simulation plot).

In low permeability settings, a composite model is often used to match the test response. The parameters derived from inner zone or near well zone is considered more representative of the disturbed zone from drilling effects and the lower transmissivity outer zone is considered more representative for the undisturbed formation parameters.

Often the inner zone transmissivity is well constrained by flattening of the pressure derivative data indicating pseudo radial flow period. Pressure matching to this leveling off in the derivative data yields an estimate of inner zone transmissivity; however, the derivative for the outer zone typically does not level off, but only transitional data or upward slope in the pressure derivative data is observed. As a result, the trend in the upward slope is extrapolated to the assumed radial flow period to derive the outer zone transmissivity that will be at a higher pressure than the final measured pressure derivative.

Hydrobench can apply multi-dimensional flow models. The flow model is selected based on the review of the derivative data on log-log plots along with the information for geological model. If there is slope in the derivative data that is characteristic for a flow geometry other than two-dimensional for radial flow such as one dimensional (positive half slope) or three-dimensional flow (negative half slope), alternative non-radial flow geometry models would be used to match the test response. The slope of derivative data is equal to 1-n/2 where n is the flow dimension; hence for linear flow which has a flow dimension of one (1) as flow area does not increase with distance from well results in a positive half slope in the derivative data. Inputting a flow dimension of 1 into the equation above yields a derivative slope of 1/2 on the log-log plot. Often in low permeability setting, a composite flow model is observed that is consistent with a near well zone of higher transmissivity with a flow dimension of 2 and outer zone of lower transmissivity more representative of the undisturbed formation. Allowing flow geometry to be a fitted parameter in manual or automated matching would allow for an improved match because there are more parameters applied to the fit, but would result in a flow model that is not consistent with the measured data and conceptual geologic understanding. Therefore, the additional fitted parameters would only be used to compensate for inaccuracies in representing the borehole history effects and results in more uncertainty although improving the match. This would be a case where a good match does translate to a well constrained interpretation. Unless there is good geological and derivative data to support non-radial flow geometry, a parsimonious approach is often preferred with the flow model consistent with geology and data. Often non-radial flow geometry is reserved for higher permeability settings where the radius of influence is greater than 10's of centimetres and up to several kilometres from the borehole.

Hydraulic parameters were derived as follows:

- Transmissivity is derived from the pressure match to the extrapolated radial flow acting period of the derivative data on the log-log plot;
- Bulk hydraulic conductivity is estimated by dividing the transmissivity by the interval length;
- Skin is derived from type curve match and correlated to the input storativity;
- Wellbore storage is a type curve match parameter for shut-in following slug test phases and input parameter for slug (open tubing) and pulses (shut-in);
- Composite model discontinuity radius between inner and outer zone transmissivity is a type curve match and correlated to the input storativity; and
- Initial formation pressure for the purposes of the analyses was derived by the extrapolation of the shut-in periods in semi-logarithmic coordinates towards infinite elapsed time (Horner Plot in HydroBench), using the matched flow model type curve.

It should be noted that the accuracy of the derived initial formation pressure is strongly dependent on the accuracy of the representation of the borehole pressure history. Generally, the longer and the more complicated the borehole pressure history period, the greater the uncertainties due to difficulties in accurately representing this period in the analysis. Lower transmissivities are more strongly influenced by uncertainties in the borehole pressure history. To reduce the influence of borehole pressure history on the derivation of transmissivity, a PSR phase was included at the start of each test to dissipate a portion of the borehole pressure history prior to initiation of the active phases, and each test was completed with a relatively long lasting shut-in recovery phase when borehole pressure history effects will be minimal compared to the early portion of the test.

A description of the test interval, test procedure and results are summarized in the following sections. Test plots and analyses details are presented in Appendix C. In Appendix C, four plots are shown for each test:

- Pressure Sequence – Plot of interval temperature and multizone (bottom, interval, annulus, and tubing) pressure versus time. Each test sequence is identified and labeled.
- Transmissivity Normalized Plot – Displays transmissivity versus time in log-log scale as a visual tool for evaluating similar formation responses related to the flow model and enables the comparison of transmissivity from multiple tests phases.
- Pressure and pressure derivative log-log plot – Plot of test pressure and pressure derivative versus time on a log-log scale with the simulation match produced by HydroBench shown in red.
- Test pressure match plot – Plot of test pressure versus time with the simulation match produced by HydroBench shown in red. HydroBench simulates the test pressure response based on the input parameters.

A summary of the test results is provided in Table 3. Data Quality Confirmation forms are provided within the Data Deliverable package.

To develop a robust set of parameters, the analysis includes the following main steps:

1) Review the data on log-log plots to diagnose the formation flow model;
2) Match the data on log-log plots;
3) Check the selected model and parameters on the entire simulation match; and
4) Iterate between log-log and entire simulation plots until an optimal match is obtain on both plots.

6.2.1 IG_BH01_HT001 (130.0 m – 149.8 m)

HT001 was selected to assess the relatively shallow rock mass. The interval contained several intact veins and joints, but no broken joints.

The test was initiated with a shut-in initial pressure recovery phase followed by a pulse withdrawal and pressure recovery with the shut-in valve closed. The total testing time (from end of packer inflation until start of packer deflations) was 12.2 hours. Bottom zone and upper zone monitoring indicated no packer bypass. No hydraulic bypass above or below the test interval was detectable when the shut-in tool was closed that could compromise the derivation of transmissivity.

A good match based on visual assessment of radial flow phase of the recovery was achieved and fitted with a positive skin. The estimated transmissivity was 6E-11 m^2/sec.

6.2.2 IG_BH01_HT002 (451.9 m – 471.7 m)

HT002 was selected to assess the bedrock above a potential repository horizon. Multiple broken joints were observed in the core, but no indication of fracture flow was noted during drilling or during flowing fluid electric conductivity (FFEC) logging post-drilling.

The test was initiated with a shut-in initial pressure recovery phase followed by an unsuccessful pulse test attempt due to upper packer bypass as evidenced by an accelerated decrease in the annulus pressure and increase in the tubing pressure during the pulse withdrawal shut-in (PWS) phase. After adjusting the packer inflation pressure and obtaining a good packer seal, a slug and slug recovery was completed successfully. The slug recovery consisted of an open recovery phase followed by a shut-in recovery phase with no indications of packer bypass. The total testing time was 39.5 hours.

A two-shell composite model was applied to account for higher transmissivity observed in the early time pressure derivative often caused by near borehole damage or fractures of limited extent. The analyses provided a good match based on visual assessment of the radial flow phase of the recovery. The estimated transmissivity was 3E-10 m^2/sec.

6.2.3 IG_BH01_HT003 (475.0 m – 494.8 m)

HT003 was selected to assess the bedrock above a potential repository horizon. The interval contained several intact veins, but no broken joints and therefore would be representative of a relatively intact rock mass.

The test was initiated with a shut-in initial pressure recovery phase (PSR phase). The water level in the test interval was lowered twice with a submersible pump and followed by opening then closing the shut-in valve to assess the pressure recovery, which was decreasing after each lowering of the water level due to borehole pressure history effects. A pulse test and recovery with the shut-in tool closed was completed after the PSR phase was complete. The total testing time was 24.4 hours.

The analyses provided a good match based on visual assessment of the transitioning phase to radial flow of the recovery. No hydraulic bypass above or below the test interval was detectable when the shut-in tool was closed that could compromise the derivation of transmissivity. The estimated transmissivity was 7E-11 m^2/sec.

6.2.4 IG_BH01_HT004 (496.0 m – 515.8 m)

HT004 was selected to assess the bedrock at a potential repository horizon. Three broken joints were observed in the core, but no indication of fluid loss was noted during drilling and FFEC logging post-drilling.

The test was initiated with a shut-in initial pressure recovery phase. The pressure increased during the PSR, which may have been responding to borehole pressure history effects. A pulse test and recovery with the shut-in tool closed was completed after the PSR phase. The total testing time was 12.7 hours.

The analyses provided a good match based on visual assessment to the transitioning phase to radial flow of the recovery. No hydraulic bypass above or below the test interval was detected when the shut-in tool was closed that could compromise the derivation of transmissivity. The estimated transmissivity was 7E-11 m^2/sec.

6.2.5 IG_BH01_HT005 (518.0 m – 537.7 m)

HT005 was selected to assess the bedrock at a potential repository horizon. Three broken joints were observed in the core. Approximately 110 litres of drill fluid loss were observed while drilling through this interval although the FFEC logging did not indicate flow.

The test was initiated with a shut-in initial pressure recovery phase (PSR). The interval pressure initially increased after closing the shut-in tool for the PSR phase due to the near-borehole formation pressure responding to the borehole history effect. The water level was lowered in the test tubing to induce a pulse withdrawal test. The shut-in tool was opened to introduce the pulse withdrawal then closed to monitor the pressure recovery. Intermittent leakage from the annular space above the packer to the test tubing was observed, but appeared to have no impact on the pulse withdrawal recovery during shut-in. The total testing time was 21.7 hours.

The analyses provided a good match based on visual assessment of the transitioning phase to radial flow of the recovery. No hydraulic bypass above or below the test interval was detected when the shut-in tool was closed that could compromise the derivation of transmissivity. The estimated transmissivity was 2E-10 m^2/sec.

6.2.6 IG_BH01_HT006 (559.0 m – 578.8 m)

HT006 was selected to assess the bedrock at a potential repository horizon. This interval targeted a feldspar-phyric felsic dyke with one broken joint within the interval. No indication of fluid loss was observed during drilling and FFEC logging post-drilling.

The test was initiated with a shut-in initial pressure recovery phase (PSR). The interval pressure initially increased after closing the shut-in tool for the PSR phase due to the near-borehole formation pressure responding to the borehole pressure history effect. The water level was lowered in the test tubing to induce a pulse withdrawal test. The shut-in tool was opened to introduce the pulse withdrawal then closed to monitor the pressure recovery. Consistent leakage from the test tubing to the annular space above the upper packer was observed, but appeared to have no impact to the test pulse withdrawal recovery during shut-in. The total testing time was 31.4 hours.

The analyses provided a good match based on visual assessment of the transitioning phase to radial flow of the recovery. No hydraulic bypass above or below the test interval was detected when the shut-in tool was closed that could compromise the derivation of transmissivity. The estimated transmissivity was 5E-11 m^2/sec.

6.2.7 IG_BH01_HT007 (580.0 m – 599.8 m)

HT007 was selected to assess the bedrock at a potential repository horizon. Four broken joints were observed in the core. No indication of fluid loss was observed during drilling and FFEC logging post-drilling.

The test was initiated with a shut-in initial pressure recovery phase. The water level was lowered in the test tubing to induce a pulse withdrawal test. The shut-in tool was opened to introduce the pulse withdrawal then closed to monitor the pressure recovery. Consistent leakage from the test tubing to the annular space above the upper packer was observed, but appeared to have no impact to the test pulse withdrawal recovery during shut-in. The total testing time was 36.2 hours.

The analyses provided a good match based on visual assessment of the transitioning phase to radial flow of the recovery. No hydraulic bypass above or below the test interval was detected when the shut-in tool was closed that could compromise the derivation of transmissivity. The estimated transmissivity was 3E-11 m^2/sec.

6.2.8 IG_BH01_HT008 (538.0 m – 557.8 m)

HT008 was selected to assess the bedrock at a potential repository horizon while targeting a zone of increased frequency of broken joints and borehole inflow as indicated by an increase in fluid electrical conductivity during logging (FFEC) as part of WP 5 - Geophysical Logging and Interpretation for IG_BH01. Hematization was noted on the broken joints in the core in addition to a measured loss of 160 litres of drill fluid during drilling.

The test was initiated with a shut-in initial pressure recovery phase. In contrast to previous tests, no increasing pressure in the interval was noted post inflation. The water level was lowered in the test tubing to induce a slug withdrawal test as planned in the case of potentially quicker pressure responses during testing. The shut-in tool was opened to introduce the slug withdrawal. After a slug withdrawal recovery phase, the shut-in tool was closed for a shut-in recovery phase. After the shut-in recovery phase, the shut-in tool was opened to allow water to enter the test tubing from the interval as part of the interval purging prior to groundwater sampling as part of WP7 (GW006). The total testing time was 22.2 hours excluding the time required for groundwater sample collection.

The slug withdrawal recovery was not selected for analyses due to test rod leakage as demonstrated in a significant increase shown on the transmissivity normalized plot (Figure C15) and the increasing pressure in the test tubing and corresponding decreasing pressure in the upper annulus while the shut-in tool was closed. However, no leakage was observed from the test interval during the shut-in phase of the slug recovery. The estimated transmissivity from the SWS phase was 4E-09 m^2/sec providing a good match based on visual assessment of the radial flow phase of the recovery.

6.2.9 IG_BH01_HT009 (625.2 m – 644.9 m)

HT009 was selected to assess the bedrock at a potential repository horizon while targeting a zone of increased frequency of broken joints and borehole inflow as indicated by an increase in fluid electrical conductivity during logging (FFEC) as part of WP 5. Hematization was noted on the broken joints in the core.

The test was initiated with a shut-in initial pressure recovery phase. The water level was lowered in the test tubing to induce a slug withdrawal test. The shut-in tool was opened to introduce the slug withdrawal. After a slug withdrawal recovery phase, the shut-in tool was closed for a shut-in recovery phase. At the end of the shut-in recovery phase, a rod leakage test was undertaken by filling the annulus with a slug of water. An interval pressure response to filling the annulus was observed (Figure C17). The packer pressure was momentarily released without the packers unseating and re-pressurized to 2.0 MPa. With the shut-in tool closed, the water level was lowered in the test tubing. The shut-in tool was subsequently opened to induce a slug withdrawal. During the second slug withdrawal recovery phase, water added to the annulus did not impact the pressure within the test interval indicating the upper packer seal was restored. The total testing time was 34.1 hours excluding the time required for groundwater sample collection.

The initial slug withdrawal recovery with the shut-in tool open was not selected for analyses due to the upper packer bypass. The rod leakage from the annulus during the second slug withdrawal recovery open phase (SW2) causes the estimated transmissivity of 1E-07 m^2/sec to be considered an upper limit while the analysis provided a good match based on visual assessment of the radial flow phase of the recovery.

6.2.10 IG_BH01_HT010 Bottom Zone (906.6 m – 1001.5 m)

HT010 was planned from 886 m to 905.8 m and intended originally to target a narrow zone of increased frequency of broken joints and borehole inflow indicated by an increase in fluid electrical conductivity (FFEC) during logging for WP5.

The test was initiated with a shut-in initial pressure recovery phase. During the PSR phase, hydraulic connection between the interval and the annulus was occurring. The packers were deflated and re-inflated twice with the same hydraulic connection observed by similar pressure responses within the interval and annulus. During the test attempts, the bottom zone (bottom of borehole below the bottom packer) appeared to be successfully isolated from the rest of the borehole. In addition, the packer inflations caused pulse-like phases followed with pressure recovery phases. These phases are labelled PIR1 to 3 in Figure C19. The total testing time was 3.4 hours. The bottom zone pressure was analyzed for transmissivity.

The analyses provided consistent transmissivity values for the three induced ”pseudo” pulse tests in the bottom zone (906.6 m to 1001.5 m) with a good match based on visual assessment of the radial flow phase of the recoveries. Several pressure fluctuations within the bottom zone were observed during the recovery phases, which are likely due to the small movements in the test tool due to loading and unloading from filling and lowering of the tubing and annulus. The estimated transmissivity was 8E-09 m^2/sec. The transmissivity estimate is characteristic of the large interval length, which brackets a few zones of increased broken joint frequencies, but exhibited no fracture flow from the FFEC logging.

6.2.11 IG_BH01_HT011 (865.1 m – 884.9 m)

HT011 was intended to target an increase in fluid electrical conductivity near 895 m as seen in FFEC logging for WP5. HT011 was not part of the original test plan, but the opportunity was taken to seat the bottom packer above this zone of increased inflow at 895 m in order to compare the pressure response within the bottom of the borehole to HT010, which did not include this increased flow zone.

The test was initiated with a shut-in initial pressure recovery phase. During this phase, hydraulic communication between the annulus and the test interval was observed due to a leak in the test tool, likely within the shut-in tool above the upper packer. While the packers were inflated, the bottom zone (bottom of borehole below the bottom packer) was isolated from the rest of the borehole. The total testing time was 3.0 hours.

No analyses of the interval test pressure were performed due to the upper packer bypass. Unlike in HT010, the packer inflation did not produce a pressure pulse in the bottom zone sufficient to analyze with confidence. In addition, the relatively faster response of the bottom zone pressure to packer inflation as compared to HT010 may suggest that the FFEC inflow zone observed at 809 m is of higher permeability than the interval tested in HT010 although the magnitude is unknown.

6.2.12 IG_BH01_HT012 (775.9 m – 795.7 m)

HT012 was intended to target a zone of increased frequency of broken joints associated with fine-grained felsic dykes and amphibolite lenses, as well as a zone of borehole inflow indicated by an increase in fluid electrical conductivity (FFEC) during WP5 logging.

The test was initiated with a shut-in initial pressure recovery phase. During this phase, hydraulic communication between the annulus and the test interval was observed due to a leak in the test tool (Figure C22). Also, several broken fractures present where both upper and lower packers contact the borehole wall may have contributed to the bypass of the upper packer. It was not practical to adjust the test interval length for one test to confirm the packer seat. While the packers were inflated, the bottom zone (bottom of borehole below the bottom packer) appeared isolated from the rest of the borehole. The total testing time was 12.1 hours.

No analyses of the interval test pressure were performed due to the upper packer bypass. The packer inflation did not produce a pressure pulse in the bottom zone that could be analyzed with confidence.

6.2.13 IG_BH01_HT013 (404.0 m – 423. 8 m)

HT013 was selected to assess hydraulic conductivity in a zone with multiple intact joints above a potential repository horizon, though no indication of fluid loss was observed during FFEC logging.

The test at HT013 was first attempted using Tool Configuration 2 (HT013a); however, significant bypass through the test tubing occurred and the tool was brought to surface. The tool was changed to Tool Configuration 1 and lowered to the same depth interval after completing a successful leak test within the surface casing (Casing Test 2).

The test was initiated with a shut-in initial pressure recovery phase which produced a rise in the interval pressure for approximately 30 minutes before slowly decreasing as result of borehole pressure history, similar to previous tests within zones of low permeability. A pulse withdrawal phase was completed, but hydraulic connection between the interval and annulus was observed at the end of the test. The packer pressure was reset and a second slug withdraw phase was completed. Hydraulic connection between the test interval and the annulus was still present, but reduced. The total testing time was 21.3 hours.

The analyses provided transmissivity values with a good match based on visual assessment of the radial flow phase of the recoveries within ½ order of magnitude for the three test phases, while the PW phase was selected for reporting as it was the highest estimated transmissivity of the three phases. It can not be determined whether the hydraulic connection between the interval and the annulus is a result of a leakage in the tool or bypass within the formation. Therefore, the estimated transmissivity of 2E-09 m^2/sec should be considered an upper limit.

7.0 SUMMARY OF RESULTS

Hydraulic testing was completed or attempted in thirteen intervals (HT001 – HT013). Ten of the tests were successful, all above, within and below a potential repository depth. Transmissivity values were estimated to be mostly in the range of 10^{-9} to 10^{-11} m^2/s with hydraulic conductivities in the magnitude of 10^{-10} to 10^{-12} m/s. There was one exception, HT009, which had a transmissivity of 10^{-7} m^2/s and hydraulic conductivity of 10^{-9} m/s in the interval between 625.2 to 644.9 m. This result is consistent with indications of locally enhanced flow in the FFEC logging and increased frequency of broken joints in rock core. Radius of influence of the tests is within 1 metre of the borehole.

Tests HT010, HT011, HT012 and HT013 showed hydraulic connection between the test interval and the annulus. Accordingly, results from these tests are not reliable and therefore not presented. Troubleshooting attempts did not determine the cause of the hydraulic connection. Casing tests performed during the program did not show this connection, indicating that if the cause was due to a leakage in the tool (as opposed to formation bypass), the occurrence was intermittent.

The primary uncertainties in estimation of transmissivity are the uncertainty in the input parameters, inherent uncertainties in representation of borehole pressure history effects and, to a lesser degree, temperature transients. Uncertainty in hydraulic conductivity also stems from the assumption of formation length across which flow occurs. Generally, with transmissivity below about 10^{-7} to 10^{-8} m^2/s, the influence of borehole history and temperature transients starts to become material, resulting in increasing uncertainty as the transmissivity decreases.

There were several steps taken to minimize the uncertainty as summarized below:

- Test tools included a downhole shut-in tool to minimize wellbore storage and pressure gauges with a relatively high degree of accuracy.
- Casing Tests and functions checks were performed during the testing program to estimate the lower transmissivity limit of the tools and confirm that the packer seals were adequate.

- Tests where communication was observed between the test interval and the annulus were not considered reliable and not presented.
- Test design and performance included the following:
  - PSR phase to dissipate part of the borehole pressure history and temperature history effects;
  - Test phases optimal to the magnitude of transmissivity with slug phases for higher transmissivity and pulse phases for lower transmissivity; and
  - Test duration was extended so either radial flow period was reached or transition to radial flow was reached during the main test phases using real time analysis.
- Analysis included the use of transmissivity normalized plots for all test phases for optimal resolution in evaluating formation response and consistency between phases and matching on both log-log and entire simulation matches to validate the parameters and flow model are consistent with the measured data.

However, there is an inherent uncertainty in the analysis for hydraulic parameters. Based on Golder's experience with hydraulic testing and sensitivity analyses for nuclear repository programs (e.g. Enachescu et al., 1997), the uncertainty can be summarized as follows:

- For the test with transmissivity in the magnitude if 10^{-7} m^2/s, the uncertainty is considered in the magnitude of plus/minus a factor of five or less as the borehole pressure history and temperature history effects will be minimal in this range of transmissivity.
- For the remaining tests in the magnitude of 10^{-9} to 10^{-11} m^2/s, the uncertainty is considered to range between plus/minus a factor of 5 to plus or minus a factor of 10 as borehole pressure history and temperature history effects become more material in this transmissivity range and difficult to accurately replicate in the analysis.

As discussed, the static formation pressure was derived for the purposes of the analysis. However, all values will need to be updated with results from the long-term monitoring from the multi-level Westbay monitoring system (WP9) that are considered more reliable as less influence by short-term transients induced by drilling and logging as the formation pressure equilibrates toward static conditions.

Test results are presented in Table 3 and shown on Figure 13 and Figure 14.

Table 3: Summary of Test Results.

TEST ID	Tool Config.	Top of Interval along Borehole (mbgs)	Bottom of Interval along Borehole (mbgs)	Interval Length (m)	Static Test Pressure (kPa)	WBS (m3/Pa) SIT Open - Tubing Related	WBS (m3/Pa) SIT Closed	HydroBench Analysis Inner Shell T (m2/sec)	HydroBench Analysis Outer Shell T (m2/sec)	HydroBench Analysis Radius (m)	HydroBench Analysis Skin	Transmissivity (m2/sec)	Bulk Hydraulic Conductivity[2] (m/sec)
HT001	1	130.0	149.8	19.78	1113	3E-07	3E-10	6E-11	--	--	1.0	6E-11	3E-12
HT013a	2	404.0	423.8	19.78									
HT013b	1	404.0	423.8	19.78	4056	3E-07	3E-10	2E-09*	--	--	-1	2E-09*	1E-10*
HT002	1	451.9	471.7	19.78	4222	3E-07	3E-10	3E-09	3E-10	0.6	0.0	3E-10	2E-11
HT003	1	475.0	494.8	19.78	4557	3E-07	3E-10	7E-11	--	--	0.0	7E-11	4E-12
HT004	1	496.0	515.8	19.78	4819	3E-07	3E-10	7E-11	--	--	-0.5	7E-11	4E-12
HT005	1	518.0	537.7	19.78	4850	3E-07	3E-10	2E-10	--	--	0.0	2E-10	1E-11
HT008	1	538.0	557.8	19.78	5097	3E-07	3E-10	4E-09*	--	--	3.8	4E-09*	2E-10*
HT006	1	559.0	578.8	19.78	5322	3E-07	3E-10	5E-11	--	--	0.0	5E-11	3E-12
HT007	1	580.0	599.8	19.78	5556	3E-07	3E-10	3E-11	--	--	-3.4	3E-11	2E-12
HT009	2	625.2	644.9	19.78	5979	3E-07	2E-09	1E-07*	--	--	-2.7	1E-07*	5E-09*
HT012	2	775.9	795.7	19.78									
HT011	2	865.1	884.9	19.78									
HT010	2	886.0	905.8	19.78									

Notes:

1) "*" – value considered an upper limit due to rod leakage.
2) Bulk hydraulic conductivity is calculated by transmissivity / interval length.

Transmissivity and hydraulic conductivity results are plotted relative to depth on Figure 13 and Figure 14.

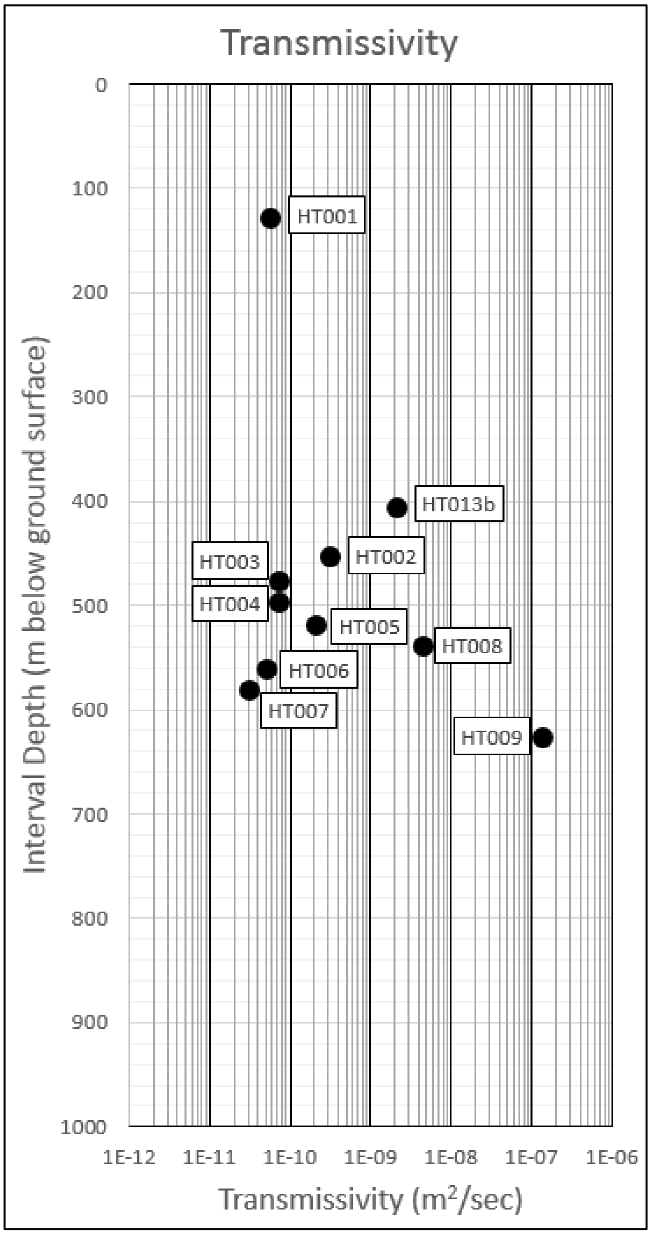

Figure 13: Transmissivity

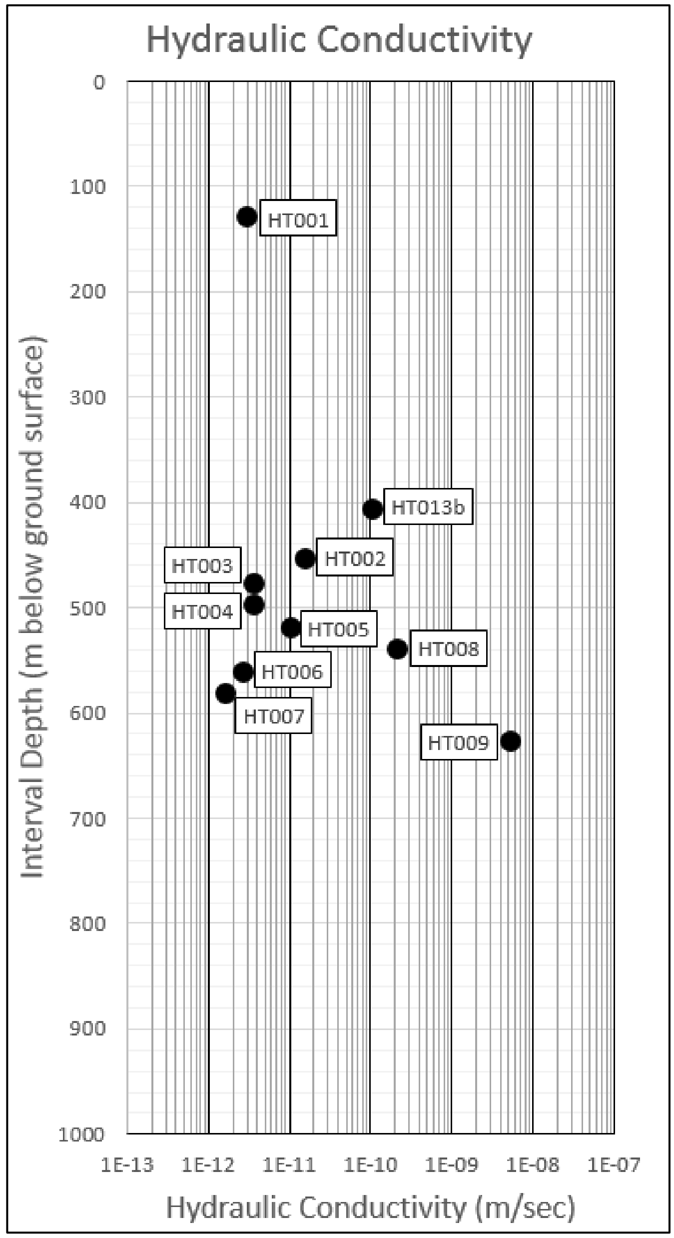

Figure 14: Hydraulic Conductivity

8.0 REFERENCES

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Kennedy, K.G. and Davidson, L.M., 1989. Oberbauenstock (OBS) 1987: Results of the hydrogeological testing program OBS-1. – Nagra Technical Report, NTB 88-03, Nagra, Baden.

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APPENDIX A

Photos of Equipment

Photo 1 – Hydraulic testing trailer containing flat pack.

Photo 2 – Flat pack.

Photo 3 – Top of shut-in protective casing and flat pack connection.

Photo 4 – Bottom of shut-in tool protective casing with thread crossovers to top packer.

Photo 5 – Bottom of top packer and crossovers to tool carrier.

Photo 6 – Perforated tool carrier (blue in center of photo). Inflation line for lower packer and porting line to bottom zone also shown

Photo 7 – Top of bottom packer.

APPENDIX B

Calibration Certificates

CERTIFICATE OF CALIBRATION

434065

Certification Number
Issued By

WESCAN CALIBRATION
Unit# 9 - 12240 Horseshoe Way

Richmond, BC V7A 4X9
Ph: (604) 275-0600
Fax: (604) 275-0610

ACCREDITED
Calibration CERT# 1500.02

Certification Issued To: **GOLDER ASSOCIATES LTD. (BURNABY)**
300 - 3811 North Fraser Way
Burnaby, BC V5J 5J2

Purchase Order Number: **881410/9000**

Instrument ID: 2892054

Type: PRESSURE GAUGE, DIGITAL (0 to 2 000) psi

Manufacturer: OMEGA

Model Number: DPG4000-2K

Serial Number: 2892054

Size: (0 to 2 000) psi

Department: N/A

Date Instrument Calibrated: Jan 15 2018

Date Next Calibration Due: Jan 15 2019

Laboratory Temperature: 20.4 °C

Laboratory Humidity: 34 %RH

Calibration Procedure Used: P1002

Technician Performing Calibration:

ROMY ACLAN DAPOC

Calibration Approved By:

NEAL DESPINS 01/17/2018
Quality Assurance

Calibrated In: WESCAN CALIBRATION SERVICES INC. (VANCOUVER)

Wescan Calibration certifies that the above instrument was calibrated in compliance, as applicable, with the requirements of ISO/IEC 17025:2005, ANSI/NCSLI Z540.1-1994 (R2002), ANSI/NCSLI Z540.3-2006 and/or the technical requirements of the customer. Additionally, Wescan's quality management system meets the principles of ISO 9001:2008 and is aligned with its pertinent requirements. Wescan Calibration is accredited by the American Association for Laboratory Accreditation (A2LA). Measurements within Wescan Calibration's Scope of Accreditation are traceable to the International System of Units (SI units) in accordance with A2LA's traceability policy. All Wescan Calibration measurements are traceable to SI units, through the National Research Council (NRC), the National Institute of Standards and Technology (NIST), other National Measurement Institutes (NMIs), or to physical constants, consensus standards, or ratio measurements. Uncertainties are calculated in accordance with JCGM 100:2008, Guide to the Expression of Uncertainty in Measurement, at a confidence level of approximately 95% using a coverage factor, k = 2. Measured values apply only at the time of calibration. After that time any number of factors may cause measured values to change. The information in this certificate applies only to the identified instrument and may not be reproduced, except in full, without the written consent of Wescan Calibration.

See Attached Data Sheet For Additional Calibration Data

Data Sheet

434065
Certification Number

INSTRUMENT ACCURACY

±0.05 % FULL SCALE (±1 psi)

INSTRUMENT CONDITION

FOUND AND LEFT WITH MEASURED VALUES LYING WITHIN SPECIFICATION LIMITS. SEE ATTACHED CALIBRATION DATA.

NOTE 1: WHEN TEST UNCERTAINTY RATIOS (TURS) ARE LESS THAN 4:1 AND GREATER THAN 1.1:1, IN ORDER TO ENSURE 2% OR LESS FALSE ACCEPT PROBABILITIES WHEN MAKING CONFORMANCE STATEMENTS, WESCAN CALIBRATION GUARDBANDS AT A PERCENTAGE OF SPECIFICATION LIMITS.

NOTE 2: WHEN TURS ARE LESS THAN 1.1:1 WESCAN CALIBRATION DOES NOT MAKE CONFORMANCE STATEMENTS BUT INSTEAD REPORTS MEASURED VALUES AND UNCERTAINTIES.

NOTE 3: ON OCCASIONS WHEN TURS FALL IN THE RANGE DESCRIBED IN NOTE 1, BUT GUARDBANDING IS NOT PRACTICAL, THIS IS SEPARATELY NOTED.

STANDARDS USED FOR THIS CALIBRATION

Unique ID	Description	Due Date
101026	PRESSURE GAUGE, DIGITAL XP2i (0 to 5 000) psi	01/31/2018

Traceable Reference: (101026)409975

End of Report

Calibration procedure P1002
Item type Pressure gauge
Full scale 2000 psi
Accuracy 0.05 % of full scale
Note: this data sheet applies to calibrations where the test item is set to an exact gauge marking

	Nominal	Test item	Lower limit	Standard	Upper limit	% limits used	Uncertainty	TUR if <4:1
	% of range	psi	psi	psi	psi		psi	
increasing	10%	200.0	199.0	200.1	201.0	-10.0%	1.0	1.00
	20%	400.0	399.0	400.1	401.0	-10.0%	1.0	1.00
	30%	600.0	599.0	600.1	601.0	-10.0%	1.0	1.00
	40%	800.0	799.0	800.0	801.0	0.0%	1.0	1.00
	50%	1000.0	999.0	999.9	1001.0	10.0%	1.2	1.00
	60%	1200.0	1199.0	1199.7	1201.0	30.0%	1.4	0.83
	70%	1400.0	1399.0	1399.7	1401.0	30.0%	1.7	0.71
	80%	1600.0	1599.0	1599.6	1601.0	40.0%	1.9	0.62
	90%	1800.0	1799.0	1799.5	1801.0	50.0%	2.2	0.56
	100%	2000.0	1999.0	1999.4	2001.0	60.0%	2.4	0.50
decreasing	90%	1800.0	1799.0	1799.6	1801.0	40.0%	2.2	0.56
	80%	1600.0	1599.0	1599.7	1601.0	30.0%	1.9	0.62
	70%	1400.0	1399.0	1399.8	1401.0	20.0%	1.7	0.71
	60%	1200.0	1199.0	1199.8	1201.0	20.0%	1.4	0.83
	50%	1000.0	999.0	999.9	1001.0	10.0%	1.2	1.00
	40%	800.0	799.0	800.0	801.0	0.0%	1.0	1.00
	30%	600.0	599.0	600.1	601.0	-10.0%	1.0	1.00
	20%	400.0	399.0	400.1	401.0	-10.0%	1.0	1.00
	10%	200.0	199.0	200.1	201.0	-10.0%	1.0	1.00

End of calibration data

All points tested met acceptance criteria

In-Situ Inc.

Calibration Report

Report Number: 20171220-562539
221 East Lincoln Avenue, Fort Collins, CO 80524 USA
1-970-498-1500, 1-800-446-7488, FAX: 1-970-498-1598
Visit us at www.in-situ.com

Instrument Details:

Instrument Model:	**Level TROLL 700**
Full Scale Pressure Range:	**1000 PSI / 693 m / 2273 ft / non-vented**
Serial Number:	**562539**
Hardware Version:	**3**
Firmware Version:	**2.1**

Calibration Details:

Calibration Result:	**PASS**
Calibration Date:	2017-12-20 09:12:04 (UTC)
Nominal Range of Applied Temperature:	-5 C to +50 C
Temperature Accuracy Specification:	+/- 0.1 C From -5 C to +50 C
Nominal Range of Applied Pressure:	7 PSI to 1000 PSI
Pressure Accuracy Specification:	+/- 0.1 %FS from -5 C to +50 C, +/- 0.05 %FS at +15 C

Post-Calibration Check:

Parameter	Applied	Reported	Deviation	Unit
Pressure	1000.0000	999.9047	-0.0953	PSI
Pressure	424.0600	424.1352	0.0752	PSI
Pressure	6.9997	6.9875	-0.0121	PSI
Temperature	24.7050	24.6847	-0.0203	C

Calibration Procedures and Equipment Used:

Automated calibration procedures used.
Manu Agilent Model 34980A SerialNo MY44009431
Manu Instrulab Model 4312A-15 SerialNo 30117
Manu Instrulab Model 832-151-01 SerialNo 12068
Manu Mensor Model CPC6000 SerialNo 410009W9
Manu Agilent Model 53131A-010 SerialNo MY47002282
Manu MENSOR Model 600 SerialNo 622742

Notes:

1. Standards used in this calibration are traceable to the National Institute of Standards and Technology.
2. This calibration report shall not be reproduced, except in full, without the written approval of In-Situ, Inc.
3. A calibration interval of 12 to 18 months is recommended.

In-Situ
Crafted with pride by
April T.

Performed By: WR

In-Situ Inc.

Calibration Report

Report Number: 20170426165853-406237

221 East Lincoln Avenue, Fort Collins, CO 80524 USA
1-970-498-1500, 1-800-446-7488, FAX: 1-970-498-1598
Visit us at www.in-situ.com

Instrument Details:

Instrument Model:	**Level TROLL 700**
Full Scale Pressure Range	**1000 PSI non-vented**
Serial Number:	**406237**

Calibration Details:

Calibration Result:	**PASS**
Calibration Date:	2017-04-26 16:58:53 (UTC)
Nominal Range of Applied Temperature:	-5 C to +50 C
Temperature Accuracy Specification:	+/- 0.1 C From -5 C to +50 C
Nominal Range of Applied Pressure:	7.0 PSI to 1000.0 PSI
Pressure Accuracy Specification:	+/- 0.1 %FS from -5 C to +50 C, +/- 0.05 %FS at +15 C

Post-Calibration Check:

Parameter	Applied	Reported	Deviation
Pressure	1000.0100	1000.1380	0.0128
Pressure	424.0610	424.1927	0.0132
Pressure	6.9918	7.0380	0.0046
Temperature	24.6760	24.7000	0.0240

Calibration Procedures and Equipment Used:

Automated calibration procedures used.
Manu Agilent Model 34980A SerialNo MY44014053
Manu Instrulab Model 4312A-15 SerialNo 30117
Manu Instrulab Model 832-151-01 SerialNo 12086
Manu Mensor Model CPC6000 SerialNo 410009W9

Notes:

1. Standards used in this calibration are traceable to the National Institute of Standards and Technology.
2. This calibration report shall not be reproduced, except in full, without the written approval of In-Situ, Inc.
3. A calibration interval of 12 to 18 months is recommended.

Performed By: FM

Manufacturers Certificate

certificate no: 20180216-K5955
16-Feb-2018

Instrument	**Manufacturer:**	**Van Essen Instruments**
Identification:	Product:	Baro-Diver
	Type:	DI500
	Serial number:	K5955
Pressure	Range:	0-150 cmH2O
	Accuracy:	± 2 cmH2O
Temperature	Range:	-20°C - 80°C (calibrated range 0°C - 40°C)
	Accuracy:	± 0.2°C

Method of calibration:

Pressure: The pressure was calibrated using a PACE6000 pressure controller-calibrator (GE Druck) with air/nitrogen as the medium at 5 points. A cycle of increasing and decreasing pressures was applied at two different temperatures.

Temperature: The temperature was calibrated using a reference temperature sensor at two different temperatures. The instrument was totally immersed in water at a temperature of (15 ± 0.2) degrees Celsius and in water at a temperature of (35 ± 0.2) degrees Celsius.

Results: The results are stated on the following page.

Uncertainty: The uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, which provides a confidence level of approximately 95 %. The standard uncertainty has been determined in accordance with EA 04/2.

Traceability: The measurements have been executed using standards for which the traceability to (inter)national standards has been demonstrated.

Delft, The Netherlands, 16-Feb-2018

Van Essen Instruments

Name: Tatiana Markovska signature:
Function: Production Coordinator

Name: Johan van Bruggen signature:
Function: General Manager

Manufacturers Certificate

certificate no: 20180216-K5955
16-Feb-2018

Test results serial number: K5955

Pressure

calibration date: 10-Jun-2011

temperature: 15 °C reference [cmH20]	reading [cmH2O] increasing	 decreasing
475.00	474.87	474.88
625.00	624.83	624.84
775.00	774.77	774.80
925.00	924.80	924.82
1075.00	1074.80	1074.83

Max. deviation : 0.23 cmH2O

Temperature

reference [°C]	reading [°C]
15.00	14.94
35.00	34.95

Max. deviation: 0.06 % F.S.

Pioneer Petrotech Services Inc.
#1, 1431 - 40 Ave. NE
Calgary, AB, Canada, T2E 8N6
Tel: +1 (403)282-7669
Fax: +1 (403)282-0509
www.pioneerps.com

Calibration Certificate

Model:	**PPS25**	**Pressure Range:**	**6,000 psi**
Serial Number:	**5231**	**Calibration Date:**	**Aug 23, 2016**

Specifications

Pressure Range:	Minimum:	13 psia	Maximum:	6,000 psia
Temperature Range:	Minimum:	0 °C	Maximum:	150 °C
Pressure Accuracy:			±	0.03 %F.S.
Temperature Accuracy:			±	0.5 °C
Housing Material:				SS 17-4
Housing OD				0.75"

Calibration Summary

Calibration Pressure Range:	Minimum:	13.12 psia	Maximum:	5,998 psia
Calibration Temperature Range:	Minimum:	0.90 °C	Maximum:	150 °C
Pressure Accuracy (Maximum Error):			+	1.70 psi
Temperature Accuracy (Maximum Error):			−	0.11 °C

Working Standards

Pressure: Fluke DH Instruments piston-cylinder, 30kpsi (±0.01% of reading)
Temperature: Fluke Hart Scientific RTD (±0.05°C)

Traceability Statement

All working standards are traceable to nationally or internationally recognized standards.

Pioneer Petrotech Services Inc.

Sep 09 2016
Date

Pioneer Petrotech Services Inc.

April 05, 2019

Golder Associates Ltd.
2920 Virtual Way, Suite 200
Vancouver, BC V5M 0C4

Attention: Mike Dobr

Mike,

In response to your concerns with calibration of the PPS25 Downhole Memory Gauge S/N 5231, please note the following:

- Attached verification accuracy table with the values based on previous calibration
- We used the old calibration coefficients (from Aug. 23/16) and applied it to the most recent verification data (Apr. 23/18)
- This demonstrates that the pressure accuracy of the 2016 Calibration is within the specification as of the date of the 2018 Calibration. Based on the verification data the Gauge was within the product specification range during the calibration period between 2016 and 2018
    - Pressure Accuracy Specification: +/- .03% FS (6,000 psi Gauge = +/- 1.8 psi)
    - Temp Accuracy Specification: +/- 0.5 C

Also note that Gauge S/N 5231 was recently recalibrated and was shipped back yesterday, April 04, 2019.

Let us know if you require additional information.

Regards

Pioneer Petrotech Services Inc.
PPS
Alberta Canada

Norm Roscovich
VP Business Development
Pioneer Petrotech Services Inc.

Pioneer Petrotech Services Inc.
#1, 1431 – 40 Avenue NE
Calgary, Alberta, Canada, T2E 8N6
Tel: 1-403-282-7669
Fax: 1-403-282-0509
Toll Free in NA: 1-888-PP-GAUGE (774-2843)
Email: infopps@pioneerps.com

Pioneer Petrotech Services Inc.

Calibration Verification Table

5231, 04/25/2018

Ref (PSI)	Ref (C)	Tool (PSI)	Tool (C)	PSI Diff	Temp Diff
Ref	Ref	5231	5231		
PSI	C	PSI	C	PSI	C
15.300	26.233	14.334	25.884	-0.966	-0.349
301.803	26.141	300.994	25.797	-0.809	-0.344
1499.142	26.167	1496.650	25.872	-2.492	-0.295
2998.294	26.155	2998.246	25.795	-0.048	-0.360
4496.579	26.424	4497.533	26.059	0.954	-0.365
4499.251	26.337	4497.023	25.990	-2.228	-0.347
3002.977	26.155	3001.497	25.830	-1.479	-0.326
1496.453	26.386	1495.203	26.028	-1.250	-0.359
303.276	26.062	301.399	25.733	-1.877	-0.329
100.030	75.855	99.080	75.330	-0.951	-0.525
300.043	75.754	299.160	75.231	-0.883	-0.523
1500.414	75.713	1499.528	75.170	-0.886	-0.543
2999.988	75.672	2999.691	75.138	-0.297	-0.534
4501.962	75.674	4502.304	75.134	0.342	-0.540
5999.944	75.654	5995.180	75.134	-4.764	-0.520
4499.247	75.781	4499.402	75.262	0.155	-0.518
2999.726	75.767	2999.829	75.266	0.103	-0.501
1498.561	75.838	1497.853	75.308	-0.708	-0.530
299.916	75.740	299.128	75.222	-0.787	-0.518
100.175	109.156	99.215	108.560	-0.960	-0.596
300.553	109.164	299.671	108.576	-0.882	-0.588
1500.024	109.172	1499.273	108.559	-0.751	-0.613
3001.636	109.174	3001.040	108.566	-0.596	-0.608
4500.065	109.239	4499.562	108.612	-0.503	-0.627
5999.893	109.346	6000.369	108.701	0.476	-0.645
4498.335	109.331	4498.099	108.694	-0.237	-0.637
2999.067	109.334	2998.355	108.708	-0.712	-0.626
1499.980	109.270	1499.570	108.620	-0.410	-0.650
300.015	109.231	299.135	108.621	-0.880	-0.610
100.198	134.012	99.215	133.317	-0.983	-0.695
301.068	134.048	300.001	133.347	-1.067	-0.701
1501.357	134.029	1500.708	133.327	-0.649	-0.702
3001.363	134.068	3001.142	133.367	-0.221	-0.701
4500.978	134.050	4500.373	133.350	-0.605	-0.700
6000.059	134.058	5999.719	133.392	-0.341	-0.665
4500.017	134.035	4500.654	133.378	0.636	-0.657
2999.362	134.105	2999.478	133.402	0.116	-0.703
1499.654	134.083	1499.451	133.374	-0.202	-0.710
299.408	134.090	298.550	133.381	-0.858	-0.708

Pioneer Petrotech Services Inc.
#1, 1431 – 40 Avenue NE
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Fax: 1-403-282-0509
Toll Free in NA: 1-888-PP-GAUGE (774-2843)
Email: infopps@pioneerps.com

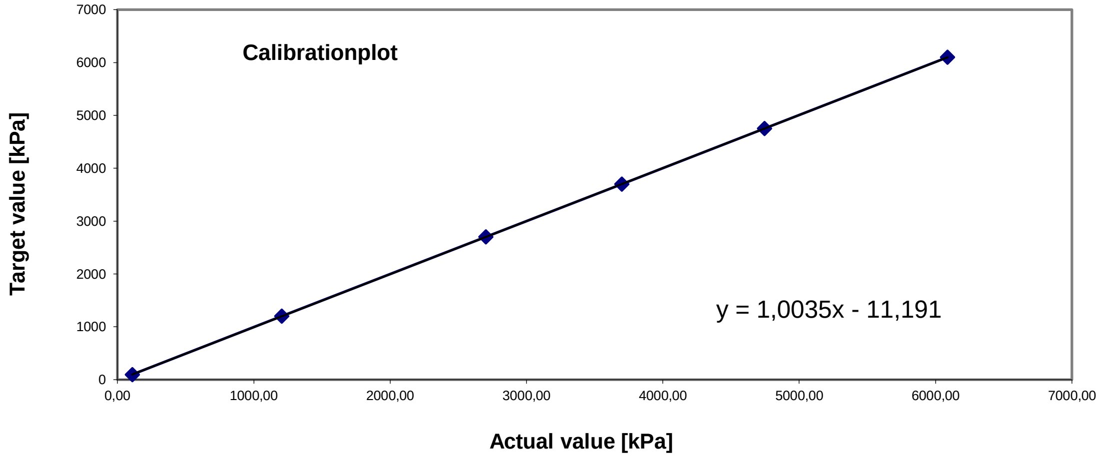
Calibration Protocol

Device type	Pressure transducer
Manufacturer	Aquitronic
Identification	ATM 18 #1461, absolute
Internal Number	Tool #2-P1 #122
First calibration	2017.11.15
Measurement unit	kPa
Measurement range	min. / max. 0 / 6000 kPa
Maximal pressure	6000 kPa
Monitoring unit	DH Budenberg Hydr.Dead-Weight Tester 580DX 1-700bar
Calibrated on	2017.11.15
Accuracy	+/- 0.015% Full Scale + 0.006% of reading
Test medium	Hydraulik oel HLP 10
Temperature	23 °C
Airpressure	96,91 kPa

Test series

Aquitronic	**Budenberg**			
Actual Value kPa (x)	Target Value kPa (y)	Calibration kPa	Deviation kPa	Dev. of Full Scale %
108,49	96,91	97,68	-0,77	-0,0128
1204,76	1200,00	1197,79	2,21	0,0369
2702,14	2700,00	2700,41	-0,41	-0,0068
3700,11	3700,00	3701,87	-1,87	-0,0312
4745,39	4750,00	4750,81	-0,81	-0,0135
6088,66	6100,00	6098,78	1,22	0,0203

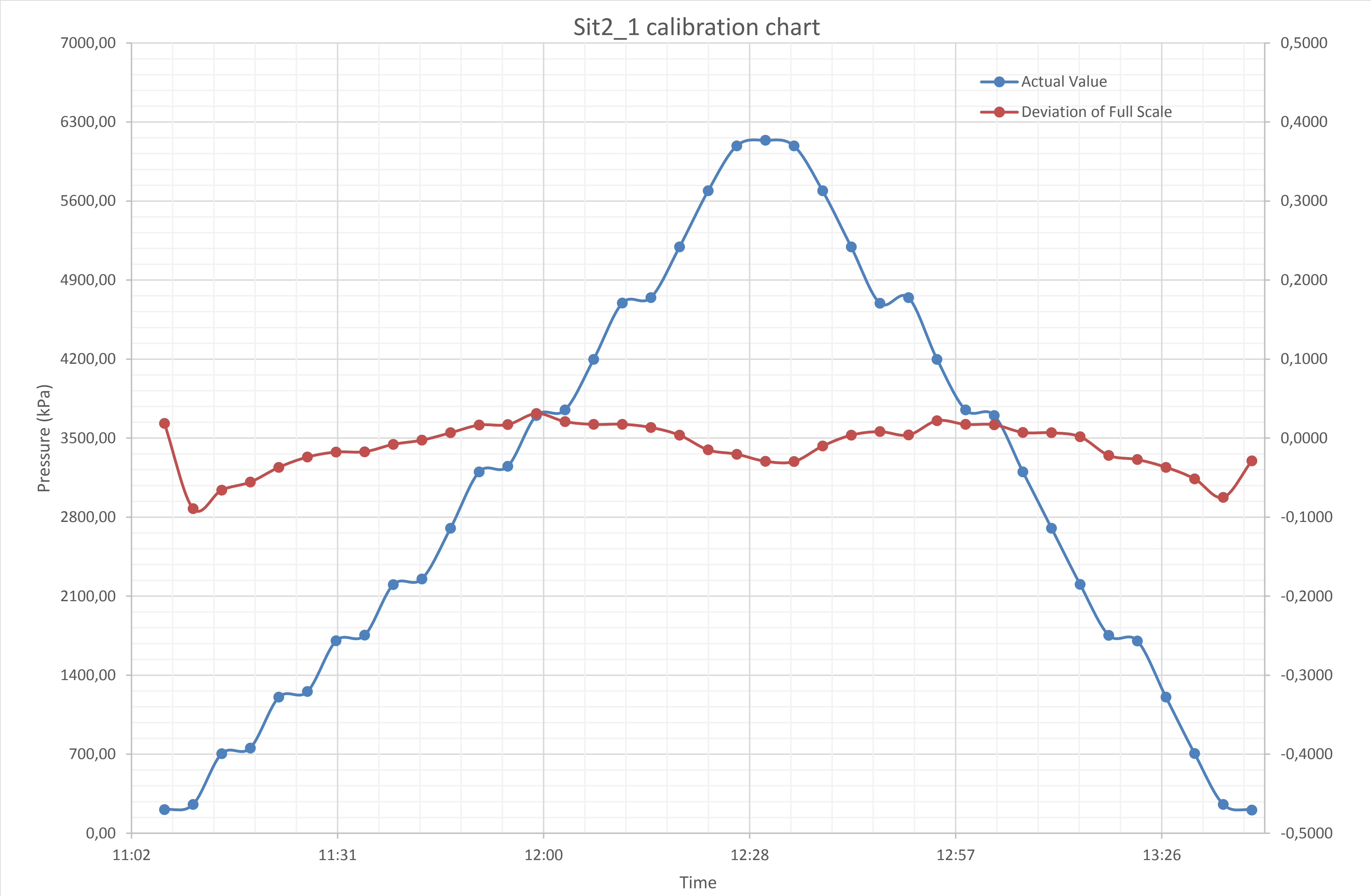
Multiplier 1,0035
Offset -11,1910



* Manufacturer's instructions; Deviation of the pressure cells should be below 0.1% of the final value.

2017.11.15 — Date of calibration

Zsolt Kasler — calibrated by



Sit2_1 calibration chart
Actual Value
Deviation of Full Scale
Pressure (kPa)
7000,00
6300,00
5600,00
4900,00
4200,00
3500,00
2800,00
2100,00
1400,00
700,00
0,00
0,5000
0,4000
0,3000
0,2000
0,1000
0,0000
-0,1000
-0,2000
-0,3000
-0,4000
-0,5000
11:02
11:31
12:00
12:28
12:57
13:26
Time

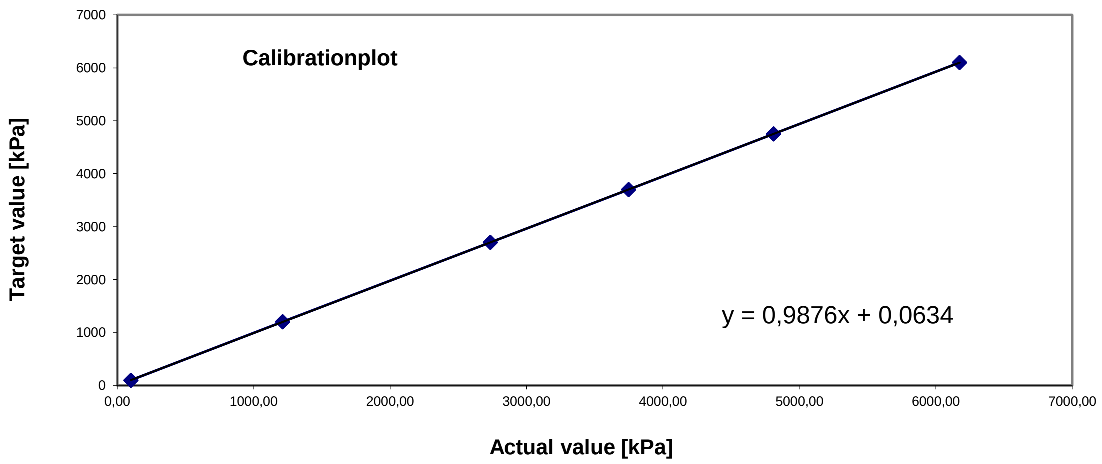
Calibration Protocol

Device type	Pressure transducer
Manufacturer	Aquitronic
Identification	ATM 18 #1461, absolute
Internal Number	Tool #2-P2 #258
First calibration	2017.11.15
Measurement unit	kPa
Measurement range	min. / max. 0 / 6000 kPa
Maximal pressure	6000 kPa
Monitoring unit	DH Budenberg Hydr.Dead-Weight Tester 580DX 1-700bar
Calibrated on	2017.11.15
Accuracy	+/- 0.015% Full Scale + 0.006% of reading
Test medium	Hydraulik oel HLP 10
Temperature	23 °C
Airpressure	96,91 kPa

Test series

Aquitronic	Budenberg			
Actual Value kPa (x)	Target Value kPa (y)	Calibration kPa	Deviation kPa	Dev. of Full Scale %
99,87	96,91	98,70	-1,78	-0,0297
1211,63	1200,00	1196,67	3,33	0,0555
2733,90	2700,00	2700,06	-0,06	-0,0011
3748,37	3700,00	3701,95	-1,95	-0,0326
4811,06	4750,00	4751,47	-1,47	-0,0244
6175,32	6100,00	6098,81	1,19	0,0198

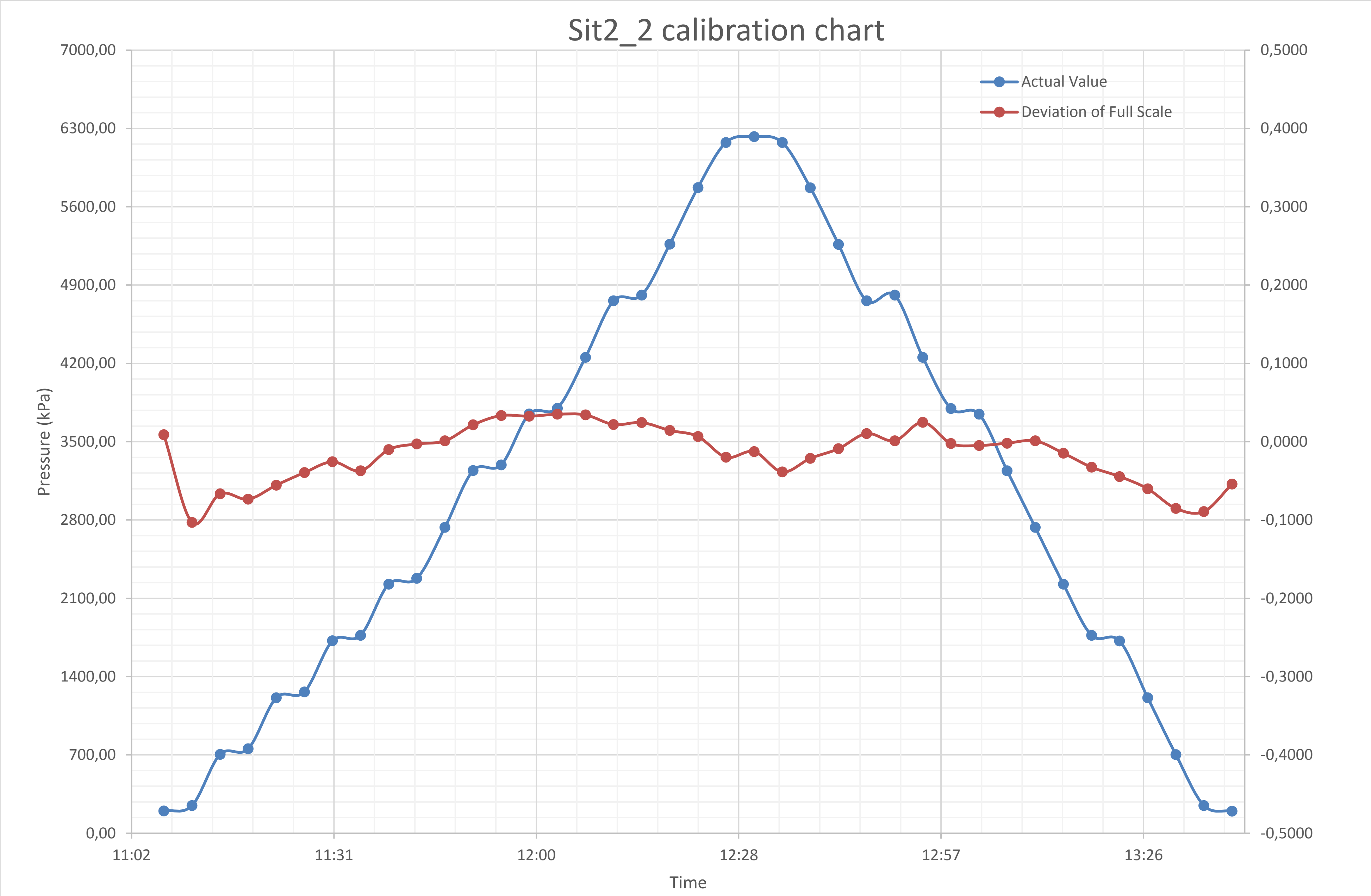
Multiplier 0,9876
Offset 0,0634



* Manufacturer's instructions; Deviation of the pressure cells should be below 0.1% of the final value.

2017.11.15 Zsolt Kasler

Date of calibration calibrated by


Sit2_2 calibration chart
Actual Value
Deviation of Full Scale
Pressure (kPa)
Time
7000,00
6300,00
5600,00
4900,00
4200,00
3500,00
2800,00
2100,00
1400,00
700,00
0,00
0,5000
0,4000
0,3000
0,2000
0,1000
0,0000
-0,1000
-0,2000
-0,3000
-0,4000
-0,5000
11:02
11:31
12:00
12:28
12:57
13:26

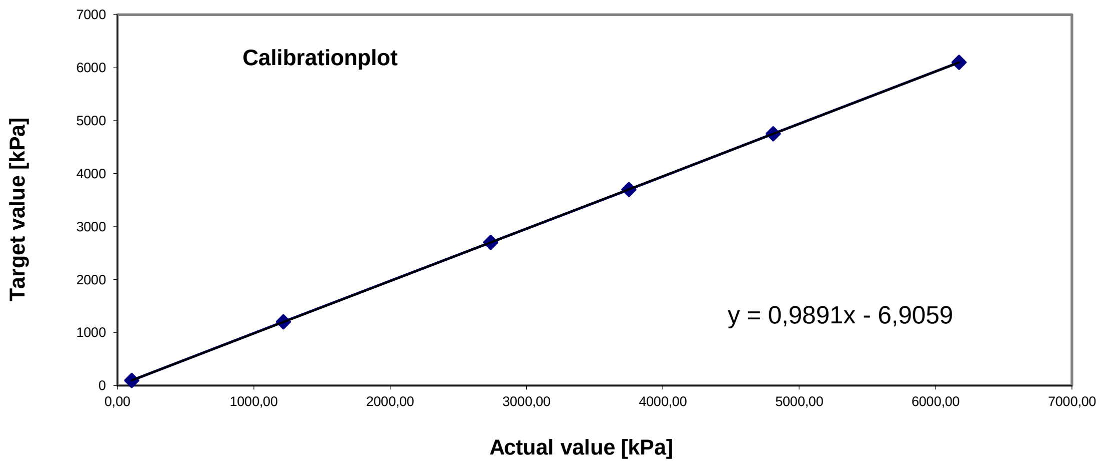
Calibration Protocol

Device type	Pressure transducer
Manufacturer	Aquitronic
Identification	ATM 18 #1461, absolute
Internal Number	Tool #2-P3 #255
First calibration	2017.11.15
Measurement unit	kPa
Measurement range	min. / max. 0 / 6000 kPa
Maximal pressure	6000 kPa
Monitoring unit	DH Budenberg Hydr.Dead-Weight Tester 580DX 1-700bar
Calibrated on	2017.11.15
Accuracy	+/- 0.015% Full Scale + 0.006% of reading
Test medium	Hydraulik oel HLP 10
Temperature	23 °C
Airpressure	96,91 kPa

Test series

Aquitronic	**Budenberg**			
Actual Value kPa (x)	Target Value kPa (y)	Calibration kPa	Deviation kPa	Dev. of Full Scale %
105,84	96,91	97,78	-0,87	-0,0145
1217,51	1200,00	1197,33	2,67	0,0444
2737,41	2700,00	2700,67	-0,67	-0,0111
3749,93	3700,00	3702,15	-2,15	-0,0358
4809,88	4750,00	4750,55	-0,55	-0,0091
6172,80	6100,00	6098,61	1,39	0,0232

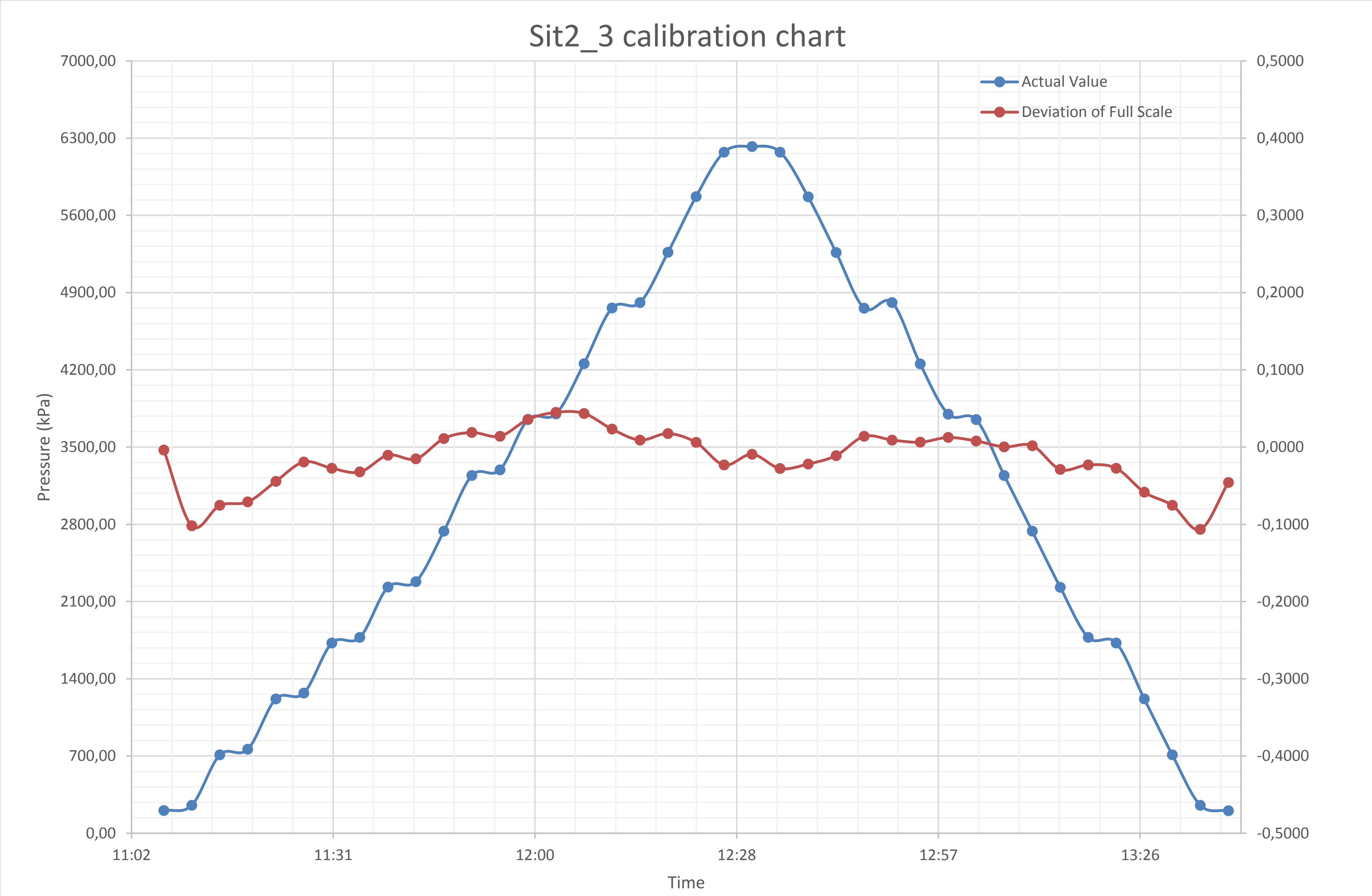
Multiplier 0,9891
Offset -6,9059



* Manufacturer's instructions; Deviation of the pressure cells should be below 0.1% of the final value.

2017.11.15 — Date of calibration

Zsolt Kasler — calibrated by



Sit2_3 calibration chart
Actual Value
Deviation of Full Scale
Pressure (kPa)
Time
7000,00
6300,00
5600,00
4900,00
4200,00
3500,00
2800,00
2100,00
1400,00
700,00
0,00
0,5000
0,4000
0,3000
0,2000
0,1000
0,0000
-0,1000
-0,2000
-0,3000
-0,4000
-0,5000
11:02
11:31
12:00
12:28
12:57
13:26

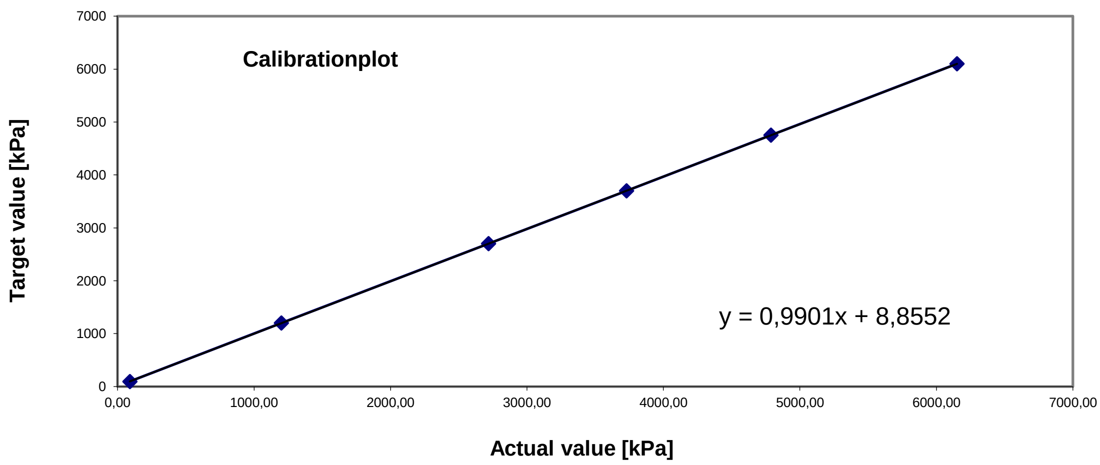
Calibration Protocol

Device type	Pressure transducer
Manufacturer	Aquitronic
Identification	ATM 18 #1461, absolute
Internal Number	Tool #2-P4 #257
First calibration	2017.11.15
Measurement unit	kPa
Measurement range	min. / max. 0 / 6000 kPa
Maximal pressure	6000 kPa
Monitoring unit	DH Budenberg Hydr.Dead-Weight Tester 580DX 1-700bar
Calibrated on	2017.11.15
Accuracy	+/- 0.015% Full Scale + 0.006% of reading
Test medium	Hydraulik oel HLP 10
Temperature	23 °C
Airpressure	96,91 kPa

Test series

Aquitronic Actual Value kPa (x)	**Budenberg** Target Value kPa (y)	Calibration kPa	Deviation kPa	Dev. of Full Scale %
89,79	96,91	97,76	-0,84	-0,0141
1200,23	1200,00	1197,20	2,80	0,0466
2719,12	2700,00	2701,06	-1,06	-0,0176
3730,68	3700,00	3702,60	-2,60	-0,0434
4787,93	4750,00	4749,38	0,62	0,0103
6151,16	6100,00	6099,12	0,88	0,0147

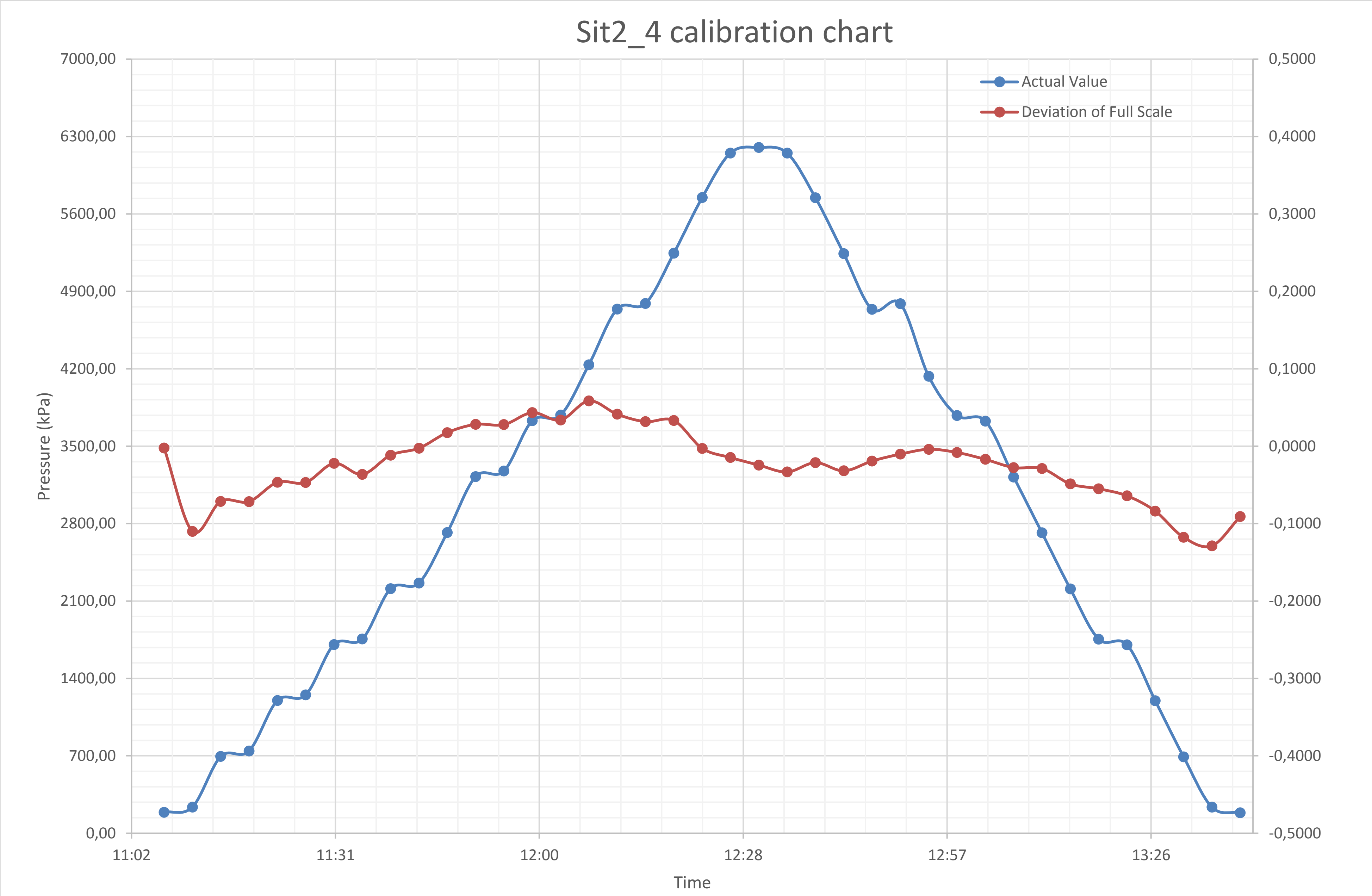
Multiplier 0,9901
Offset 8,8552



* Manufacturer's instructions; Deviation of the pressure cells should be below 0.1% of the final value.

2017.11.15 — Zsolt Kasler

Date of calibration — calibrated by



Sit2_4 calibration chart
Actual Value
Deviation of Full Scale
Pressure (kPa)
7000,00
6300,00
5600,00
4900,00
4200,00
3500,00
2800,00
2100,00
1400,00
700,00
0,00
0,5000
0,4000
0,3000
0,2000
0,1000
0,0000
-0,1000
-0,2000
-0,3000
-0,4000
-0,5000
11:02
11:31
12:00
12:28
12:57
13:26
Time

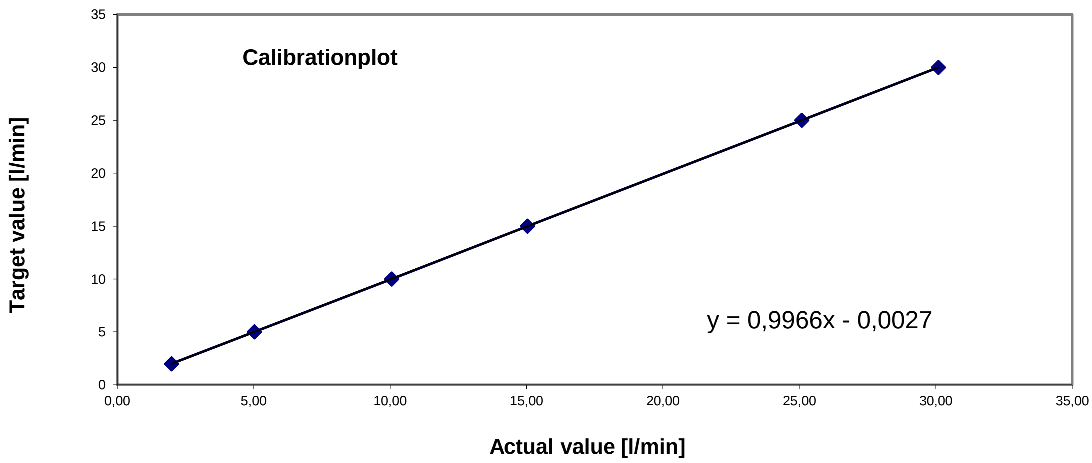
Calibration Protocol

Device type	Digital flowmeter
Manufacturer	Endress+Hauser
Serial number	J4201719000
First calibration	2017.11.13
Measurement unit	l/min
Measurement range	min. / max. 0 / 30 l/min
Maximal flowrate	30 l/min
Monitoring unit	T-Logg datalogger
Calibrated on	2017.11.13
Accuracy	+/- 0,5% of full scale (at nominal temperature)
Test medium	Water
Temperature	12 °C

Test series

T-Logg	**Flowmeter**			
Actual Value l/min (x)	Target Value l/min (y)	Calibration l/min	Deviation l/min	Dev. of Full Scale %
1,99	2,00	1,98	0,02	0,0649
5,03	5,00	5,01	-0,01	-0,0340
10,06	10,00	10,02	-0,02	-0,0770
15,04	15,00	14,99	0,01	0,0461
25,09	25,00	25,00	0,00	-0,0066
30,10	30,00	29,99	0,01	0,0168

Multiplier 0,9966
Offset -0,0027



2017.11.13
Date of calibration

Zsolt Kasler
calibrated by

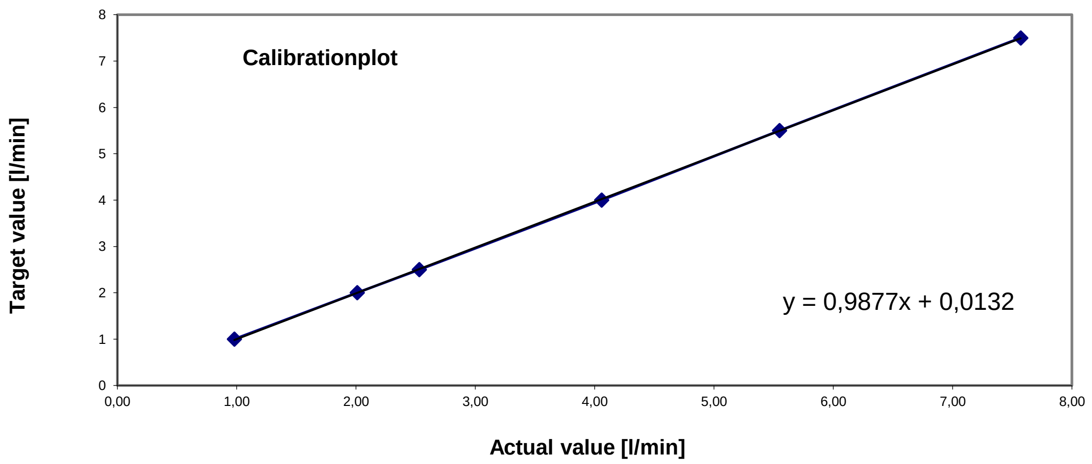
Calibration Protocol

Device type	Digital flowmeter
Manufacturer	Endress+Hauser
Serial number	750AA019000
First calibration	2017.11.13
Measurement unit	l/min
Measurement range	min. / max. 0 / 7,5 l/min
Maximal flowrate	7,5 l/min
Monitoring unit	T-Logg datalogger
Calibrated on	2017.11.13
Accuracy	+/- 0,5% of full scale (at nominal temperature)
Test medium	Water
Temperature	12 °C

Test series

T-Logg	**Flowmeter**			
Actual Value l/min (x)	Target Value l/min (y)	Calibration l/min	Deviation l/min	Dev. of Full Scale %
0,98	1,00	0,98	0,02	0,2514
2,01	2,00	2,00	0,00	0,0203
2,53	2,50	2,51	-0,01	-0,1611
4,06	4,00	4,02	-0,02	-0,3102
5,55	5,50	5,49	0,01	0,0675
7,57	7,50	7,49	0,01	0,1321

Multiplier 0,9877
Offset 0,0132



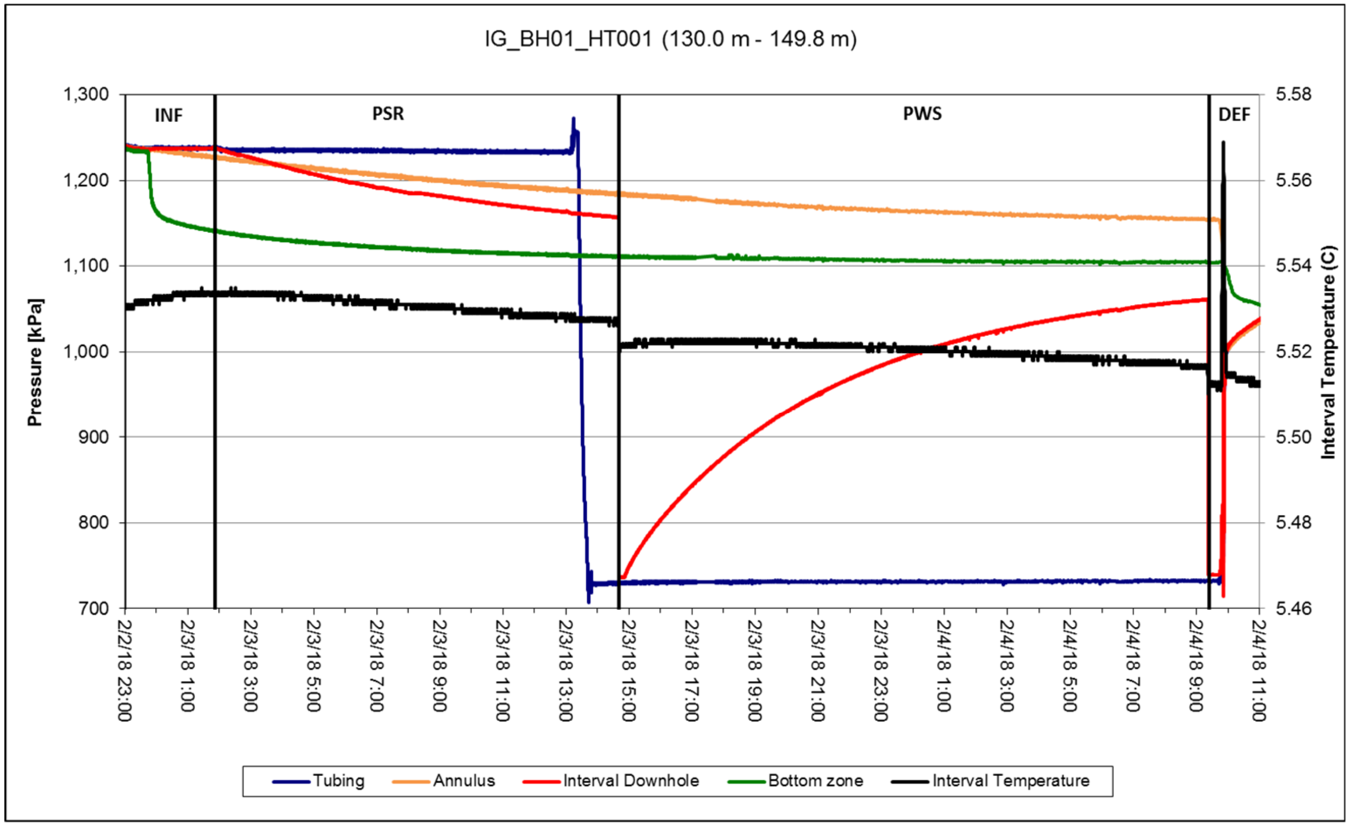
2017.11.13
Date of calibration

Zsolt Kasler
calibrated by

APPENDIX C

Test Results

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT001 (130.0 m – 149.8 m)	Figure C1



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT001
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m^3)	0.152
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	1113
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m^3)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m^3/Pa]
INF	Variable Pressure	0.00	1240.04		2.9e-07
PSR	Recovery	2.79	1238.04		3.0e-10
PWS	Pulse	15.86	736.60	1155.9	3.0e-10
DEF	Variable Pressure	34.35	1060.87		2.9e-07

GOLDER

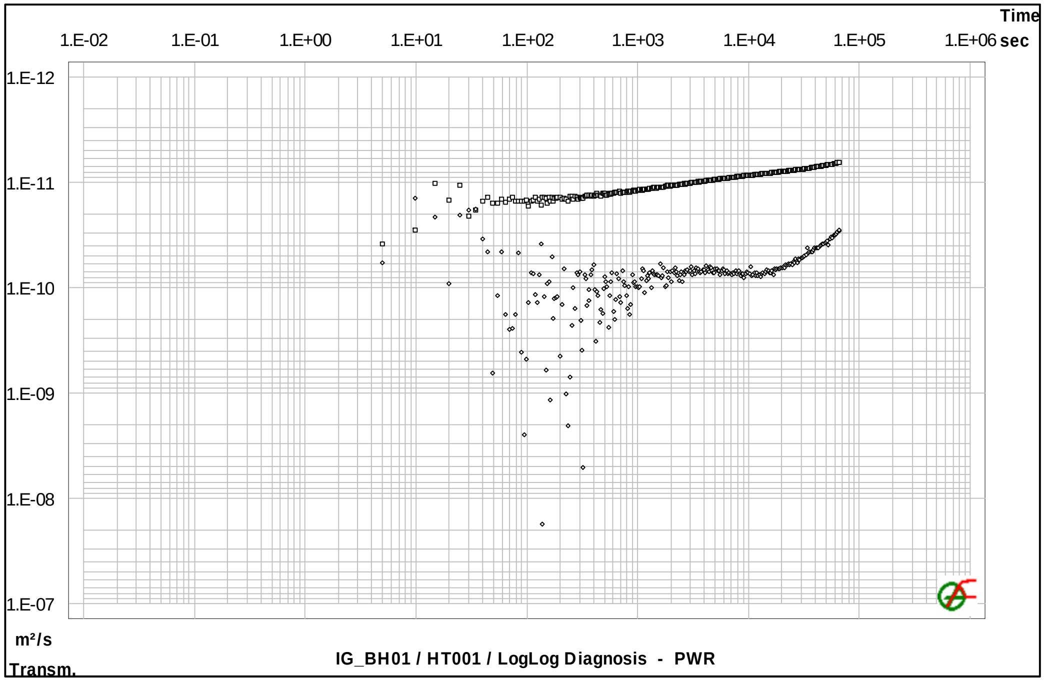
Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01
HT001 (130.0 m – 149.8 m)

Figure C2

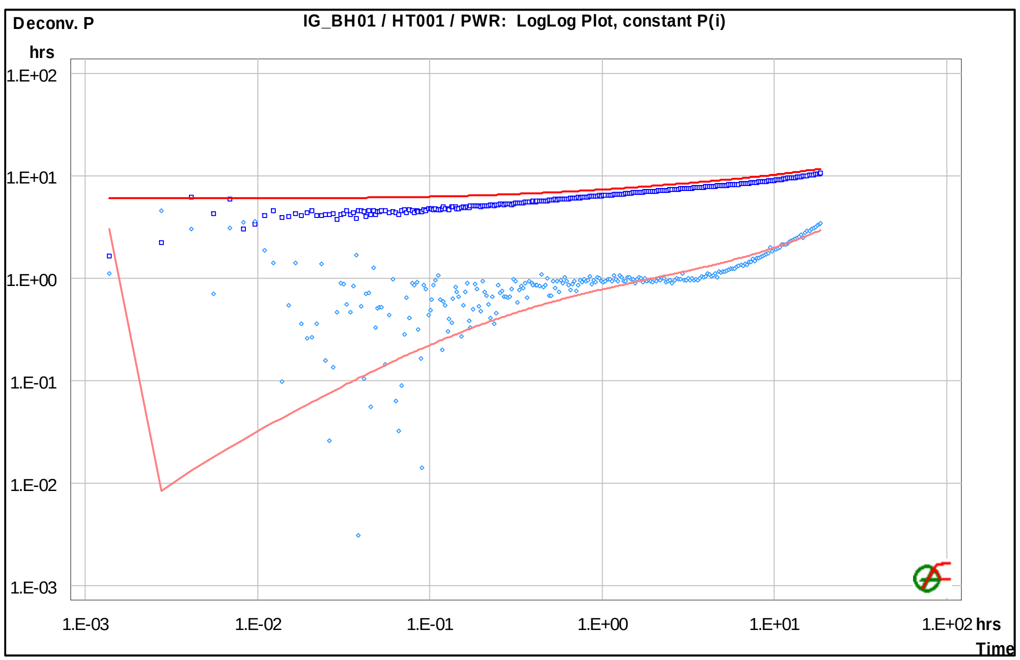
Transmissivity Normalized Plot

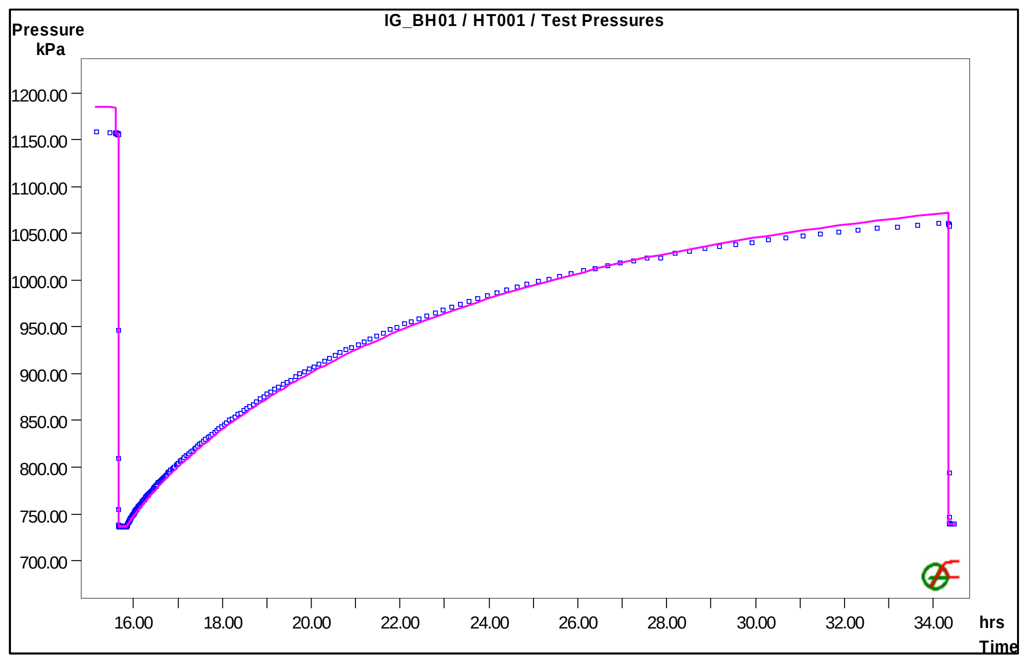


Analysis Parameters

Phase	Transmissivity [m²/s]	Skin [-]	Flow Dimension [-]
PWS	6e-11	1.0	2D

Pressure simulation fit shown in red



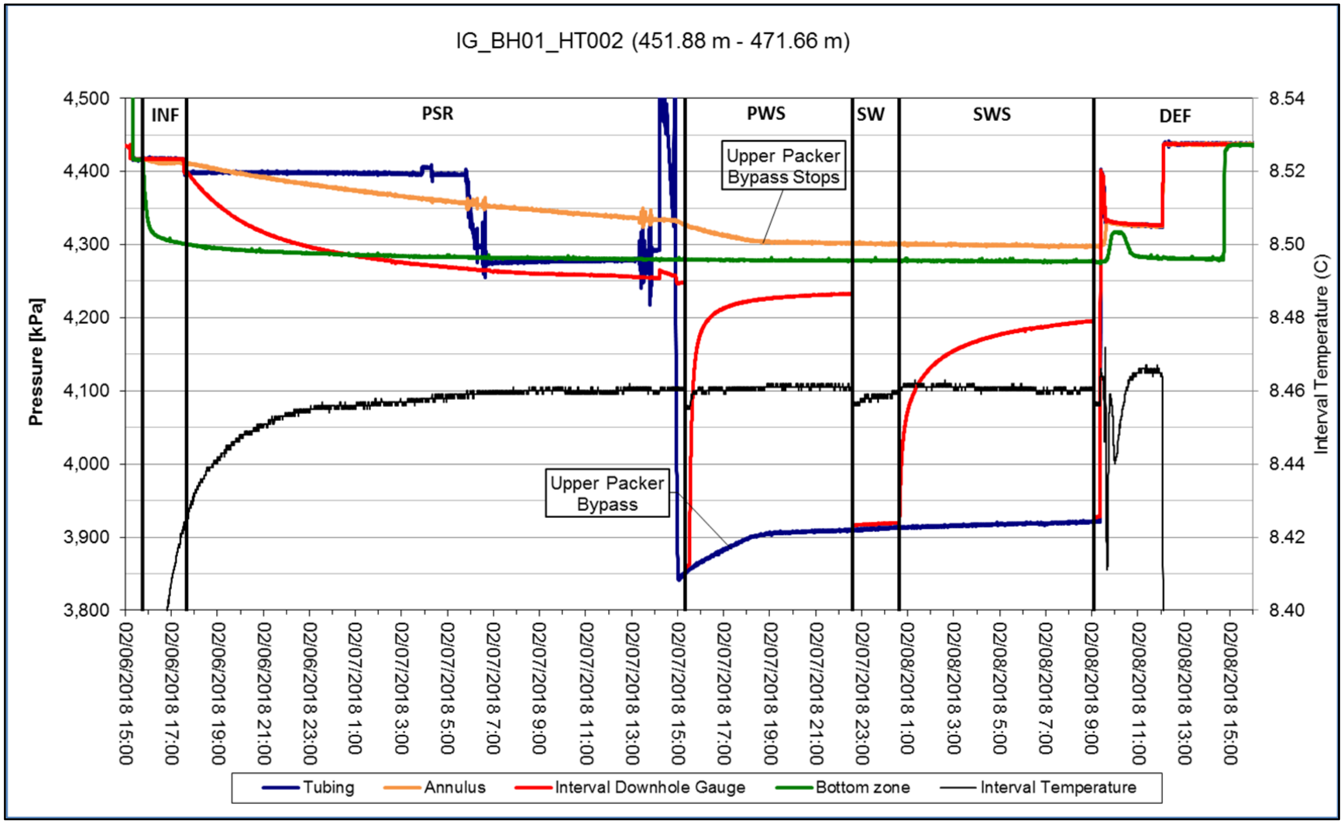


GOLDER

Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT002 (451.9 m – 471.8 m)	Figure C3



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT002
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m^3)	0.152
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	4222
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m^3)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m^3/Pa]
INF	Variable Pressure	0.00	4417.10		2.9e-07
PSR	Recovery	1.97	4398.00		3.0e-10
SW	Slug	30.86	3916.00	4231.9	2.9e-07
SWS	Recovery	32.89	3920.50		3.0e-10
DEF	Variable Pressure	41.32	4195.60		2.9e-07

GOLDER

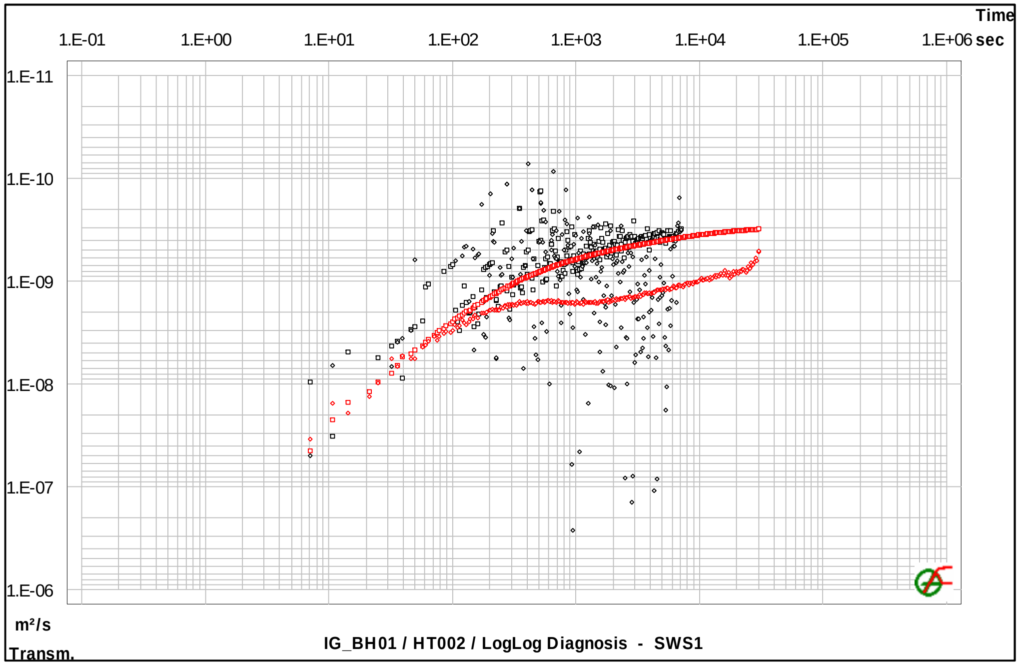
Project #: 1671632

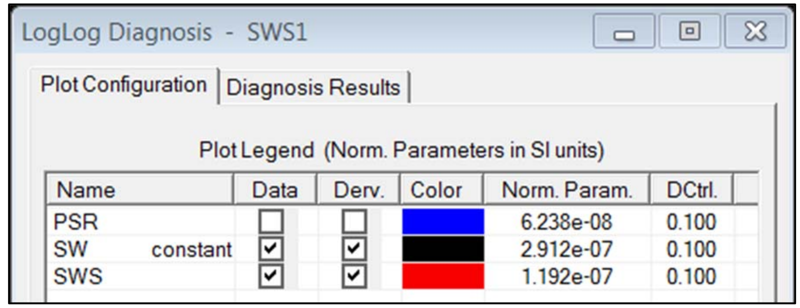
Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01
HT002 (451.9 m – 471.8 m)

Figure C4

Transmissivity Normalized Plot



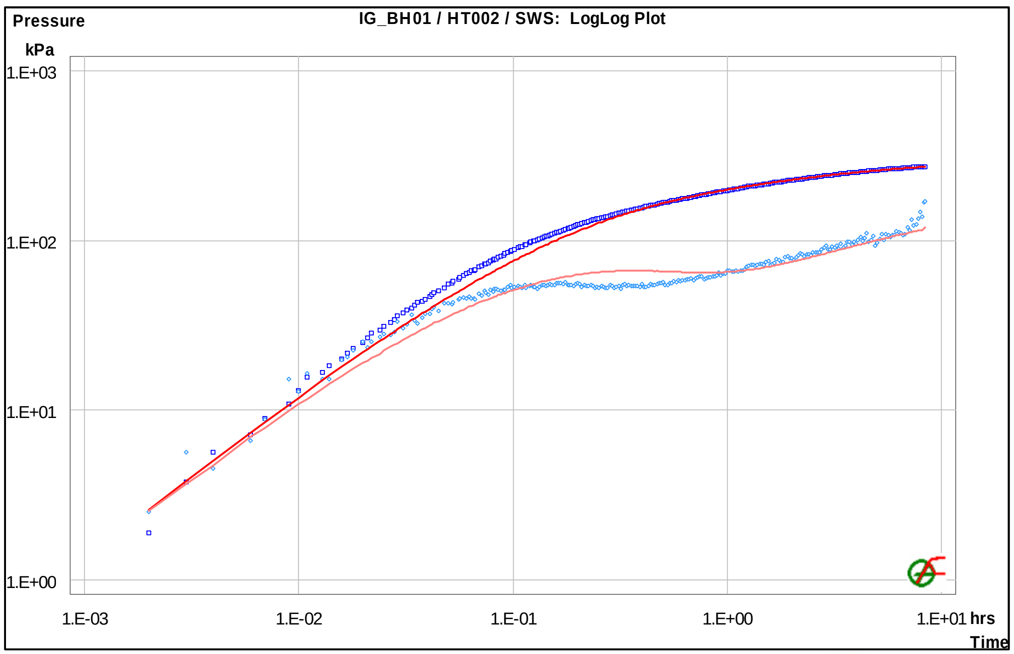


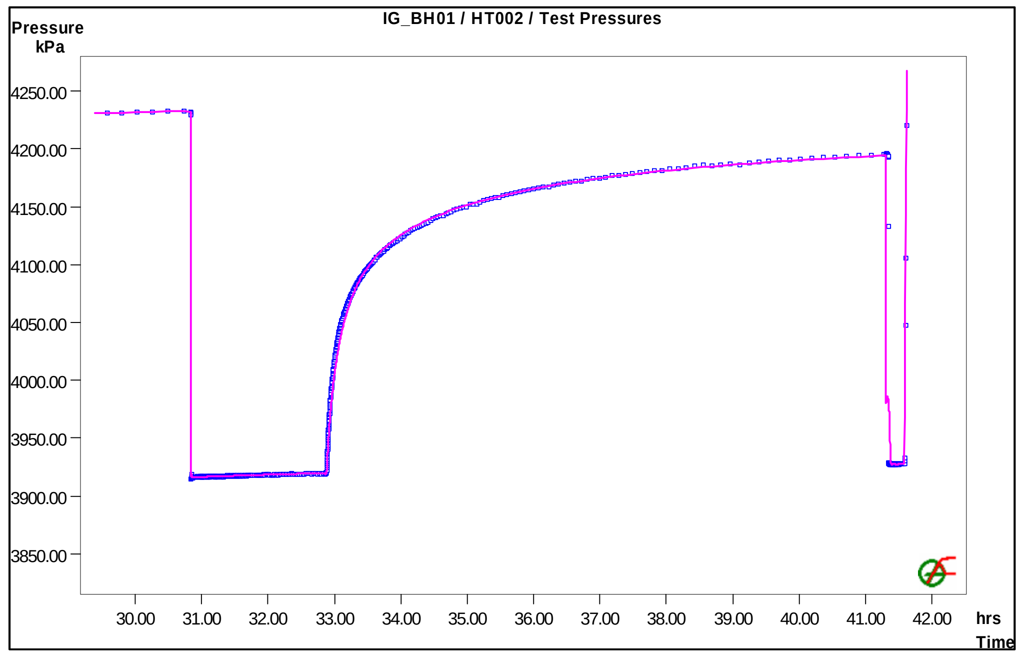
Name	Data	Derv.	Color	Norm. Param.	DCtrl.
PSR	☐	☐		6.238e-08	0.100
SW constant	☑	☑		2.912e-07	0.100
SWS	☑	☑		1.192e-07	0.100

Analysis Parameters

Phase	Shell 1 T [m²/s]	Shell 2 T [m²/s]	Skin	Radius [m]	Flow Dimension
SW/ SWS	3e-9	3e-10	0	0.6	2D

Simulation fit to SWS phase shown in red





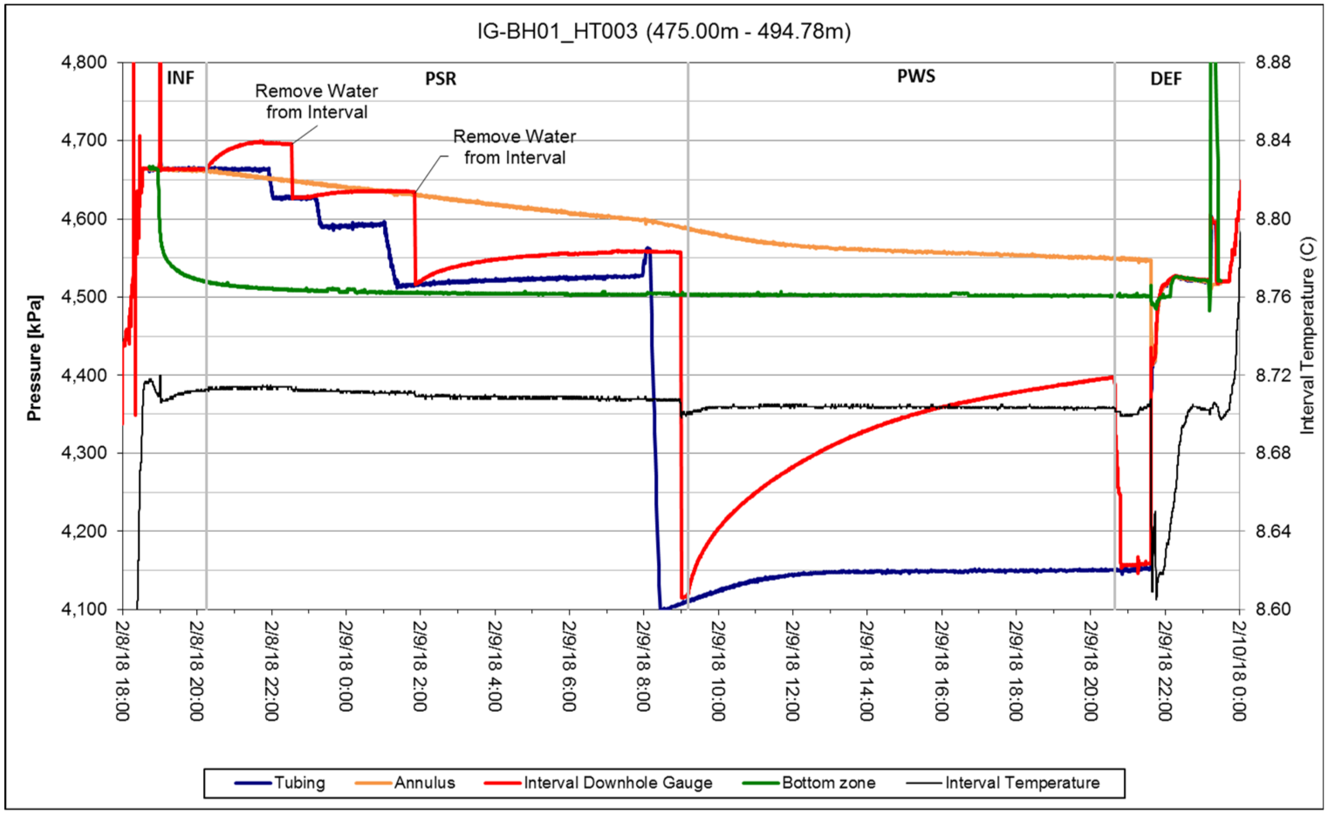
GOLDER

Project #: 1671632

Date: May 2018

Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT003 (475.0 m – 494.8 m)	Figure C5



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT003
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m^3)	0.152
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	4557
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m^3)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m^3/Pa]
INF	Variable Pressure	0.00	4663.50		2.9e-07
PSR	Recovery	1.43	4663.40		3.0e-10
dP	dP-Event	14.17	4557.30		2.9e-07
PWS	Pulse	14.35	4117.30	4557	3.0e-10
DEF	Variable Pressure	25.81	4397.60		2.9e-07

GOLDER

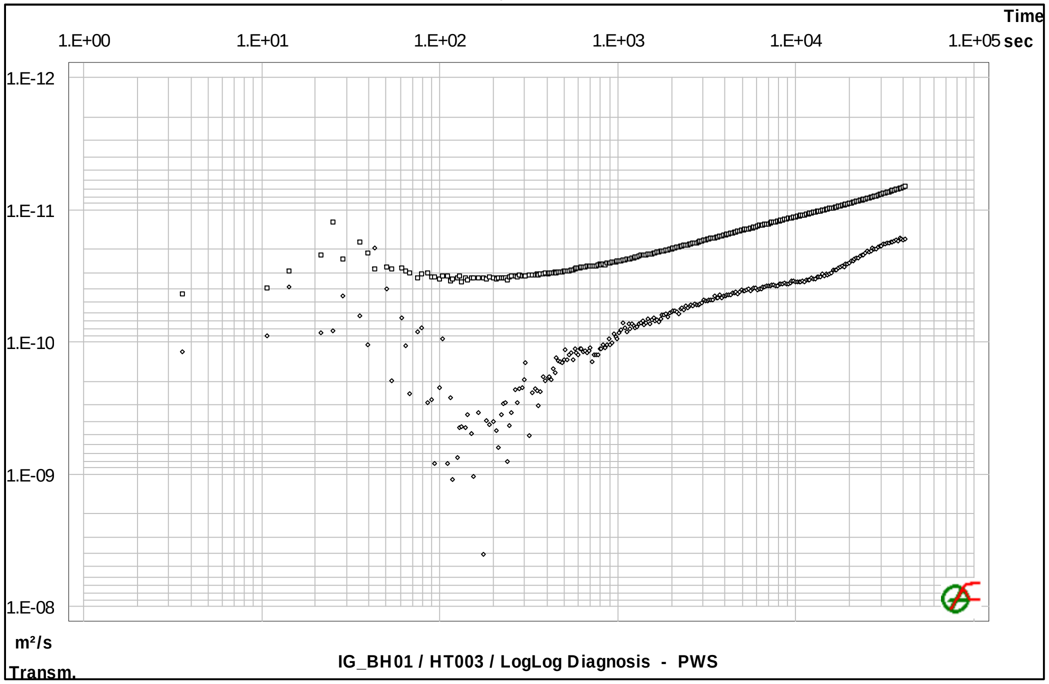
Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT003 (475.0 m – 494.8 m)

Figure C6

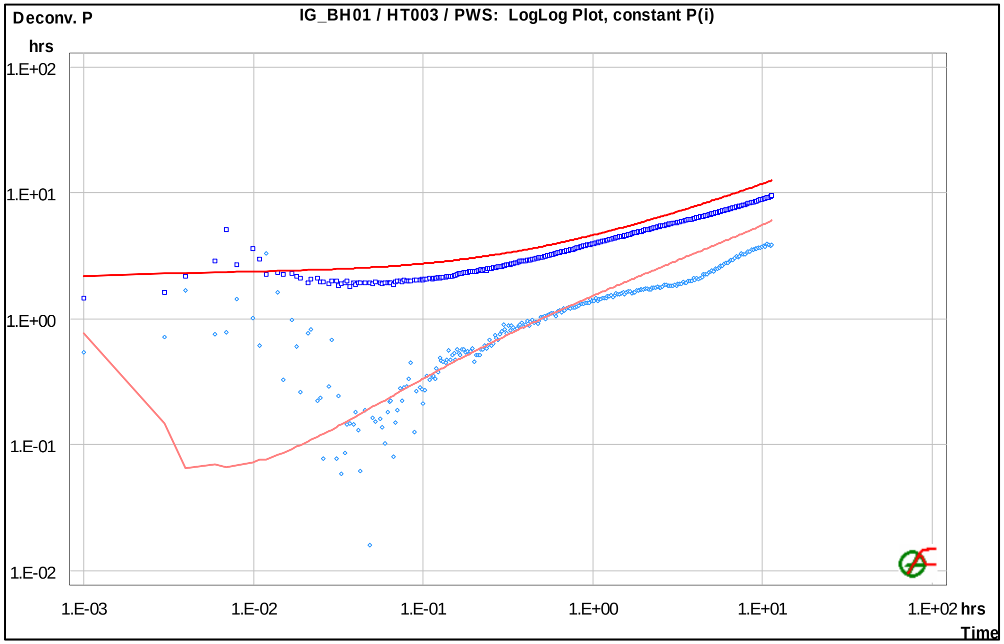
Transmissivity Normalized Plot

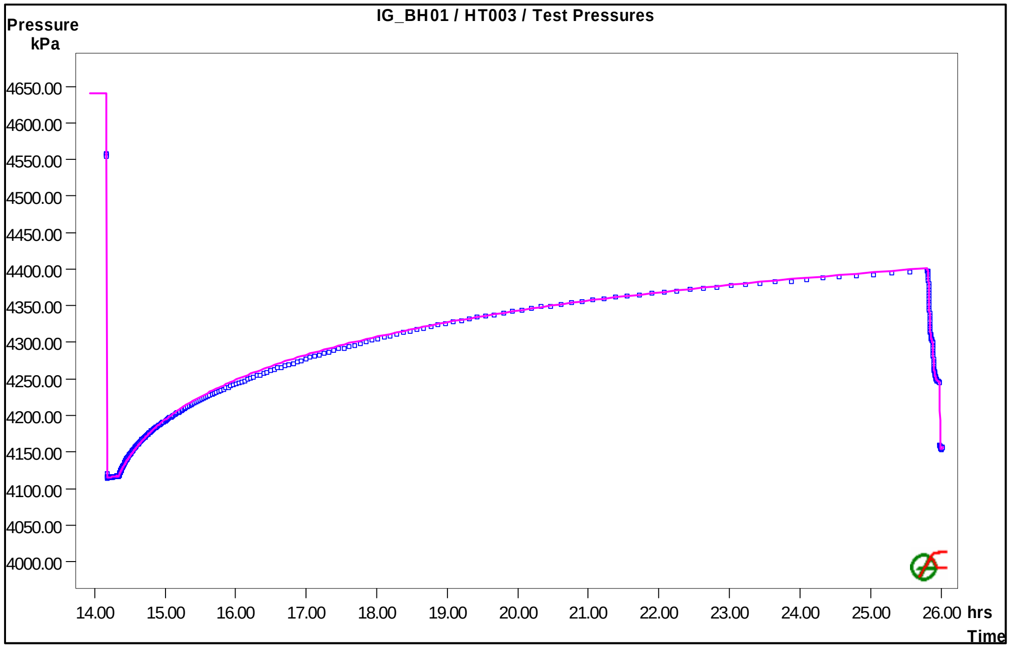


Analysis Parameters

Phase	Transmissivity [m²/s]	Skin	Radius [m]	Flow Dimension
PWS	7e-11	-3.6	--	2D

Simulation fit shown in red





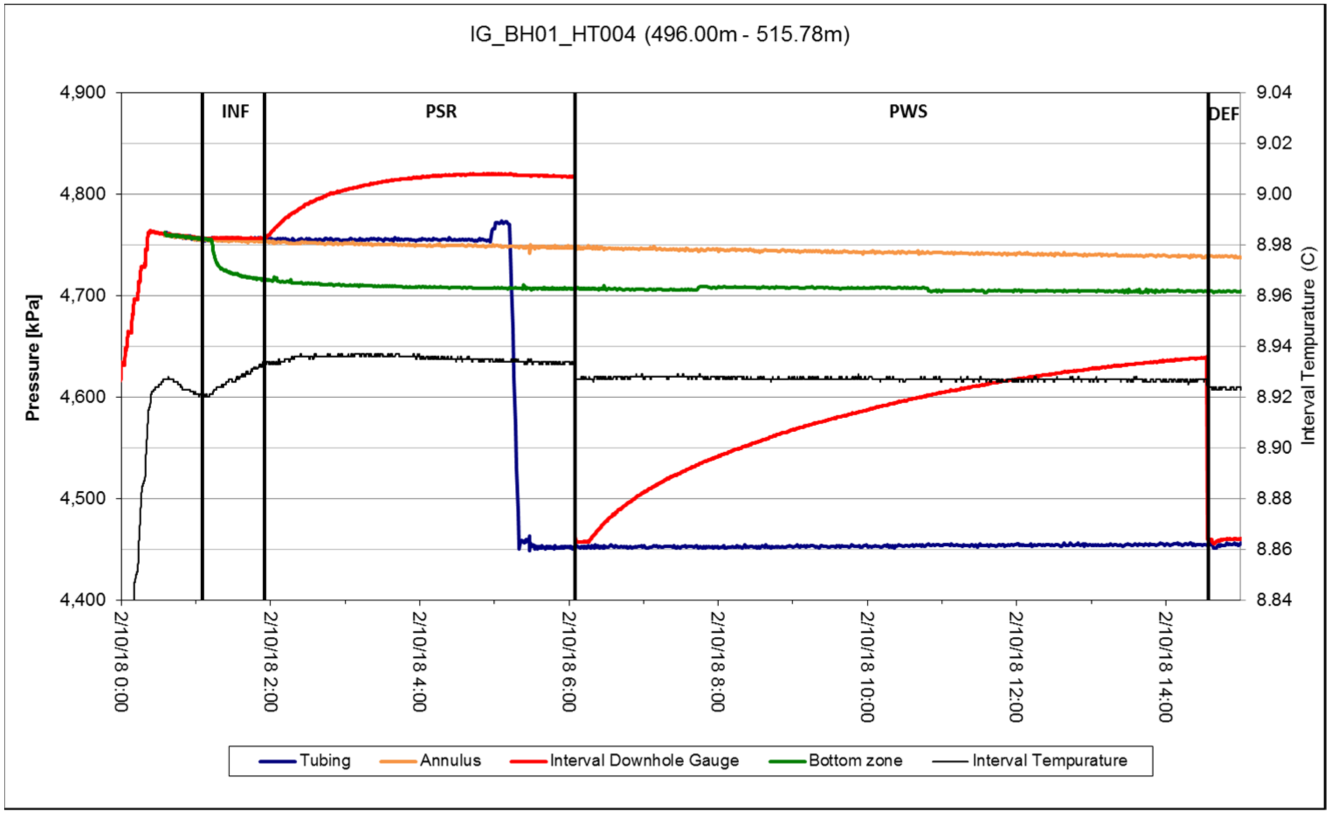
GOLDER

Project #: 1671632

Date: May 2018

Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT004 (496.0 m – 515.8 m)	Figure C7



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT004
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m^3)	0.152
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	4818.9
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m^3)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m³/Pa]
INF	Variable Pressure	0.00000	4758.30		2.9e-07
PSR	Recovery	0.93500	4758.40		3.0e-10
dP	dP-Event	5.07400	4818.90		2.9e-07
PWS	Pulse	5.26700	4459.00	4818.9	3.0e-10
DEF	Variable Pressure	13.32500	4639.50		2.9e-07

GOLDER

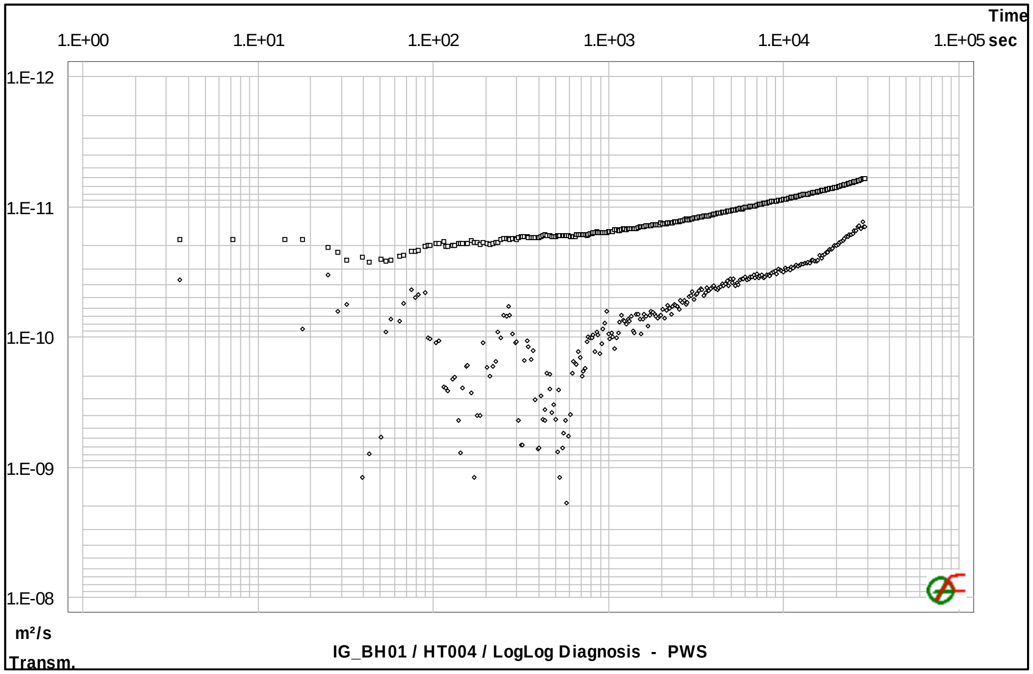
Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01
HT004 (496.0 m – 515.8 m)

Figure C8

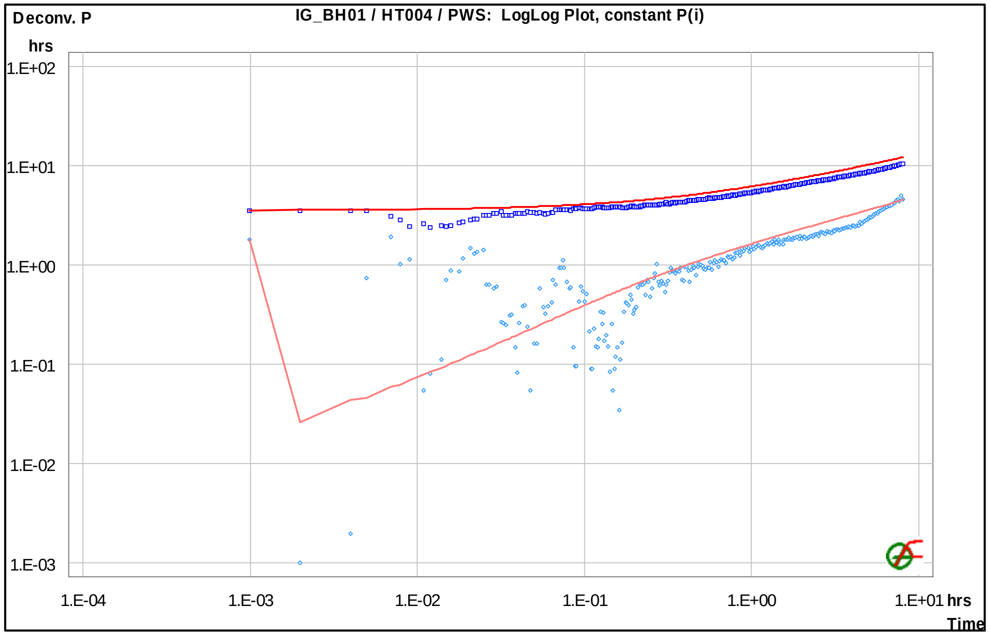
Transmissivity Normalized Plot

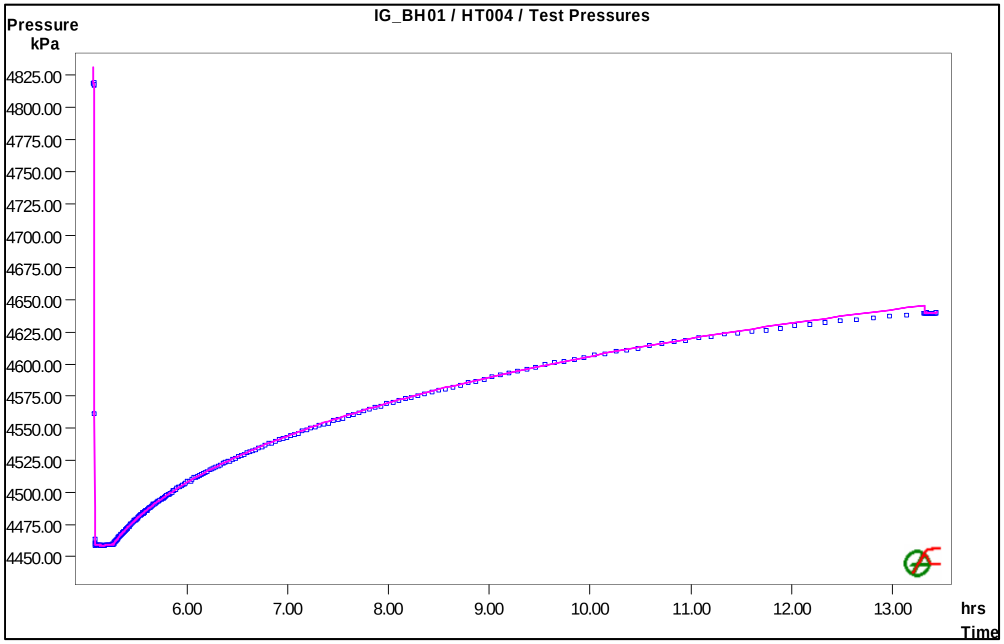


Analysis Parameters

Phase	Transmissivity [m²/s]	Skin	Radius [m]	Flow Dimension
PWS	7e-11	-0.5	--	2D

Simulation fit shown in red



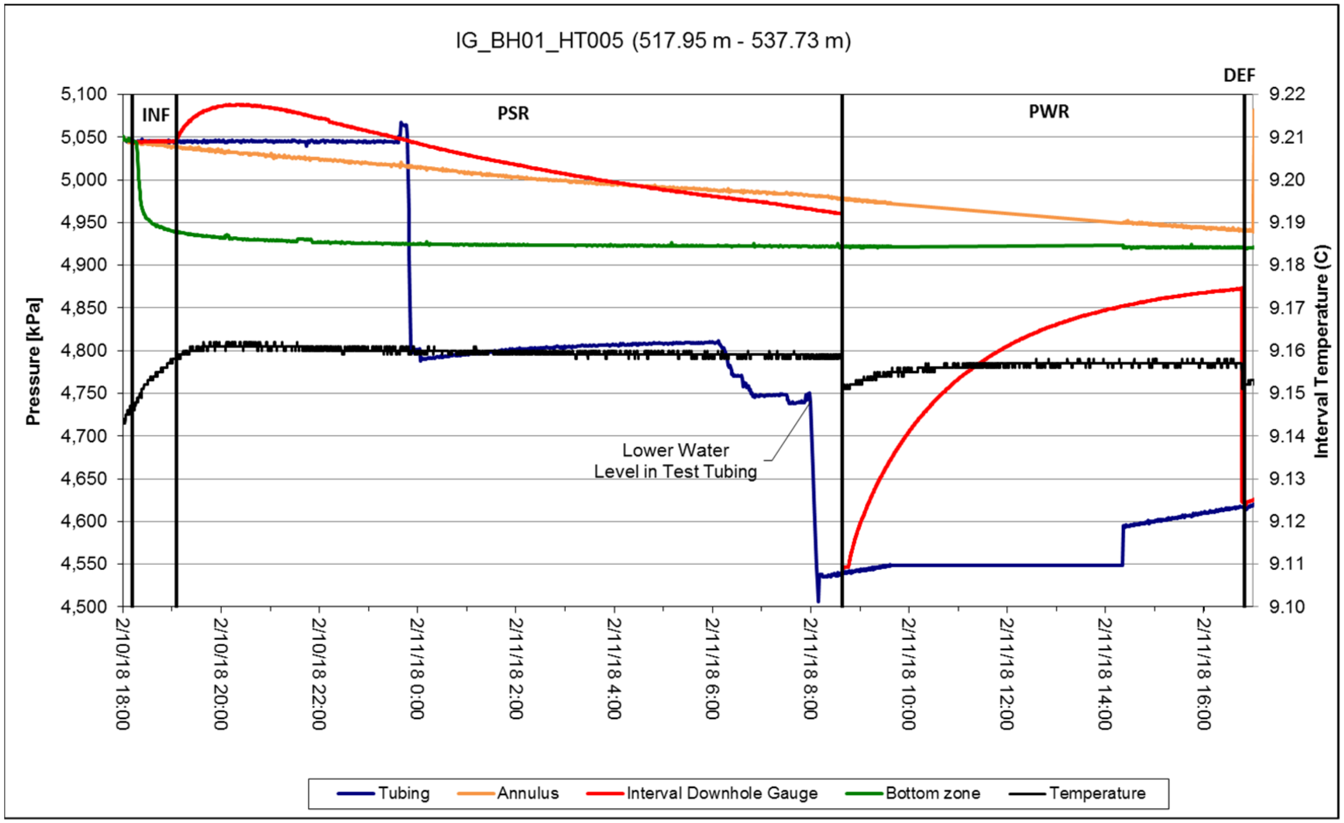


GOLDER

Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT005 (518.0 m – 537.7 m)	Figure C9



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT005
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m^3)	0.152
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	4850
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m^3)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m^3/Pa]
INF	Variable Pressure	0.00000	5047.00		3e-07
PSR	Recovery	1.08200	5045.50		3e-10
dP	dP-Event	14.62500	4960.10		3e-07
PWS	Pulse	14.78300	4551.50	4850	3e-10
DEF	Variable Pressure	22.74400	4872.10		3e-07

GOLDER

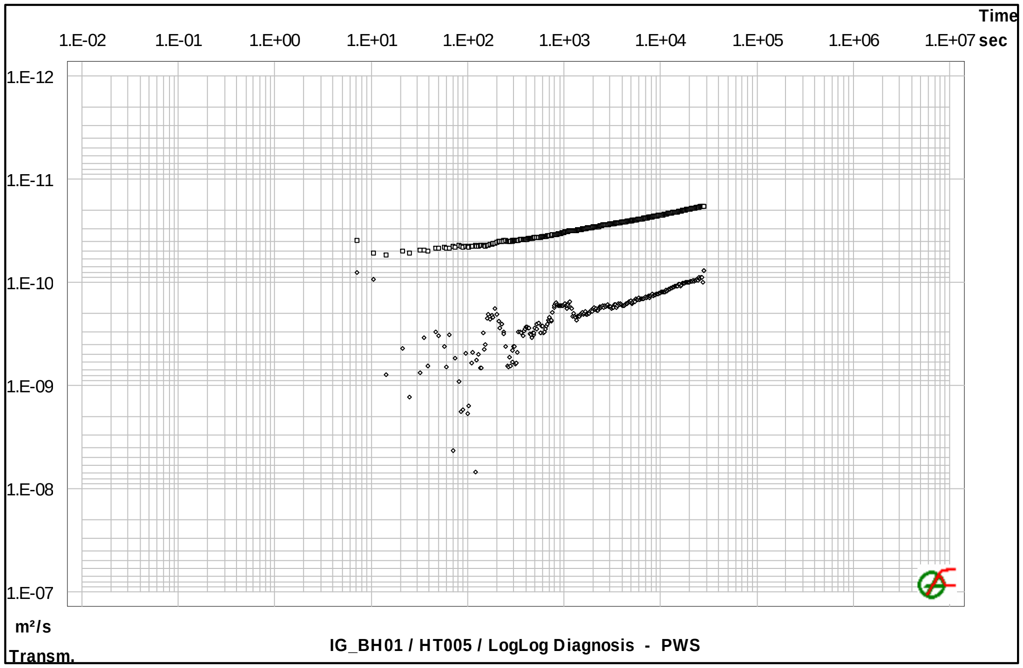
Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01
HT005 (518.0 m – 537.7 m)

Figure C10

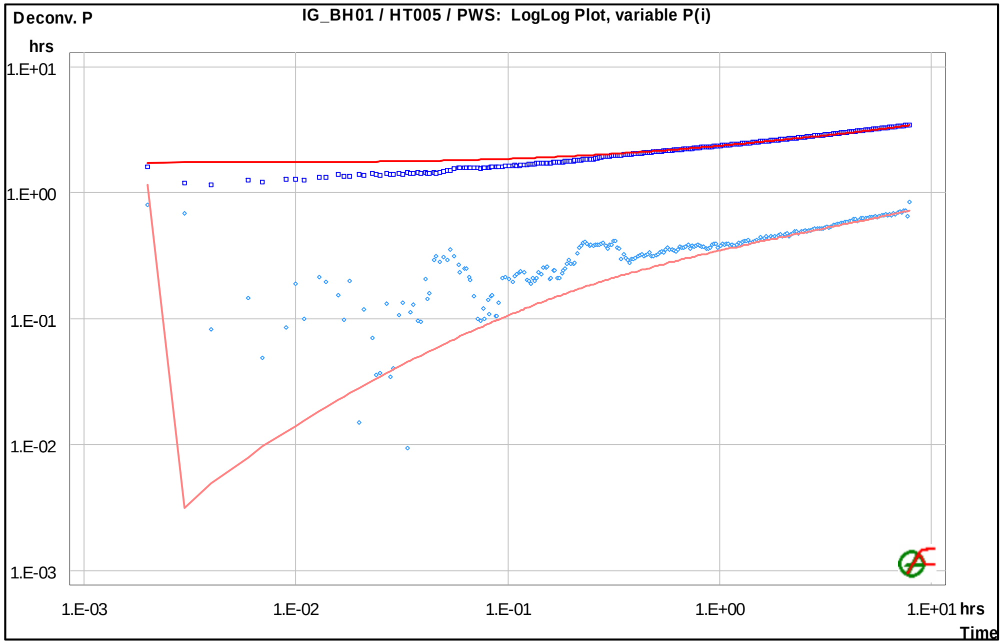
Transmissivity Normalized Plot

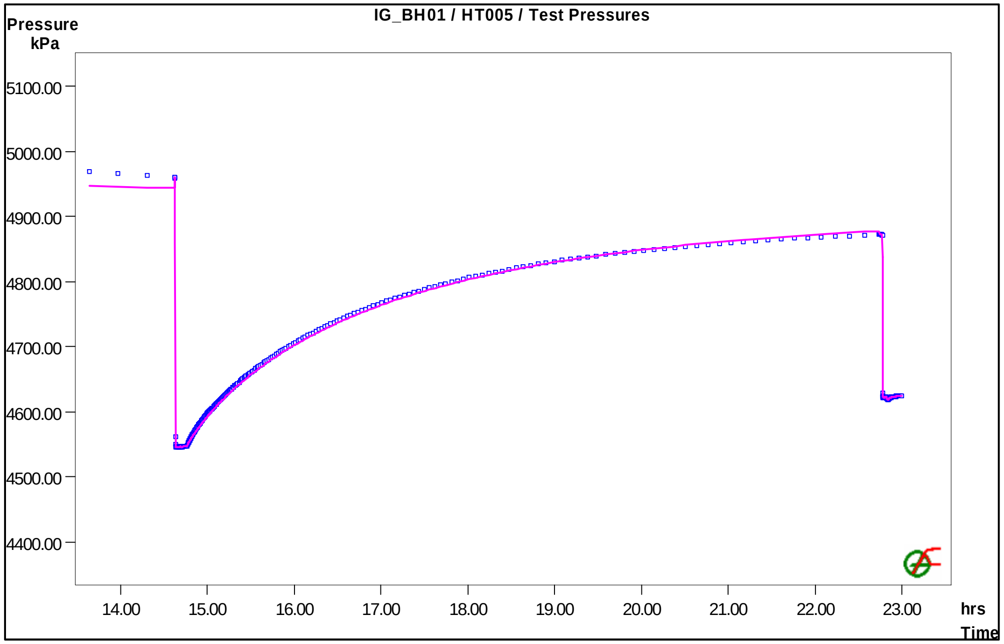


Analysis Parameters

Phase	Transmissivity [m²/s]	Skin	Radius [m]	Flow Dimension
PWS	2e-10	0	--	2D

Simulation fit shown in red





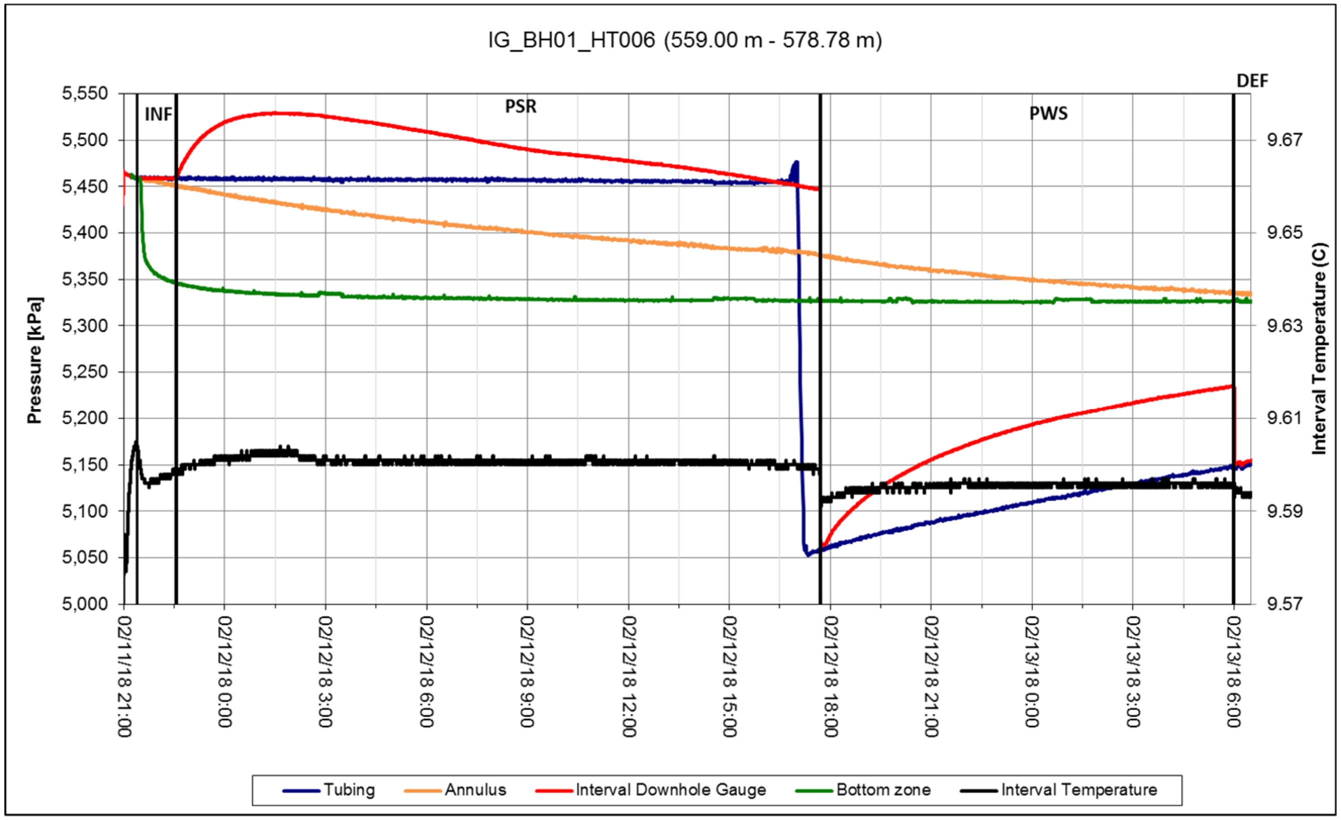
GOLDER

Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01
HT006 (559.0 m – 578.8 m)

Figure C11



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT006
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m^3)	0.152
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	5322
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m^3)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m^3/Pa]
INF	Variable Pressure	0.00	5463.50		3e-07
PSR	Recovery	1.56	5458.60		3e-10
dP	dP-Event	20.70	5446.30		3e-07
PWS	Pulse	20.87	5064.80	5322	3e-10
DEF	Variable Pressure	32.97	5234.90		3e-07

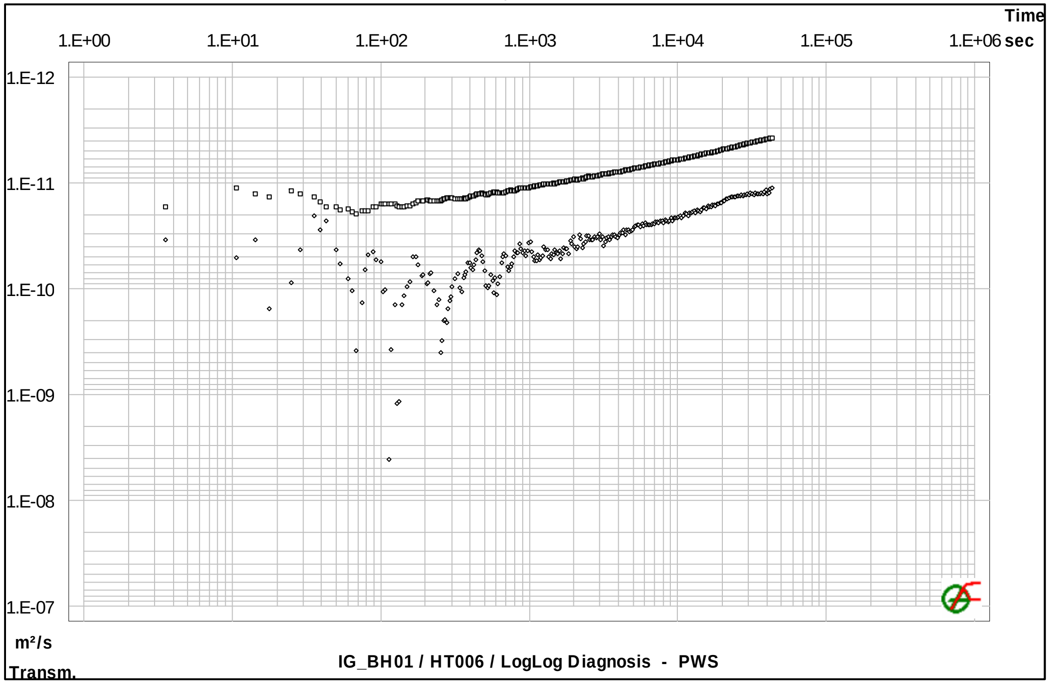
GOLDER

Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT006 (559.0 m – 578.8 m)	Figure C12

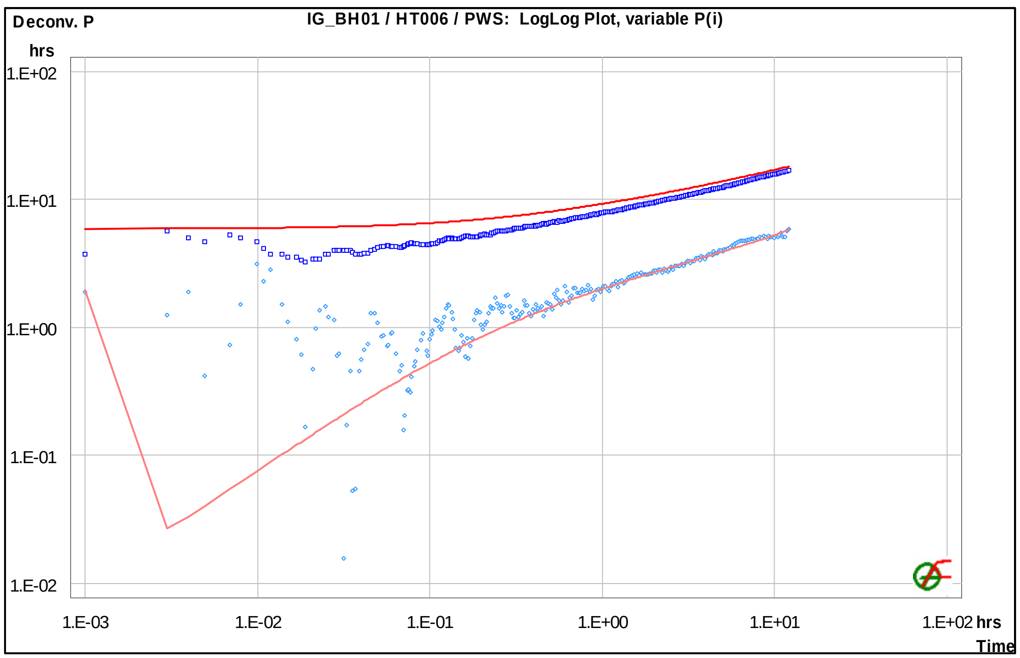
Transmissivity Normalized Plot

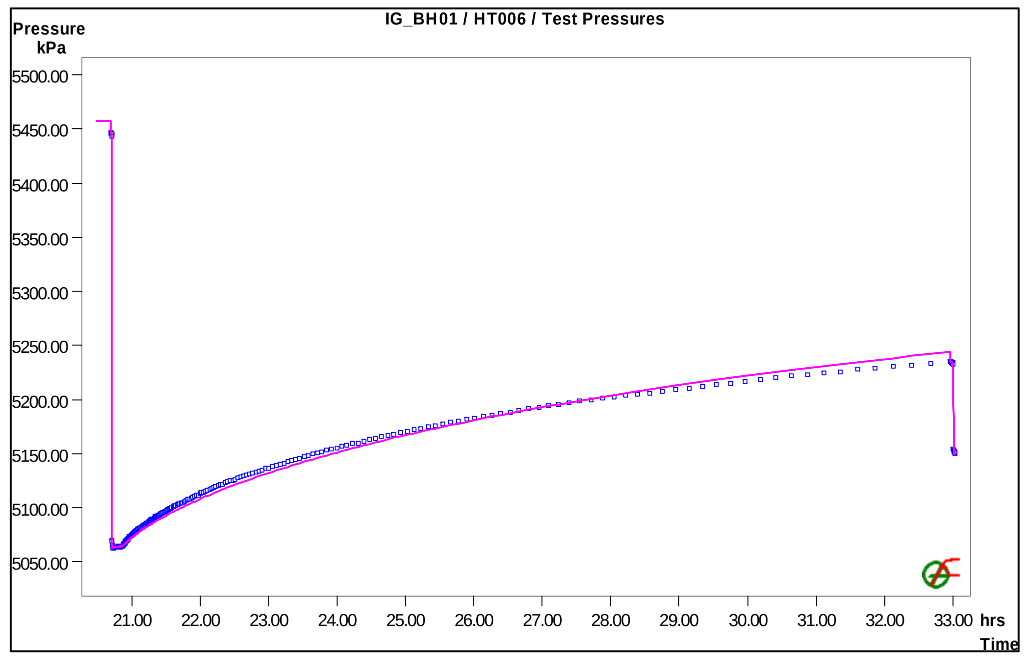


Analysis Parameters

Phase	Transmissivity [m²/s]	Skin	Radius [m]	Flow Dimension
PWS	5e-11	0.0	--	2D

Simulation fit shown in red





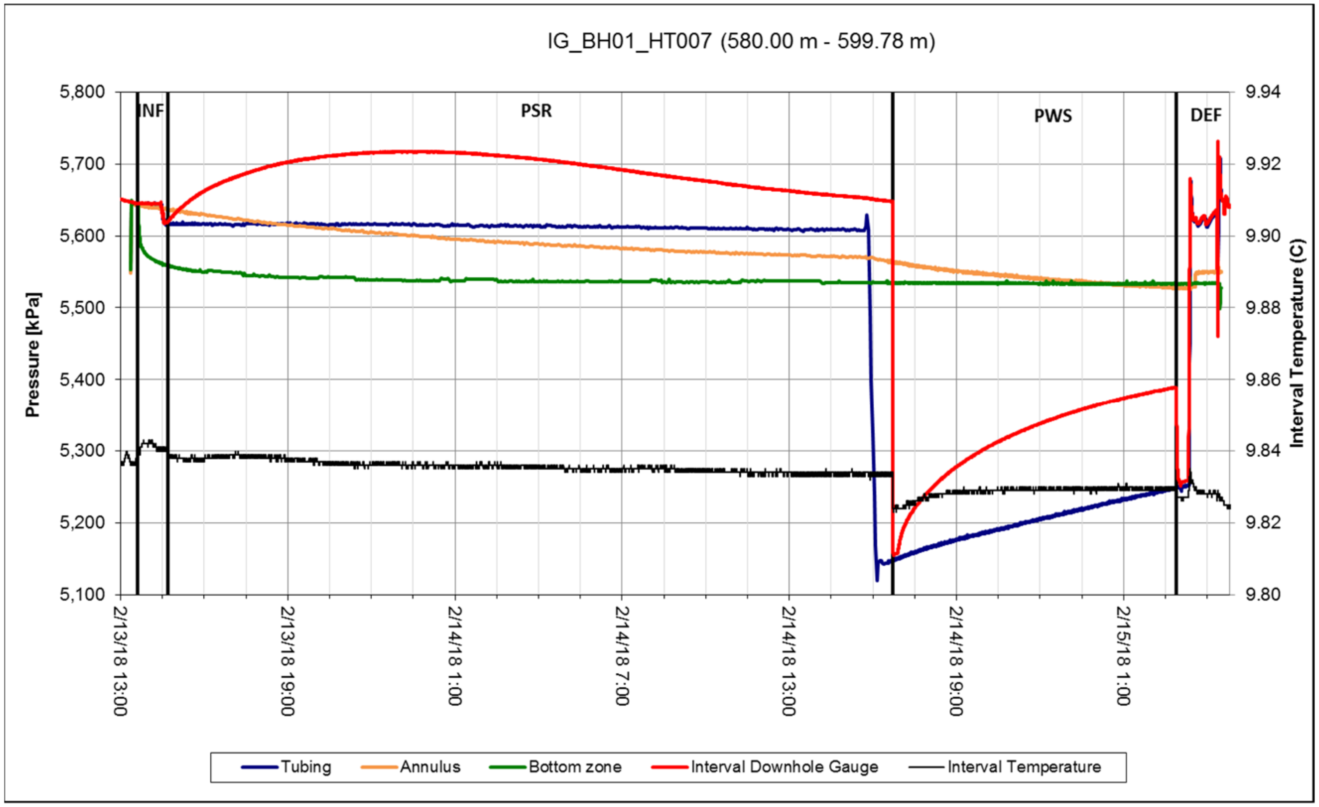
GOLDER

Project #: 1671632

Date: May 2018

Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT007 (580.0 m – 599.8 m)	Figure C13



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT007
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m^3)	0.152
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	5556
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m^3)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m³/Pa]
INF	Variable Pressure	0.00	5651.20		3e-07
PSR	Recovery	1.68	5618.60		3e-10
dP	dP-Event	27.71	5647.90		3e-07
PWS	Pulse	27.89	5158.70	5556	3e-10
DEF	Variable Pressure	37.84	5388.70		3e-07

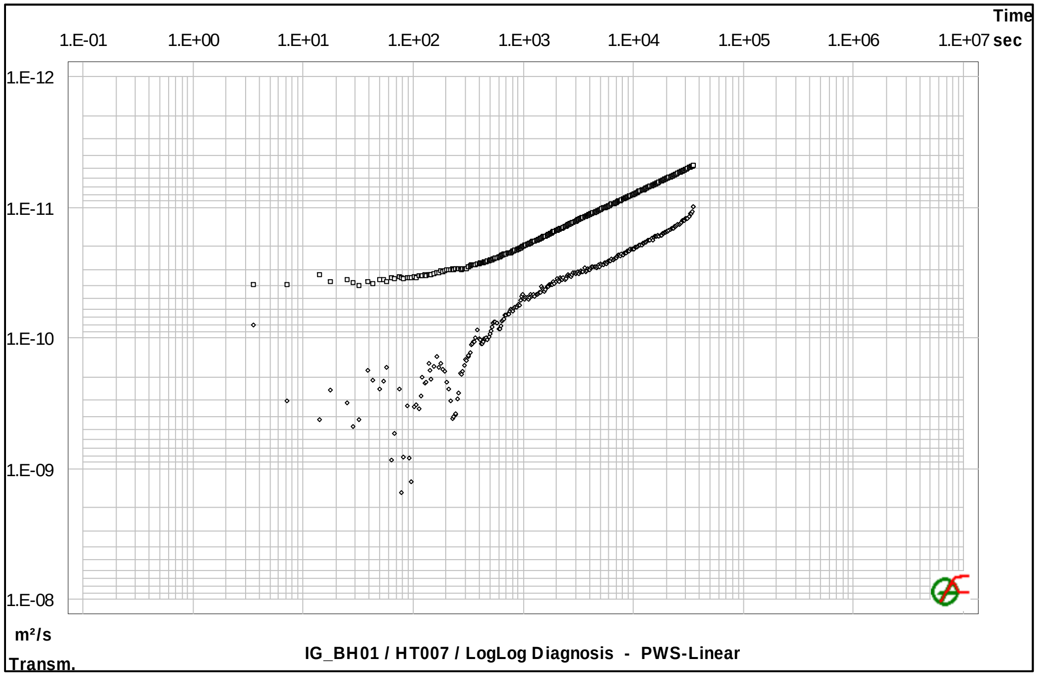
GOLDER

Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT007 (580.0 m – 599.8 m)	Figure C14

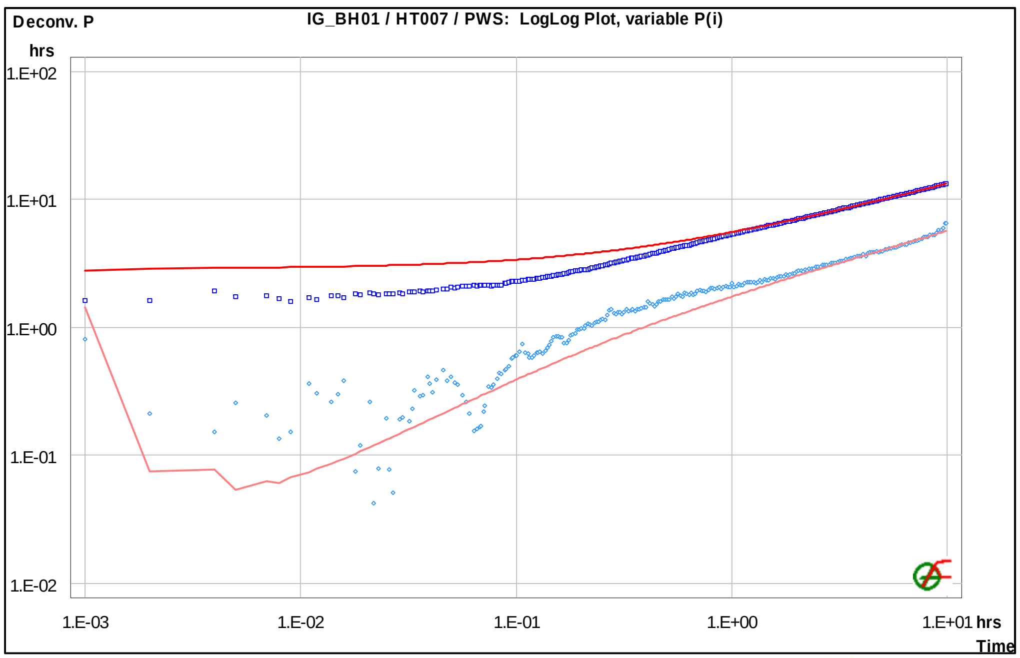
Transmissivity Normalized Plot

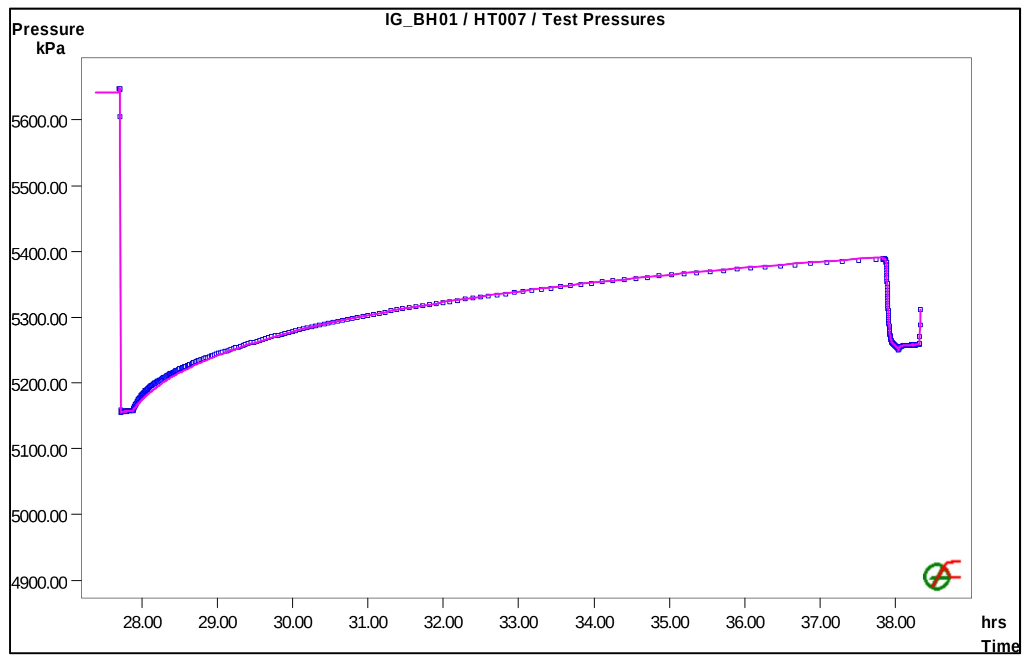


Analysis Parameters

Phase	Transmissivity [m²/s]	Skin	Radius [m]	Flow Dimension
PWS	3e-11	-3.4	--	2D

Simulation fit shown in red





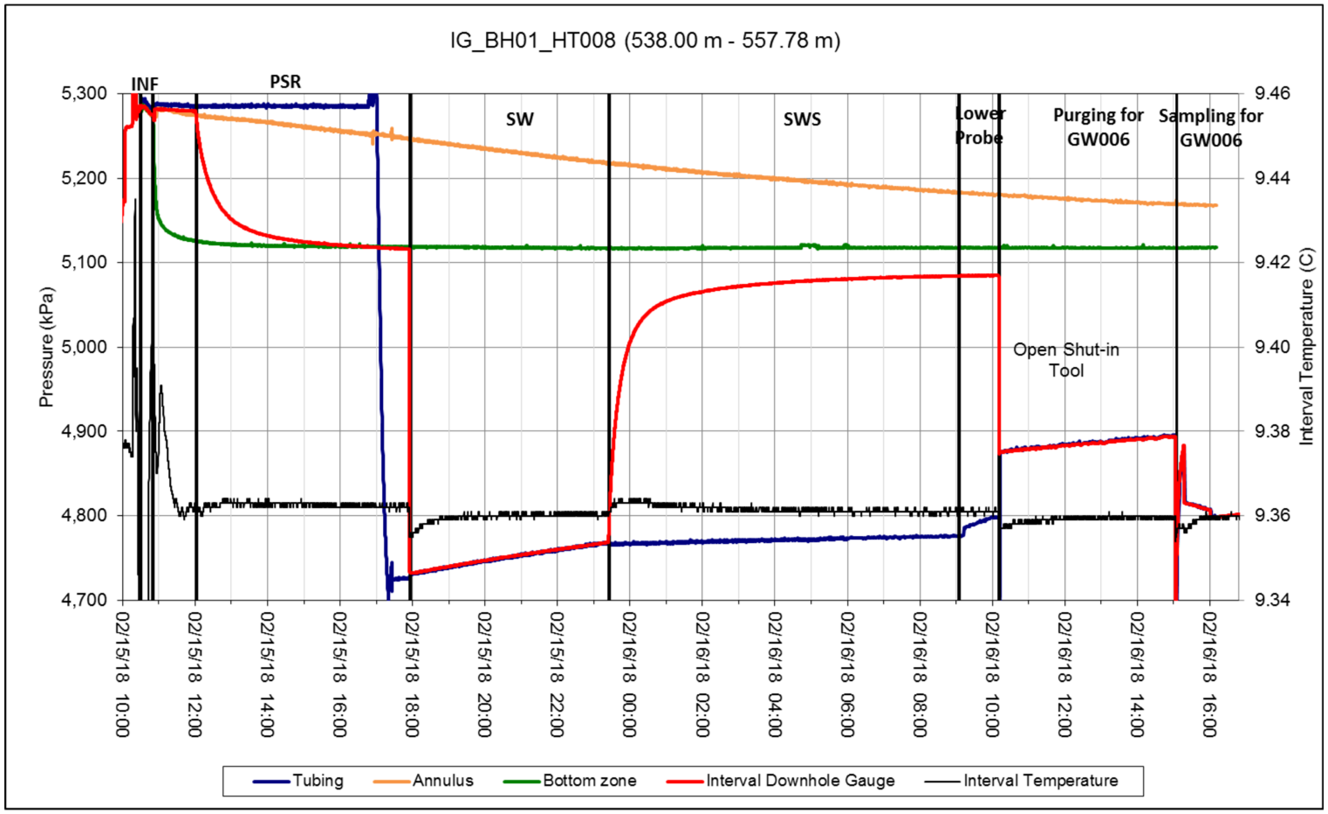
GOLDER

Project #: 1671632

Date: May 2018

Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT008 (538.0 m – 557.8 m)	Figure C15



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT008
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m^3)	0.152
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	5097
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m^3)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m^3/Pa]
INF	Variable Pressure	0.00	5285.30		2.9e-07
PSR	Recovery	1.52	5279.00		3.0e-10
dP	dP-Event	7.40	5115.90		2.9e-07
SW	Slug	7.50	4731.80	5115.9	2.9e-07
SWS	Recovery	12.90	4768.50		3.0e-10

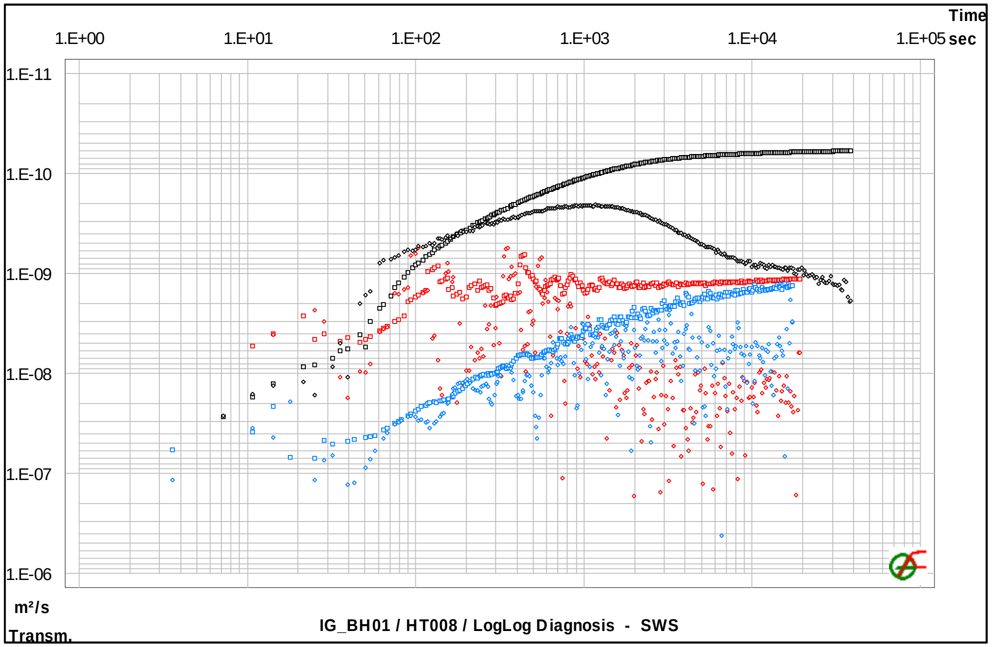
GOLDER

Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT008 (538.0 m – 557.8 m)	Figure C16

Transmissivity Normalized Plot



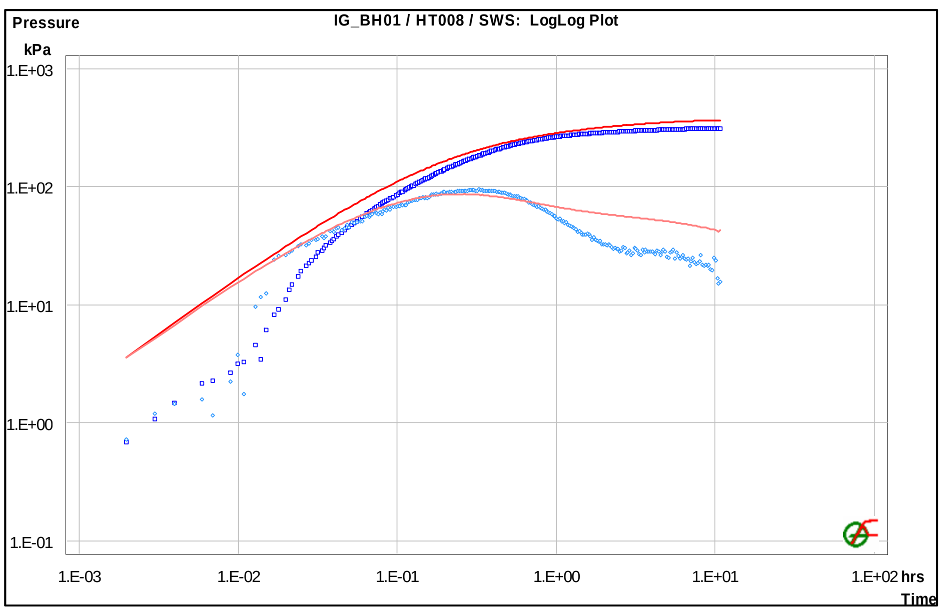
Plot Legend (Norm. Parameters in SI units)

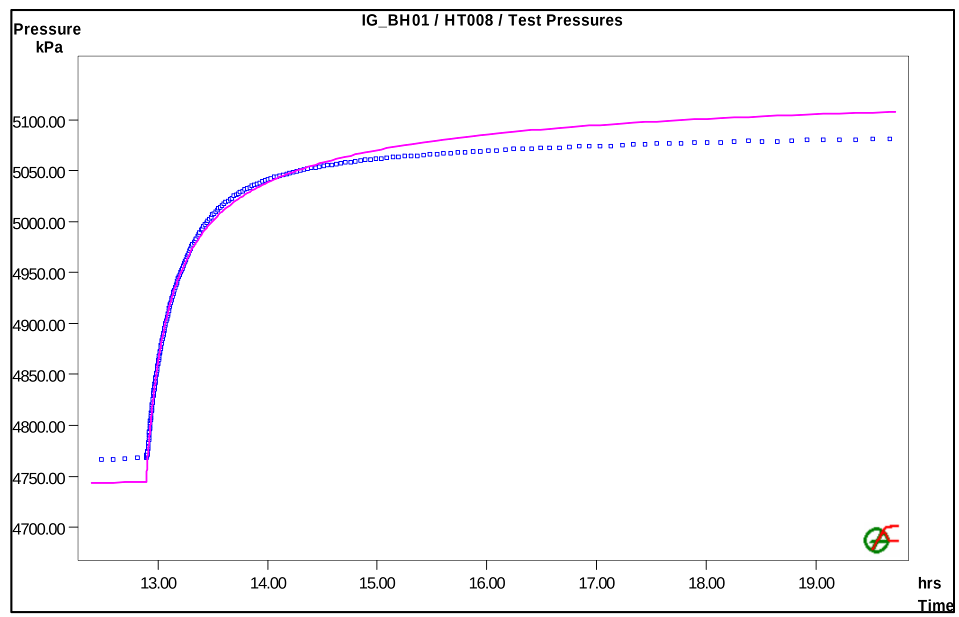
Name		Data	Derv.	Color	Norm. Param.	DCtrl.
PR		☐	☐		7.812e-08	0.100
PSR		☐	☐		3.333e-08	0.100
SW	constant	☑	☑		2.912e-07	0.100
	variable	☐	☐			
SWS		☑	☑		2.500e-08	0.100
SW2	constant	☑	☑		2.912e-07	0.100
	variable	☐	☐			

Analysis Parameters

Phase	Transmissivity [m²/s]	Skin	Radius [m]	Flow Dimension
SWS	4E-9	3.8	--	2D

Simulation fit shown in red





GOLDER

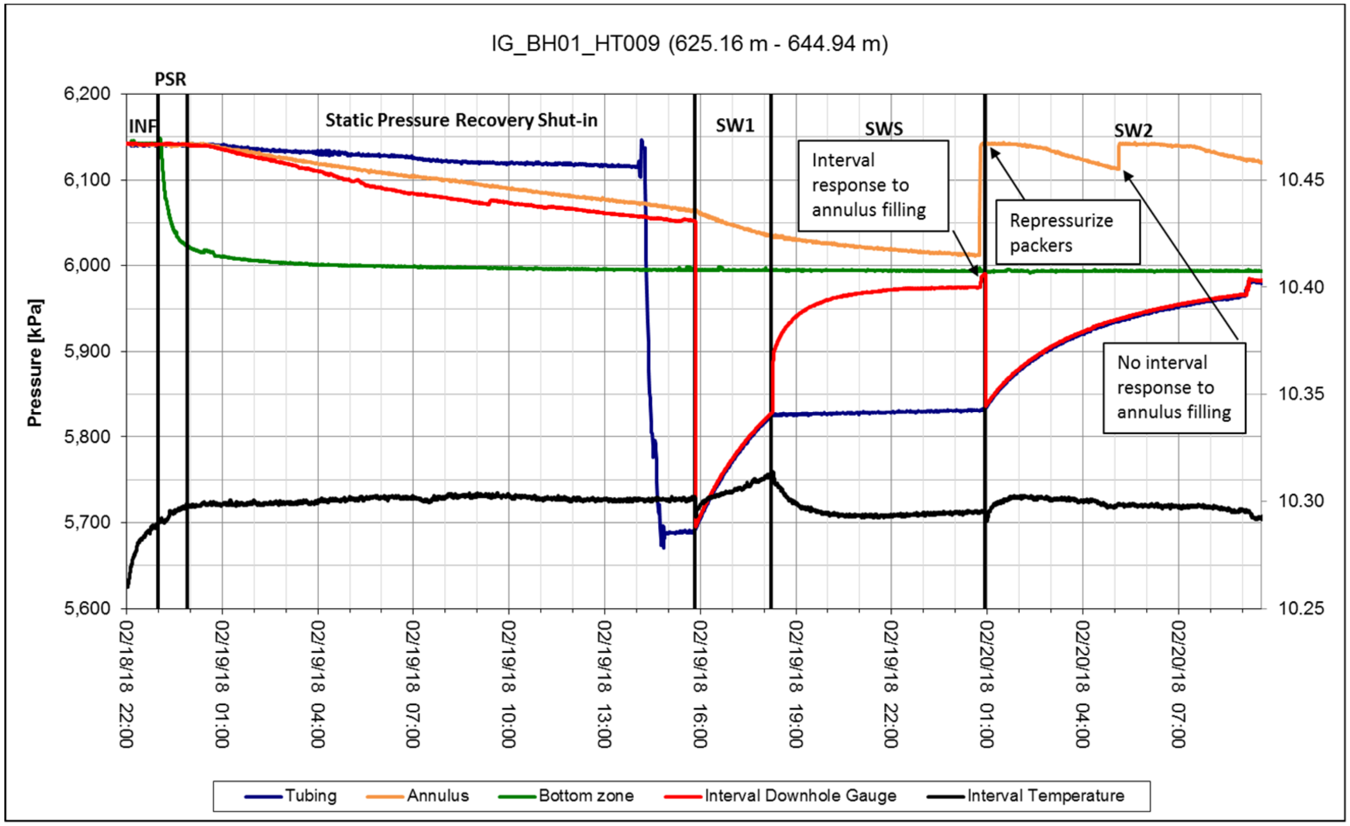
Project #: 1671632

Date: May 2018

Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01
HT009 (625.2 m – 644.9 m)

Figure C17



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT009
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m^3)	0.687
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	5979
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m^3)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m^3/Pa]
INF	Variable Pressure	0.00	6142.50		2.9e-07
PSR	Recovery	2.62	6139.40		1.5e-09
dP1	dP-Event	17.86	6050.80		2.9e-07
SW1	Slug	17.87	5697.20	6050.8	2.9e-07
SWS	Recovery	20.28	5830.70		1.5e-09
VP	Variable Pressure	26.78	5974.60		2.9e-07
dP2	dP-Event	26.96	5987.90		2.9e-07
SW2	Slug	26.97	5837.10	5979	2.9e-07

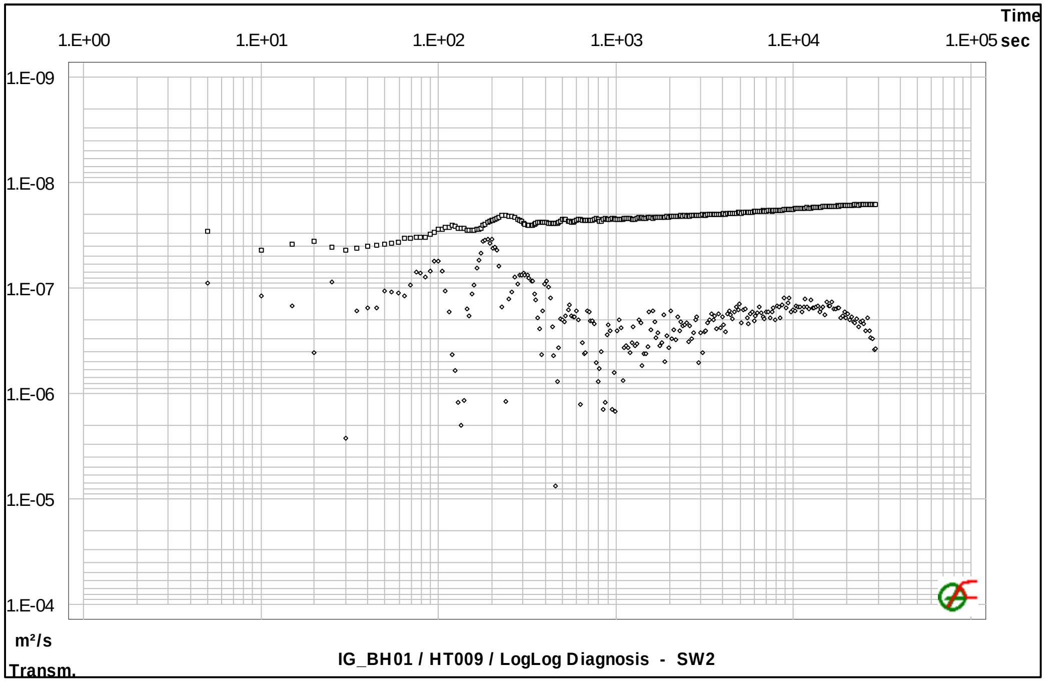
GOLDER

Project #: 1671632

Date: May 2018
Checked: MLe

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT009 (625.2 m – 644.9 m)	Figure C18

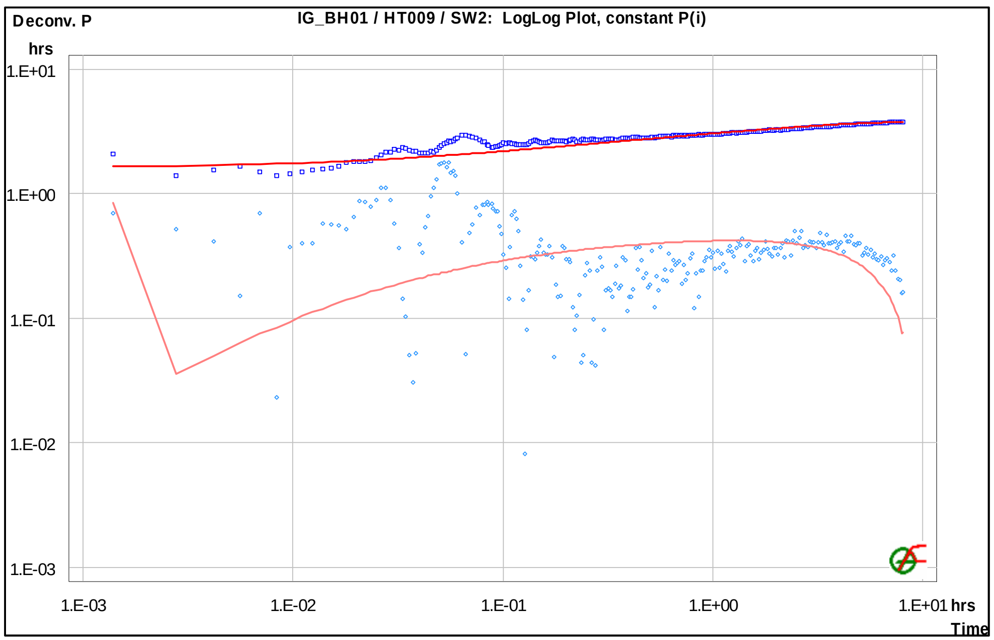
Transmissivity Normalized Plot

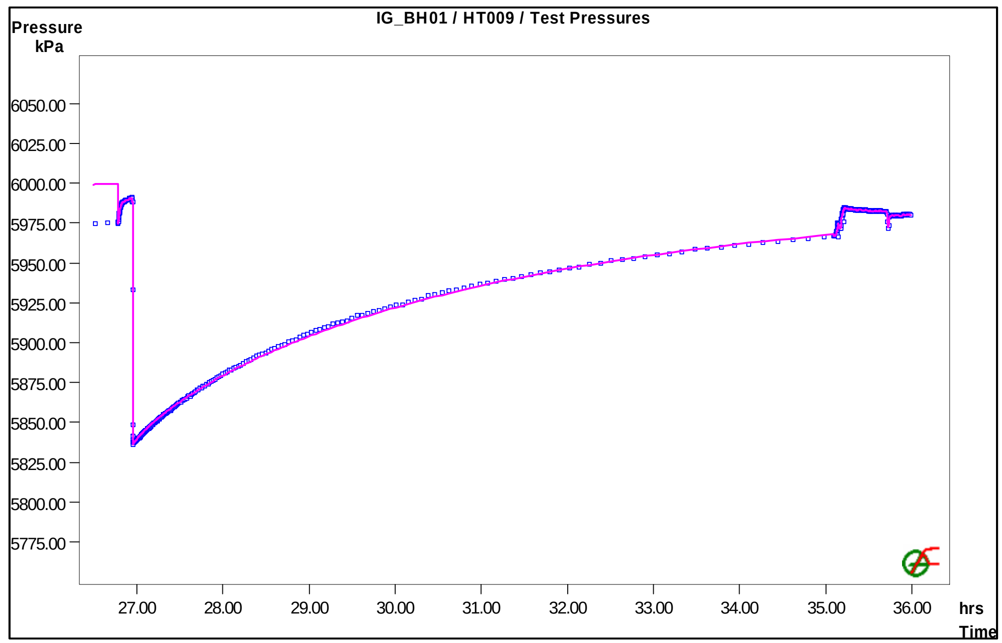


Analysis Parameters

Phase	Transmissivity [m²/s]	Skin	Radius [m]	Flow Dimension
SW2	1e-07	-2.7	--	2D

Simulation fit shown in red





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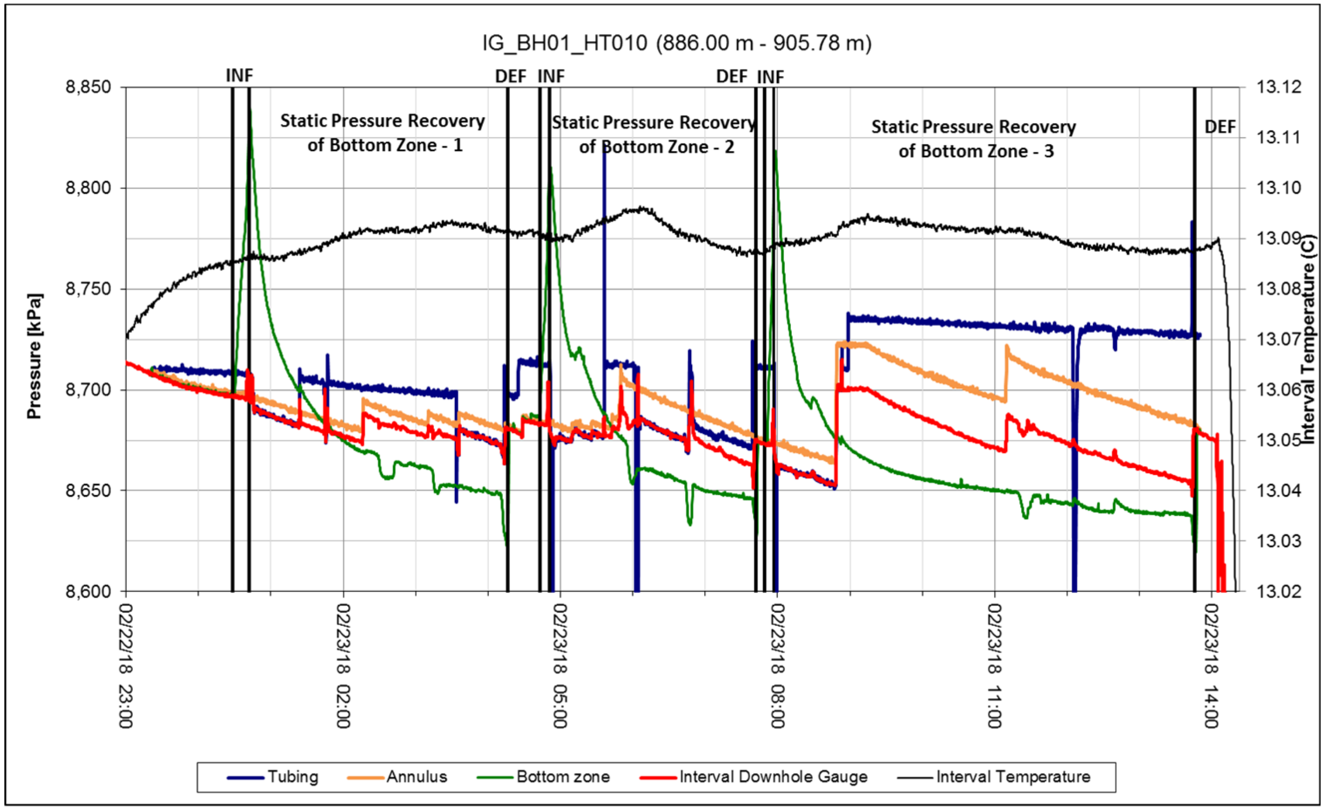


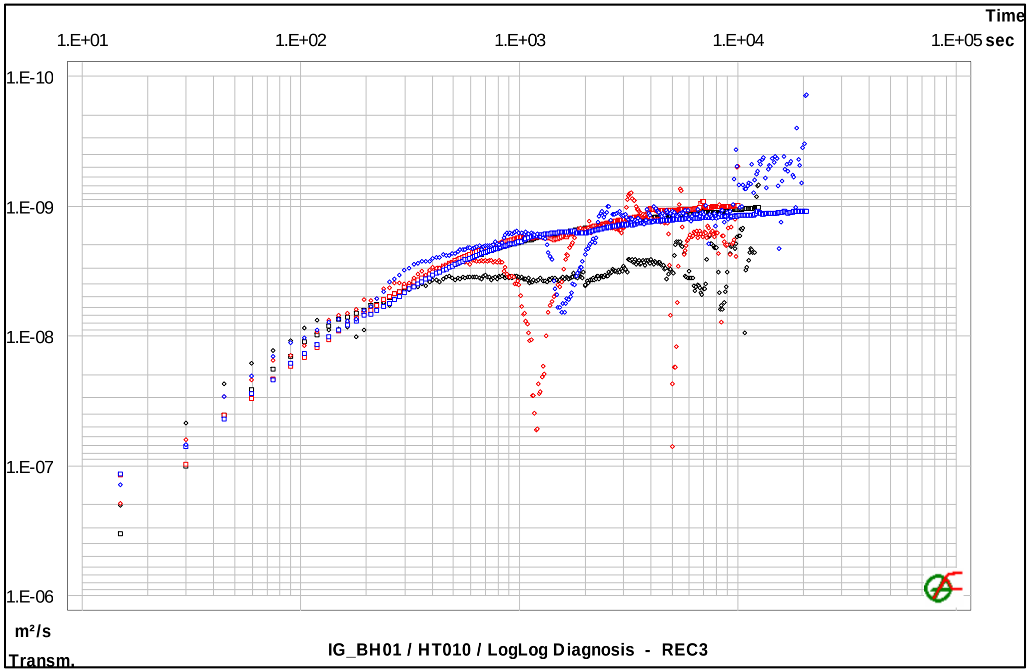
Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT010
Interval Length (m)	95.1
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m³)	0.687
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	8626
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m³)	1000
Storativity (m/Pa)	1.3e-05

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m³/Pa]
INF	Recovery	0.00	8710.30		1.4e-09
dP1	dP-Event	1.14	8697.60		1.4e-09
PIR1	Pulse	1.35	8842.10	8697.6	1.4e-09
dP2	dP-Event	4.83	8647.90		1.4e-09
PIR2	Pulse	5.50	8811.70	8687.0	1.4e-09
dP3	dP-Event	8.30	8646.10	-	1.4e-09
PIR3	Pulse	8.61	8818.30	8674.4	1.4e-09
DEF	Variable Pressure	14.37	8637.40		1.4e-09

WP6 – HYDRAULIC TESTING FOR IG_BH01 HT010 (886.0 m – 905.8 m) Bottom Zone (906.4 m – 1001.5 m)	Figure C20

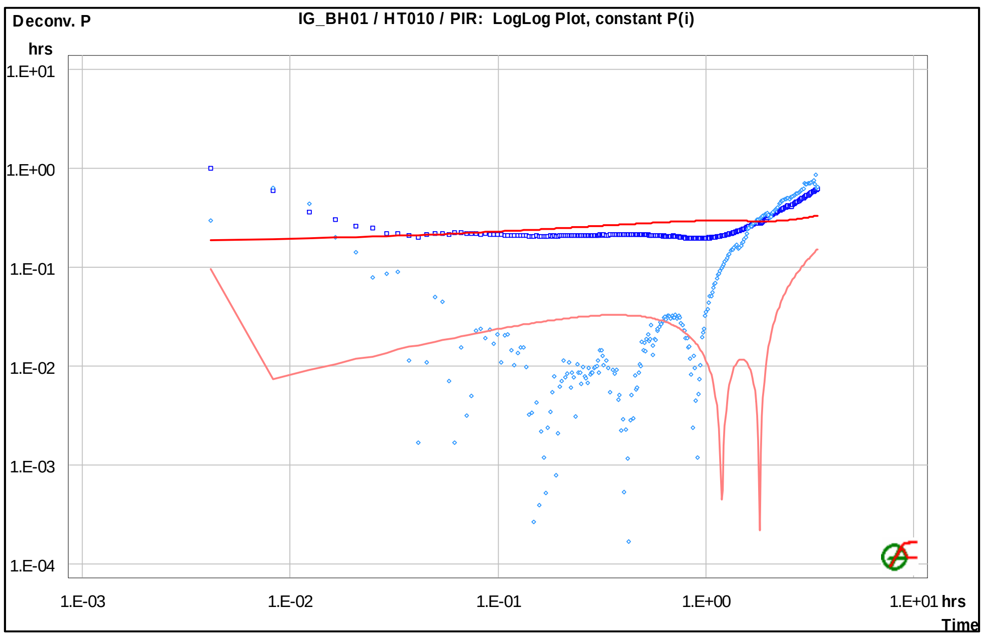
Transmissivity Normalized Plot

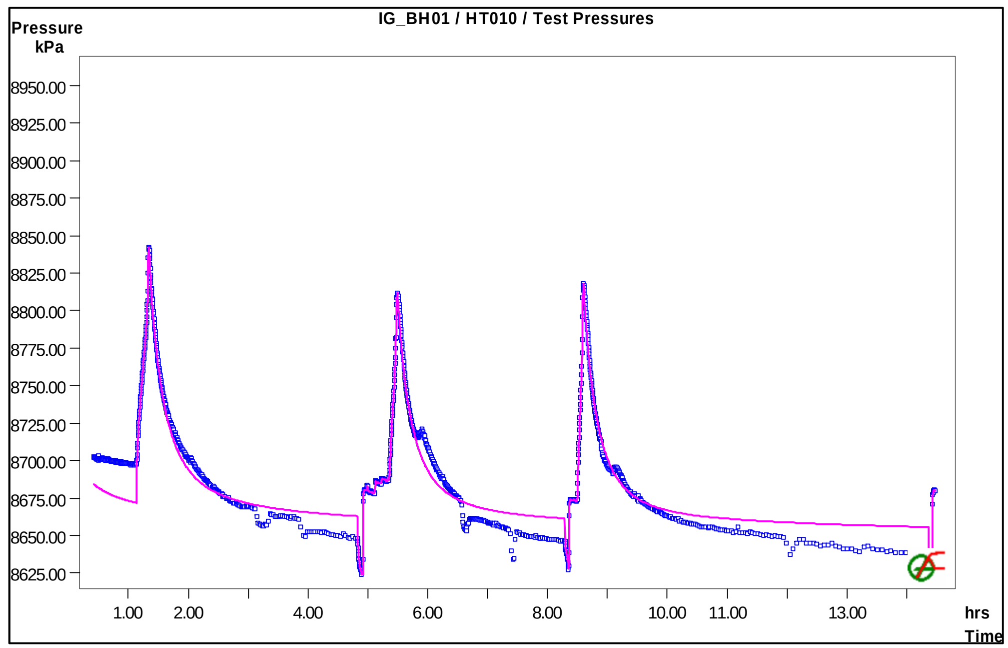


Analysis Parameters

Phase	Transmissivity [m²/s]	Skin	Radius [m]	Flow Dimension
PIR1 (black)	8e-09	0	--	2D
PIR2 (red)	8e-09	0	--	2D
PIR3 (blue)	8e-09	0	--	2D

PIR3 phase shown below. Simulation fit shown in red





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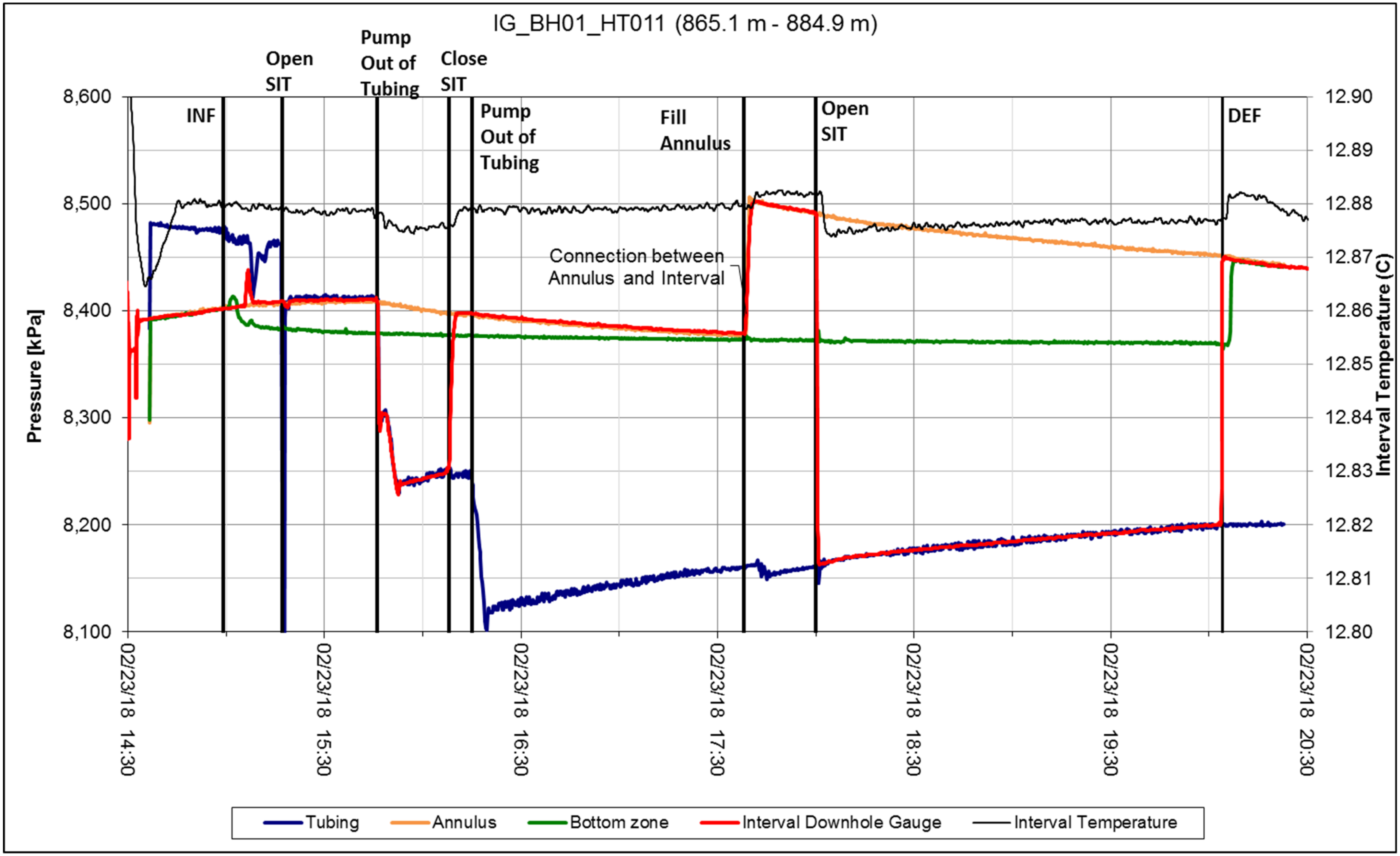
WP6 – HYDRAULIC TESTING FOR IG_BH01 HT011 (865.1 m – 884.9 m) Bottom Zone (885.8 m – 1001.5 m)	Figure C21



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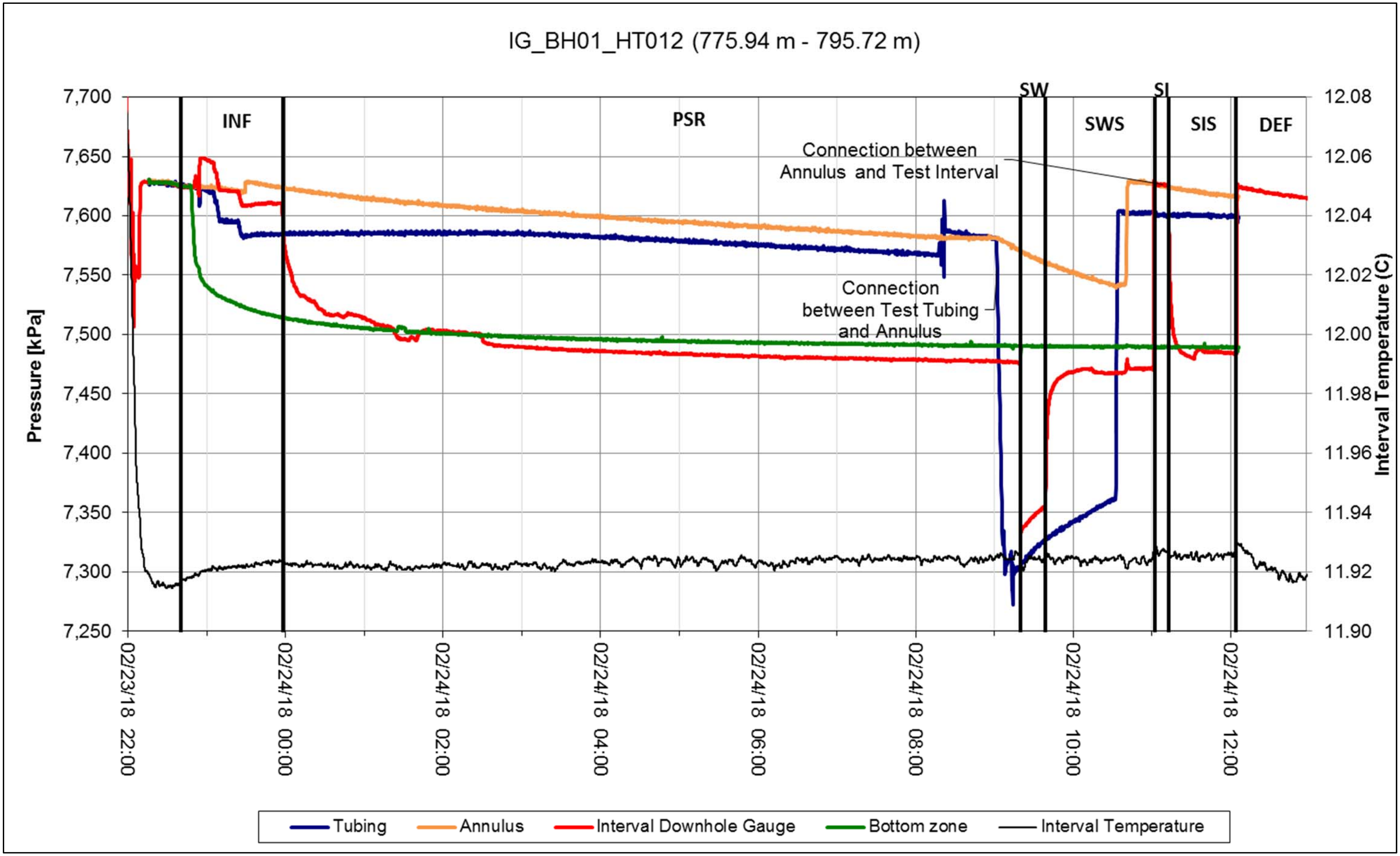
WP6 – HYDRAULIC TESTING FOR IG_BH01 HT012 (775.9 m – 795.7 m) Bottom Zone (796.6 m – 1001.5 m)	Figure C22



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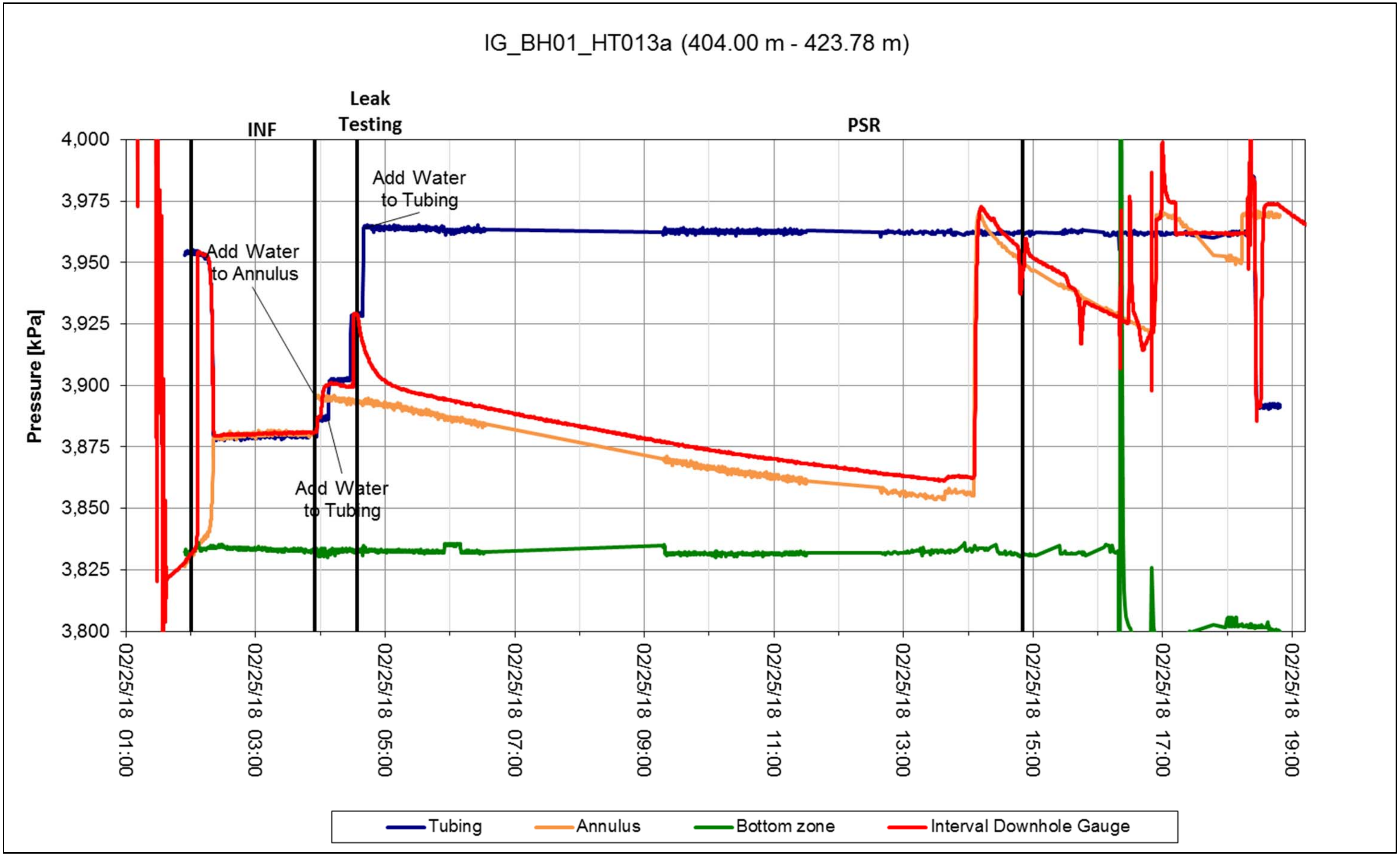
WP6 – HYDRAULIC TESTING FOR IG_BH01 HT013a (404.0 m – 423.8 m)	Figure C23



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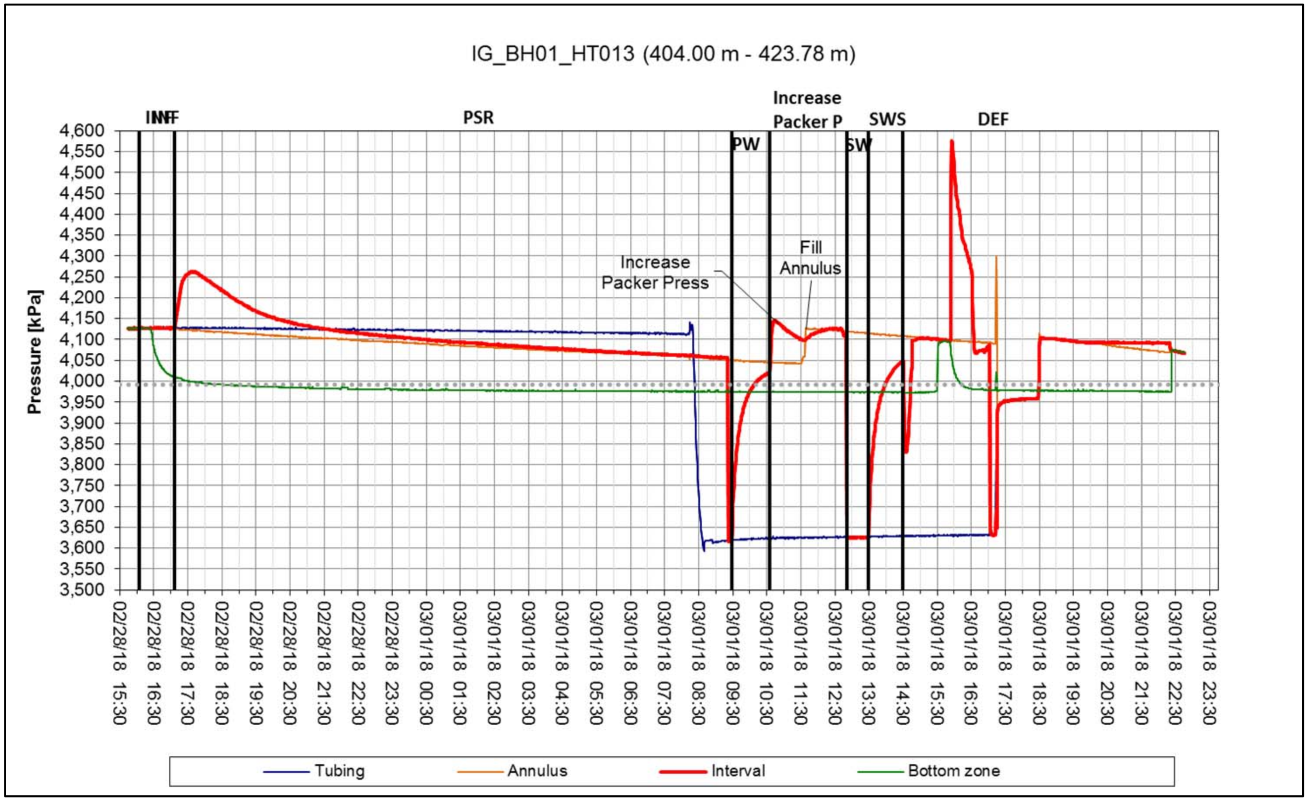
WP6 – HYDRAULIC TESTING FOR IG_BH01
HT013 (404.0 m – 423.8 m)

Figure C24



Input Parameters	
Site	Ignace
Borehole ID	IG_BH01
Test Name	HT013
Interval Length (m)	19.78
Borehole Radius (m)	0.048
Test Tubing Radius (m)	0.030
Test Volume (m³)	0.152
Test Zone Compressibility (1/Pa)	2e-09
Test Zone Static Pressure (kPa)	4056
Fluid Viscosity (Pa*s)	0.001
Fluid Density (kg/m³)	1000
Storativity (m/Pa)	2.7e-06

Test Phase Detail

Phase Name	Category	t(o) [hrs]	P(o) [kPa]	P(i) [kPa]	Wellbore Storage [m³/Pa]
INF	Recovery	0.00	4126.20		2.9e-07
PSR	Recovery	1.97	4262.40		3.0e-10
dP1	dP-Event	17.59	4055.80		2.9e-07
PW	Pulse	17.72	3617.50	4055.8	3.0e-10
VP	Variable Pressure	18.84	4021.80		2.9e-07
dP2	dP-Event	21.07	4103.20		2.9e-07
SW	Slug	21.11	3625.50	4103.2	2.9e-07
SWS	Recovery	21.74	3626.10		1.0e-10

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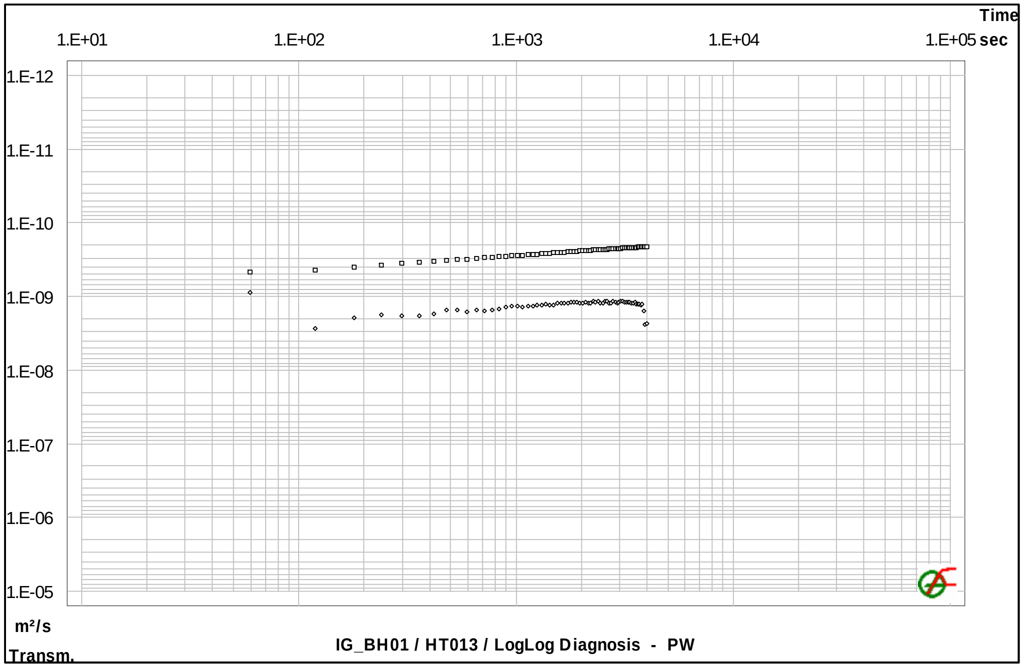
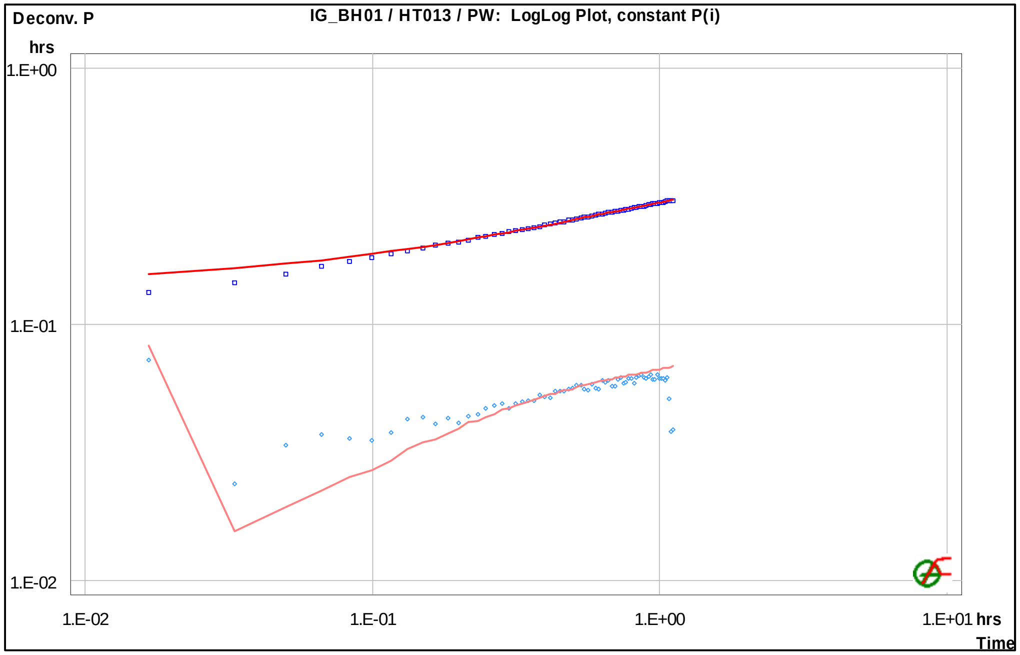
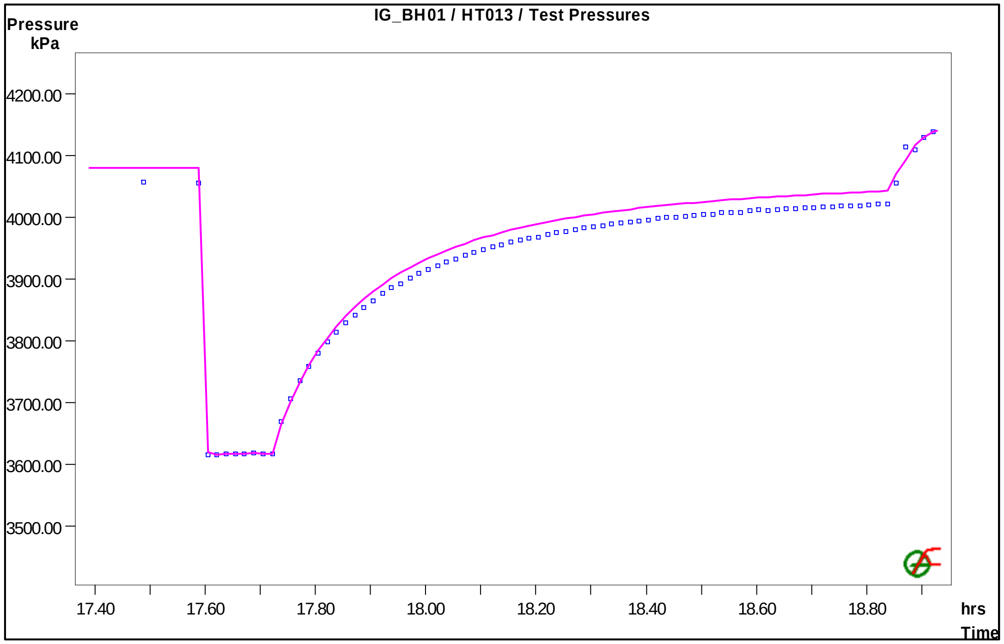
WP6 – HYDRAULIC TESTING FOR IG_BH01 HT013 (404.0 m – 423.8 m)	Figure C25



Analysis Parameters

Phase	Transmissivity [m²/s]	Skin	Radius [m]	Flow Dimension
PW	2e-09	-1	--	2D





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APPENDIX D

Legend for Hydrogeological Testing and Analyses

LEGEND – Hydrogeological Testing and Analyses

EQB	Pressure Equilibration
COM	Compliance Phase in packer system, Measurement of the Historic Flow phase
DAS	Data acquisition system
DEF	Deflation of packer
HI	Constant head injection
HIR	Pressure recovery after constant head injection
HIS	Pressure recovery after constant head injection - shut in
HW	Constant head withdrawal
HWR	Pressure recovery after constant head withdrawal
HWS	Pressure recovery after constant head withdrawal - shut in
INF	Packer inflation
PI	Pulse injection
PIS	Pulse injection recovery – shut in
PSR	Static pressure recovery - shut in
PW	Pulse withdrawal
PWS	Pressure recovery after pulse withdrawal – shut in
RI	Constant rate injection
RIR	Pressure recovery after constant rate injection
RIS	Pressure recovery after constant rate injection - shut in
RW	Constant rate withdrawal
RWR	Pressure recovery after constant rate withdrawal
RWS	Pressure recovery after constant rate withdrawal - shut in
SAM	Sampling
SI	Slug injection
SIS	Pressure recovery after slug injection - shut in
SW	Slug withdrawal
SWS	Pressure recovery after slug withdrawal - shut in

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