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PROTOTYPE REPOSITORY

Tracer dilution tests during operation phase, test campaign 3

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May 2010

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Key words: Äspö HRL, Prototype Repository, groundwater flow, fracture, hydraulic tests, tracer dilution test.

Abstract

The Prototype Repository project is focused on testing and demonstrating the function of the SKB deep repository system.

The third tracer dilution campaign during the Prototype Repository operation period was performed in January 2010. The purpose was to estimate the groundwater flows and hydraulic gradients in the boreholes vicinity and will function as a reference for comparison with results from modeling and prior assumptions.

The test campaign consisted of tracer dilution tests in 13 different borehole sections. Each test consisted of approximately 15-55 min tracer injection time and about 1-3 days dilution test time depending on the transmissivity of the test section. The data interpretation also included estimates of the local hydraulic gradients in the vicinity of the borehole sections.

Sammanfattning

Huvudsyftet med Prototypförvaret är att testa och demonstrera funktionen av en del av SKB:s djupförvarssystem.

Den tredje utspädningskampanjen i Prototypförvarets driftperiod genomfördes i januari 2010. Syftet var att mäta grundvattenflöden och hydrauliska gradienter i hålens omgivning och dessa värden kommer att fungera som fullskaliga referenser vid modellering och antaganden om flödesfördelningen i berget.

I testkampanjen mättes 13 testsektioner med utspädningsmetoden. Varje test genomfördes så att ett spårämne injicerades under en period av ca 15-55 minuter med en påföljande provtagningsperiod av sektionsvatten under ungefär 1-3 dygn. Utvärderingen inkluderade också en uppskattning av den lokala hydrauliska gradienten intill borrhålet.

Executive summary

The Prototype Repository project is focused on testing and demonstrating the function of the SKB deep repository system. Activities aimed at contributing to development and testing of the practical, engineering measures required to rationally perform the steps of a deposition sequence are also included in the project but are also part of other projects. This report describes the third tracer dilution test campaign during the operation period of the Prototype Repository, after the closing of the Prototype Repository tunnel. The purpose was to estimate groundwater flow and will function as a full scale reference for comparison with results from modeling and prior assumptions.
The test campaign consisted of tracer dilution tests in 13 different sections. Each test consisted of approximately 15-55 min tracer injection time, depending on the volume of the injected test section, followed by a 1–3 days dilution time, during which water sampling from the test section was performed. Two of the sections were sampled longer than 3 days in order to get a better result.
The dilution method is based on a tracer being injected into the test section with a constant flow rate during simultaneous circulation/mixing until a homogeneous tracer concentration is reached in the system. When groundwater flows through the section the tracer will be diluted. The groundwater flow is calculated as a function of the decreasing tracer concentration with time as shown in the equation below as well as in *Figure 1*.

$$\ln(c/c_0) = -(Q_{bh}/V) \cdot \Delta t$$

By plotting $\ln(c/c_0)$ versus Δt, and by knowing the borehole volume V, Q_{bh} may then be obtained from the slope of the straight line. If c_0 is constant it is sufficient to use $\ln c$ in the plot instead of $\ln(c/c_0)$, cf. *Figure 1*.

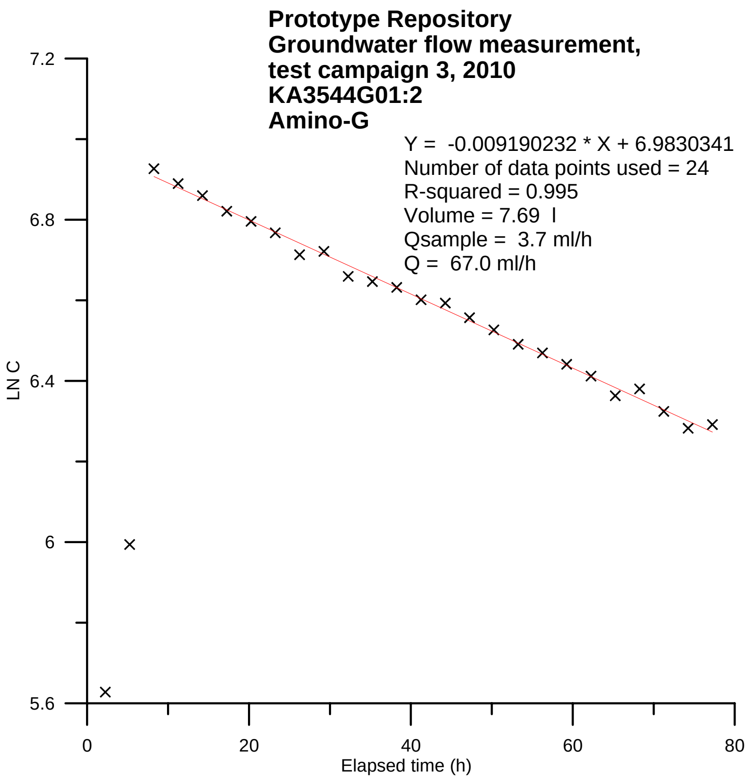

***Figure 1** Example of a tracer dilution test diagram*

Apart from the period between 2004-11-01 and 2004-12-06, the Prototype Repository tunnel has been drained. Generally speaking, the pressure in the vicinity of the tunnel has decreased since the construction of the tunnel which is likely to lead to a decreasing hydraulic gradient. In April 2007 construction of the nearby located TASS-tunnel started resulting in large disturbances in the pressure distribution around the Prototype Repository.

There were no major pressure disturbances observed during the tests. It seems however, that the dilution test in section *KA3539G:2* affect the pressures in *KA3542G01:5*, the three upper sections in *KA3554G01* and *KG0048A01:1*, indicating that these sections may be hydraulically connected. Hydraulic connection can also be observed between *KA3542G01:3* and boreholes *KA3544G01, KA3550G01* and *KA3546G01* which all are affected by the test in *KA3542G01:3.*

The magnitude of flow is governed by the local transmissivity of the borehole section and the hydraulic gradient. Prevailing flow rates in Prototype Repository vary between 1.1-68 ml/h, excluding sections believed to suffer from packer system leakage. Between test campaigns 1 and 2 an average flow decrease of about 50% was seen for the non-leaking sections. The lower flow was consistent with the expectations since the general pressure conditions in the surrounding rock had decreased in time. Between campaign 2 and 3 most of the sections still displayed decreasing flows up to 93%. Two of the supposed non-leaking sections however had an increased flow since test campaign 2, but the changes overall are rather small. The construction work (mining and grouting) of the nearby located TASS tunnel has most probably significantly affected the flow rates around the Prototype Repository.

Two sections (*KA3550G01:2* and *KA3544G01:*2) with suspected packer leakage were also measured and the leakage was confirmed. The sections *KA3539G:2* and *KA3546G01:2* were also discovered to have some kind of short-cut or leakage since the pressures in all sections were very similar and strongly correlated to each other. The flow in the rock could not be estimated from these sections since the determined values represent leakage rather than flow through fractures intersecting the sections. Sections *KA3552G01:2, KA3574G01:3, KA3566G01:2* and *KA3566G02:2* were not tested. When the sections were connected and opened no water could be circulated through the section, probably due to clogged connecting hoses to the sections.

Estimated local gradients vary between 0.03 and 43 m/m for the 9 non-leaking sections. The four leaking sections exhibit large values, as expected.

Table 1. Results from tracer dilution tests in the Prototype Repository, a comparison between test campaigns 1, 2 and 3. Values within brackets are from leaking sections, hence judged to be non-representative of the rock.

Test section	$Q_{natural}$, camp. 1 (ml/h)	$Q_{natural}$ camp. 2 (ml/h)	$Q_{natural}$ camp. 3 (ml/h)	Flow change campaign 2 to 3 (%)	Accuracy camp. 3 ± (ml/h) [2]		Comments
KA3539G:2	56	43	(44)	1	3.2	3.5	Packer system leakage
KA3542G01:3	220	38	9.7	-74	2.5	1.5	Extended test duration
KA3542G02:2	9.0	5.9	18	200	2.1	2.5	
KA3544G01:2	(380)	(180)	(67)	-63	0.1	1.5	Packer system leakage
KA3546G01:2	(15) [1]	8.2	(57)	600	6.4	1.0	Packer system leakage
KA3548A01:3	90	60	68	14	7.5	2.0	
KA3550G01:2	(260)	(260)	(47)	-82	3.0	2.5	Packer system leakage, Extended test duration

Test section	$Q_{natural}$, camp. 1 (ml/h)	$Q_{natural}$ camp. 2 (ml/h)	$Q_{natural}$ camp. 3 (ml/h)	Flow change campaign 2 to 3 (%)	Accuracy camp. 3 ± (ml/h) [2)]		Comments
KA3552G01:2	12	4.6	-		0.0		Not measured
KA3554G01:2	66	23	13	-46	0.1	5.0	
KA3554G02:4	8.4	6.4	7.2	13	0.0	1.2	
KA3563G:4	14	0.4	1.3	-230	0.1	0.5	
KA3566G01:2	19	11	-		0.0		Not measured
KA3566G02:2	3.1	-	-		0.0		Not measured
KA3572G01:2	6.0	2.0	1.1	-43	0.1	0.3	
KA3574G01:3	3.8	1.6	-		0.0		Not measured
KG0021A01:3	56	45	2.0	-95	0.3	0.4	
KG0048A01:3	7.8	4.2	8.6	106	1.1	0.3	

[1)] Valve leakage during the dilution of campaign 1.
[2)] The uncertainty of the calculated flow constitutes of two parts. In the first column the uncertainty due to the volume approximation is described. The second column reports the uncertainty contributed by the fortuitous aspect of the graph fitting, which is the base for the flow rate calculations. The uncertainties can be considered independent and may be added together.

Table 2. Results of tracer dilution tests in the Prototype Repository, a comparison between hydraulic gradients calculated during campaign 1, 2 and 3. Values within brackets are from leaking sections, hence judged to be non-representative of the rock.

Test section	I Gradient camp. 1 (m/m)	I Gradient camp. 2 (m/m)	I Gradient camp. 3 (m/m)	Decrease (%)	Comments
KA3539G:2	0.1	0.1	(0.04)	22	Packer system leakage
KA3542G01:3	13	1.8	0.14	96	Extended test duration
KA3542G02:2	19	23	43	-97	
KA3544G01:2	95	(45)	(17)	83	Packer system leakage
KA3546G01:2	25[1)]	16	(95)	-280	Packer system leakage
KA3548A01:3	1.5	1.3	1.4	24	
KA3550G01:2	110	(110)	(20)	81	Packer system leakage, Extended test duration
KA3552G01:2	2.7	10			Not measured
KA3554G01:2	0.2	0.1	0.052	81	
KA3554G02:4	1.3	1.1	1.0	14	
KA3563G:4	0.2	0.01	0.048	90	
KA3566G01:2	270	62			Not measured
KA3566G02:2	0.7	-			Not measured
KA3572G01:2	3.1	1.0	0.60	81	
KA3574G01:3	19	7.7			Not measured
KG0021A01:3	0.1	0.1	0.03	96	
KG0048A01:3	0.2	0.1	0.42	-11	

1) Valve leakage during the dilution of campaign 1.

Contents

1 Background

1.1 Äspö Hard Rock Laboratory

In order to prepare for siting and licensing of a spent fuel repository, SKB has constructed an underground research laboratory. In the autumn of 1990, SKB began the construction of Äspö Hard Rock Laboratory, Äspö HRL, near Oskarshamn in the south-eastern part of Sweden. A 3.6 km long tunnel was excavated in crystalline rock down to a depth of approximately 460 m. The laboratory was completed in 1995 and research concerning the disposal of nuclear waste in crystalline rock has been carried out since then.

1.2 Prototype repository

The Äspö Hard Rock Laboratory is an essential part of the research, development and demonstration work performed by SKB in preparation for construction and operation of the deep repository for spent fuel. Within the scope of the SKB program for RD&D 1995, SKB has decided to carry out a project with the designation “Prototype Repository Test”. The aim of the project is to test important components in the SKB deep repository system in full scale and in a realistic environment.

The Prototype Repository Test is focused on testing and demonstrating the function of the SKB deep repository system. Activities aimed at contributing to the development and testing of the practical, engineering measures required to rationally perform the steps of a deposition sequence are also included. However, efforts in this direction are limited, since these matters are addressed in the Demonstration of Repository Technology project and to some extent in the Backfill and Plug Test.

1.2.1 General objectives

The Prototype Repository should simulate as many aspects as possible of a real repository, regarding for example geometry, materials and rock environment. The Prototype Repository is a demonstration of the integrated function of the repository components. Results will be compared with models and assumptions tested for their validity.

The major objectives for the Prototype Repository are

- To test and demonstrate the integrated function of the repository components under realistic conditions in full scale and to compare results with models and assumptions.
- To develop, test and demonstrate appropriate engineering standards and quality assurance methods.
- To simulate appropriate parts of the repository design and construction process.

The objective for the operation phase program is to monitor processes and properties in the buffer material, backfill and near-field rock mass.

2 Objective

The objective of the tracer dilution tests during test campaign 3 is to measure the groundwater flow through 17 borehole sections in the Prototype Repository during natural conditions. The results will be compared to results from similar tests performed during drained conditions in October-November 2004 (Gröhn et al., 2005) and in November-December 2006 (Gokall-Norman and Andersson, 2007). The measurements will function as a full scale reference for comparison with results from modeling and prior assumptions.

3 Scope

Tracer dilution tests were performed in 13 borehole sections in the Prototype Repository tunnel, four of the boreholes could not be tested due to equipment failures in the sections cf. *Table 3-1*. The tested intervals and basic test data are listed in *Table 3-1*.

Table 3-1. List of borehole test sections included in the third tracer dilution test campaign in January and February of 2010.

Borehole	Section	Test start	Test stop
KA3539G:2	15.85 – 17.6	2010-01-14 12:47	2010-01-15 09:50
KA3542G01:3	18.6 – 20.3	2010-01-13 13:22	2010-01-14 12:43
KA3542G02:2	25.6 – 27.2	2010-01-21 11:34	2010-01-22 07:38
KA3544G01:2	8.9 – 10.65	2010-01-22 07:49	2010-01-25 15:45
KA3546G01:2	6.75 – 8.3	2010-01-20 10:26	2010-01-21 11:12
KA3548A01:3	8.8 – 10.75	2010-01-18 15:47	2010-01-19 12:50
KA3550G01:2	5.2 – 7.3	2010-01-28 09:53	2010-02-01 15:40
KA3552G01:2[1)]	4.35 - 6.05	-	-
KA3554G01:2	22.6 – 24.15	2010-01-26 16:04	2010-01-27 13:35
KA3554G02:4	10.5 – 12.2	2010-01-12 12:35	2010-01-13 12:59
KA3563G:4	1.5 – 3	2010-01-25 15:40	2010-01-26 15:39
KA3566G01:2[1)]	20- 21.5	-	-
KA3566G02:2 [1)]	16 – 18	-	-
KA3572G01:2	2.7 – 5.3	2010-01-15 10:00	2010-01-18 15:25
KA3574G01:3[1)]	1.8 – 4.1	-	-
KG0021A01:3	35 – 36	2010-01-27 13:49	2010-01-28 09:45
KG0048A01:3	32.8 – 33.8	2010-01-19 12:58	2010-01-20 10:18

[1)] Section not tested due to problems in the circulation connections.

4 Equipment

4.1 Description of equipment

The 17 characterization boreholes in the Prototype Repository involved in the dilution tests are instrumented with 1-4 inflatable packers, isolating 1-5 borehole sections each (Rhén et al., 2001). All isolated borehole sections are connected, via polyamide tubes, to pressure transducers placed in the G-tunnel. The transducers are connected to the HMS-system at Äspö HRL by means of data loggers (Datascan). The sections used for tracer dilution tests are equipped with two additional polyamide tubes with an inner diameter of 4 mm. These are used for injection, sampling and circulation of tracer solution in the borehole section. The borehole sections are also equipped with volume reducers (dummies) made of polyamide.

A schematic drawing of the dilution test equipment used in the Prototype Repository is shown in *Figure 4-1*. The basic idea is to have an internal circulation in the borehole section. The circulation makes it possible to obtain a homogeneous tracer concentration in the borehole section and to sample the tracer concentration outside the borehole in order to monitor the dilution rate with time.

Circulation is controlled by a pump with variable speed (A) and measured by a flow meter (B). Tracer injections are made with a HPLC plunger pump (C) and sampling is made by continuously extracting a small volume of water from the system through a flow controller (constant leak) to a fractional sampler (D). Pictures of the equipment are shown in *Figure 4-2*.

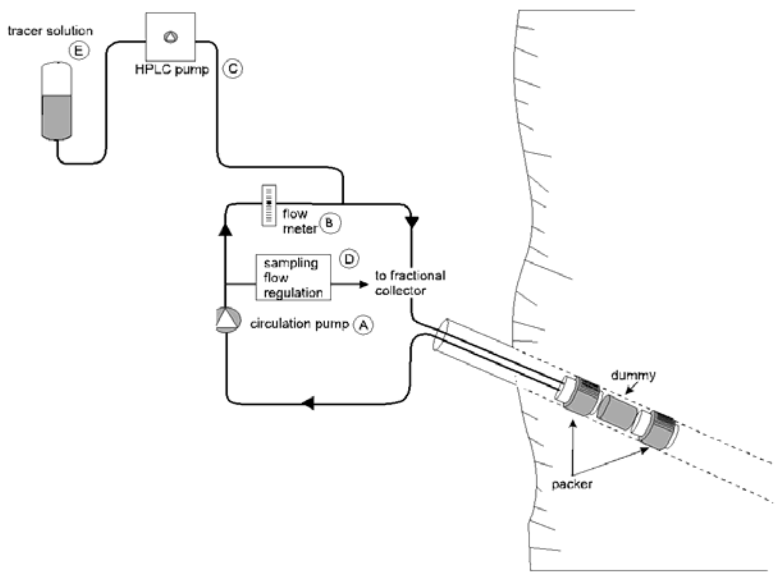

Figure 4-1. *Schematic drawing of the tracer injection/sampling system used in the Prototype Repository.*

Figure 4-2. *Equipment from the dilution test: flow controller and fractional sampler (upper picture), circulation- and injection pump (middle) and the circulation board with flow meter and manometer (lower picture).*

4.2 Tracers used

The tracers used were two fluorescent dye tracers, Uranine (Sodium Fluorescein) from Merck (purum quality) and Amino G Acid from Aldrich (techn. quality). These tracers have been used extensively in the TRUE-1, TRUE Block Scale and TRUE Continuation tracer and dilution tests (Andersson et al., 2002, 2004). The tracers have been found to be conservative (non-reactive) in Äspö bedrock conditions.

5 Execution

5.1 Preparations

The preparations included functionality checks of the equipment. The test equipment was serviced and checked at the Geosigma engineering workshop in Uppsala, just prior to the test campaign. It was also important to check that no other activities which may cause pressure disturbances occurred in the neighborhood of the test area.

Protocols were prepared for tracer injection and sampling. Tracer stock solutions were prepared at the Geosigma laboratory in Uppsala.

5.2 Performance of the dilution tests

The test campaign involved 17 different borehole sections, identical to the ones in campaign 1 and 2, performed in October-November 2004 (Gröhn et al., 2005) and November-December 2006 (Gokall-Norman and Andersson, 2007). Based on values of transmissivity (Rhén and Forsmark., 2001; Forsmark, 2007 and 2008) and borehole volumes (see *Appendix 3)* as well as results from dilution tests campaign 1 and 2, the duration for each test was estimated to about 24 hours. Some of the low-transmissive fractures had the test duration increased to approximately 72 hours. For exact dates and times of each test, see *Table 3-1*.

Four of the sections intended for testing could not be measured due to problems with the connections preventing circulation of the sections. Results are therefore only presented from 13 sections in this report.

The dilution method is based on a tracer being injected into the section with a constant flow rate during simultaneous circulation/mixing, until a homogeneous tracer concentration is reached in the system. For the Uranine tracer, this was achieved by injecting a 50 ppm tracer solution during a time period equivalent to the time it takes to circulate one section volume. During the tracer injection, the sampling flow rate is the same as the injection flow rate in order to avoid any pressure changes in the test section. The injection to circulation rate was set to 1/100 implying that the start concentration in the borehole should be about 0.5 ppm for the Uranine tracer. When using the Amino-G tracer, the concentration of the injected solution was 100 ppm aiming at a start concentration in the test section of 1.0 ppm. The higher start concentration of Amino-G solution is used to avoid background noise in the analyzing process.

When groundwater flows through the section the tracer will be diluted. The groundwater flow is calculated as a function of the decreasing tracer concentration with time, cf. *Chapter 5.4*.

As a complement, pressure was monitored (Äspö Hydro Monitoring System) in each of the tested boreholes in order to investigate any potential interferences or pressure disturbances during the performed dilution tests.

Table 5-1 summarises the test set-ups including calculated transmissivities and volumes from previous investigations (Rhén and Forsmark., 2001), (Forsmark T., 2007 and 2008). In a few cases, no new tests have been conducted since campaign 1 and in those cases the same value was used in campaign 2 and 3 as well. Locations of the boreholes in the Prototype Repository are shown in *Figure 5-1* in both vertical and plan view.

Table 5-1. Data on test sections used in the Prototype Repository tracer dilution tests.

Bh section	Secup	Seclow	T (campaign 1) (m^2/s)	T (campaign 2) (m^2/s)	T (campaign 3) (m^2/s)*	$V_{section +tubing}$ (dm^3)	Comments
KA3539G:2	15.85	17.6	1.0E-06	7.2E-07	1.80E-06	7.66	
KA3542G01:3	18.6	20.3	3.1E-08	3.8E-08	1.30E-07	7.68	
KA3542G02:2	25.6	27.2	8.7E-10	4.6E-10	7.50E-10	7.49	
KA3544G01:2	8.9	10.65	7.4E-09	7.4E-09	7.40E-09	7.69	Packer system leakage
KA3546G01:2	6.75	8.3	1.1E-09	9.6E-10	1.10E-09	6.83	
KA3548A01:3	8.8	10.75	1.1E-07	8.6E-08	9.20E-08	8.29	
KA3550G01:2	5.2	7.3	4.4E-09	4.4E-09	4.40E-09	9.05	Packer system leakage
KA3552G01:2	4.35	6.05	8.1E-09	8.0E-10	8.20E-10	7.36	Not measured
KA3554G01:2	22.6	24.15	4.9E-07	4.4E-07	4.40E-07	7.19	
KA3554G02:4	10.5	12.2	1.2E-08	1.1E-08	1.30E-08	7.60	
KA3563G:4	1.5	3	1.7E-07	5.1E-08	5.10E-08	3.78	
KA3566G01:2	20	21.5	1.3E-10	3.3E-10	3.30E-10	4.08	Not measured
KA3566G02:2	16	18	8.7E-09	8.7E-09	8.70E-09	4.15	Packer system leakage, Not measured
KA3572G01:2	2.7	5.3	3.5E-09	3.5E-09	3.50E-09	3.99	
KA3574G01:3	1.8	4.1	3.7E-10	3.7E-10	3.70E-10	4.09	Not measured
KG0021A01:3	35	36	8.0E-07	5.7E-07	1.20E-07	2.52	
KG0048A01:3	32.8	33.8	8.0E-08	7.4E-08	3.80E-08	2.47	

* From estimated transmissivity for test sections in Rhén I., Forsmark T., 2001, Forsmark T., 2007 and Forsmark T., 2008.

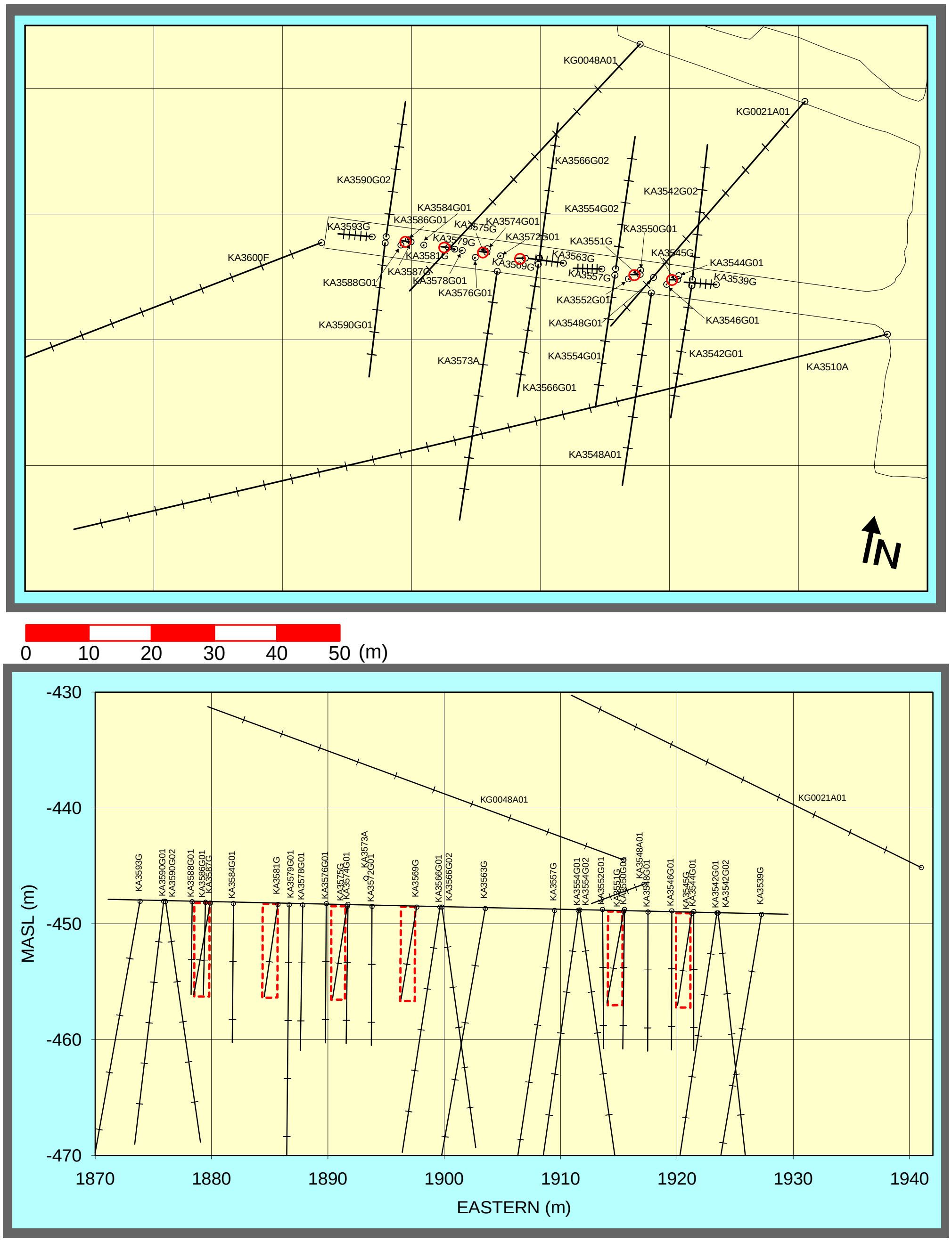

Figure 5-1. *Plan view (upper) and vertical view (below) of the location of the boreholes in the Prototype Repository. In the plan view the G-tunnel, where the equipment was set up, is shown in the upper part of the picture.*

5.3 Laboratory analyses

For practical reasons, some of the analyses were performed at Äspö Laboratory using Turner Biosystems TD-700 fluorometer. The rest of the analyses were made at the Geosigma Laboratory using a Jasco FP 777 Spectrofluorometer.

5.4 Evaluation and interpretation

5.4.1 Tracer dilution tests

Flow rates were calculated from the decay of tracer concentration versus time by means of dilution with natural unlabelled groundwater, cf. Gustafsson (2002). The so-called "dilution curves" were plotted as the natural logarithm of concentration versus time. Theoretically, a straight-line relationship exists between the natural logarithm of the relative tracer concentration (c/c_0) and time (Δt):

$$\ln (c/c_0) = -(Q/V) \cdot \Delta t \qquad (5\text{-}1)$$

where Q (m^3/s) is the groundwater flow rate and V (m^3) is the volume of the borehole section. By plotting ln (c/c_0) versus Δt, and by knowing the borehole volume V, Q may then be obtained from the slope of the straight line. If c_0 is constant it is sufficient to use ln c in the plot.

The sampling procedure with a constant flow, Q_{sample}, of 3-4 ml/h also creates a dilution of tracer. This flow rate is therefore subtracted from the value obtained from eq. 5-1 so that the actual groundwater flow through the borehole section, Q_{bh}, is obtained from:

$$Q_{bh} = Q - Q_{sample} \qquad (5\text{-}2)$$

5.4.2 Hydraulic gradient

Hydraulic gradients are roughly estimated from Darcy´s law where the gradient *(I)* is calculated as the function of the Darcy velocity *(v)* with the conductivity *(K):*

$$I = \frac{v}{K} = \frac{Q_{bh} \cdot L_{bh}}{\alpha \cdot A \cdot T_{bh}} = \frac{Q_{bh} \cdot L_{bh}}{2 \cdot d_{bh} \cdot L_{bh} \cdot T_{bh}} \qquad (5\text{-}3)$$

where Q_{bh} is the groundwater rate through the borehole section , L_{bh} is the length of the borehole section, T_{bh} the transmissivity of the section, A the cross section area between the packers and d_{bh} the borehole diameter which for the boreholes in the Prototype Repository is 76 mm.

The contraction factor α depends on the interference of the flow field in the fracture plane locally surrounding the borehole. For a homogeneous rock with the fracture cutting the borehole axis in 90^o the contraction factor α is equal to 2 according to Gustafsson (2002). Since the rock is mostly heterogeneous and the angles in the sections are not always 90^o, the calculation of the hydraulic gradient must be considered a rough estimate.

5.4.3 Nonconformities

- Sections *KA3552G01:2, KA3574G01:3, KA3566G01:2* and *KA3566G02:2* were not tested. When the sections were connected and opened no water could be circulated through the section, probably due to clogged connecting hoses to the sections.

- After performing the first four dilution tests, a small leakage on an inlet valve was discovered. The leakage was approximately 1 drip every 5 minute and has been compensated for in the evaluations of these tests.

- Since section *KA3542G01:3* displayed scattered results and the equipment was available, the dilution measurement was restarted about 460 hours after the tracer injection. The results from the later part of the dilution provided a better data-fit although the results were similar.

6 Results and interpretation

6.1 Hydraulic conditions

During the first test campaign (Gröhn et al., 2005), the Prototype Repository tunnel was drained and the groundwater flow in each of the 17 sections therefore represented the situation with an enhanced hydraulic gradient. Apart from a short period between 2004-11-01 and 2004-12-06, the Prototype Repository tunnel has been constantly drained. Since the construction of the Prototype Repository tunnel the water pressure in the rock surrounding the tunnel has, generally speaking, decreased. It was considered likely that the ground water flow would decrease as time passed. As seen in table 6-3 the gradient decreased in almost all of the boreholes in the period between campaign 1 and 2 (Gokall-Norman and Andersson, 2007). The results from this campaign, number 3, are not as consistent as the previous one. Some of the gradients have increased since campaign 2 while some other continued to decrease. Since test campaign 2 a new tunnel called TASS has been constructed in a direction subparallel to the Prototype Repository and only about 20 m away at the closest point, see *Figure 6-1*.. Both the mining work and the following grouting of the tunnel might have affected the hydraulic conditions in the prototype tunnel and the installed sections.

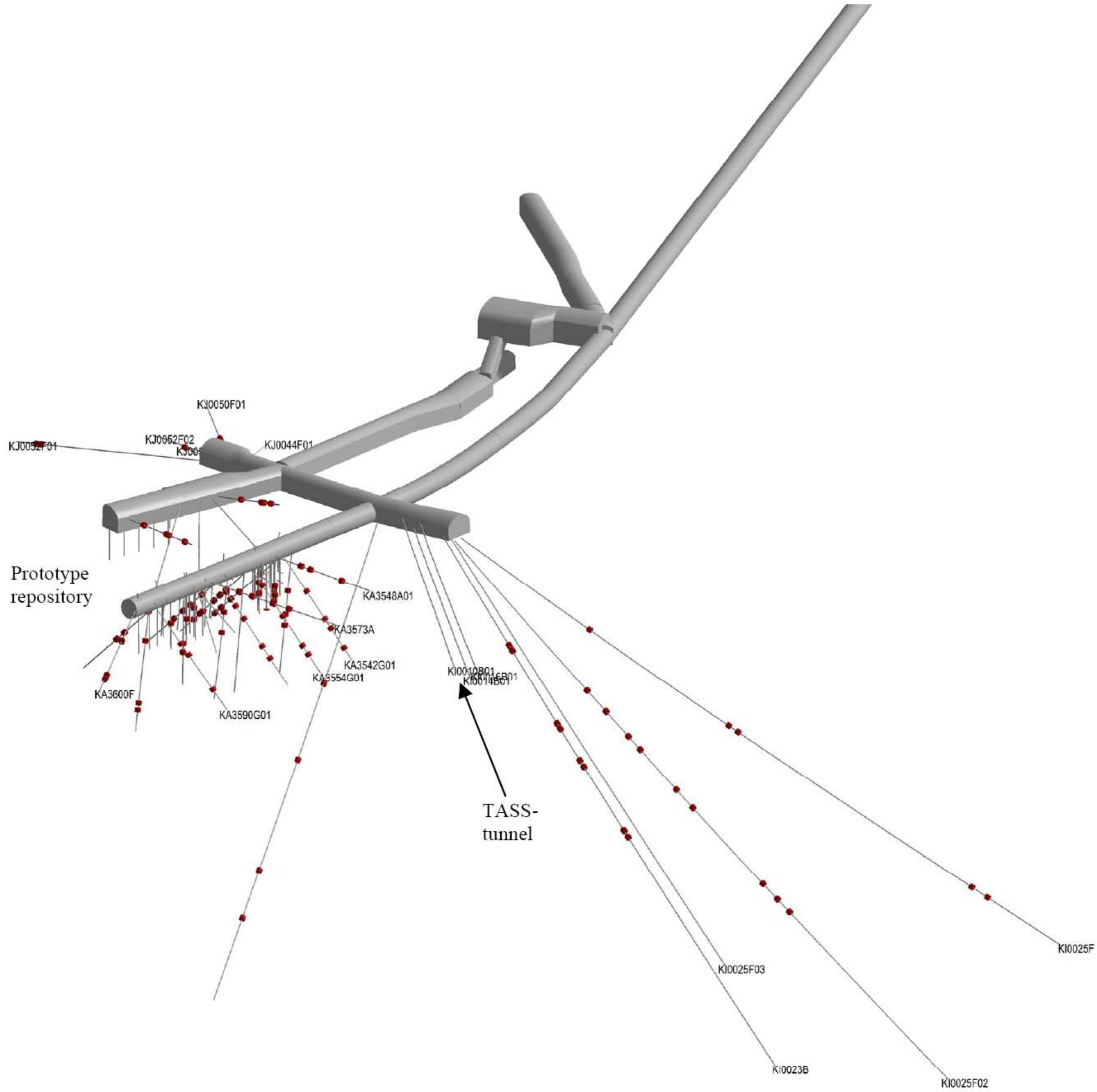

Figure 6-1. *Boreholes and location of the TASS tunnel at the 450 m level, view from south-west. Red dots show locations of borehole packers .*

In *Table 6-1* a comparison between the approximate prevailing pressure conditions in the tested borehole sections during campaign 1, 2 and 3 are presented. It is clear that sections exhibiting relatively low pressure (c. 200-500 kPa) during the first campaign have experienced an increasing pressure throughout campaign 2 and 3. Conversely, all sections with a high pressure during the first campaign, demonstrate a pressure decrease over time. Since the tunnel drains the surrounding rock the pressure in the sections during this campaign generally increases with the distance to the tunnel.

There were no major pressure disturbances observed during the tests. It seems however, cf. *Appendix 2*, that the dilution tests in section *KA3539G:2* affect the pressures in *KA3542G01:5*, the three upper sections in *KA3554G01* and *KG0048A01:1*, indicating that these sections may be hydraulically connected. Also the test in KA3542G01:3 indicate a hydraulic connection with boreholes *KA3544G01, KA3550G01* and *KA3546G01.*

Table 6-1. Approximate prevailing pressure conditions in the test sections included in the dilution tests. Comparison between campaign 2 and campaign 3.

Test section	Pressure campaign 1 (kPa)	Pressure campaign 2 (kPa)	Pressure campaign 3 (kPa)	Pressure change (kPa)	Comments
KA3539G:2	2010	1450	1560	110	Packer system leakage
KA3542G01:3	3270	2435	2020	-415	
KA3542G02:2	2320	1845	1810	-35	
KA3544G01:2	200	660	1220	560	Packer system leakage
KA3546G01:2	380	750	1240	490	Packer system leakage
KA3548A01:3	3360	2490	2030	-460	
KA3550G01:2	200	670	1250	580	Packer system leakage
KA3552G01:2	460	790	1300	510	Not measured
KA3554G01:2	3630	2730	2010	-720	
KA3554G02:4	1940	1320	1510	190	
KA3563G:4	340	750	1180	430	
KA3566G01:2	1770	1130	1120	-10	Not measured
KA3566G02:2	2780	-	1120		Not measured
KA3572G01:2	420	500	700	200	
KA3574G01:3	180	320	70	-250	Not measured
KG0021A01:3	3000	2270	2180	-90	
KG0048A01:3	3310	2530	2140	-390	

6.2 Dilution tests

The evaluated flow rates in the sections from the dilution tests performed during both campaign 1, 2 and 3 are presented in *Table 6-2*. In *Table 6-4* the hydraulic gradients from all three campaigns are presented and tracer injection data are listed in *Table 6-3.* The tests generally yield results that are consistent with the expectations and the data quality is fairly good. There are some circumstances regarding the tests or uncertainties concerning the calculation of the groundwater flow that need to be commented on:

In *Table 6-2* the accuracy of the calculated flow is reported. It is divided in two parts. The first column addresses the uncertainty due to volume calculations. In *Table 6-3* there is a comparison between the calculated injection concentration (based on known volumes) and analysed tracer concentration in the different sections included in the tests. The difference between these two parameters provides a measure of uncertainty of the volume calculations which in turn are directly proportional to the calculated flow rates. In the second column, the uncertainty from the graph fitting is given. Since the slope of the tracer dilution diagrams (*Appendix 1*) is the basis for the flow rate calculations and there is an aspect of subjective selection included in this process, an uncertainty has been appointed to the fitting procedure. The uncertainty is an approximation based on different choices of points to include in the graph fitting calculations. In most cases the real uncertainty due to graph fitting is expected to be smaller than reported. There is also a small uncertainty of ± 0.1 ml/h related to the measurement of the sampled volume which is subtracted as a sampling flow in eq.5-2.

In some of the tests, a higher dilution rate can be observed in the early time data. This is most probably an effect of the pressure disturbance created when attaching the dilution equipment. Early time data is therefore generally omitted in the test evaluation, cf. *Appendix 1*.

Between test campaigns 1 and 2 an average flow decrease of about 50% was seen for the non-leaking sections. The lower flow was consistent with expectations since the general pressure condition in the surrounding rock had decreased in time. Between campaigns 2 and 3 some of the sections still displayed decreasing flow up to 95% ,cf. *Table 6-2* and some has an increased flow up to about 235% but the changes overall are rather small.

Table 6-2. Results from all three tracer dilution tests in the Prototype Repository, a comparison between campaign 2 and 3 is made. Tubing is included in the specified section volume. Flow values within brackets are from leaking sections.

Test section	V (dm^3)	$Q_{natural}$, camp.1 (ml/h)	$Q_{natural}$ camp.2 (ml/h)	$Q_{natural}$ camp.3 (ml/h)	Flow change campaign 2 to 3 (%)	Accuracy camp. 3 ±(ml/h) [2)		R^2	Comments
KA3539G:2	7.7	56	43	(44)	1.4	3.2	3.5	0.96	Packer system leakage
KA3542G01:3	7.7	220	38	9.7	-74	2.6	1.5	0.95	
KA3542G02:2	7.5	9.0	5.9	17.8	200	2.1	2.5	0.85	
KA3544G01:2	7.7	(380)	(180)	(67)	-63	0.1	1.5	1.00	Packer system leakage,
KA3546G01:2	6.8	(15)[1)]	8.2	(57)	600	6.4	1.0	0.99	Packer system leakage
KA3548A01:3	8.3	90	60	68	14	7.5	2.0	0.98	
KA3550G01:2	9.1	(260)	(260)	(47)	-82	3.0	2.5	0.98	Packer system leakage,
KA3552G01:2	7.4	12	4.6	-		-			Not measured
KA3554G01:2	7.2	66	23	13	-46	0.1	5.0	0.69	
KA3554G02:4	7.6	8.4	6.4	7.2	13	0.0	1.2	0.79	
KA3563G:4	3.8	14	0.4	1.3	240	0.4	0.5	0.49	
KA3566G01:2	4.1	19	11	-		-			Not measured
KA3566G02:2	4.1	3.1	-	-		-		-	Not measured
KA3572G01:2	4.0	6.0	2.0	1.1	-43	0.1	0.3	0.96	
KA3574G01:3	4.1	3.8	1.6	-		-			Not measured
KG0021A01:3	2.5	56	45	2.0	-95	0.7	0.4	0.50	
KG0048A01:3	2.5	7.8	4.2	8.6	110	1.1	0.3	0.97	

[1)] Valve leakage during the dilution of campaign 1.
[2)] The uncertainty of the calculated flow constitutes of two parts. In the first column the uncertainty due to the volume approximation is described. The second column reports the uncertainty contributed by the fortuitous aspect of the graph fitting, which is the base for the flow rate calculations. The uncertainties can be considered independent and may be added together.

The exact length of the tubing from each section is not known. This will introduce some uncertainty in the volume calculations. Calculated volumes of the section between packers are however very accurate. A good check of the accuracy of the volume determination is to compare the theoretical concentration of tracer in the borehole section at the start of the test to the actually measured one. The data presented in *Table 6-3* shows that there is a reasonably good agreement in 10 of the sections.

Sections *KG0021A01:3* and *KG0048A01:3* have a very small volume which makes it important to have the correct tubing length thus, the volume, and consequently also the flow may be erroneously estimated.. This might also explain the difference between theoretical and measured concentrations in some of the other sections. It should be noted that in the previous dilution measurements, performed during campaigns 1 (Gröhn et al., 2005) and 2 (Gokall-Norman and Andersson, 2007) similar results were noted. This may be an indication of the effective section volume actually being larger in these borehole sections than has previously been reported. As a consequence of this the flow rate through the section may also be somewhat higher than reported in *Table 6-2*.

Table 6-3. Comparison of calculated injection concentration (based on known volumes) and analyzed tracer concentration from dilution tests in Prototype Repository.

Test section	Tracer	Calculated C_0 in test section (mg/l)	Analyzed C_0 in test section (mg/l)	Comments
KA3539G:2	Uranine	0.50	0.54	Packer system leakage
KA3542G01:3	Uranine	0.50	0.63	
KA3542G02:2	Uranine	0.50	0.56	
KA3544G01:2	Amino-G acid	1.0	1.0	Packer system leakage, extended measurement
KA3546G01:2	Uranine	0.50	0.56	Packer system leakage
KA3548A01:3	Uranine	0.50	0.56	
KA3550G01:2	Amino-G acid	1.0	0.93	Packer system leakage, extended measurement
KA3552G01:2	-	-		Not measured
KA3554G01:2	Uranine	0.50	0.50	
KA3554G02:4	Uranine	0.52	0.52	
KA3563G:4	Uranine	0.51	0.67	
KA3566G01:2	-	-		Not measured
KA3566G02:2	-	-		Not measured
KA3572G01:2	Uranine	0.50	0.54	Extended measurement
KA3574G01:3	-	-		Not measured
KG0021A01:3	Uranine	0.50	0.33	
KG0048A01:3	Uranine	0.51	0.44	

Also sections *KA3542G02:2* and *KA3563G:4* demonstrate inconsistencies between theoretical and actual tracer concentration indicating that the volumes may be wrongly estimated (see *Table 6-3*).

The uncertainty of the analyses of the tracers is ± 2% based on replication measurement made by Geosigma Laboratory. This affects the fits of the dilution graphs (logarithm of concentration versus time) in sections having very slow dilution (low flow).

Dilution graphs from all 13 measured sections are presented in *Appendix 1* with uncertainty presented as R-squared, see also *Table 6-2*. The fits are generally good, 10 of the 13 tests show R^2-values larger than 0.8, but in sections having low flow rates (approximately <10 ml/h) the uncertainty increases. It is evident that even analyses of sections with a low flow, produce good fits if the testing time is long enough, cf. *Table 6-2*. It is likely that some of the sections showing a less good fit would benefit from longer testing periods.

The measurement limit of the groundwater flow is set to 3 ml/h since the sampling of the water during the test is approximately 3-4 ml/h. This increases the uncertainty for the determination of low flow rates (<10 ml/h). Three of the sections had a flow below this limit, these sections were: *KA3563G:4, KA3572G01:2* and *KG0021A01:3.* Sections*,* *KA3544G01:2* and *KA3550G01:2* were expected to have a packer system leakage and this was confirmed during the performed tracer dilution tests. Furthermore during this campaign *KA3539G:2 and KA3546G01:2* also seemed to have a packer leakage or similar problems. Except for *KA3546G01:2* the groundwater flows were, however, not as large as in previous tests. The groundwater flow rates in these sections are still much higher than in the other sections, and also higher than would be expected for natural conditions. This indicates leakage of water to neighboring sections.

6.3 Leaking sections

No measurements at all could be completed in section *KA3552G01:2, KA3566G01:2*, *KA3566G02:2* and *KA3574G01:3* since no water could be circulated through these sections. The tubes connecting to these sections are probably clogged at some position.

In 4 of the sections dilution tests were made and a groundwater flow could be calculated but the pressures indicate leakage in-between sections in these boreholes. Since there is leakage in the measured sections, these calculated results are considered not representative for the rock.

Both *KA3550G01:2* and *KA3544G01:2* were found to be leaking to other sections in the boreholes already during test campaign 1 in 2004 hence the results considered unreliable. During this campaign these two sections also indicates leakage:

KA3539G:2

The pressures for the sections in KA3539G are all practically the same, as seen in *Figure 6-2*. The pattern for pressure changes is the same for all four sections and the response in between them are very fast which implies a possible leakage between sections. The small differences in pressure seen in the figure are most probable due to different calibrations of each channel. There is a period of unstable pressure starting in March 2007 and ending in December the same year as seen in *Figure 6-2*. Some pressure disturbances origin from the tunneling and grouting of the TASS-tunnel which was built parallel to the Prototype Repository tunnel. In October 2007 a pressure build-up test was performed in KA3539G. After these events the sections in the borehole seem have some kind of short circuit, most probable due to the TASS-tunnel which might have opened up fractures in-between sections. Consequently the flow rate and gradient calculated for this borehole are considered as not representative for the rock and hence omitted.

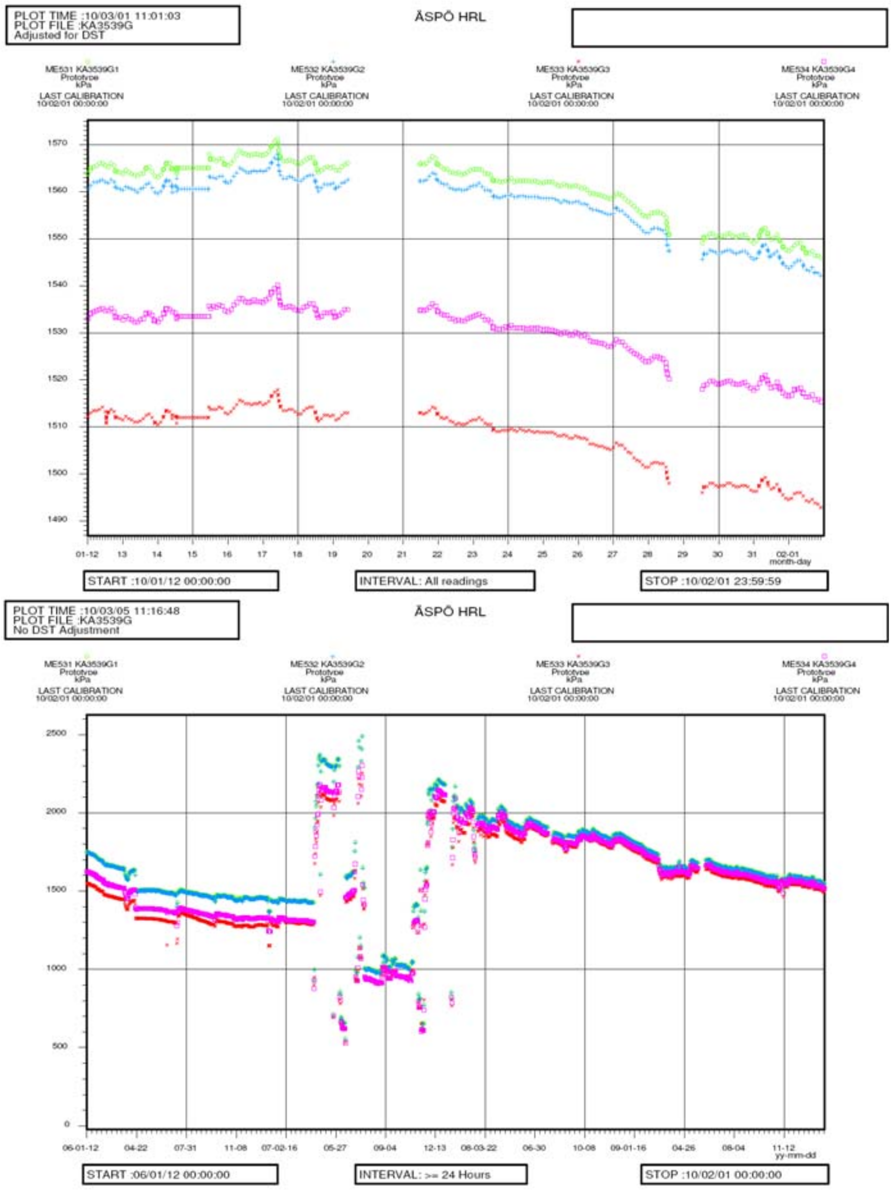

Figure 6-2. *Plot of the pressures in the sections of KA3539G during the entire period of test campaign 3 and also over a longer period of time including the transition of pressures.*

KA3546G01:2

The pressures in this borehole also have a pattern that indicates leakage in some form. As seen in *Figure 6-3* the pressure changes have the same pattern in all sections in KA3546G01 and the responses between them are very fast which implies a possible leakage between sections. The leakage could either be within the borehole caused by packer or connection failure or through some interconnecting fractures that has been opened up by activities in the surrounding rock. The lower plot in *Figure 6-3* shows that in May 2009 the pressure in section 1 increases rapidly. This event is most likely due to grouting in the TASS tunnel. Later on, in November there are some activities in the surrounding prototype boreholes that affect the pressures in all three sections.

In December 2009 the pressures then converge to practically the same level. These pressure changes are most likely induced by the activities in the TASS-tunnel, drilling and grouting, but might also depend on some mechanical errors in the packer system in the actual borehole. Consequently the flow rate and gradient calculated for this borehole are not representative for the rock and hence omitted.

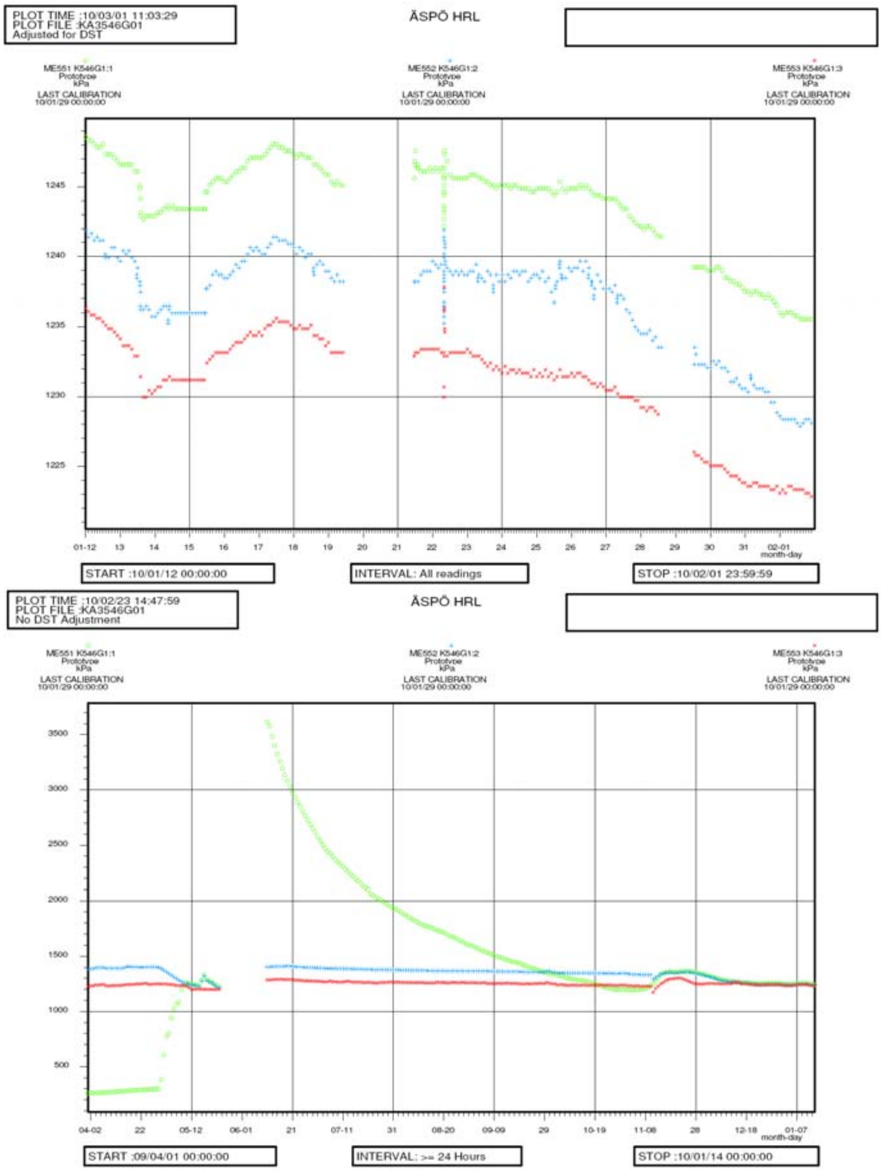

Figure 6-3. *Plot of the pressures in the sections of KA3546G01 during the entire period of test campaign 3 and also over a longer period of time including the transition of pressures*

6.4 Hydraulic gradients

The hydraulic gradients of the test sections are presented in *Table 6-4.* Note that these are rough estimates based on several assumptions, as discussed in *Chapter 5.4.2*, and should not be used as exact data. The estimated gradients for the non-leaking sections vary between 0.03 and 43 m/m for the sections. The four leaking sections results vary between 0.04 and 95 m/m and three of them exhibit large values, as expected. One section however has a surprisingly low gradient and it has decreased since earlier campaigns. The gradients are generally rather low with 9 sections having a gradient <1.5 m/m. Besides the leaking sections, only *KA3542G02:2* have a high gradient at 43 m/m.

One may expect that gradients increase towards the tunnel and thus sections having low pressures also would display high gradients. This is however not the case during campaign 3. It is not possible to see any correlations between gradient and pressures or distance to the tunnel. The exact reasons for these anomalous gradients are not known but may be a combination of uncertainties related to the determination of groundwater flow, transmissivity and the gradient itself, as discussed in *Chapter 5.4.2*.

Table 6-4. Hydraulic gradients (Eq. 5-3) from all three tracer dilution tests in the Prototype Repository, a comparison between campaign 2 and 3. Values within brackets are from leaking sections.

Test section	I Gradient (camp. 1) (m/m)	I Gradient (camp. 2) (m/m)	I Gradient (camp. 3) (m/m)	Decrease since camp. 2(%)	Comments
KA3539G:2	0.1	0.1	(0.04)	56	Packer system leakage
KA3542G01:3	13	1.8	0.14	92	
KA3542G02:2	19	23	43	-88	
KA3544G01:2	(95)	(45)	(17)	63	Packer system leakage
KA3546G01:2	(25) 1)	16	(95)	-500	Packer system leakage
KA3548A01:3	1.5	1.3	1.4	-4	
KA3550G01:2	(110)	(110)	(20)	82	Packer system leakage
KA3552G01:2	2.7	10			Not measured
KA3554G01:2	0.2	0.1	0.05	48	
KA3554G02:4	1.3	1.1	1.0	8	
KA3563G:4	0.2	0.01	0.05	-380	
KA3566G01:2	270	62			Not measured
KA3566G02:2	0.7	-			Not measured
KA3572G01:2	3.1	1.0	0.60	40	
KA3574G01:3	19	7.7			Not measured
KG0021A01:3	0.1	0.1	0.03	70	
KG0048A01:3	0.2	0.1	0.42	-320	

1) Valve leakage during the dilution of campaign 1.

6.5 Supporting data

The pressure data from each section, collected by HMS during the tests, are displayed in *Appendix 2*. In *Figure A2-1* and *A2-2*, pressure data from all sections included in the dilution test, for the duration of the entire test campaign, are presented. In these diagrams, a possible interference between sections and pressure disturbing activities may be discovered. In *Figure A2-3* through *A2-14*, pressure data for each section, at the time of each individual dilution test, are shown. There are no major pressure disturbing activities observed during the period. However, a few of the sections show pressure changes related to the tracer dilution tests. Section *KA3572G01:2* is the only section that displayed a clear pressure response on the tracer injection and sampling. The pressure drops about 100 kPa during the tracer injection and goes back to normal when the sampling is stopped. This pressure drop is caused by the opening of the section for tracer injection. As mentioned earlier in section 5.4.2 the calculations of the gradients are considered as rough estimates and this pressure drop is not considered to affect the results significantly.

Figures *A2-15* through *A2-27* display the pressure of all sections in every individual borehole that was included in the dilution tests. These diagrams can be used to identify possible hydraulic connections between different sections of the same borehole. There seems to be some interference in some of the boreholes, described earlier in section 6.1. No major disturbances are seen on the pressure data even if the tracer injection in some cases causes a short pressure change in adjacent sections.

A general observation is that in most sections of low transmissivity ($T<10^{-8}$ m^2/s), there is a decreasing pressure in the beginning of the test period for each borehole. This is probably due to the opening of the section and the following tracer injection. This affects the pressure in the low transmissive sections, but not notably in the high transmissive sections. The sampling flow rate has been subtracted from the results.

7 Discussion and conclusions

The determination of flow rates using the tracer dilution method was performed under prevailing gradients and represents the groundwater flow through each of the 13 sections during natural conditions. There was no major pressure disturbance during the tests but some interference between the sections was observed. The dilution test in *KA3539G:2* affect the pressures in *KA3542G01:5*, the three upper sections in *KA3554G01* and *KG0048A01:1*, indicating that these sections may be hydraulically connected. The dilution test in *KA3542G01:3* gives pressure changes in boreholes *KA3544G01, KA3550G01* and *KA3546G01* indicating hydraulic connections.

The magnitude of flow is governed by the local transmissivity of the borehole section and the hydraulic gradient. During prevailing gradient conditions, flow rates in the Prototype Repository vary by between 1.1 and 68 ml/h (c.f. *Table 6-2*). There is a weak correlation between transmissivity and flow rate, as shown in *Figure 7-1.* This correlation was better in 2006 (*Figure 7-2*) and in 2004 (*Figure 7-3)*.

The non-leaking sections included in the test exhibit varying flow changes since the last campaign. Of the 9 sections measured, 6 have an increased flow since 2006 with a change ranging from 13 up to 235%. Since the first campaign though the flow generally still is lower in all sections but two, *KA3542G02:2* and *KG0048A01:3* which have a flow increase of 97 and 11% respectively. Presumably due to the generally lower pressure levels that are prevailing in the rock surrounding the Prototype repository tunnel compared to the conditions during test campaign 1.

The hydraulic gradients, which are derived from the groundwater flow and the borehole section transmissivities, are generally low for the non-leaking sections ranging from 0.03 up to 1.4. The exception is *KA3542G02:2* which has a gradient of 43 resulting from the low transmissivity (7.5E-10 m^2/s) and the relatively high flow (18 ml/h).

Many of the low flowing sections would presumably benefit from longer measuring times in order to get more certain estimates of flow rate.

One may expect that gradients increase towards the tunnel and thus sections having low pressures also would display high gradients. This is however not seen in the results from this campaign, no correlations between gradient and pressures or distance to the tunnel is found. The exact reasons for these anomalous gradients are not known but may be a combination of uncertainties related to the determination of groundwater flow, transmissivity and the gradient itself, as discussed in Chapter 5.4.2.

The construction of the TASS tunnel parallel to the Prototype Repository tunnel probably affects the gradients and hydraulic connections in and between most of the boreholes extensively as it works as drainage for the surrounding rock. Looking at long-term plots for the sections shows that the pressures are strongly influenced by the work in the TASS-tunnel in 2007.The pressures are generally higher after the building of the tunnel and has been dropping constantly since December 2007. A typical example is shown in *Figure 7-4* for borehole KG0048A01.

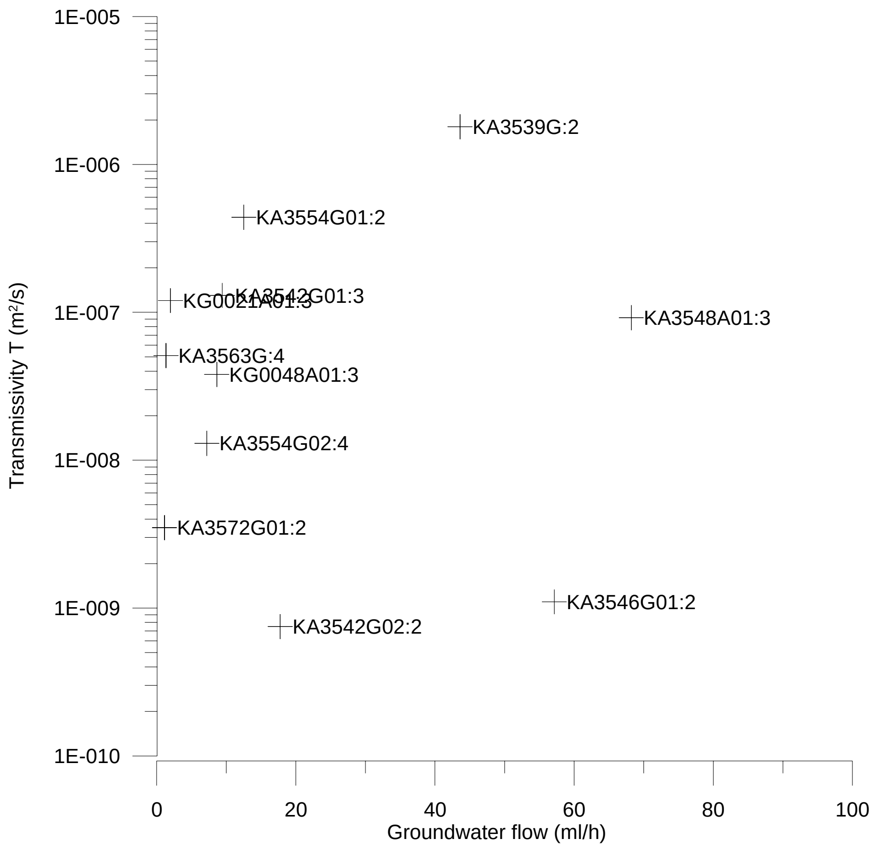

Figure 7-1. *Logarithm of transmissivity versus groundwater flow rate for the sections measured in the tracer dilution test, campaign 3 (leaking sections excluded).*

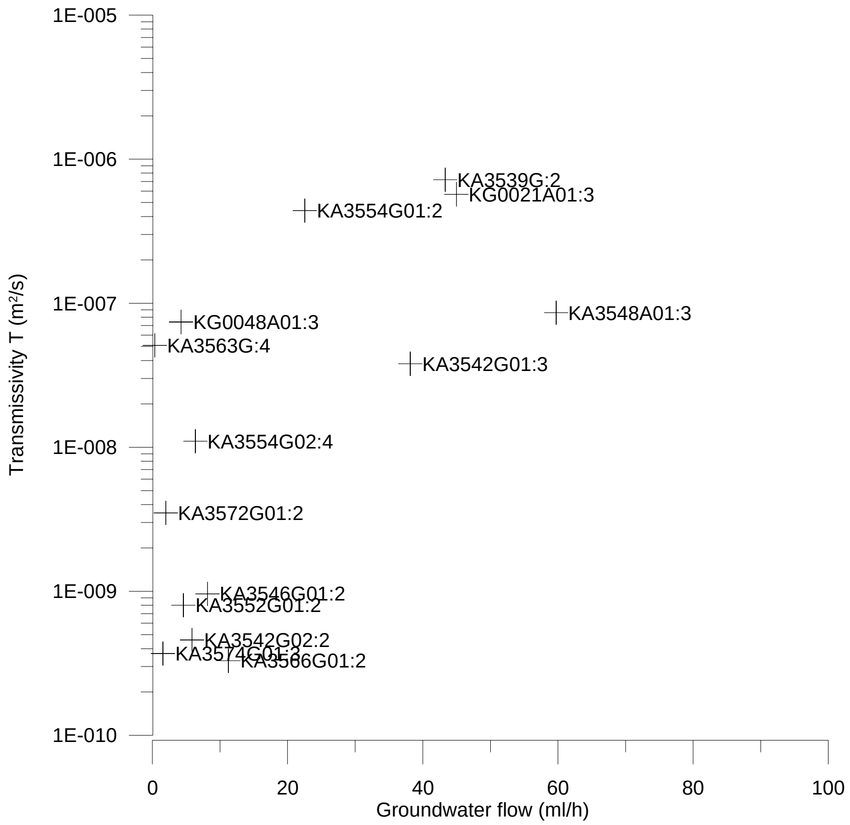

Figure 7-2. *Logarithm of transmissivity versus groundwater flow rate for the sections measured in the tracer dilution test, campaign 2 (leaking sections excluded).*

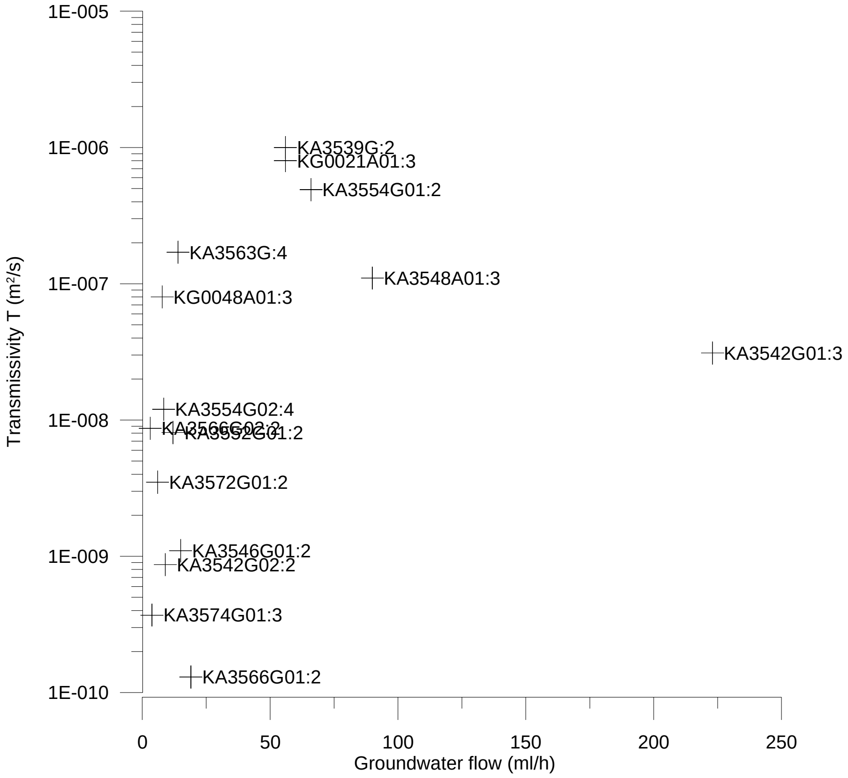

Figure 7-3. *Logarithm of transmissivity versus groundwater flow rate for the sections measured in the tracer dilution test, campaign 1 (leaking sections excluded).*

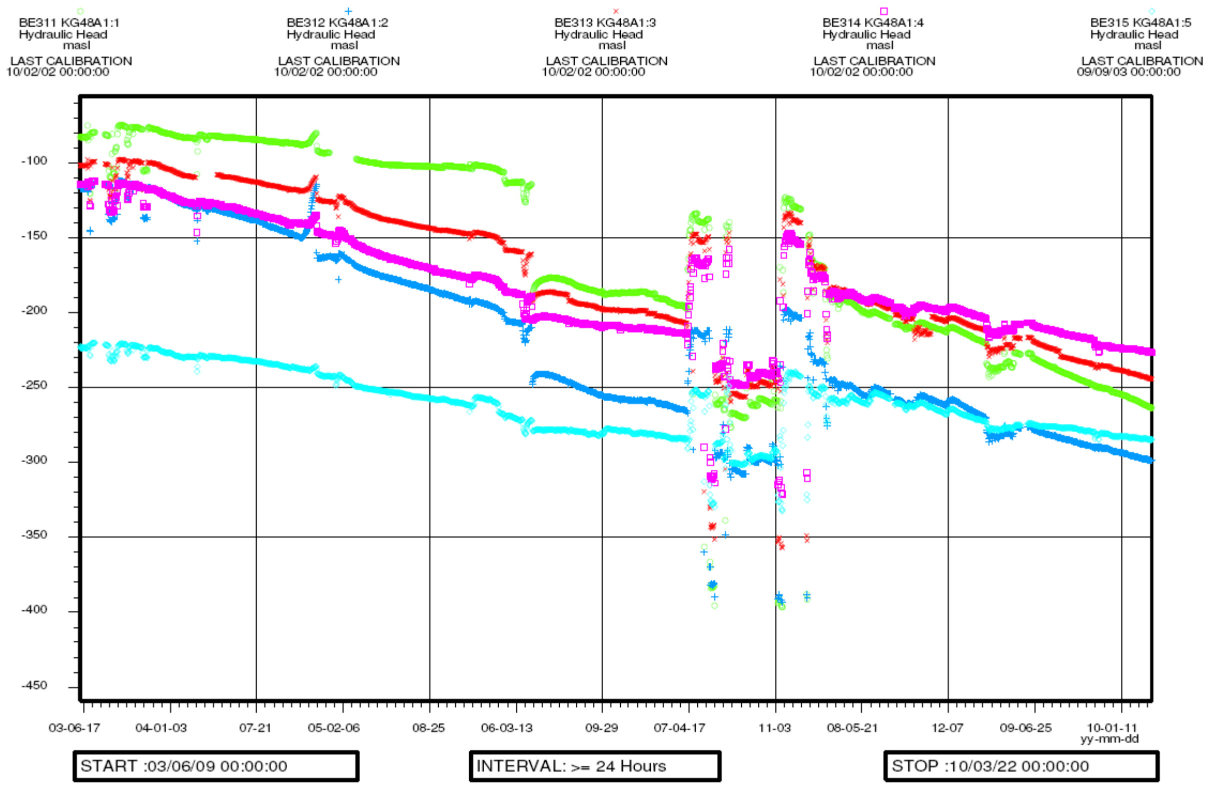

Figure 7-4. *Pressure data from borehole KG0048A01 during the period June 2003 to March 2010.*

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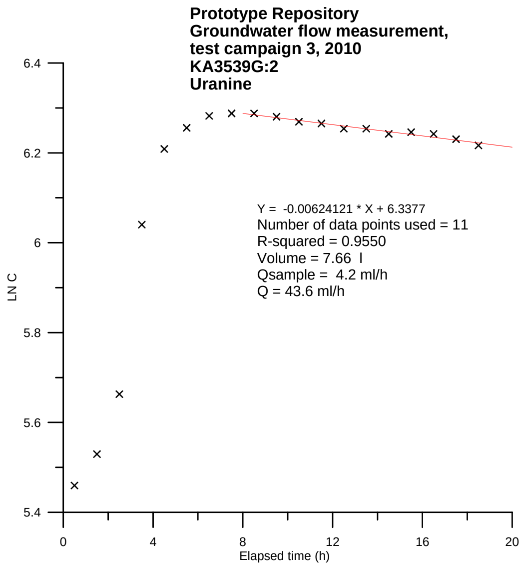
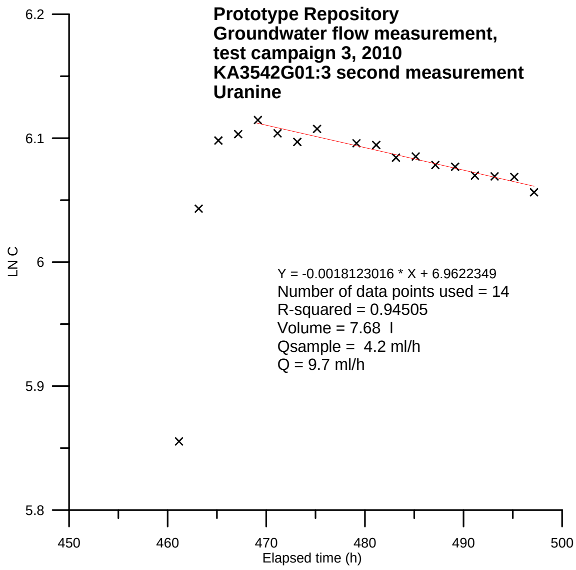
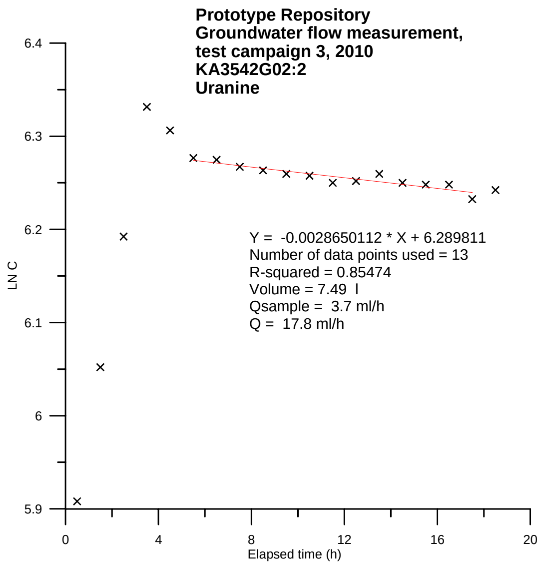
9 Appendices

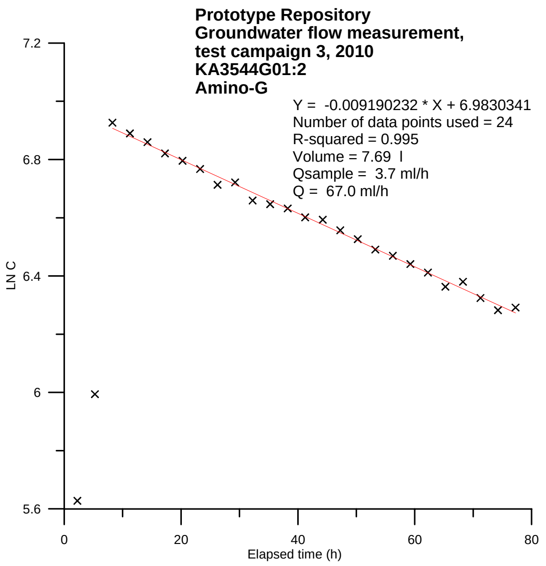
Appendix 1

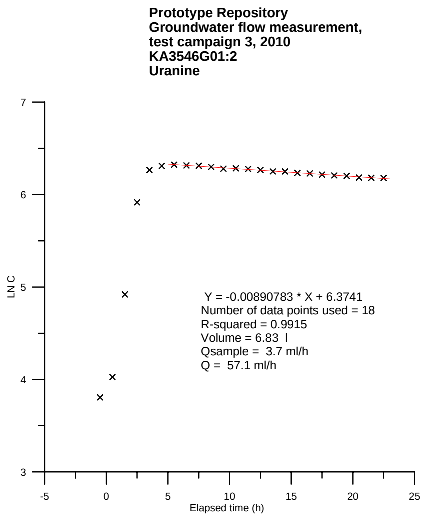
Tracer dilution diagrams







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Groundwater flow measurement,
test campaign 3, 2010
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Uranine
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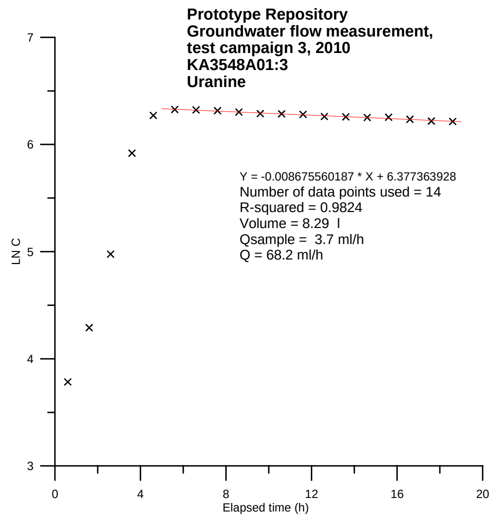
Number of data points used = 18
R-squared = 0.9915
Volume = 6.83 l
Qsample = 3.7 ml/h
Q = 57.1 ml/h
LN C
Elapsed time (h)


Prototype Repository
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test campaign 3, 2010
KA3548A01:3
Uranine
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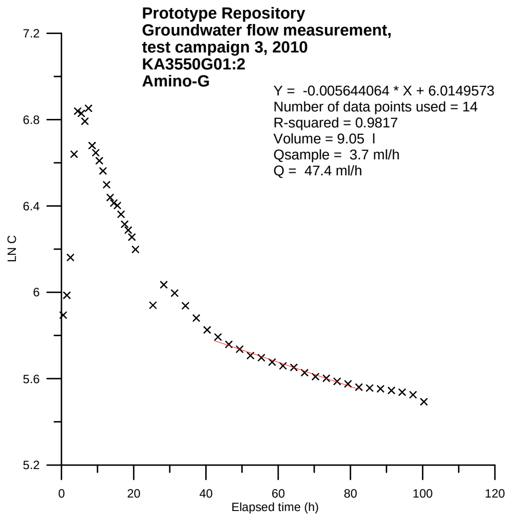
LN C
Elapsed time (h)


Prototype Repository
Groundwater flow measurement,
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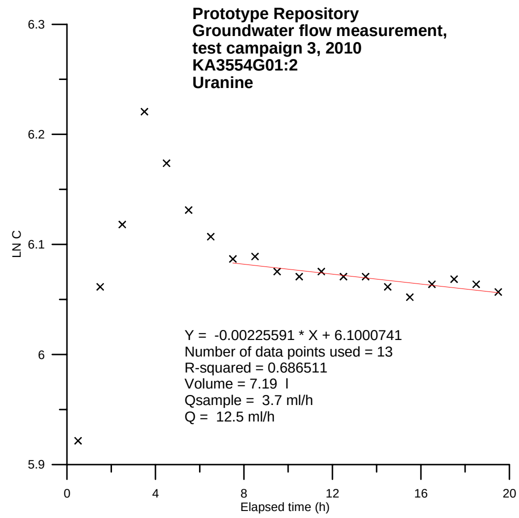
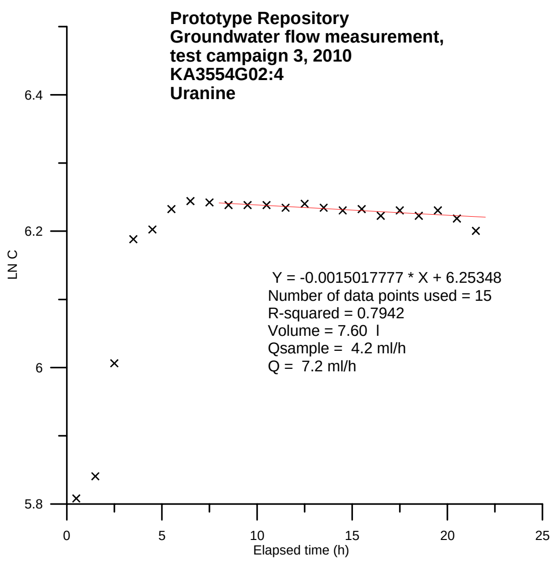
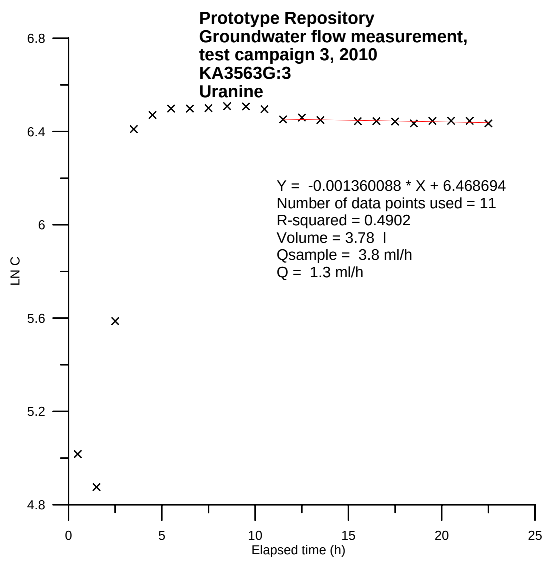
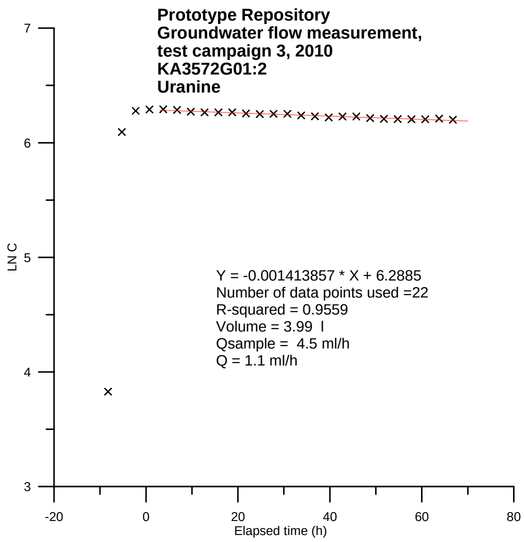
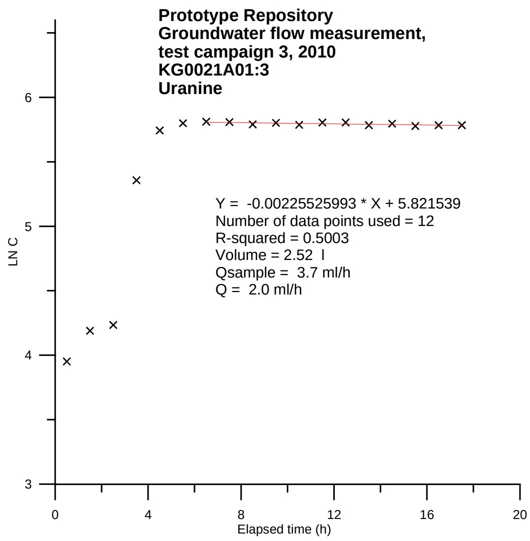
KA3550G01:2
Amino-G
Y = -0.005644064 * X + 6.0149573
Number of data points used = 14
R-squared = 0.9817
Volume = 9.05 l
Qsample = 3.7 ml/h
Q = 47.4 ml/h
LN C
Elapsed time (h)

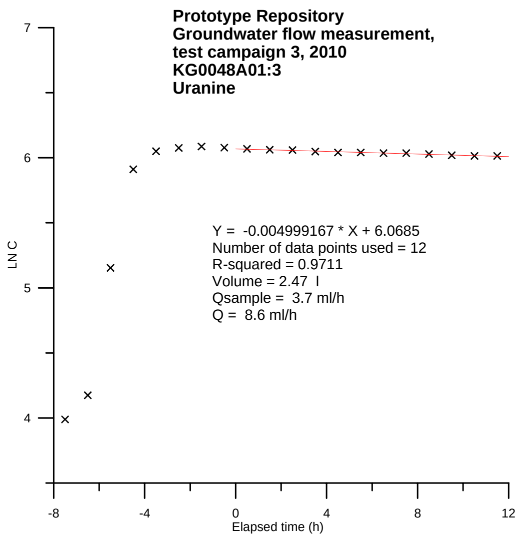

Prototype Repository
Groundwater flow measurement,
test campaign 3, 2010
KA3554G01:2
Uranine
Y = -0.00225591 * X + 6.1000741
Number of data points used = 13
R-squared = 0.686511
Volume = 7.19 l
Qsample = 3.7 ml/h
Q = 12.5 ml/h
LN C
Elapsed time (h)


Prototype Repository
Groundwater flow measurement,
test campaign 3, 2010
KA3554G02:4
Uranine
Y = -0.0015017777 * X + 6.25348
Number of data points used = 15
R-squared = 0.7942
Volume = 7.60 l
Qsample = 4.2 ml/h
Q = 7.2 ml/h
LN C
Elapsed time (h)


Prototype Repository
Groundwater flow measurement,
test campaign 3, 2010
KA3563G:3
Uranine
Y = -0.001360088 * X + 6.468694
Number of data points used = 11
R-squared = 0.4902
Volume = 3.78 l
Qsample = 3.8 ml/h
Q = 1.3 ml/h
LN C
Elapsed time (h)


Prototype Repository
Groundwater flow measurement,
test campaign 3, 2010
KA3572G01:2
Uranine
Y = -0.001413857 * X + 6.2885
Number of data points used =22
R-squared = 0.9559
Volume = 3.99 l
Qsample = 4.5 ml/h
Q = 1.1 ml/h
LN C
Elapsed time (h)


Prototype Repository
Groundwater flow measurement,
test campaign 3, 2010
KG0021A01:3
Uranine
Y = -0.00225525993 * X + 5.821539
Number of data points used = 12
R-squared = 0.5003
Volume = 2.52 l
Qsample = 3.7 ml/h
Q = 2.0 ml/h
LN C
Elapsed time (h)


Prototype Repository
Groundwater flow measurement,
test campaign 3, 2010
KG0048A01:3
Uranine
Y = -0.004999167 * X + 6.0685
Number of data points used = 12
R-squared = 0.9711
Volume = 2.47 l
Qsample = 3.7 ml/h
Q = 8.6 ml/h
LN C
Elapsed time (h)

Appendix 2

Pressure data from included test sections

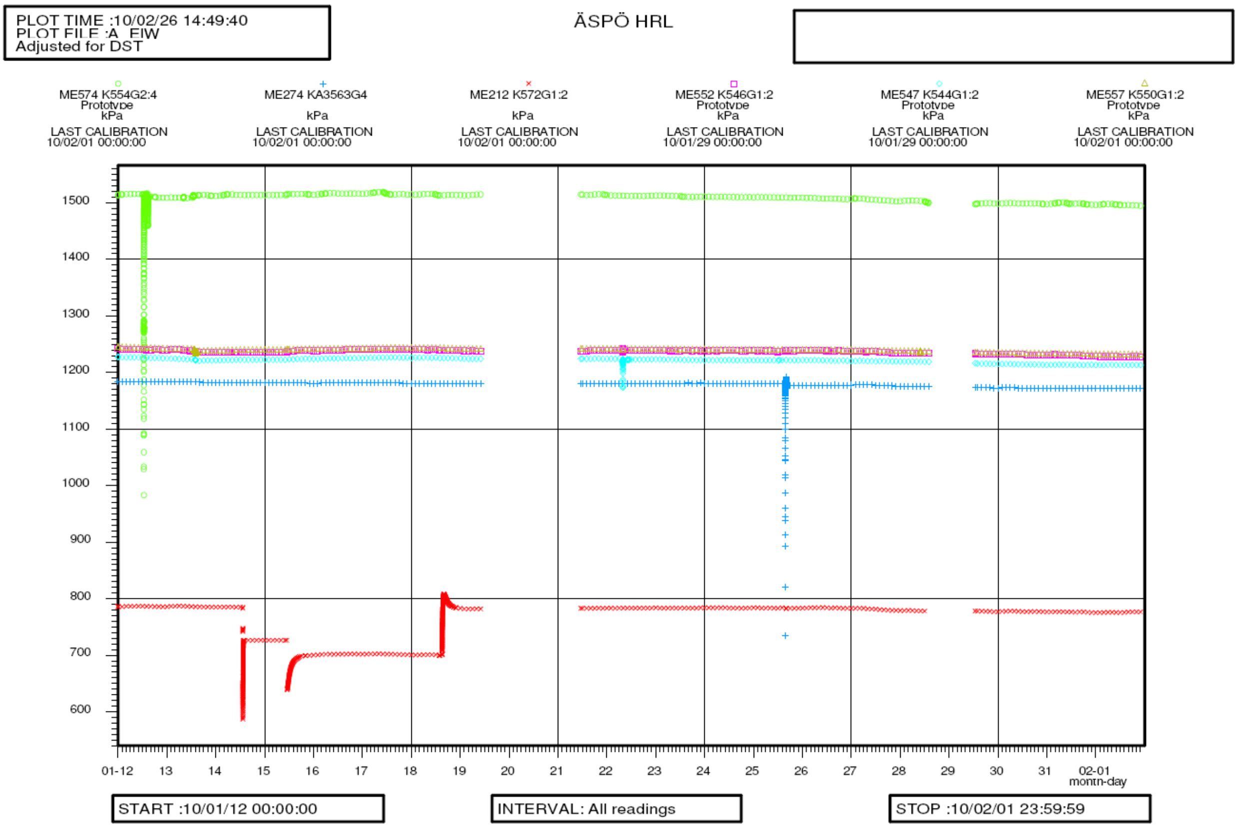


Figure A2-1. Plot showing the pressure in selected sections included in the dilution test during the duration of the entire test.

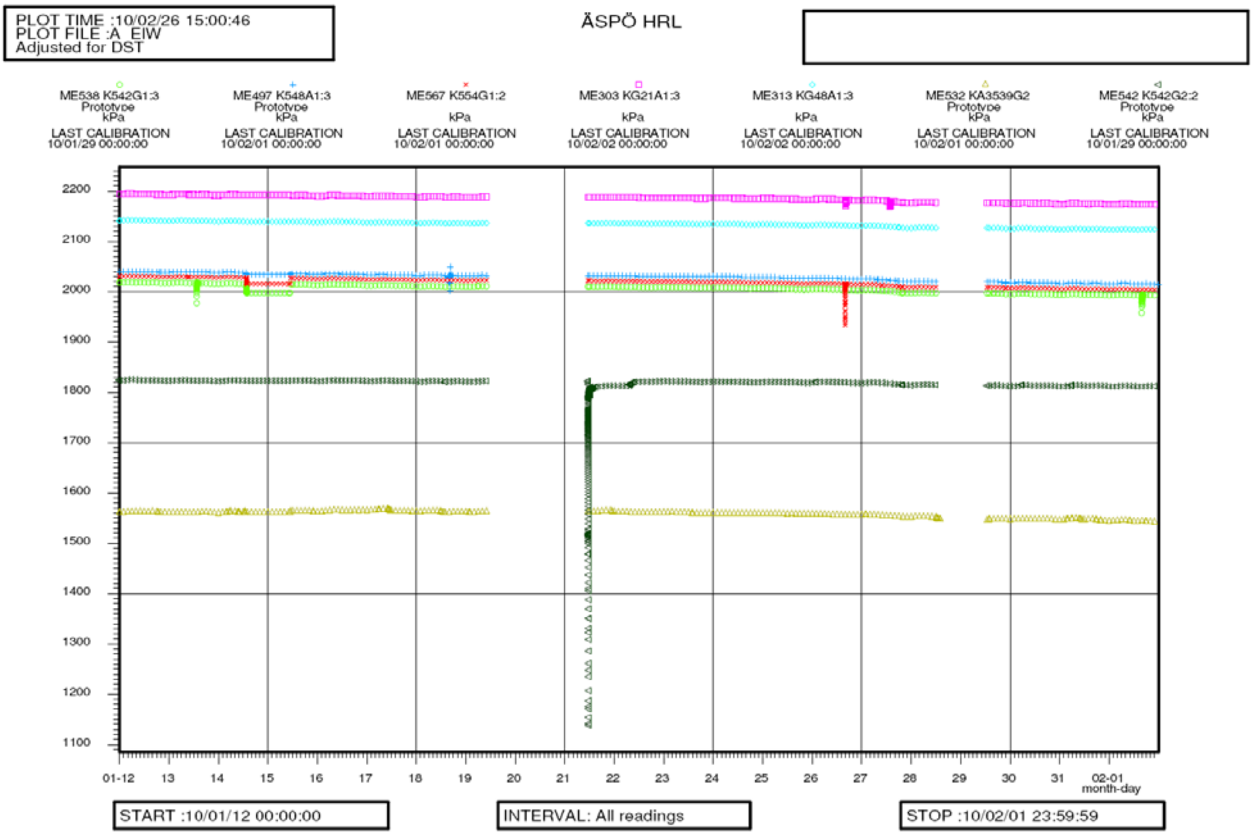


Figure A2-2. Plot showing the pressure in selected sections included in the dilution test during the duration of the entire test.

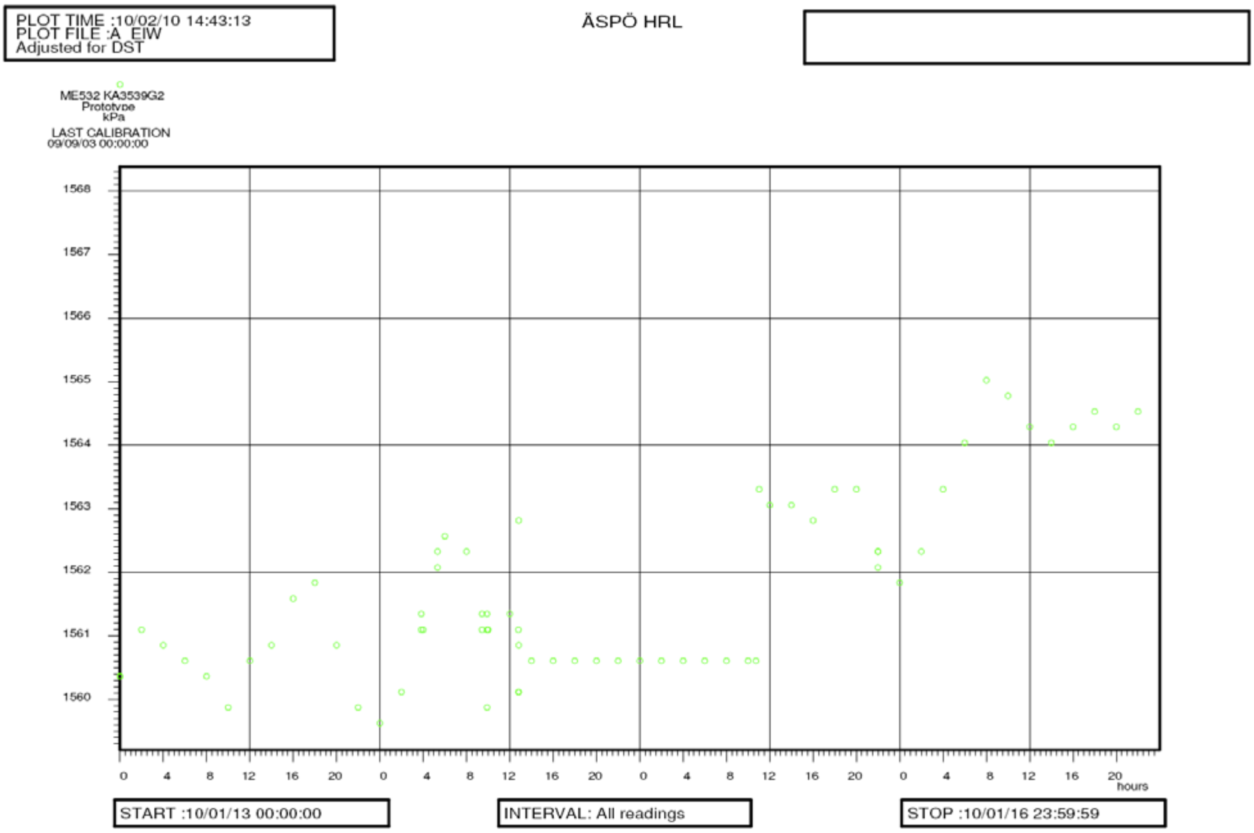


Figure A2-3. *Plot showing the pressure in KA3539G:2 during the performed dilution test in the section*

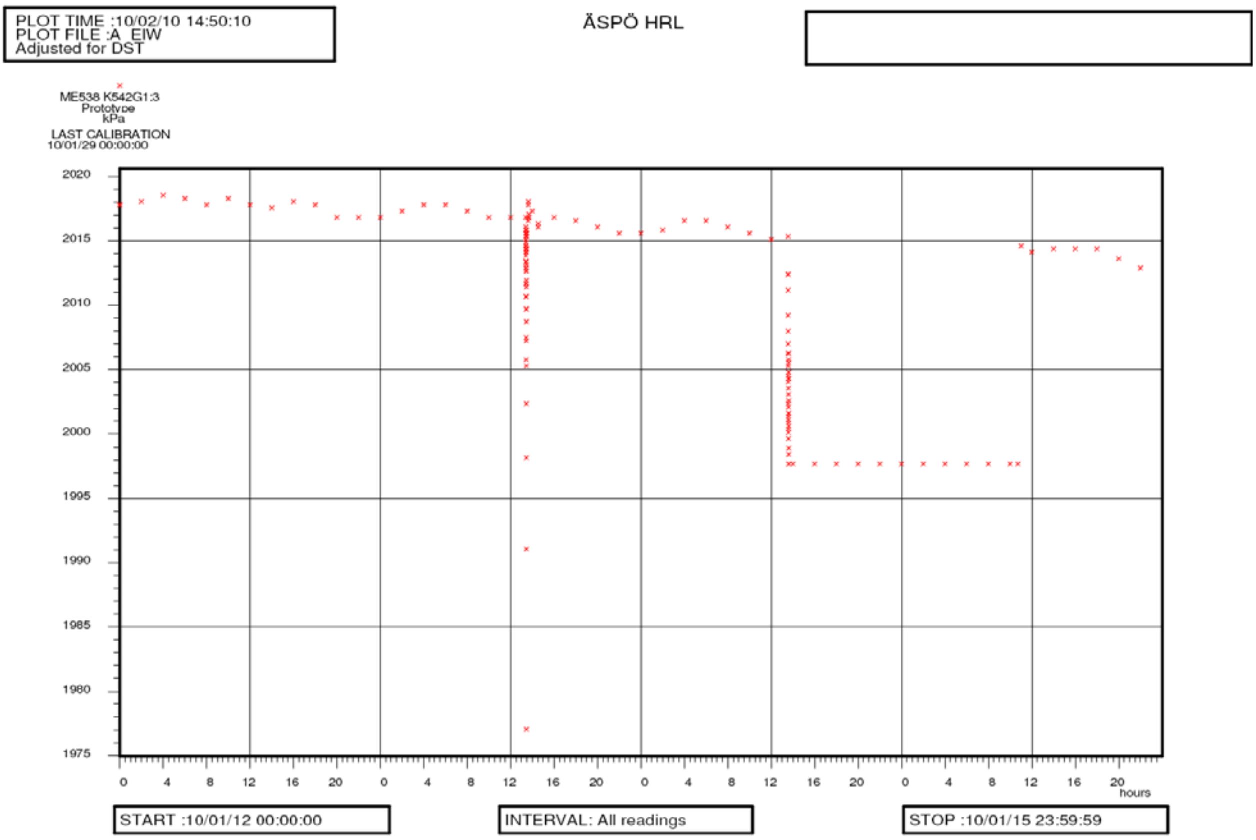


Figure A2-4. *Plot showing the pressure in KA3542G01:3 during the performed dilution test in the section.*

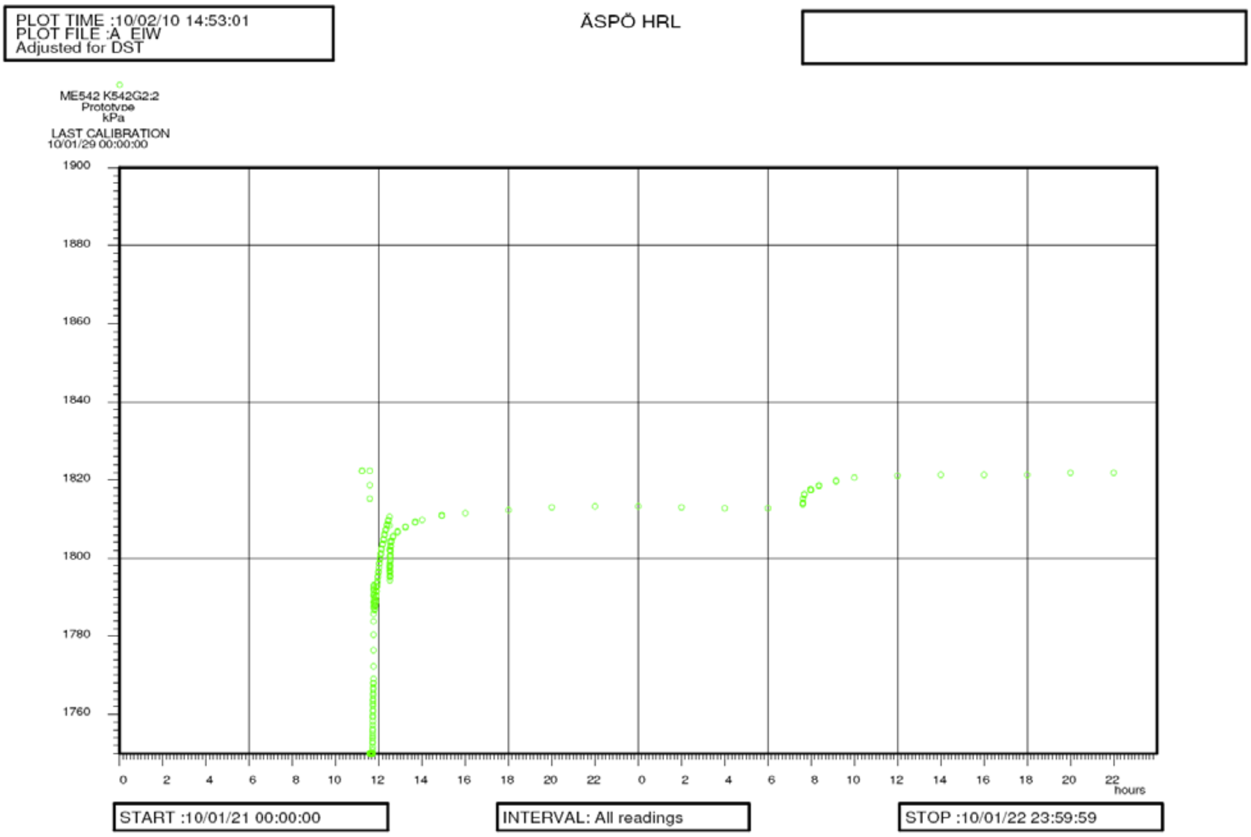


Figure A2-5. *Plot showing the pressure in KA3542G02:2 during the performed dilution test in the section.*

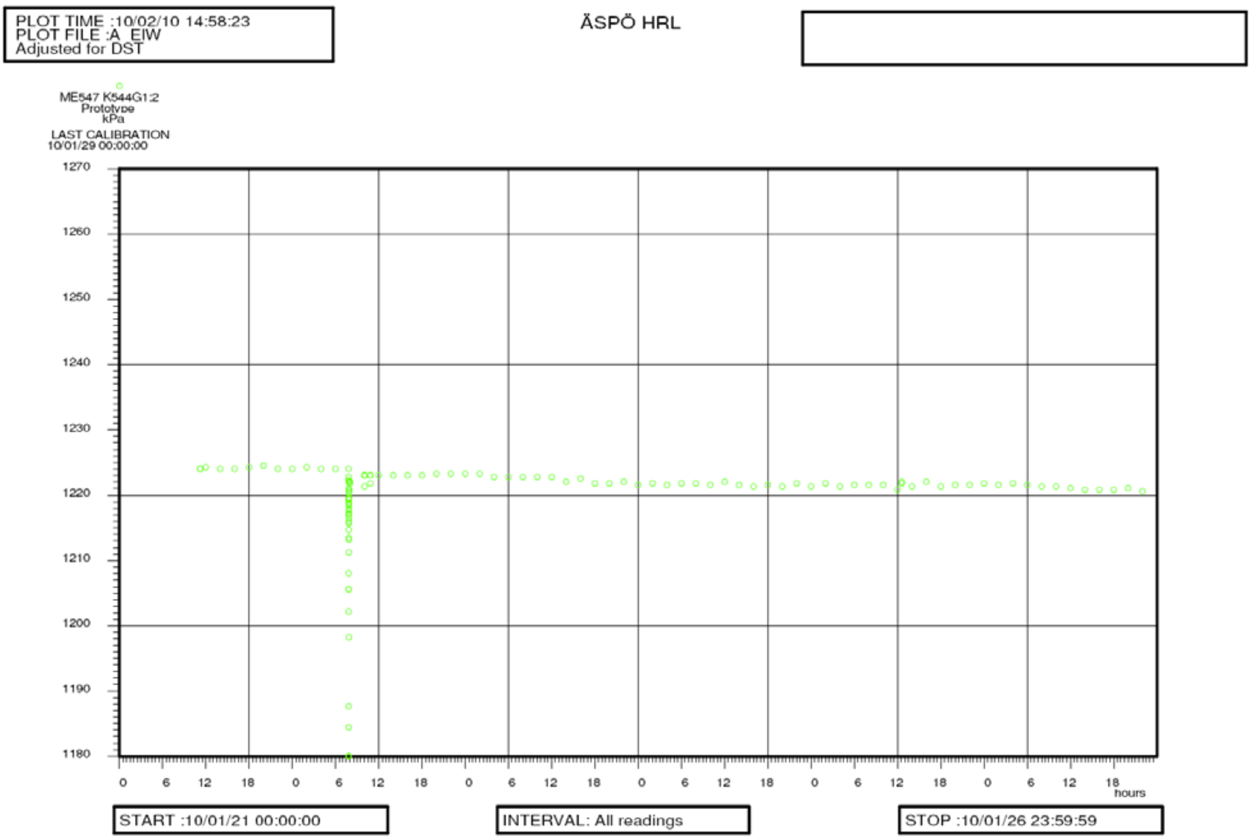


Figure A2:6. *Plot showing the pressure in KA3544G01:2 during the performed dilution test in the section.*

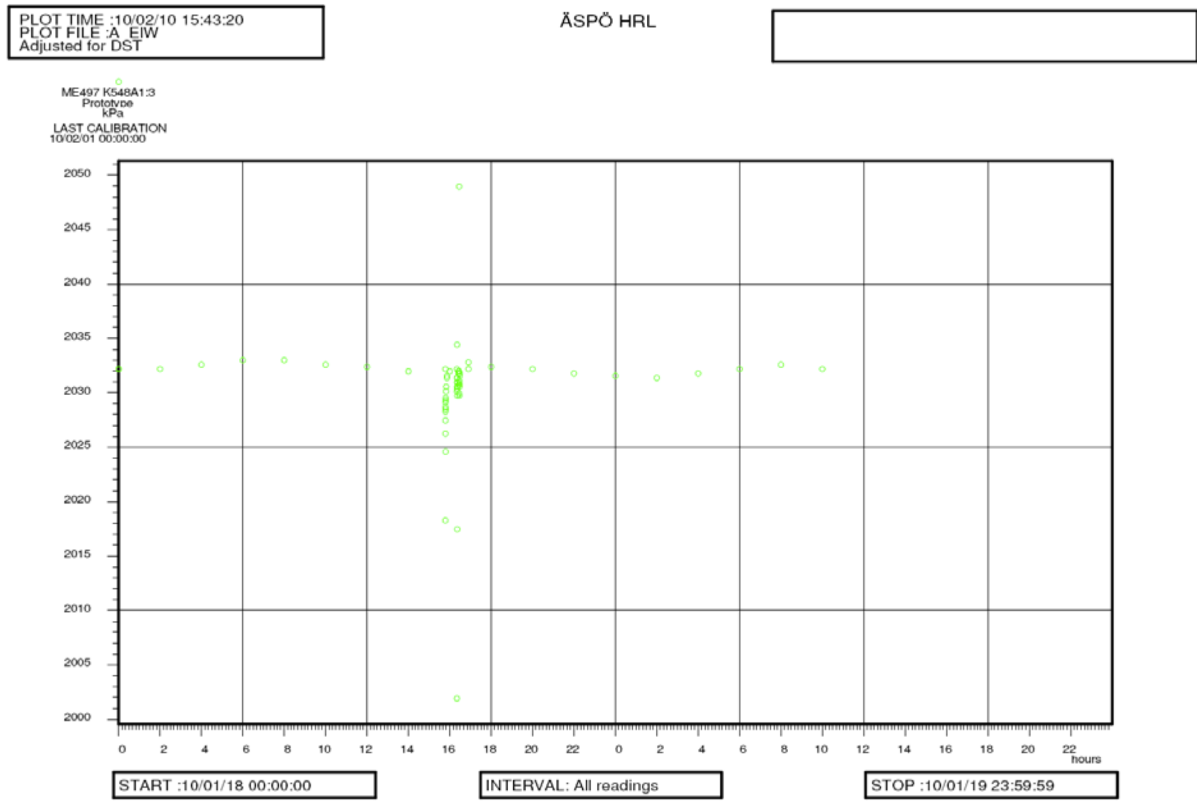


Figure A2-7. *Plot showing the pressure in KA3548A01:3 during the performed dilution test in the section. Section KA3546G01:2 were missing pressure data in HMS during the test period.*

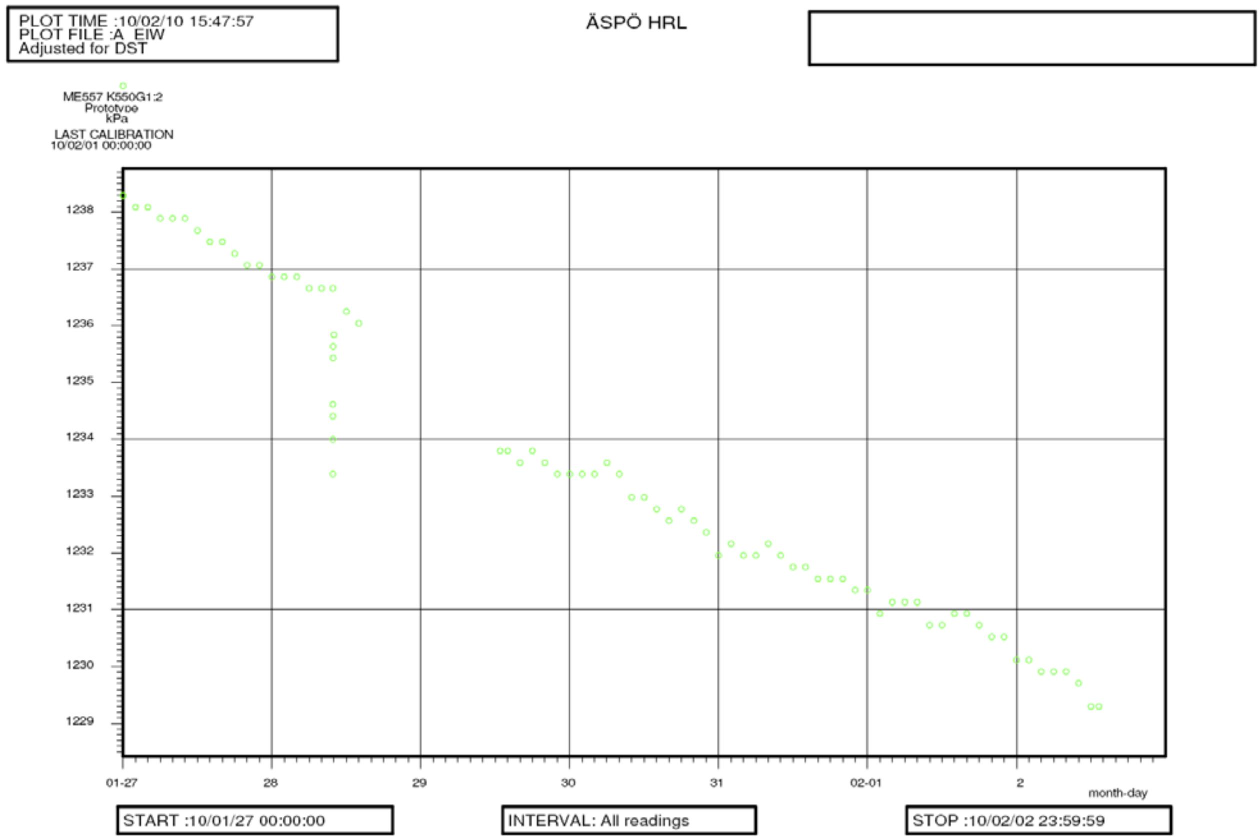


Figure A2-8. *Plot showing the pressure in KA3550G01:2 during the performed dilution test in the section.*

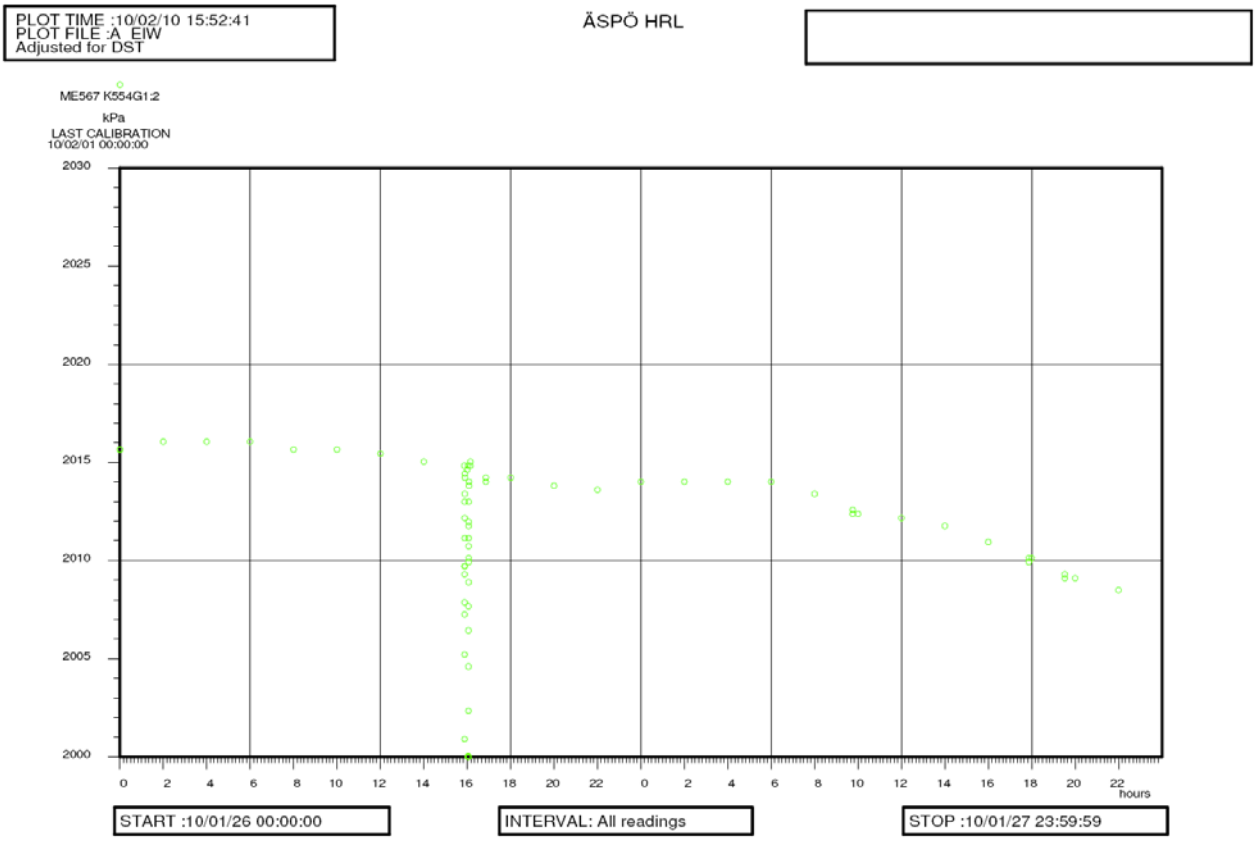


Figure A2-9. *Plot showing the pressure in KA3554G01:2 during the performed dilution test in the section.*

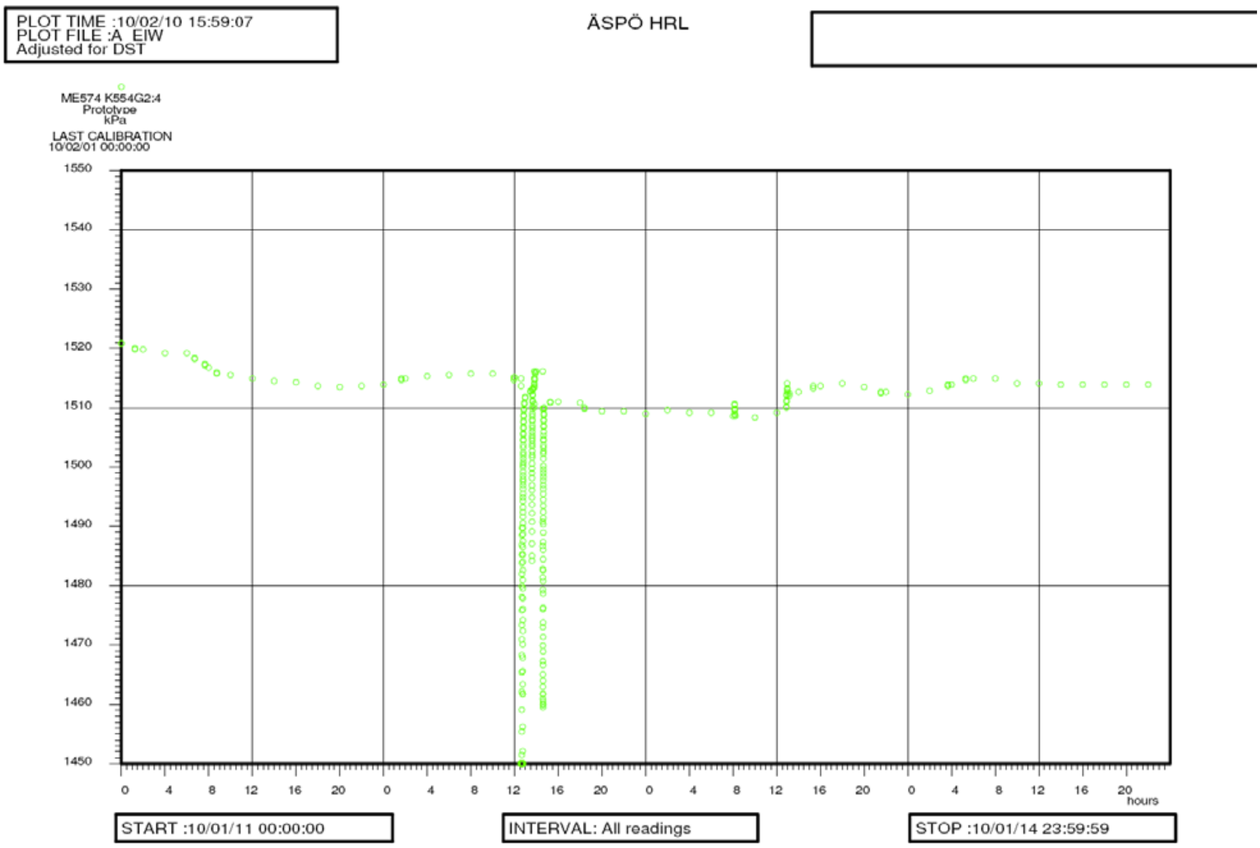


Figure A2-10. *Plot showing the pressure in KA3554G02:4 during the performed dilution test in the section.*

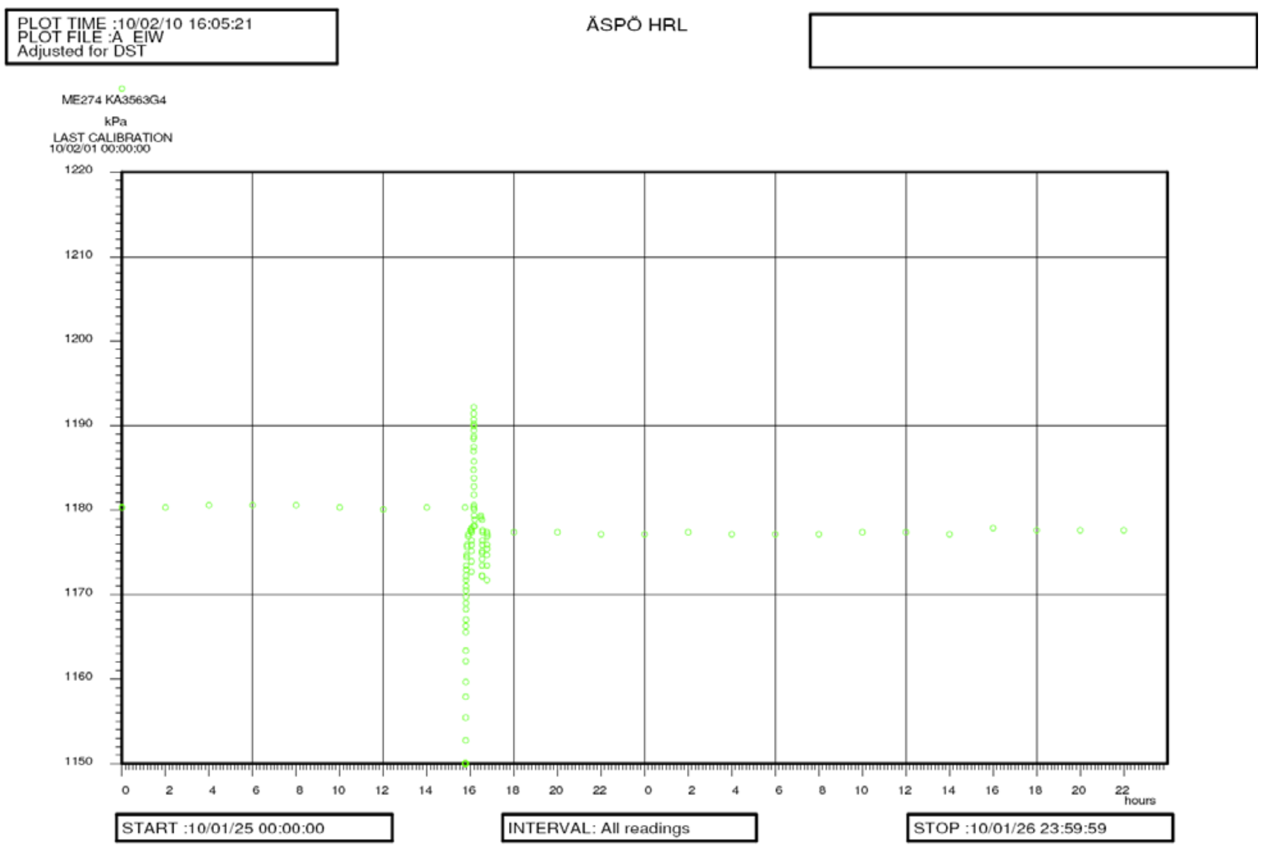


Figure A2-11. *Plot showing the pressure in KA3563G:4 during the performed dilution test in the section.*

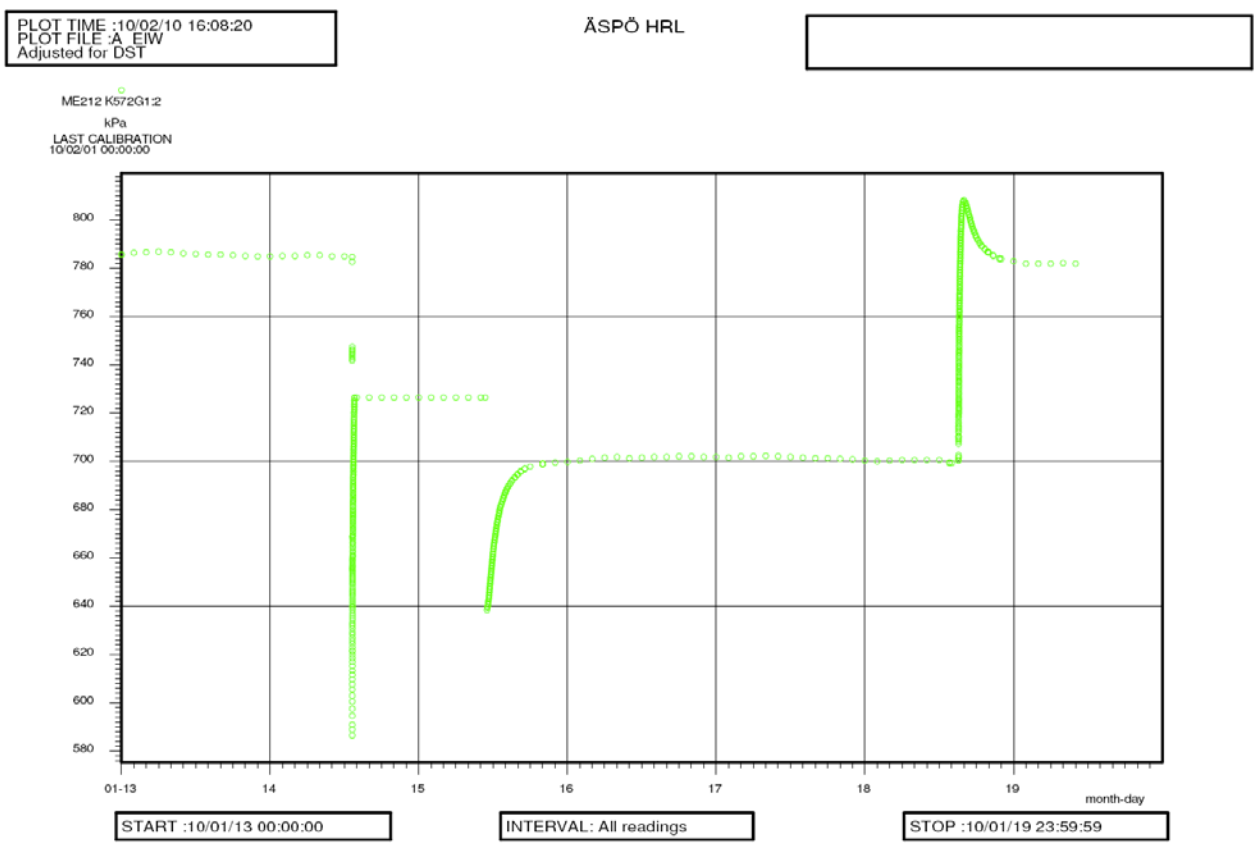


Figure A2-12. *Plot showing the pressure in KA3572G01:2 during the performed dilution test in the section.*

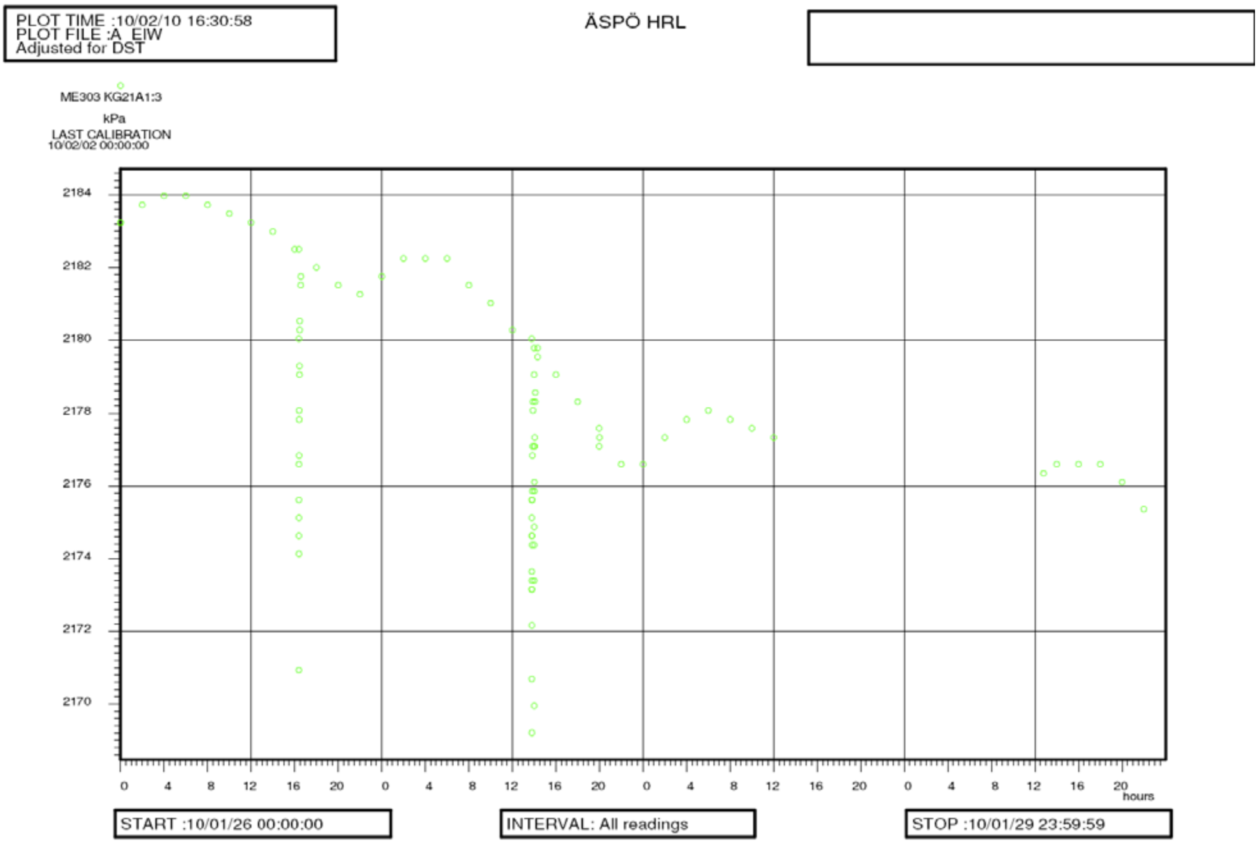


Figure A2-13. *Plot showing the pressure in KG0021A01:3 during the performed dilution test in the section.*

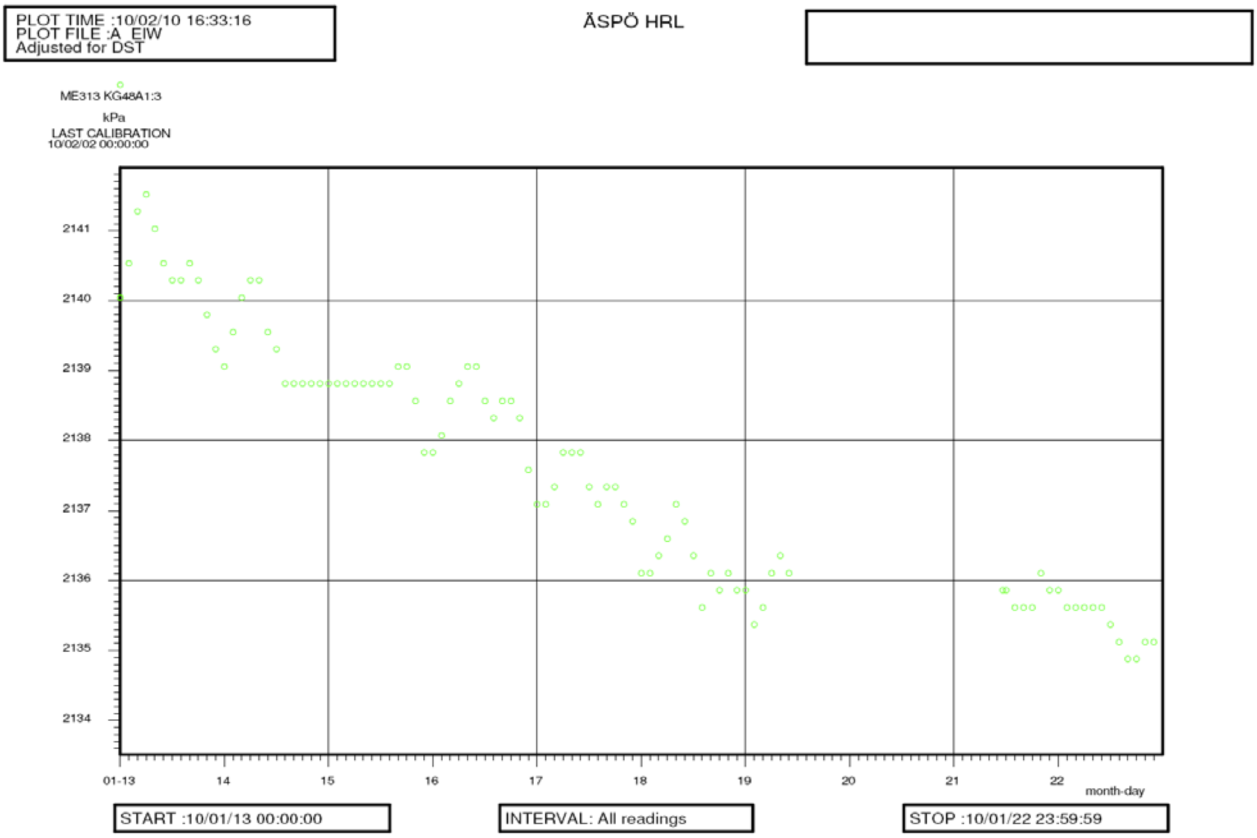


Figure A2-14. *Plot showing the pressure in KG0048A01:3 during the performed dilution test in the section*

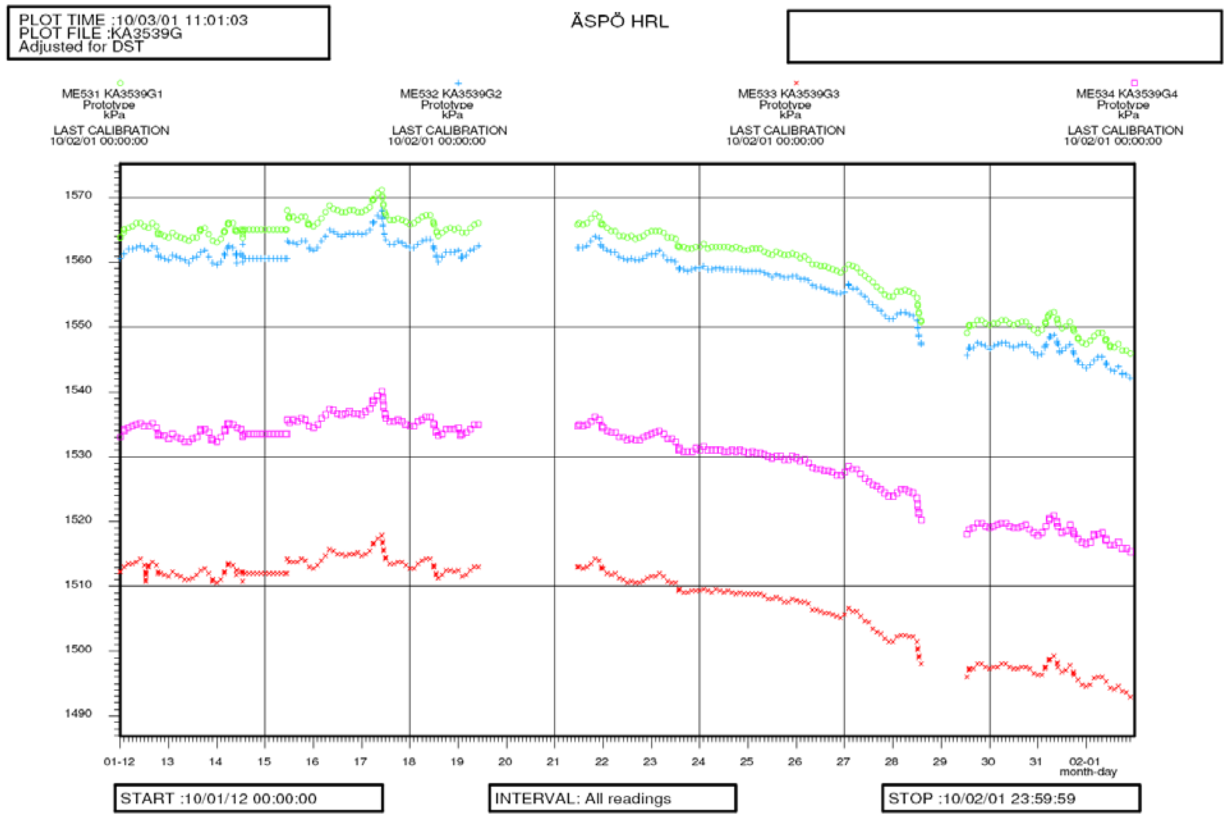


Figure A2-15. *Plot showing the pressure in all sections of KA3539G for the duration of the entire dilution test period. Test performed in the section from 2010-01-14 to 2010-01-15. Possible leakage in-between sections.*

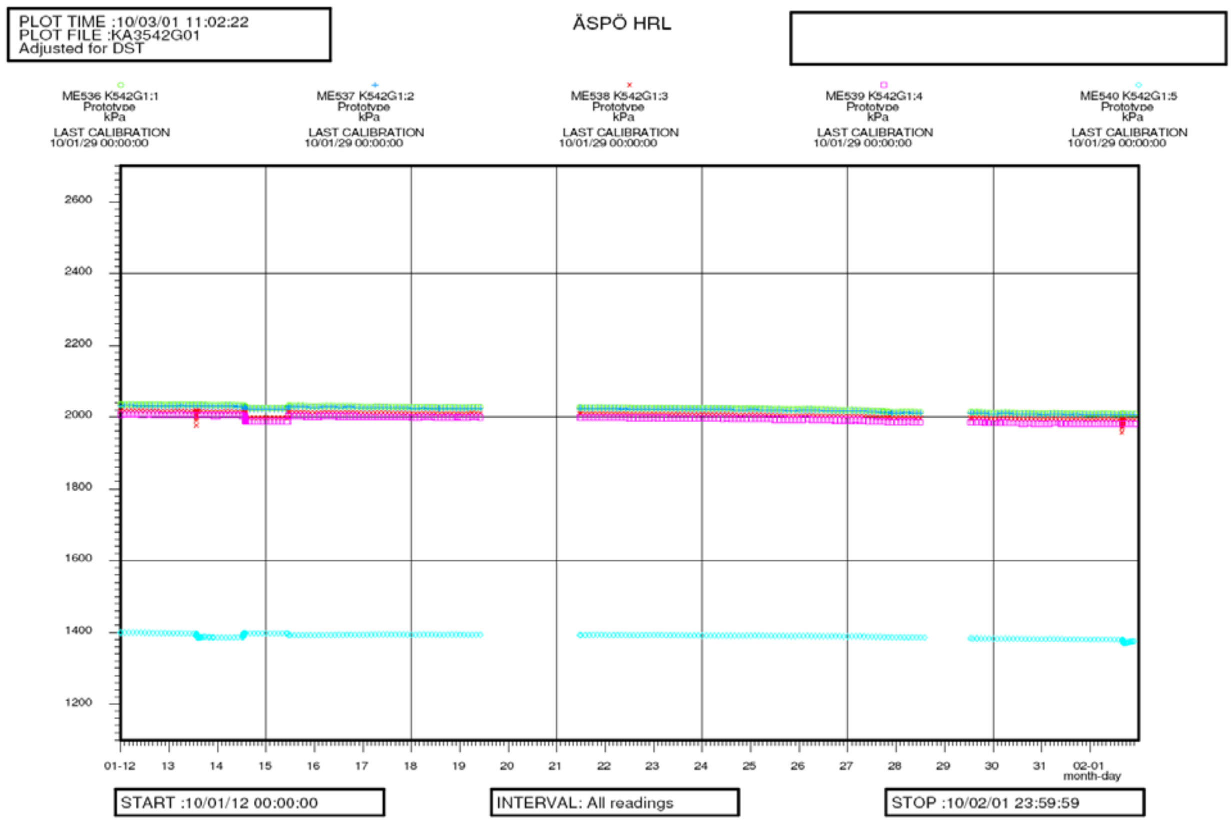


Figure A2-16. *Plot showing the pressure in all sections of KA3542G01 for the duration of the entire dilution test period. Test performed in the section from 2010-01-13 to 2010-01-14.*

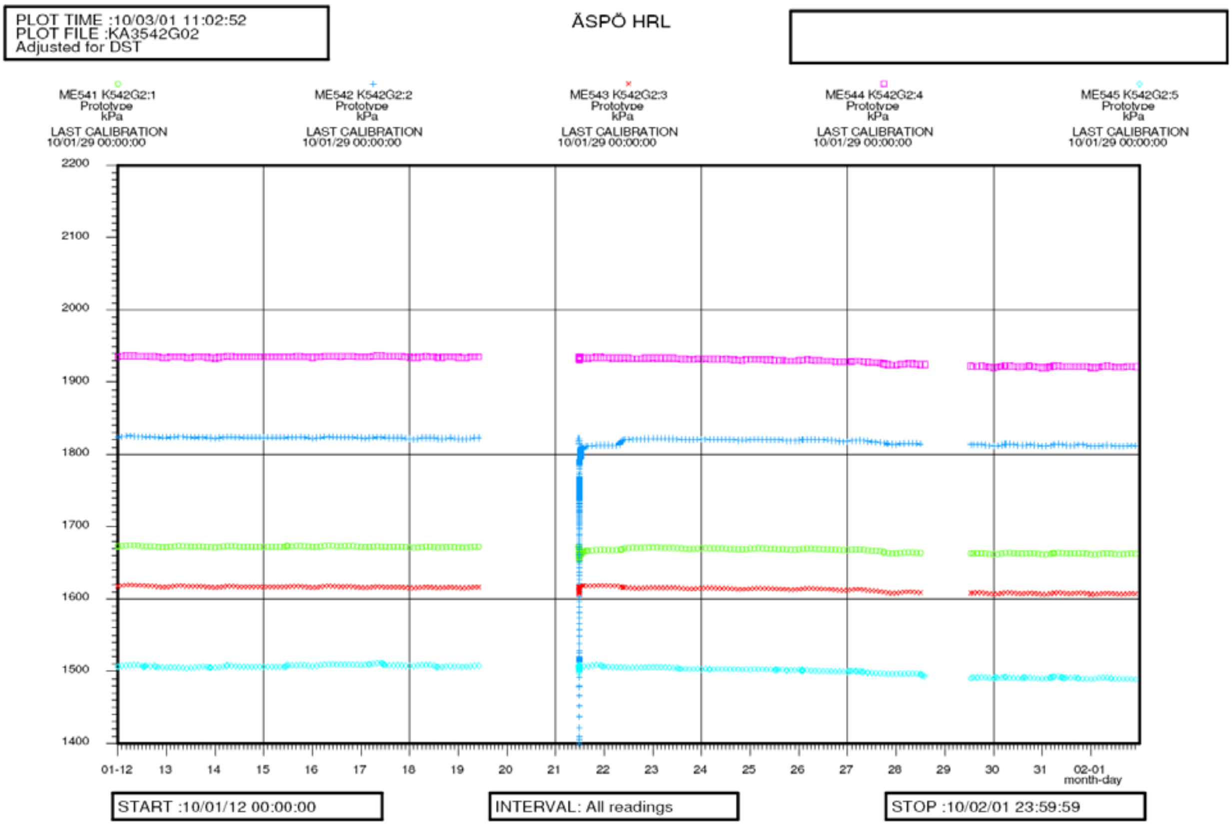


Figure A2-17. *Plot showing the pressure in all sections of KA3542G02 for the duration of the entire dilution test period. Test performed in the section from 2010-01-21 to 2010-01-22.*

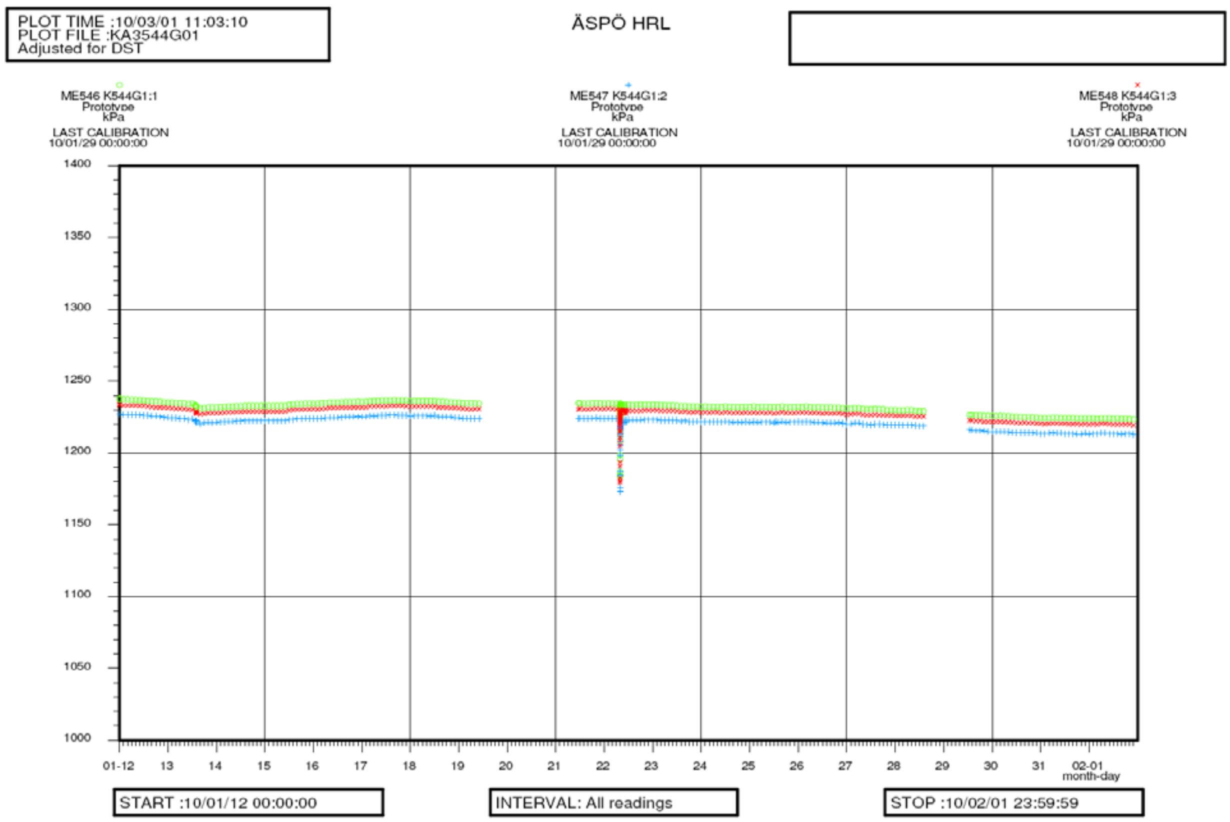


Figure A2-18. *Plot showing the pressure in all sections of KA3544G01 for the duration of the entire dilution test period. Test performed in the section from 2010-01-22 to 2010-01-25. Possible leakage in-between sections.*

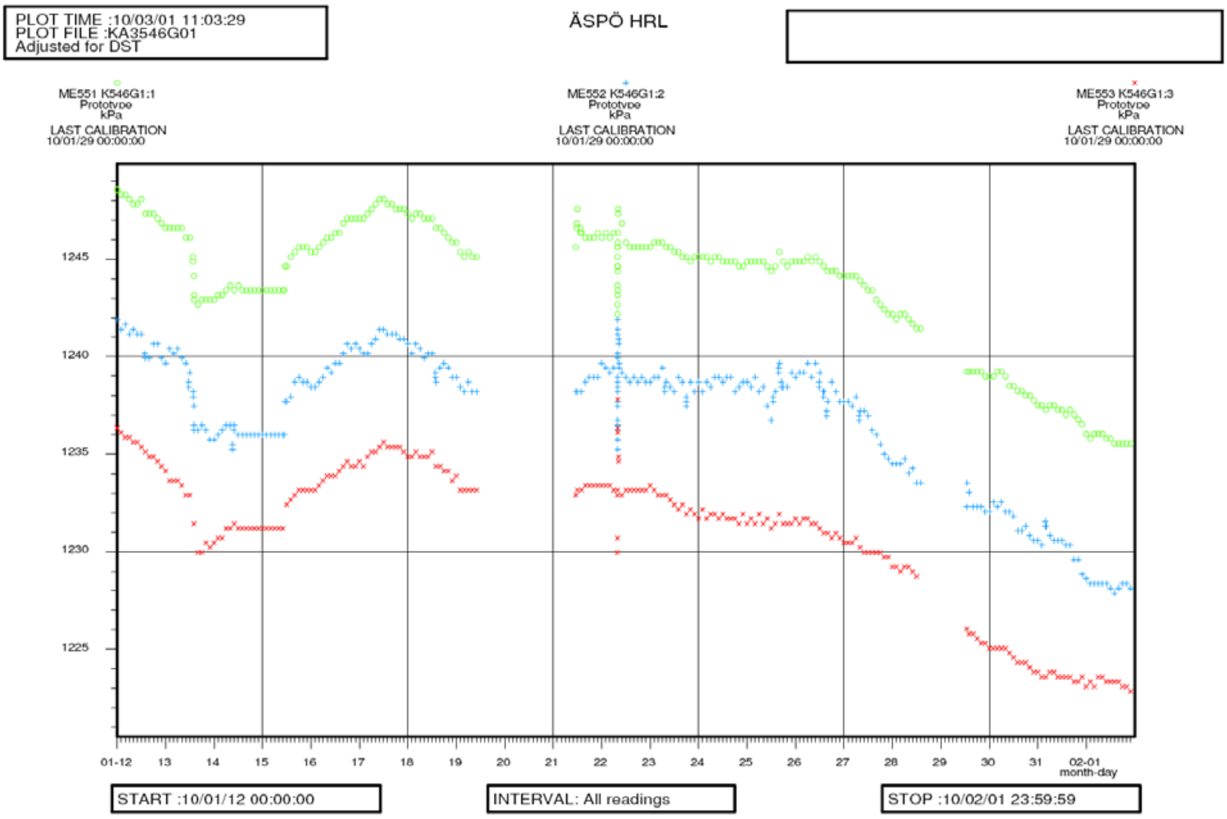


Figure A2-19. *Plot showing the pressure in all sections of KA3546G01 for the duration of the entire dilution test period. Test performed in the section from 2010-01-20 to 2010-01-21. Possible leakage in-between sections.*

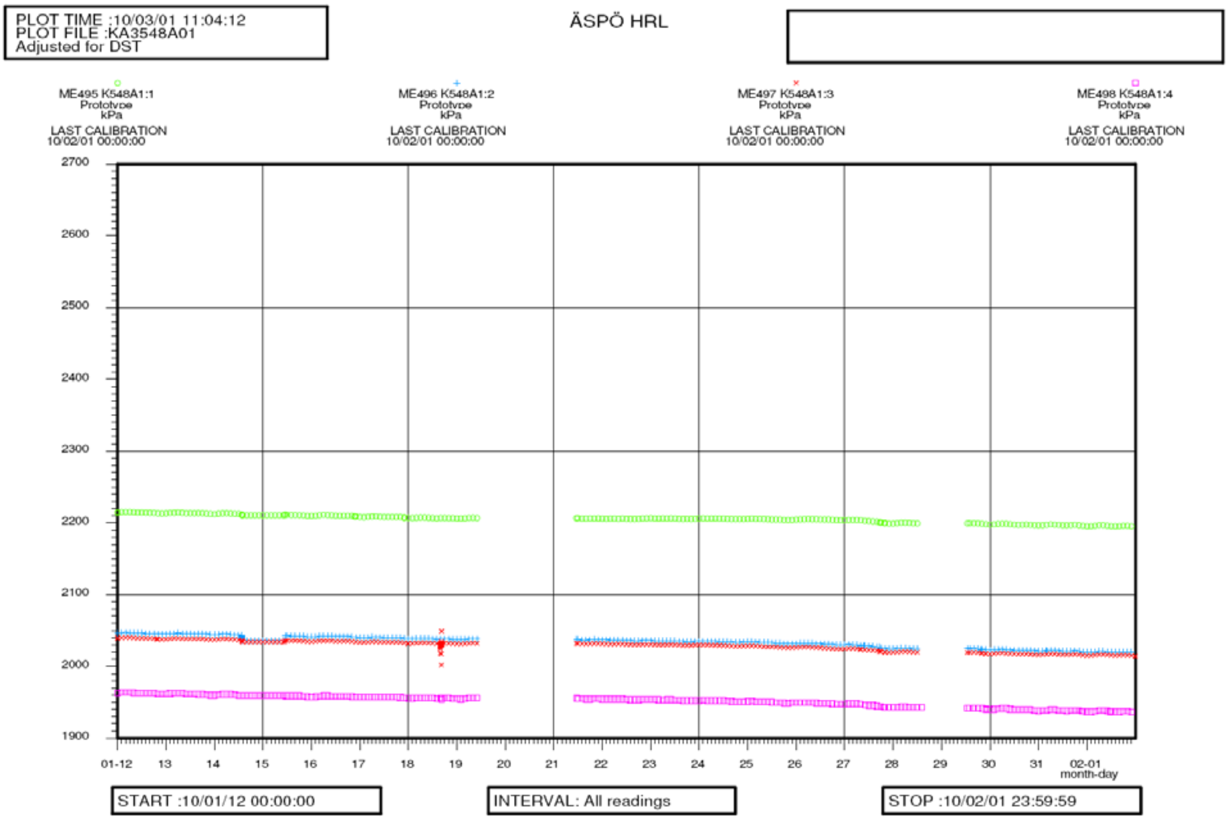


Figure A2-20. *Plot showing the pressure in all sections of KA3548A01 for the duration of the entire dilution test period. Test performed in the section from 2010-01-18 to 2010-01-19.*

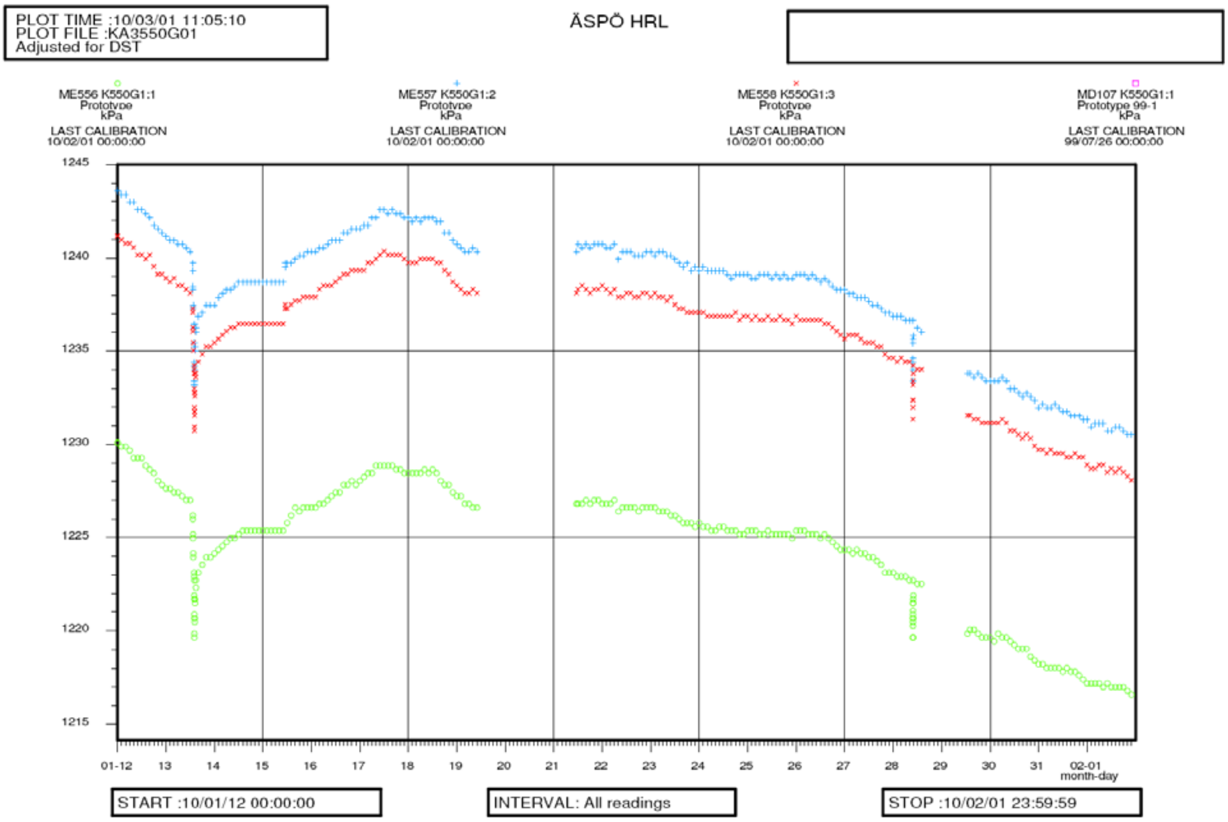


Figure A2-21. *Plot showing the pressure in all sections of KA3550G01 for the duration of the entire dilution test period. Test performed in the section from 2010-01-28 to 2010-02-01. Possible leakage in-between sections.*

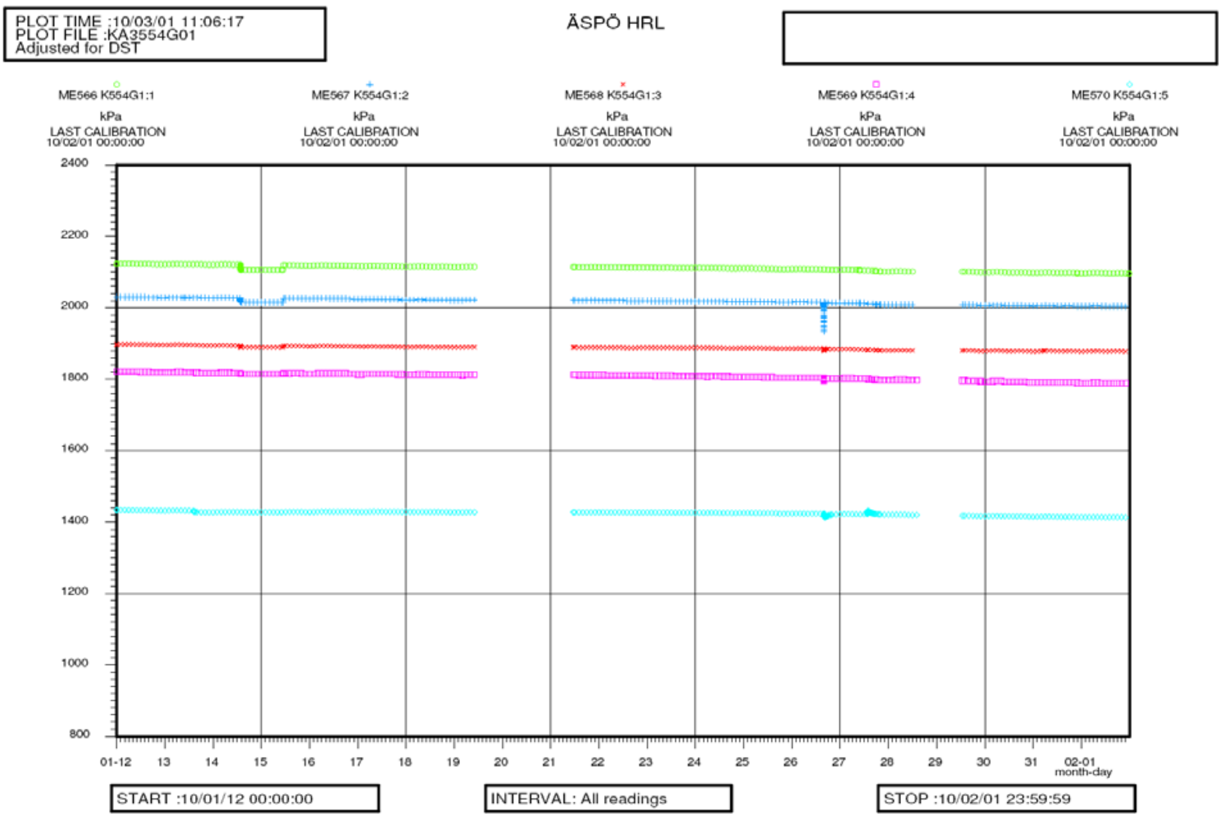


Figure A2-22. *Plot showing the pressure in all sections of KA3554G01 for the duration of the entire dilution test period. Test performed in the section from 2010-01-26 to 2010-01-27.*

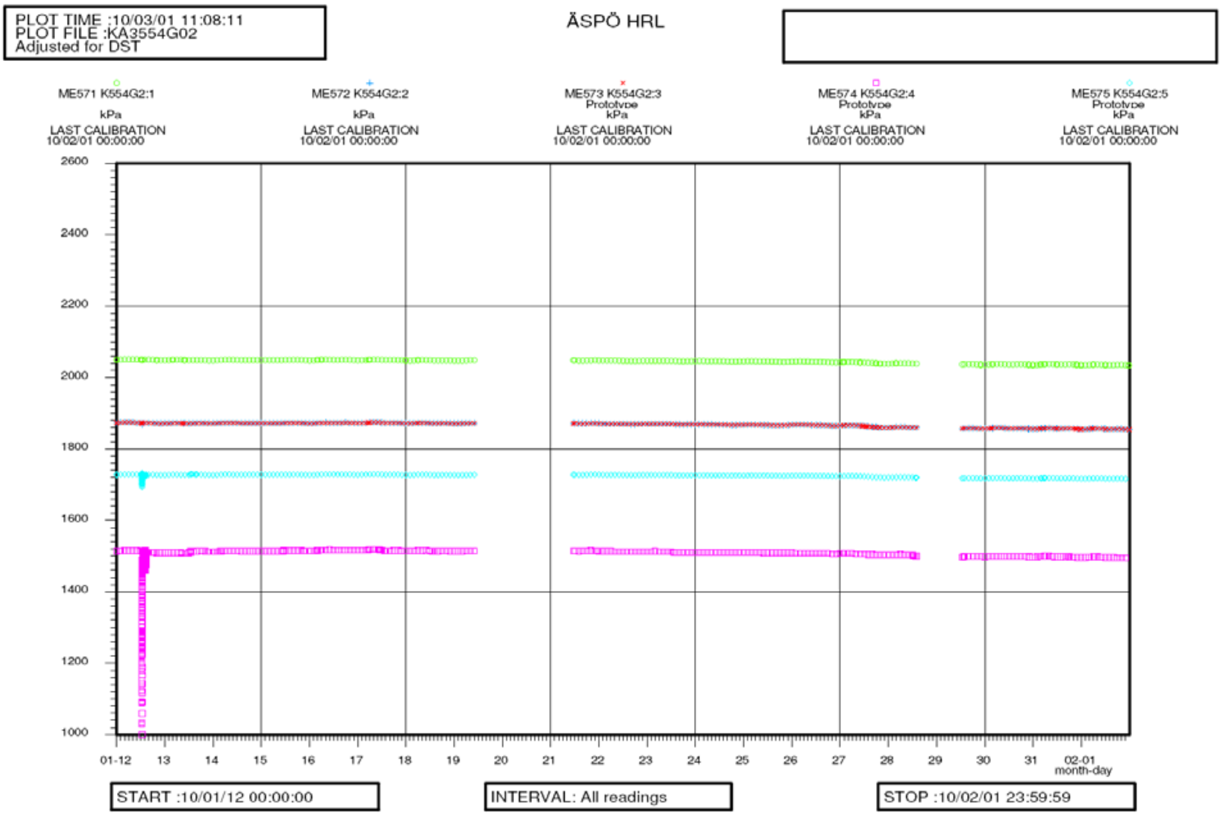


Figure A2-23. *Plot showing the pressure in all sections of KA3554G02 for the duration of the entire dilution test period. Test performed in the section from 2010-01-12 to 2010-01-13.*

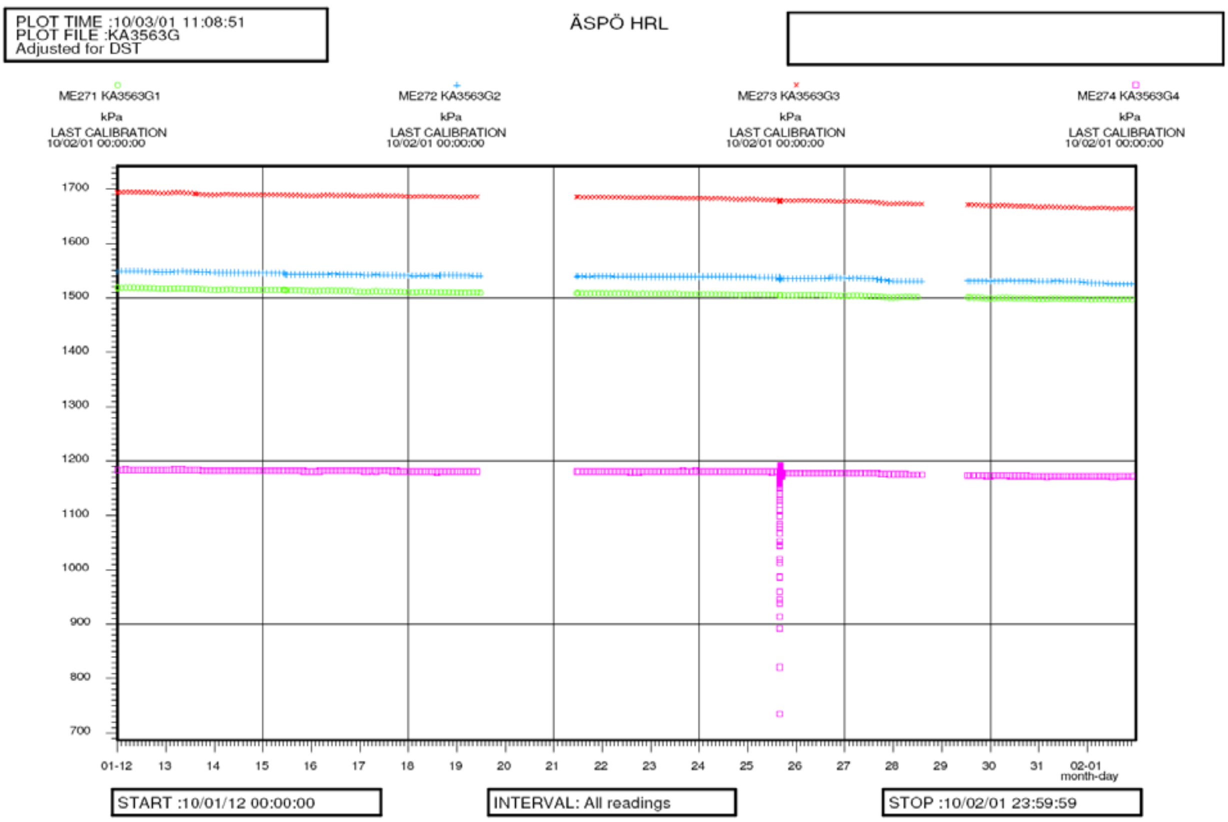


Figure A2-24. *Plot showing the pressure in all sections of KA3563G for the duration of the entire dilution test period. Test performed in the section from 2010-01-25 to 2010-01-26.*

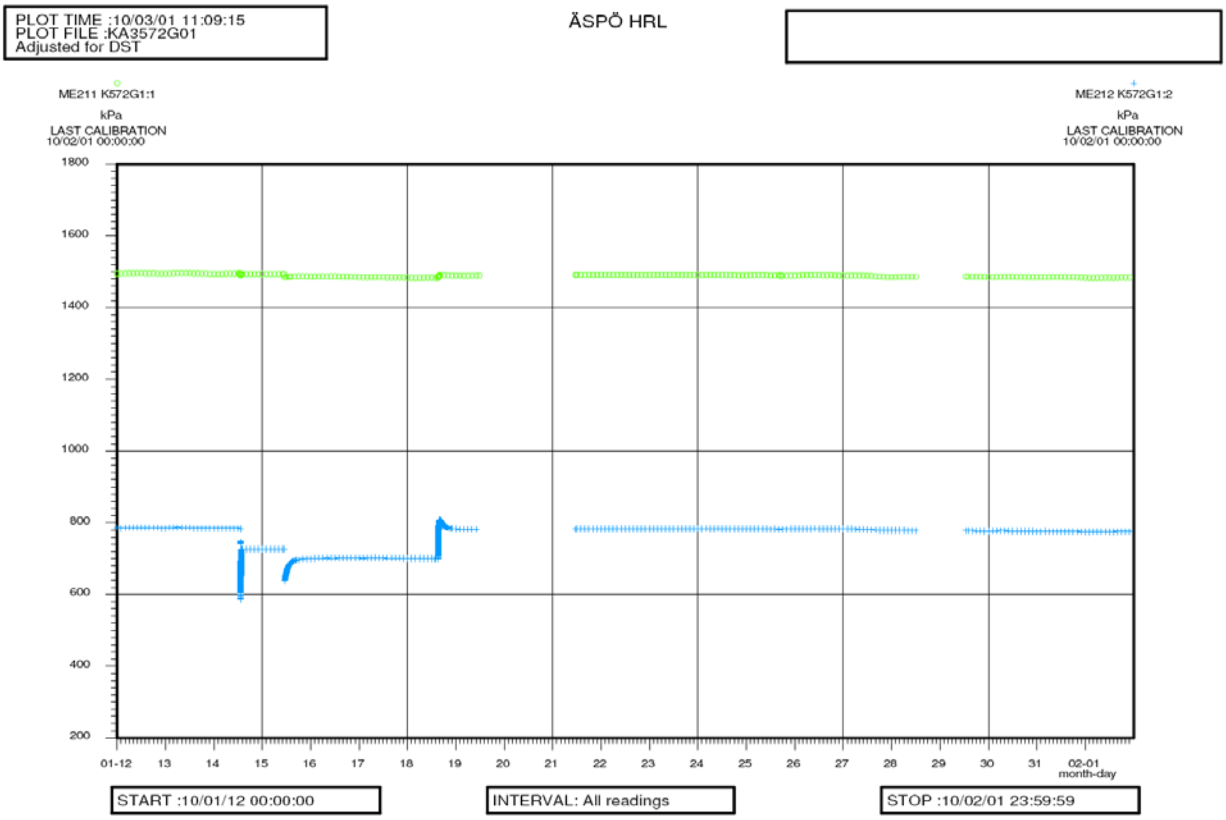


Figure A2-25. *Plot showing the pressure in all sections of KA3572G01 for the duration of the entire dilution test period. Test performed in the section from 2010-01-15 to 2010-01-18.*

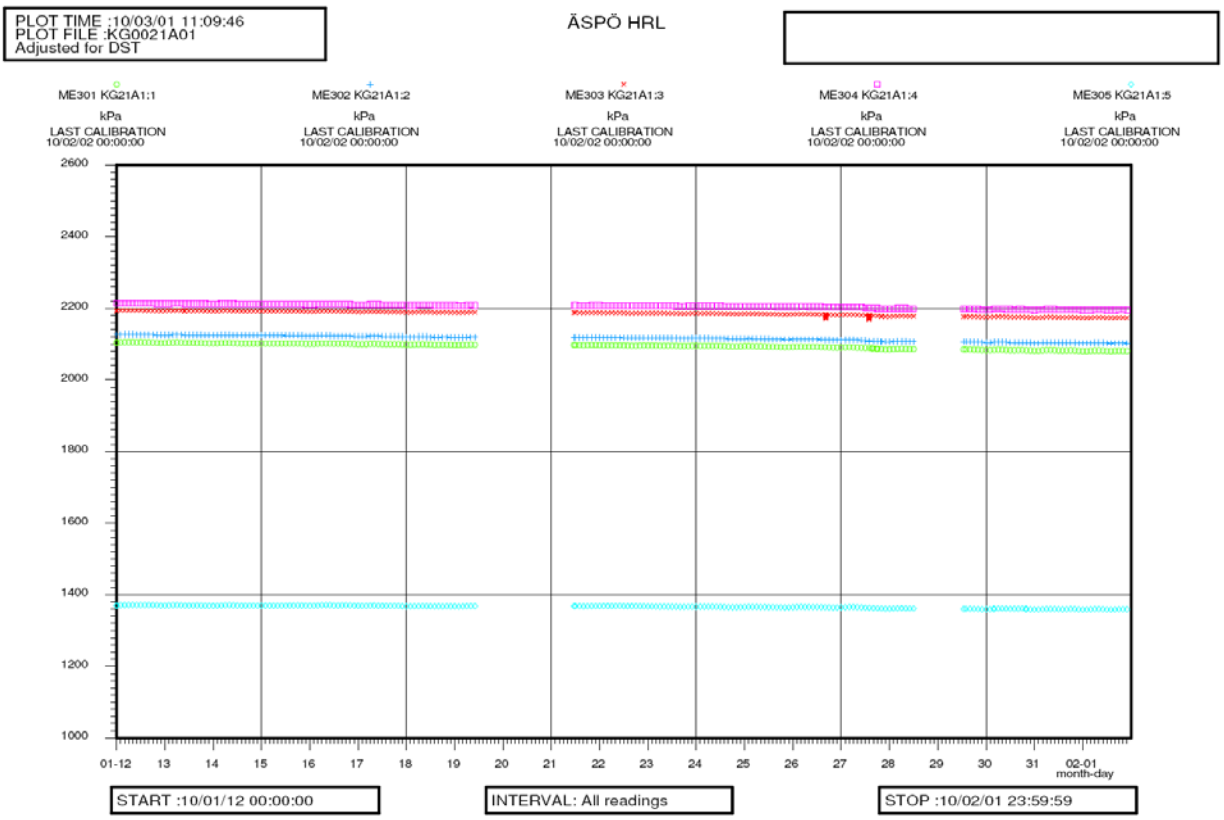


Figure A2-26. *Plot showing the pressure in all sections of KG0021A01 for the duration of the entire dilution test period. Test performed in the section from 2010-01-27 to 2010-01-28.*

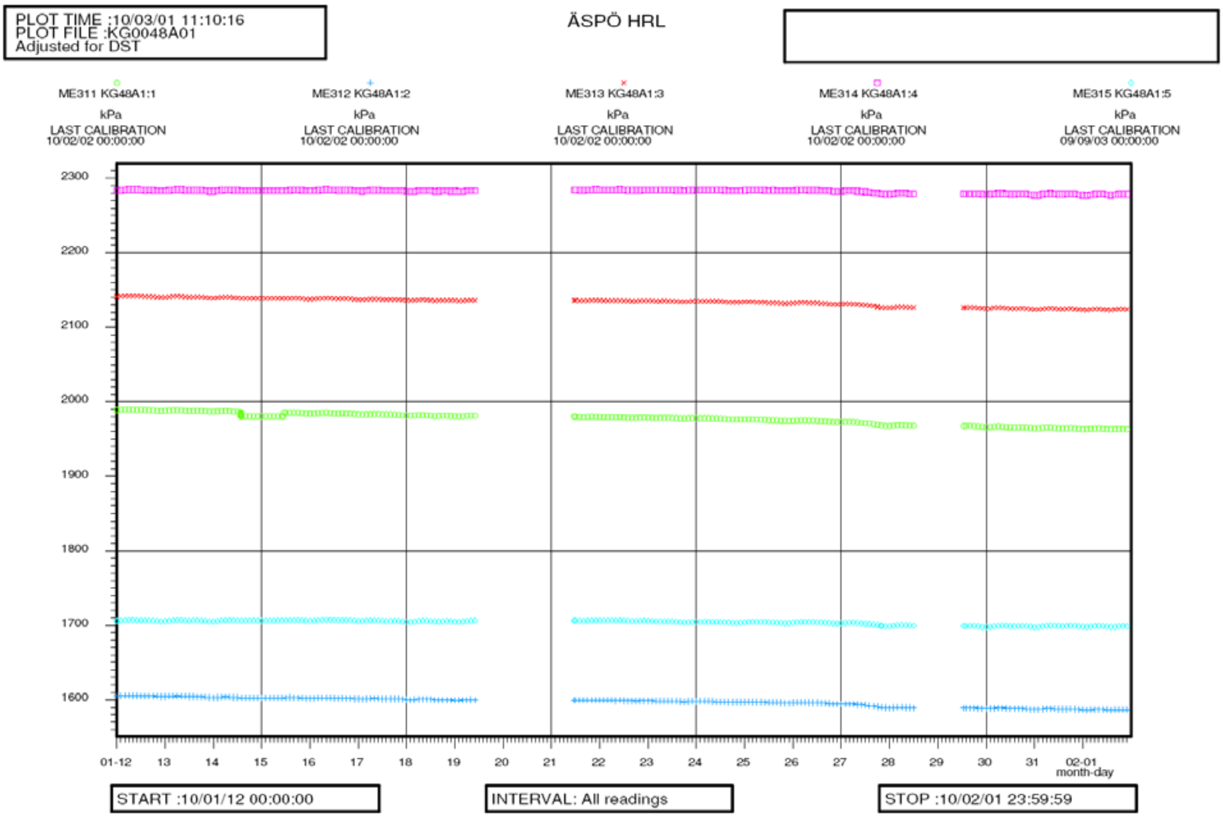


Figure A2-27. *Plot showing the pressure in all sections of KG0048A01 for the duration of the entire dilution test period. Test performed in the section from 2010-01-19 to 2010-01-20.*

Appendix 3

Volumes of borehole sections and borehole tubing

Borehole	**$V_{section}$ (dm^3)**	**V_{tubing} (dm^3)**	**V_{total} (dm^3)**
KA3539G:2	5.10	2.56	7.66
KA3542G01:3	4.84	2.84	7.68
KA3542G02:2	4.48	3.01	7.49
KA3544G01:2	5.10	2.59	7.69
KA3546G01:2	4.27	2.56	6.83
KA3548A01:3	5.80	2.49	8.29
KA3550G01:2	6.55	2.50	9.05
KA3552G01:2	4.88	2.48	7.36
KA3554G01:2	4.26	2.93	7.19
KA3554G02:4	4.97	2.63	7.60
KA3563G:4	1.29	2.49	3.78
KA3566G01:2	1.29	2.79	4.08
KA3566G02:2	1.46	2.69	4.15
KA3572G01:2	1.63	2.36	3.99
KA3574G01:3	1.54	2.55	4.09
KG0021A01:3	1.17	1.35	2.52
KG0048A01:3	1.17	1.30	2.47