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Äspö Hard Rock Laboratory

LTDE Long-Term Diffusion Experiment

Hydraulic conditions of the LTDE experimental volume – results from Pre-Tests 0.1 - 6

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November 2005

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Abstract

This report describes the performance and results of Pre-tests 0.1-6 in the LTDE (Long Term Diffusion Experiment) Project. The pre-tests have included flow-logging, pressure build-up tests, pressure interference tests and tracer tests (dilution tests and leakage tests) with non-sorbing tracers. The objective was to investigate the hydraulic conditions in the area as a preparation for the main LTDE test.

The pre-tests involved eight different test set-ups. Two tests (Test 0.1 and 0.2) were performed in autumn 2000, i.e. before borehole KA3065A03 was lengthened with the small diameter (36 mm) borehole drilled in the centre of the stub and the installation of the equipment in the borehole. These two tests were performed with the aim to locate and quantify conductive structures in the, at that time, inner section in KA3065A03 and also to provide information regarding the connectivity in the LTDE area. The other tests, Test 1-6, were executed during spring/summer 2004 when KA3065A03 was fully equipped. Three tests (Test 1, 5 and 6) were performed to investigate possible interference between LTDE-boreholes and some surrounding boreholes. The other three tests (Test 2, 3 and 4) comprised tracer dilution tests in some borehole sections to estimate natural flow rates and gradients and a tracer test to show that tracer can be recovered by establishing a sink in the pilot borehole KA3065A02 if leakage occurs from the test section in borehole KA3065A03.

The results from the interference tests show that the structures NW-2 and NW-3, surrounding the LTDE area, are most important regarding the LTDE boreholes. The openings of boreholes KA3010A (Structure NW-2) and SA3045A (Structure NW-3) gave the highest and fastest responses in the LTDE boreholes. The responses from the openings of KXTT-boreholes (TRUE-1) were quite fast, but not very high.

The natural groundwater flow, determined from dilution tests in three selected borehole sections, was about 100 ml/h for sections within Structure NW-3 and about 15 ml/h for the section within Structure NW-2. The hydraulic gradients in the area are small and the direction is towards borehole KA3067A.

The tracer test showed that it is possible to obtain a full recovery of a tracer leakage from the test section in KA3065A03 by establishing a sink in the pilot borehole KA3065A02.

Sammanfattning

Denna rapport behandlar utförandet och resultaten av Pre-test 0.1-6 inom LTDE (Long Term Diffusion Experiment) projektet. Testerna har omfattat flödesloggning, tryckuppbyggnadstester, tryckinterferenstester samt utspädningsmätningar och spårförsök/läckagetest med icke sorberande spårämnen. Syftet med testerna har varit att undersöka de hydrauliska förhållandena i området inför det huvudsakliga LTDE-försöket.

Testerna har varit uppdelade på åtta olika försök. Två tester (Test 0.1 och 0.2) utfördes hösten 2000, dvs. innan borrhål KA3065A03 förlängdes genom att smalhålet (36 mm) borrades i stubben och instrumentering gjordes. Dessa två försök fokuserade på att lokalisera och kvantifiera konduktiva strukturer i den dåvarande inre delen av KA3065A03 samt att få fram information om konnektiviteten i LTDE-området. Övriga tester, Test 1-6, gjordes under vår/sommar 2004 när KA3065A03 var färdiginstrumenterat. Tre försök (Test 1, 5 och 6) utfördes för att undersöka eventuell interferens mellan LTDE-borrhålen och några omkringliggande borrhål. De andra tre försöken (Test 2, 3 och 4) omfattade utspädningsmätningar i några borrhålssektioner för att kunna uppskatta naturliga flöden och gradienter i området samt ett spårförsök för att visa att vid ett eventuellt läckage av spårämne från testsektionen i KA3065A03 kan detta återtas genom att etablera en sänka i det närliggande pilotborrhålet KA3065A02.

Resultaten av interferenstesterna visar att zonerna/strukturerna NW-2 och NW-3 som omger LTDE-området är av stor betydelse när det gäller störningar i LTDE-borrhålen. Störst påverkan fick öppnandet av borrhålen KA3010A i struktur NW-2 samt SA3045A i struktur NW-3 då responserna i de flesta borrhålsektioner inom LTDE blev höga och snabba. Responserna från öppnandet av KXTT-borrhål (TRUE-1) var ganska snabba, men däremot inte särskilt höga.

Utspädningsmätningarna i tre borrhålssektioner gav ett naturligt flöde på ca 100 ml/h för de sektioner som omfattar struktur NW-3 respektive ca 15 ml/h för struktur NW-2. De hydrauliska gradienterna i området är små och riktningen är mot borrhål KA3067A.

Spårförsöket visade att ett fullständigt återtag av ett eventuellt läckage från testsektionen i KA3065A03 är möjligt genom att sänka av en sektion i pilotborrhålet KA3065A02.

Contents

1 Introduction

1.1 Background

Transport of radionuclides in rock fractures is presently studied within the TRUE experimental programme. Specific matrix diffusion studies will require a somewhat modified experimental approach. Based on results from laboratory experiments (Byegård et al. 1998), the expected low matrix diffusivities for different radionuclides will make it difficult to observe matrix diffusion in the ongoing and planned dynamic experiments in the TRUE programme, given the practical time constraints of the planned experiments. Hence, a static long term diffusion experiment, LTDE, is proposed (Byegård et al. 1999).

A telescoped large-diameter borehole has been drilled to intercept a target feature identified in an existing small diameter pilot borehole. The feature is packed off using a special "packer" which seals around the developed core stub, cf. Figure 2-1. In the earlier versions of test design only the stub was planned to be used for the matrix diffusion study. However, to be able to study also the diffusion in non-decompressed rock, without open fractures, a small diameter (36 mm) borehole, approximately one metre long, was drilled in the centre of the stub in October 2001. A suitable section of the small diameter borehole is packed off for tracer circulation purposes. Further, the borehole outside the stub is packed off with mechanical and inflatable packers to avoid effects of the acting hydraulic gradient.

Tracer solutions consisting of conservative and sorbing radioactive tracers will be injected and circulated in two turns; to begin with only the section around the stub will be used but in a second turn also the section in the small diameter borehole will be included. A penetration due to diffusion in the centimeter range is expected over the duration of the experiment. Subsequently, the rock volume subject to diffusion will be over-cored, sectioned and analysed for tracer activity/concentration. The in situ experimentation is supported by various types of mineralogical, geochemical and petrophysical analyses.

The LTDE site is located in the niche at tunnel section 3065 m at a depth of approximately -410 masl, see Figure 1-1 and Figure 1-2 for locations. KA3065A03 is the experimental borehole and KA3065A02 has served as exploration pilot borehole to find a suitable target structure on which to perform the experiment. Figure 1-3 is a close up of these boreholes showing the location of the target structure in KA3065A03 at a borehole length of about 10.7 m. This figure also illustrates the correlation of fractures between the two boreholes.

As a preparation for the main LTDE tests a number of pre-tests were performed to investigate the hydraulic conditions in the experimental volume.

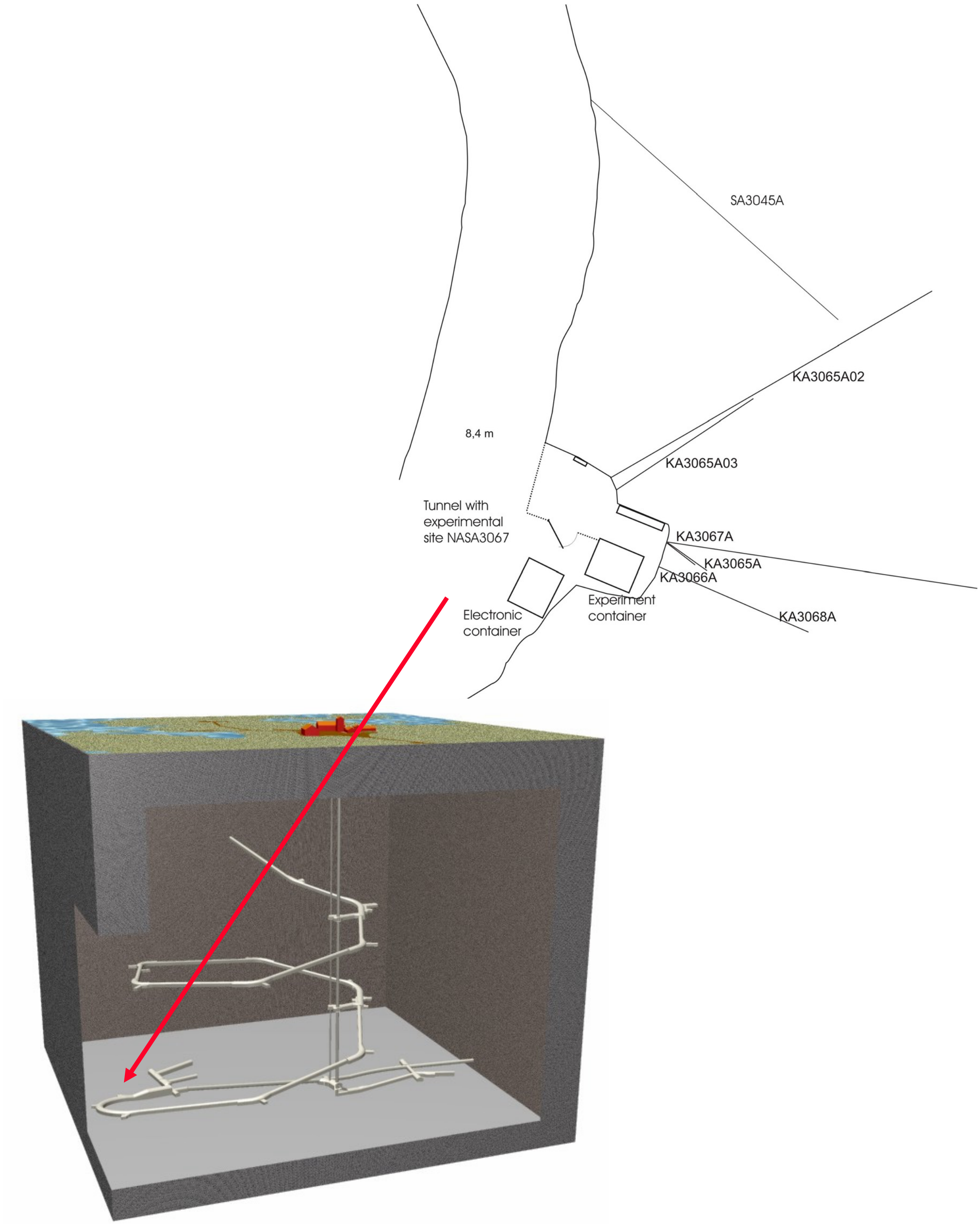


Figure 1-1. *Location of the LTDE experimental site and boreholes.*

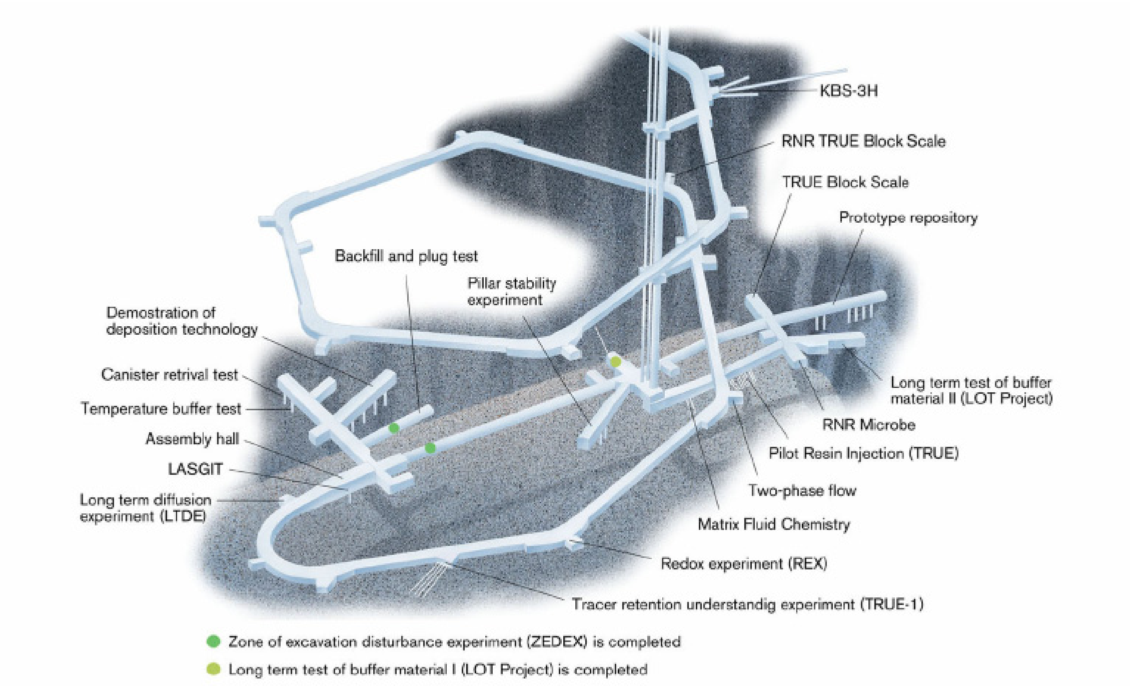


***Figure 1-2.** Location of the LTDE site relative to the other experiments in Äspö HRL.*

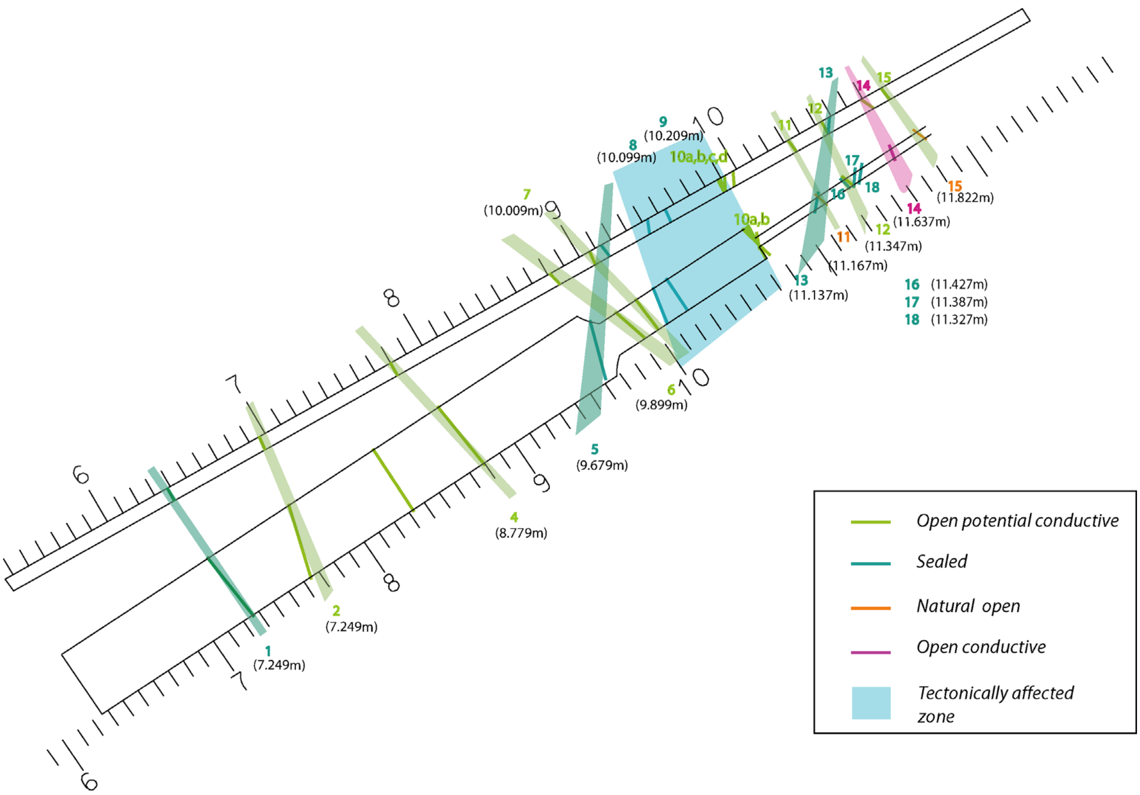


***Figure 1-3.** Visualised correlation of mapped fractures between the pilot borehole KA3065A02 and the test borehole KA3065A03 (Winberg et al., 2003).*

1.2 Objectives

The performed LTDE Pre-tests included hydraulic testing (flow logging, interference and pressure build-up tests) and tracer tests (dilution test and leakage testing) of which the objectives were to:

- locate and quantify conductive structures in the former inner section (before the 36 mm diameter borehole was drilled) in KA3065A03
- provide information regarding the connectivity in the area of KA3065A03
- estimate natural flow rates and gradients.
- show that tracer can be recovered by establishing a sink in the pilot borehole KA3065A02 if leakage occurs.
- investigate possible interference between the LTDE-boreholes and some surrounding boreholes and also the TRUE-1 boreholes.

2 Performance and evaluation procedure

2.1 Equipment and tracers used

Most of the boreholes involved in the LTDE project are instrumented with 3-4 inflatable packers isolating 3-4 borehole sections each. However, in borehole KA3068A no packers are installed, a sealing unit is mounted on the casing instead. The instrumentation in the telescoped large-diameter borehole KA3065A03 is somewhat different compared to the other boreholes. The target feature is packed off using a special "packer" which seals around the developed core stub, cf. Figure 2-1. A small diameter (36 mm) borehole, about one metre long, has been drilled in the centre of the stub and a suitable section is packed off for tracer circulation purposes. Further, the borehole outside the stub is packed off with mechanical and inflatable packers.

All isolated borehole sections are connected to the HMS-system for pressure monitoring through the PLC. In general, the sections planned to be used for tracer tests are equipped with three nylon hoses, two with an inner diameter of 4 mm and one with an inner diameter of 2 mm. The two 4-mm hoses are used for injection, sampling and circulation in the borehole section whereas the 2-mm hose is used for pressure monitoring. In borehole KA3065A03 however, the test section and the inner guard section are equipped with PEEK tubing instead of nylon hosing. The inner diameter of the PEEK tubing is 2 mm (outer diameter ⅛ inches) in the test section and ⅛ inches (outer diameter ¼ inches) in the guard section. In these sections the hoses used for pressure monitoring and circulation are of the same dimension.

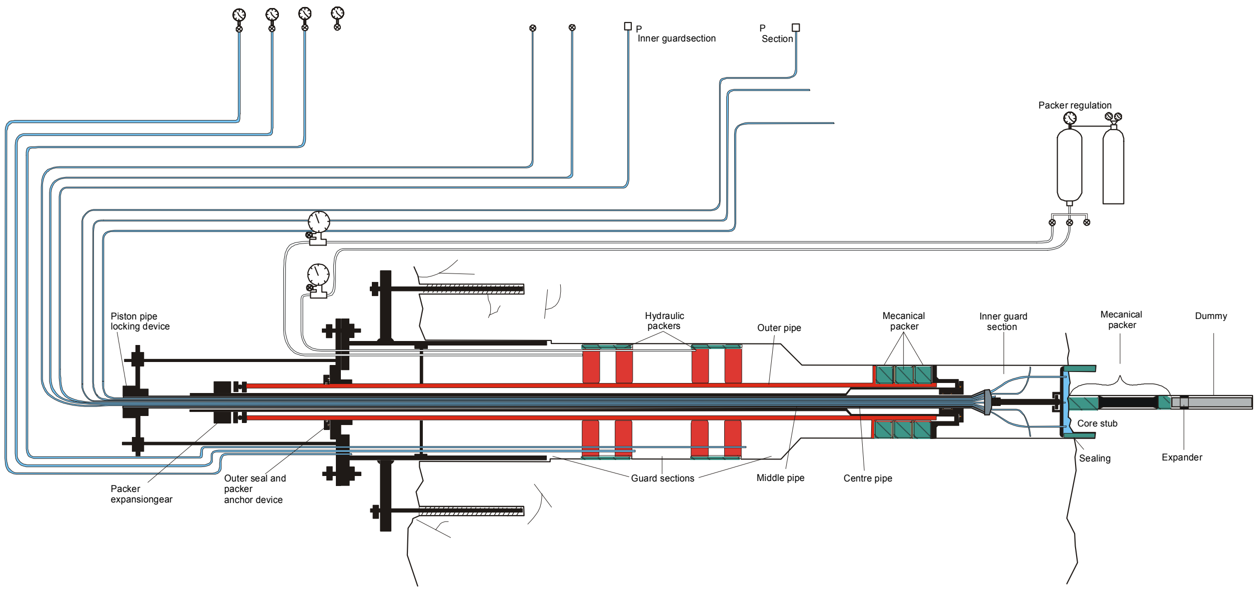


Figure 2-1. *Schematic picture of the installation in the LTDE test borehole, KA3065A03.*

The tracer dilution tests were performed using three identical equipment set-ups for tracer tests, i.e. allowing three sections to be measured simultaneously. A schematic drawing of the tracer test equipment is shown in Figure 2-2. 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 injection rate of the tracer with time, and also the dilution rate.

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). The tracer test equipment has earlier been used in the TRUE-1 and TRUE Block Scale tracer tests (e.g. Andersson et al., 2002).

The tracer used was a fluorescent dye tracer, Uranine (Sodium Fluorescein) from Merck (purum quality). This tracer has been used extensively in the TRUE-1 tracer tests and in the TRUE Block Scale tracer tests (Andersson et al., 2002).

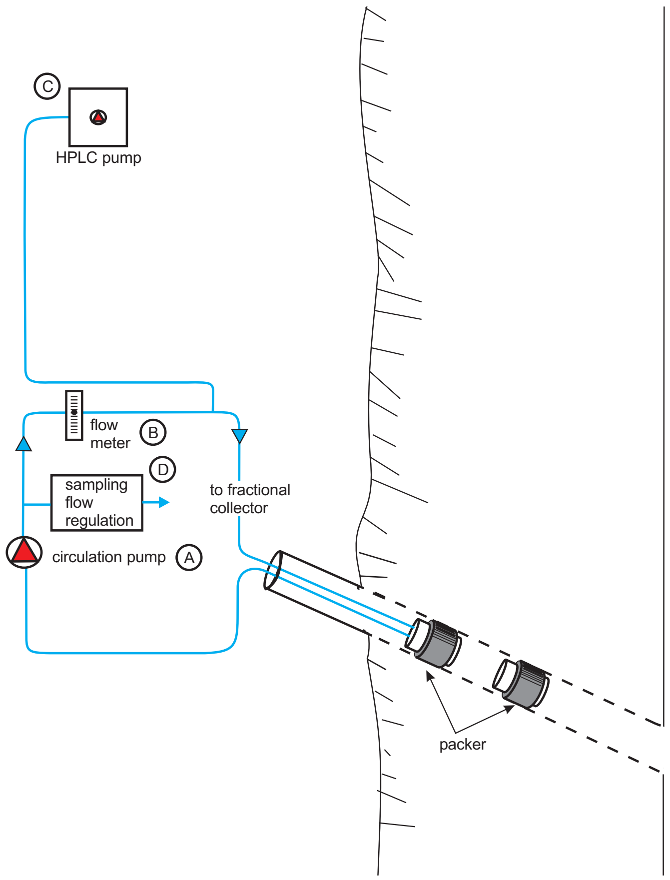


Figure 2-2. *Schematic drawing of the tracer injection/sampling system used in the LTDE Pre-tests.*

2.2 Performance of the LTDE Pre-tests

The LTDE Pre-tests were divided in eight sub-tests.

Pre-tests 0.1 and 0.2 (flow-logging and pressure build-up test in KA3065A03) were performed in October 2000, i.e. before the small diameter (36 mm) borehole was drilled in the centre of the stub and thus, also before the installation of the equipment in borehole KA3065A03.

Pre-tests 1-6 were performed during May-June 2004 with the borehole equipment installed in KA3065A03.

The LTDE Pre-tests described in this report are:

- A flow-logging test and a pressure build-up test (Pre-test 0.1 and 0.2) in KA3065A03 performed before the small diameter borehole was drilled in the centre of the stub. Flow logging in the small diameter borehole was later performed in another test, not within the frames of these Pre-tests. A brief summary is given in Chapter 3.1. The results are further presented in Gentzschein, 2001.
- A short-term interference test performed in order to study the pressure responses in the guard and test sections when some neighbouring borehole sections were opened (Pre-test 1). The evaluation of this test also included evaluation of pressure responses from installation tests performed during 2003 (pressure build-up test performed in the test section and pressure registration during excavation of the new tunnel TASQ and of the niche NASA1619A and the subsequent drilling of boreholes in these areas).
- Dilution tests and tracer test using fluorescent dyes (Pre-test 2, Pre-test 3 and Pre-test 4). The purpose was to estimate the natural flow and hydraulic gradients and also to investigate if tracer could be recovered in the pilot borehole KA3065A02 if leakage occurs.
- Major interference and pressure response tests (Pre-test 5 and Pre-test 6).

Experience from different parts of the pre-tests will be of importance for the final site installation of all experimental equipments.

2.2.1 Pre-test 0.1 – Flow logging in KA3065A03

Flow logging was performed in the inner section of borehole KA3065A03 using a hydraulic packer, a Petrometallic packer 0.5 m. The packer was lowered with 33 mm stainless steel tubes connected to the section below the packer. The equipment is shown in Figure 2-3. Measurements were made in intervals of 0.05 m from about 0.3 m from the stub to about 0.7 m. Flow measurements were made both from the inner section below the packer and from the borehole casing with graduated vessels.

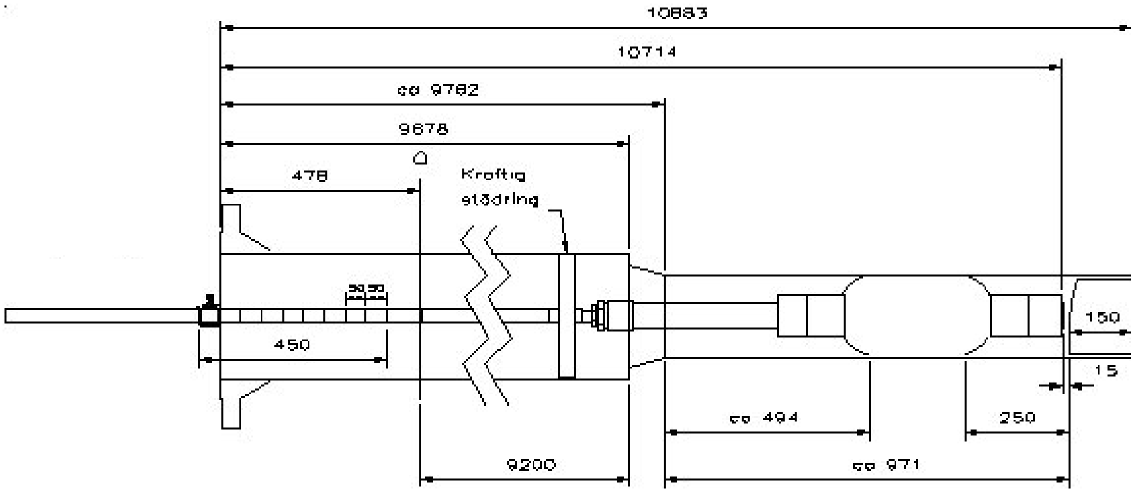


Figure 2-3. *Flow logging equipment used in the LTDE Pre-test 0.1.*

2.2.2 Pre-test 0.2 – Pressure build-up test in KA3065A03, entire borehole

The flow from borehole KA3065A03 was measured and the borehole was thereafter sealed with a steel lid. The pressure build-up in KA3065A03 was registered together with the pressure in boreholes HA1960A, KA1755A, KA2048B, KA2050A, KA2162B, KA2858A, KA2862A, KA3005A, KA3010A, SA3045A, KA3065A, KA3065A02, KA3066A, KA3067A, KA3068A, KA3105A, KA3110A, KTTT2-KXTT5, HAS06 and KAS16.

The pressure responses were registered in the Äspö Hydro Monitoring System (HMS). Boreholes SA3045A, KA3065A, KA3065A02, KA3065A03, KA3066A and KA3068A were at the time not yet connected to the HMS and the pressure registrations in these boreholes were monitored with field loggers.

2.2.3 Pre-test 1 - Short-term interference test

This test was performed to see how the test and guard sections in borehole KA3065A03 respond when some neighbouring borehole sections, KA3065A02:P3 and KA3067A:P3, respectively, are opened.

The withdrawal flow was established by opening the circulation tubes to the borehole section using the maximum sustainable flow rate. The dimension of the tubing and the hydraulic transmissivity of the section then only restricted the flow.

The pressures in the borehole sections were monitored with a high measurement frequency by the Äspö Hydro Monitoring System (HMS). Flow rates from the sink section were measured manually during the pumping phase after 1, 5, 10, 20, 30 and 60 minutes of pumping. The duration of the pumping phase was one hour.

2.2.4 Pre-test 2 - Dilution tests

Tracer dilution tests were performed under natural gradient, i.e. prevailing steady-state hydraulic gradient conditions, in borehole sections KA3065A02:P3, KA3067A:P3 and SA3045A:P2.

The tests were made by injecting a slug of tracer in the selected borehole sections and allowing the natural groundwater flow to dilute the tracer. All three sections were injected simultaneously. The tracer solution was continuously circulated and sampled using the equipment described above. The samples were analysed for dye tracer content at the Geosigma Laboratory using a Jasco FP 777 Spectrofluorometer. The duration of each test was about 24 hours.

2.2.5 Pre-test 3 - Tracer/leakage test - without sink

Tracer was injected in borehole section KA3065A03:P2 (inner guard section) during circulation of the section volume. The tracer injection was made as a decaying pulse injection, i.e. injection of a tracer pulse in a re-circulating system without excess pressure. A simple and reasonable assumption is that the amount of tracer that leaves the injection section (and into the transport part) is proportional to the tracer concentration in the injection section. Samples were continuously withdrawn both from the injection section and from the surrounding borehole sections KA3065A02:P3 and SA3045A:P2. The natural flow through KA3065A03:P2 was also determined.

2.2.6 Pre-test 4 - Tracer/leakage test - with sink

Tracer was injected in borehole section KA3065A03:P2 in the previous Test 3. The tracer concentration remaining in the injection section was found to be sufficiently high also for this test, why the tracer injection was not repeated. A week after the injection a sink was established in KA3065A02:P3 using maximum possible flow (7.2 l/min). The dimension of the tubing and the hydraulic transmissivity of the section then only restricted the flow. Sampling was continued in borehole sections KA3065A03:P2, KA3065A02:P3 and SA3045A:P2.

2.2.7 Pre-test 5 and Pre-test 6 - Major interference tests

These tests were performed with the aim to study pressure responses in KA3065A03 from opening in sequence some surrounding boreholes and also some of the TRUE-1 boreholes, simulating failure of packer inflation and accidental opening of boreholes. The TRUE-1 boreholes are of special interest since there are planned to be activities in these boreholes during the performance of the LTDE experiment, if possible.

The pressures in the borehole sections were monitored with a high measurement frequency by the Äspö Hydro Monitoring System (HMS). Flow rates from the sink section were measured manually during the pumping phase after 1, 5, 10, 20, 30 and 60 minutes of pumping and at regular intervals thereafter. The borehole was open for 60 minutes. The sinks used in the interference tests are presented in Table 2-1. See also Figure 1-2 and Figures 2-4 to 2-6 for location of the sinks relative to the LTDE test borehole KA3065A03.

Structural models of the areas around LTDE and TRUE-1 are shown in Figures 2-4 to 2-6. Unfortunately no updated model covering both the LTDE and TRUE-1 sites was available why some older ones are presented. In the overview model in Figure 2-4 the TRUE-1 site, situated at tunnel length 2950 m, is not present. A close-up of the TRUE-1 rock volume could be seen in Figure 2-6. Also, no LTDE-boreholes except KA3067A are shown in Figure 2-4, why a close-up of the LTDE area is presented in Figure 2-5. However, in Figure 2-5 the structure NW-2, important for LTDE, is missing, and so is borehole KA3068A (see Figure 1-1 for location). Note also that the structure called NNW-4w in Figure 2-4 and Figure 2-5 is called NNW-4 in Figure 2-6.

Figure 2-4 shows that two structures are of special interest for the LTDE area, Structure NW-3 and Structure NW-2. The latter is also connected with Structure NW-2´at the TRUE-1 site (Figure 2-6).

Table 2-1. Sinks used in LTDE Pre-tests 5 and 6.

Borehole:section	Sink established by:	Structure/ Feature	Distance to KA3065A03:1+2 (m)	Flow rate (l/min)
KA3110A	Packer release	NNW-4	76.7	5.5
KA3010A	Packer release	NW-2	46.7	26.5
SA3045A:P1+P2	Opening of circulation tubes	NW-3	10.0	8.0
KA3067A:P2+P3	Opening of circulation tubes	NW-2?	28.7	6.4
KXTT3:R2	Opening of circulation tubes	A	114.4	3.6
KXTT5	Packer release	NW-2´, A, B, D	114.1	100

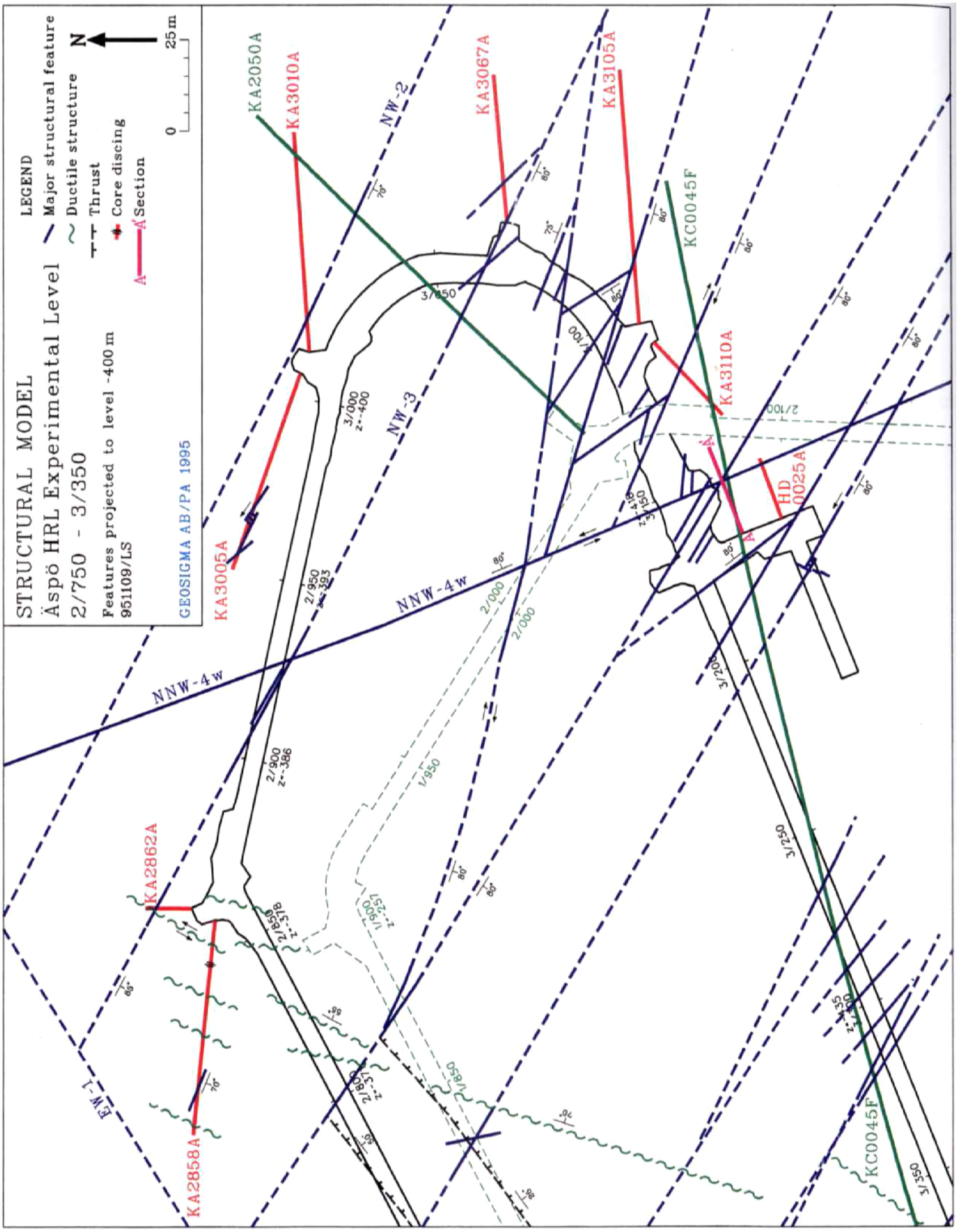


__Figure 2-4.__ Structural map of the experimental level (Z=-400 m). Compiled from results presented by Winberg et al., 1996.

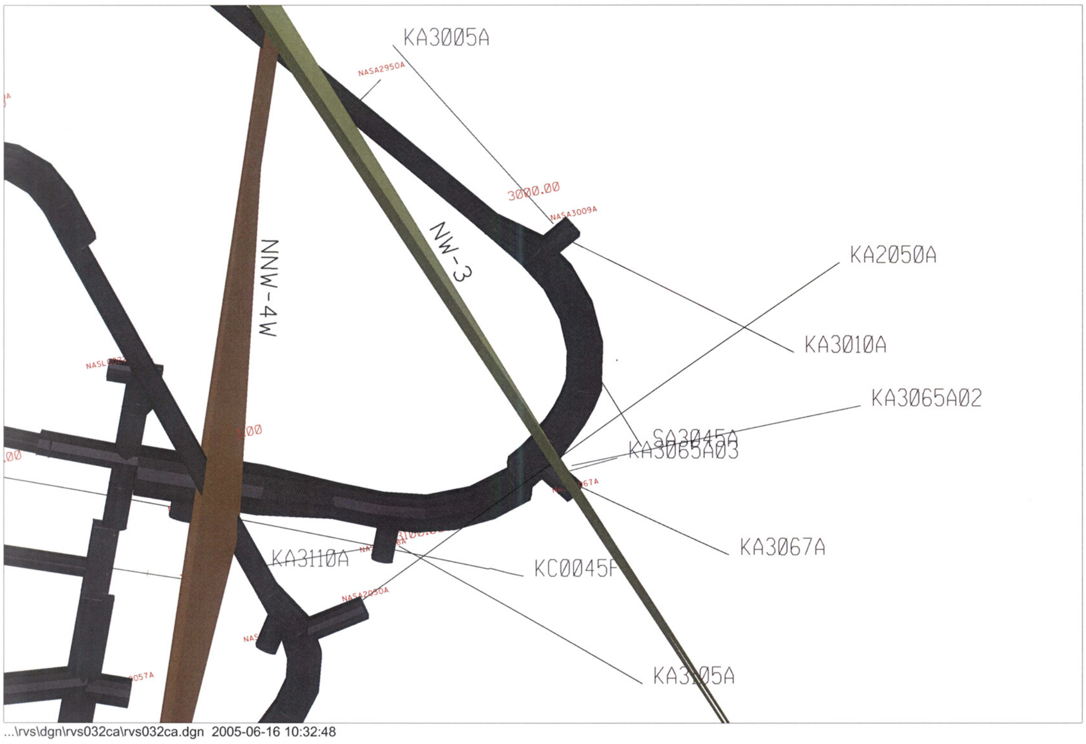


***Figure 2-5.** 3-D structural model showing the identified structures in the LTDE area.*

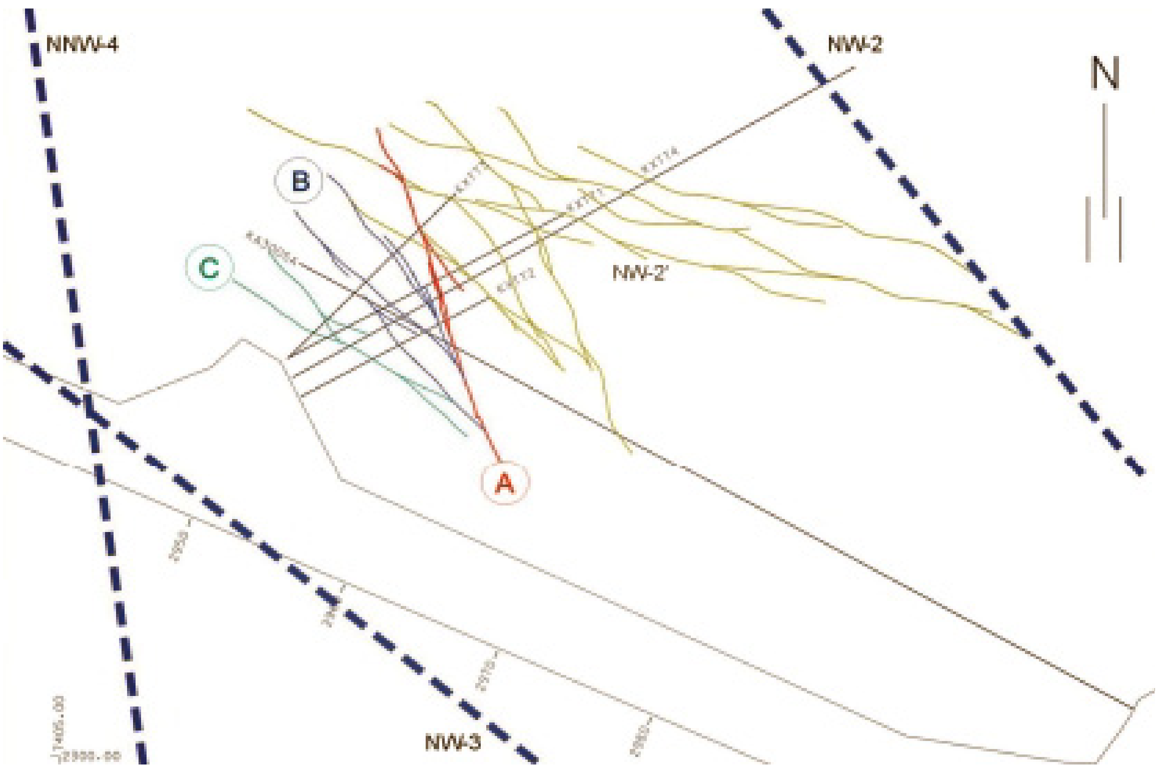


***Figure 2-6.** Horizontal section at Z=-400 masl showing structural model based on identified conductive geological structures in the TRUE-1 rock volume (Winberg et al., 2000).*

2.3 Evaluation

2.3.1 Hydraulic interference tests

The evaluation involves preparation of pressure response diagrams for each test and a common pressure response matrix for all tests.

Time-drawdown (and recovery) plots were prepared for borehole sections showing a total drawdown of more than s_p=0.1 m (1 kPa) at stop of the flow period. This threshold pressure was chosen with consideration of the amplitude of the tidal effects in the boreholes which may be in the order of 1-5 kPa. From these plots, the response times (t_R) for each section were estimated. The response time is here defined as the time after start of pumping when a drawdown (or recovery) of 1 kPa is observed (from the logarithmic plots) in the observation section. The qualitative evaluation has mainly been made on data from the drawdown phase. Data from the recovery phase were used only as supporting data.

On the X-axis of the pressure response diagrams (Figure 3-10 to Figure 3-15), the ratio of the response time (t_R) and the (squared) straight-line distance R between (the midpoint of) the sink section and (the midpoint of) each observation section (t_R/R^2) is plotted. The latter ratio is inversely related to the hydraulic diffusivity of the rock, which indicates the speed of propagation in the rock of the drawdown created in the pumping section.

The final drawdown at stop of pumping (s_p) in the observation sections was determined from the drawdown data. To account for the different flow rates used in the tests and to make the pressure response plots comparable between tests, the final drawdown is normalised with respect to the final flow rate (Q). The ratio s_p/Q is plotted on the Y-axis of the pressure response diagrams.

From the response plots of s_p/Q versus t_R/R^2 for each test, sections with anomalous, fast response times (high hydraulic diffusivity) and large (normalised) drawdown can be identified. Such sections, showing primary responses, can be assumed to have a distinct hydraulic connection to the sink section and may be intersected by a single fracture; fracture zones or other conductive structures in the rock. On the other hand, sections with delayed and weak (secondary) responses may correspond to sections in the rock mass between such structures.

From the calculated values of s_p/Q (index 1) and t_R/R^2 (index 2) for each observation section during each test, a common pressure response matrix showing the response patterns for all tests, was prepared by classifying the pressure responses by means of the above indexes 1 and 2. For index 1, the following class limits and associated drawdown characteristics were used:

Index 1 (s_p/Q)

$s_p/Q > 1 \cdot 10^5$ s/m^2	Excellent (Red)
$3 \cdot 10^4 < s_p/Q \leq 1 \cdot 10^5$ s /m^2	High (Yellow)
$1 \cdot 10^4 < s_p/Q \leq 3 \cdot 10^4$ s /m^2	Medium (Green)
$s_p/Q \leq 1 \cdot 10^4$ s /m^2	Low (Blue)

For index 2 the following class limits and associated response characteristics were used:

Index 2 (t_R/R^2)

$t_R/R^2 < 0.01$ s/m^2	Excellent (E)
$0.01 \le t_R/R^2 < 0.1$ s/m^2	Good (G)
$0.1 \le t_R/R^2 < 0.3$ s/m^2	Medium (M)
$t_R/R^2 \ge 0.3$ s/m^2	Bad (B)

It should be pointed out that the response diagrams of s_p/Q versus t_R/R^2 described above were only used as diagnostic tools to identify the most significant responses during each test and to construct the pressure response matrix. The diagrams should be used with some care since the true actual distances (along pathways) between the sink and observation sections are uncertain, which may affect the position of a certain point (i.e. section) in the horizontal direction in the diagrams. However, in most cases, the shortest (straight-line) distance between the sink and observation section, as used here, is considered as a sufficient and robust approximation for the above purpose.

Another potential source of error in the response diagrams may occur if (internal) hydraulic interaction exists between sections along an observation borehole. For example, such interaction could either be due to packer leakage (insufficient packer sealing) or leakage in the rock through interconnected fractures around the packers. This fact may give rise to a false impression that good hydraulic communication exists between such observation sections and the actual source section. However, any analysis method will suffer from this potential source of error.

2.3.2 Tracer dilution tests

Flow rates were calculated from the decay of tracer concentration versus time through dilution with natural unlabelled groundwater, c.f. Andersson et al. (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 (t):

$$\ln (c/c_0) = -(Q_{bh}/V) \cdot \Delta t \qquad (2\text{-}1)$$

where Q_{bh} (m^3/s) is the groundwater flow rate through the borehole section and V (m^3) is the volume of the borehole section. By plotting $\ln (c/c_0)$ versus t, and by knowing the borehole volume V, Q_{bh} may then be obtained from the straight-line slope.

2.3.3 Tracer / leakage test

Tracer mass recovery was calculated for the flow path KA3065A03:P2 → KA3065A02:P3. Before the injection a sample of the stock solution was taken and the tracer solution vessel was weighed. After the injection the vessel was weighed again and the tracer concentration of the stock solution sample was measured to determine the injected mass. The tracer mass recovered in the pumping borehole section was determined by integration of the breakthrough curves for mass flux (mg/h) versus time (h).

3 Results and interpretation

No major hydraulic disturbance due to other activities occurred during the Pre-tests and the equipment and test procedure worked well. A Log of events for the test period, Test-0.1 to Test-6, is presented in Table 3-1.

Table 3-1. Log of events.

Date	Time	Event
001024		**Pre-test 0.1, Flow logging in KA3065A03**
001026		**Pre-test 0.2, Pressure build-up test in KA3065A03**
		Pre-test 1, Short-term interference test
040512	09:10	Disconnecting pressure transducer in KA3065A03:P1 from tubing to the pressure regulator, connecting it to monitoring section pressure.
	13:23	Closing the short-cut between section 1 and 2 in KA3065A03.
040513	09:05	Start pumping KA3067A:P3, Q=5.5 l/min.
	10:06	Stop pumping KA3067A:P3.
	11:35	Start pumping KA3065A02:P3, Q=9.0 l/min.
	12:37	Stop pumping KA3065A02:P3.
	13:29	Disconnecting pressure transducer in KA3065A03:P1 from monitoring section pressure, connecting it to tubing to the pressure regulator.
	13:29	Opening the short-cut between section 1 and 2 in KA3065A03.
		Pre-test 2, Dilution tests
040526	08:40	Start tracer dilution test in KA3065A02:P3, natural gradient.
	11:25	Start tracer dilution test in KA3067A:P3, natural gradient.
	12:02	Start tracer dilution test in SA3045A:P2, natural gradient.
040527	09:55	Stop tracer dilution test in KA3067A:P3.
	10:07	Stop tracer dilution test in SA3045A:P2.
	10:20	Stop tracer dilution test in KA3065A02:P3.
		Pre-test 3, Tracer/leakage test, without sink
040602	17:05	Closing the short-cut between section 1 and 2 in KA3065A03.
040603	09:35	Start sampling KA3065A02:3 and SA3045A:P2.
	09:45	Start tracer injection and sampling in KA3065A03:P2.
	10:45	Stop tracer injection in KA3065A03:P2.

Date	Time	Event
		Pre-test 4, Tracer/leakage test, with sink
040610	09:30	Start pumping KA3065A02:P3, Q=7.2 l/min.
040618	13:30	Stop sampling KA3065A02:P3.
	13:35	Stop sampling KA3065A03:P2.
	13:50	Stop sampling SA3045A:P2.
	14:10	Stop pumping KA3065A02:P3.
		Pre-test 5 and Pre-test 6, Major interference tests
040629	09:30	Packer release in KA3110A, Q=5.5 l/min.
	10:32	Packer expansion in KA3110A
	12:15	Packer release in KA3010A, Q=26.5 l/min.
	13:17	Packer expansion in KA3010A.
	15:00	Open flow lines in SA3045A:P1+P2, Q=8.0 l/min.
	16:02	Close flow lines in SA3045A:P1+P2
040630	08:45	Open flow lines in KXTT3:R2, Q=3.6 l/min.
	09:47	Close flow lines in KXTT3:R2
	11:30	Packer release in KXTT5, Q=100 l/min.
	12:31	Packer expansion in KXTT5
	14:30	Open flow lines in KA3067:P2+P3, Q=6.4 l/min.
	15:31	Close flow lines in KA3067:P2+P3

3.1 Pre-test 0.1 – Flow logging in KA3065A03

This test was performed in October 2000, i.e. before the small diameter (36 mm) borehole was drilled in the centre of the stub and thus, also before the installation of the equipment in borehole KA3065A03.

The result is presented in Table 3-2. It shows that a significant increase in flow from the measured section occurs at a borehole length between 10.333 m and 10.133 m from the casing. The total flow from the borehole is changing due to the tightening of conductive fractures at different packer positions. In Figure 1-3 the mapped fractures in the borehole are shown.

Table 3-2. LTDE Pre-test 0.1 – Results from flow logging in KA3065A03. The distances are given in metres from metal casing top.

Packer position (m)	Secup (m)	Seclow (m)	Q_{pipe} (ml/min)	ΔQ_{pipe} (ml/min)	Q_{casing} (ml/min)	Q_{total} (ml/min)
10.256-10.483	10.483	10.883	355	-	9990	10345
10.206-10.433	10.433	10.883	375	20	9907	10282
10.156-10.383	10.383	10.883	462.5	87.5	9838	10300.5
10.106-10.333	10.333	10.883	487.5	25	8898	9385.5
10.056-10.283	10.283	10.883	1496	1008.5	7030	8526
10.006-10.233	10.233	10.883	3134	1638	5071	8205
9.956-10.183	10.183	10.883	5686	2552	3082	8768
9.906-10.133	10.133	10.883	10096	4410	323	10419
9.856-10.083	10.083	10.883	10279	183	235	10514

Flow logging in the small diameter borehole was performed in another test, not within the frames of these Pre-tests. Measurements were made in three intervals/sections using a single-packer equipment. The flow in all three measured sections was similar, about $2.6 \cdot 10^{-5}$ l/min, indicating that the conductive fracture was located behind the inner packer position. A probable candidate is the fracture 11.637 m from top of casing, cf. Figure 1-3. When section P3 in the pilot borehole KA3065A02 was opened the flow was reduced by about 20 %. This indicates that the inner part of the 36 mm borehole in KA3065A03 is hydraulically connected to KA3065A02:P3. The opening of A02:P3 also gave responses in a number of borehole sections within and outside the LTDE site. The performance and results are further presented in Gentzschein, 2001.

3.2 Pre-test 0.2 – Pressure build-up test in KA3065A03

This test was performed in October 2000, i.e. before the small diameter (36 mm) borehole was drilled in the centre of the stub and thus, also before the installation of the equipment in borehole KA3065A03.

The pressure response matrix for Pre-test 0.2 is shown in Table 3-3. The colours and letters coding refers to the two indexes s_p/Q (drawdown normalised to pumping rate) and t_R/R^2 (response time normalised to the distance squared) according to Chapter 2.3.1. The result is also presented in Figure 3-1 as a diagnostic plot. The flow rate from KA3065A03 measured before the borehole was sealed was 10.1 l/min.

Pressure responses (>1 kPa) were registered in 53 of 66 sections monitored. The distances were ranging between 1.1 and 420 m. The highest responses were seen in some of the LTDE borehole sections while the fastest responses occurred in boreholes KA2050A, KA3010A, KXTT2-5 and in the surface borehole HAS06.

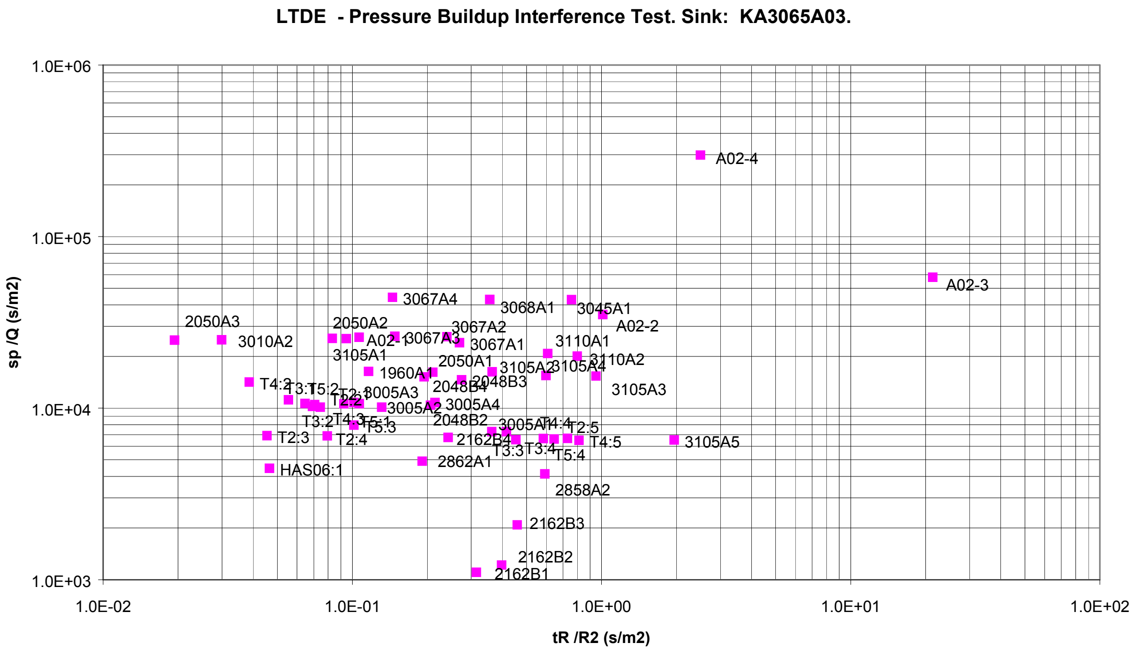
Table 3-3. Pressure response matrix for LTDE Pre-test 0.2

LTDE Pre-test 0.2 - Pressure build-up interference test. Source: KA3065A03.

Borehole	Interval (m)	R (m)		
KA1755A:P1	231-320.6	114		
KA1755A:P2	161-230	70		
KA1755A:P3	88-160	68		
KA1755A:P4	6-87	83		
HA1960A:P1	4-32	190	M	
KA2048B:P1	149.5-184.45	240	?	tight?
KA2048B:P2	100-148.5	209	M	
KA2048B:P3	50.5-99	181	M	
KA2048B:P4	5-49.5	162	M	
KA2050A:P1	155-211.57	52	M	
KA2050A:P2	102-154	39	G	
KA2050A:P3	6-101	98	G	
KA2162B:P1	201.5-288.1	360	B	
KA2162B:P2	143-200.5	301	B	
KA2162B:P3	80.5-142	258	B	
KA2162B:P4	40-79.5	228	M	
KA2858A:P2	39.77-40.77	218	B	
KA2862A:P1	7.37-15.98	206	M	
KA3005A:P1	51.03-58.11	115	B	
KA3005A:P2	46.78-50.03	109	M	
KA3005A:P3	44.78-45.78	106	M	
KA3005A:P4	39.03-43.78	103	M	
KA3010A:P2	8.56-15.06	53	G	
SA3045A:P1	5.8-20.7	7.7	B	
KA3065A:P1	1-3	10.7		
KA3065A02:P1	21-69.95	36	M	
KA3065A02:P2	14-20	7.7	B	
KA3065A02:P3	7.5-13	1.1	B	
KA3065A02:P4	4-6.5	4.1	B	
KA3066A:P1	1-2.15	10.7		
KA3067A:P1	34.55-40.05	35	M	
KA3067A:P2	30.55-33.55	30	M	
KA3067A:P3	28.05-29.55	27	M	
KA3067A:P4	6.55-27.05	16	B	
KA3068A:P1	1-16.85	12	M	
KA3105A:P1	53.01-68.95	57	G	
KA3105A:P2	25.51-52.01	48	B	
KA3105A:P3	22.51-24.51	47	B	
KA3105A:P4	17.01-19.51	49	B	
KA3105A:P5	6.51-16.01	51	B	
KA3110A:P1	20.05-28.63	86	B	
KA3110A:P2	6.55-19.05	75	B	
KXTT2:P1	16.55-18.3	108	G	
KXTT2:P2	14.55-15.55	109	G	
KXTT2:P3	11.55-13.55	109	G	
KXTT2:P4	7.55-10.55	110	G	
KXTT2:P5	3.05-6.55	111	B	
KXTT3:P1	15.42-17.43	114	G	
KXTT3:P2	12.42-14.42	114	G	
KXTT3:P3	8.92-11.42	114	B	
KXTT3:P4	3.17-7.92	115	B	
KXTT4:P2	14.92-49.31	108	G	
KXTT4:P3	11.92-13.92	110	G	
KXTT4:P4	8.42-10.92	111	B	
KXTT4:P5	3.17-7.42	112	B	
KXTT5:P1	10.81-25.8	114	M	
KXTT5:P2	9.61-9.81	114	G	
KXTT5:P3	6.11-8.61	114	M	
KXTT5:P4	5.11-3.11	114	B	
HAS06:P1	57-100	348	G	
HAS06:P2	0-56	396		
KAS16:P3	121-389	264	?	trend?

INDEX 1=sp/Q
- EXCELLENT
- HIGH
- MEDIUM
- LOW
- NO RESPONSE

INDEX 2=tr/R2
- **E**=EXCELLENT
- **G**=GOOD
- **M**=MEDIUM
- **B**=BAD



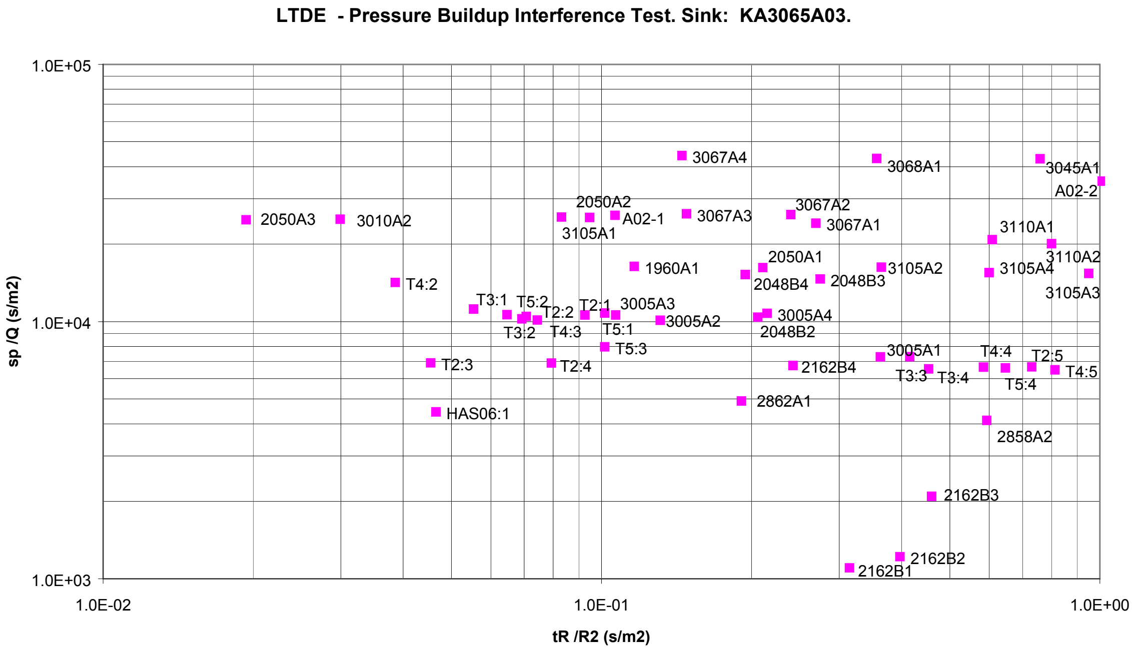


Figure 3-1. *Diagnostic plot of pressure responses during LTDE Pre-test 0.2 from pressure build-up in borehole KA3065A03. The plot below is a close-up of the one above.*

3.3 Pre-test 1 - Short term interference test

The pressure (kPa) in borehole KA3065A03 during Pre-test 1 is shown in Figure 3-2. The neighbouring borehole sections KA3067A:P3 and KA3065A02:P3 were opened during one hour respectively (cf. Table 3-1 for accurate time) and responses were monitored in the borehole sections in KA3065A03. Section 1 (test section) and section 2 (inner guard section) are of special interest for the forthcoming LTDE experiment. Section 5 is not shown in the Figure or included in the evaluation due to leakage at the casing.

During the first pumping phase when KA3067A:P3 was opened at 09.05 hours the withdrawal rate was 5.5 l/min. The distances to the different sections in KA3065A03 were ranging between 26 and 29 m with the shortest distance to section 1. The magnitude of the hydraulic responses in KA3065A03 was 15-35 kPa and section 1 (test section) showed the highest response.

The pumping from KA3065A02:P3 was started at 11.35 hours with a flow rate of 9.0 l/min. The distances to the different sections in KA3065A03 were ranging between 0.5 and 4.5 m with the shortest distance to section 1. The magnitude of the hydraulic responses in KA3065A03 was 85-230 kPa and section 1 (test section) together with section 2 (inner guard section) showed the highest responses.

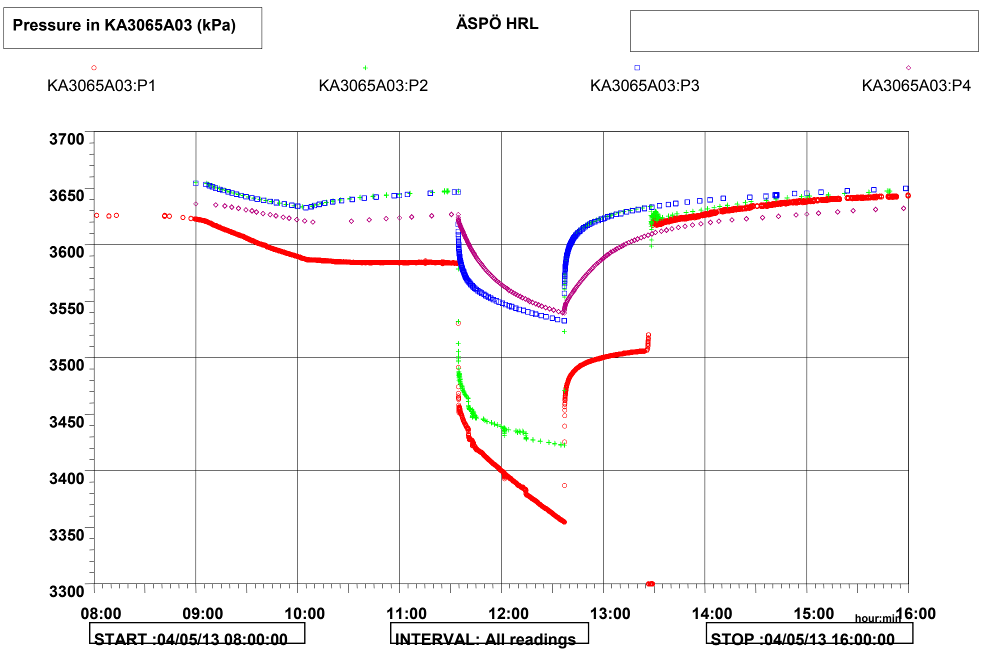


Figure 3-2. *Pressure (kPa) in borehole KA3065A03 during LTDE Pre-test 1, 2004-05-13.*

It is also of interest to investigate how the experimental set-up and test section respond to disturbances such as sudden increase in hydraulic pressure in the test section or drilling and blasting for other experiments at the Äspö HRL.

In Figure 3-3 the pressure in the test and guard sections in borehole KA3065A03 during a pressure build-up test performed in an earlier installation test is shown. This test was performed in March 2003 by injecting a small amount of water (some millilitres) in the test section increasing the pressure about 5 bar. The following pressure decrease was monitored and after about six days the pressure in the test section was back to the initial level. Laboratory tests of the polyurethane and PEEK packer, which seals around the core stub and separates the test section from the inner guard section, showed that the equipment withstands an excess pressure of 0.6 MPa (=6 bar) in the test section without leakage. The pressure decrease is therefore considered to be due to diffusion of water into the rock matrix and micro-fractures.

The pressure registration in borehole KA3067A, representing the LTDE-boreholes, during excavation of the tunnel TASQ and of the niche NASA1619A and the subsequent drilling of boreholes in these areas from April to October 2003 are presented in Figure 3-4. The response seen in all sections in KA3067A occurring 2003-06-25 is due to closing of borehole sections 1-3 in KA3065A03. The short drawdown 2003-09-15 in KA3067A:4 is caused by water sampling in borehole SA3045A. No major disturbances due to blasting or drilling can be seen. There are slow long-term pressure variations over the period but this is most probably due to a seasonal effect. KA3067A was the only borehole in the LTDE area where pressure data is available during this period. Since the LTDE boreholes are responding similar to different disturbances it is concluded that also the test borehole KA3065A03 was mainly unaffected by the blasting and drilling activities.

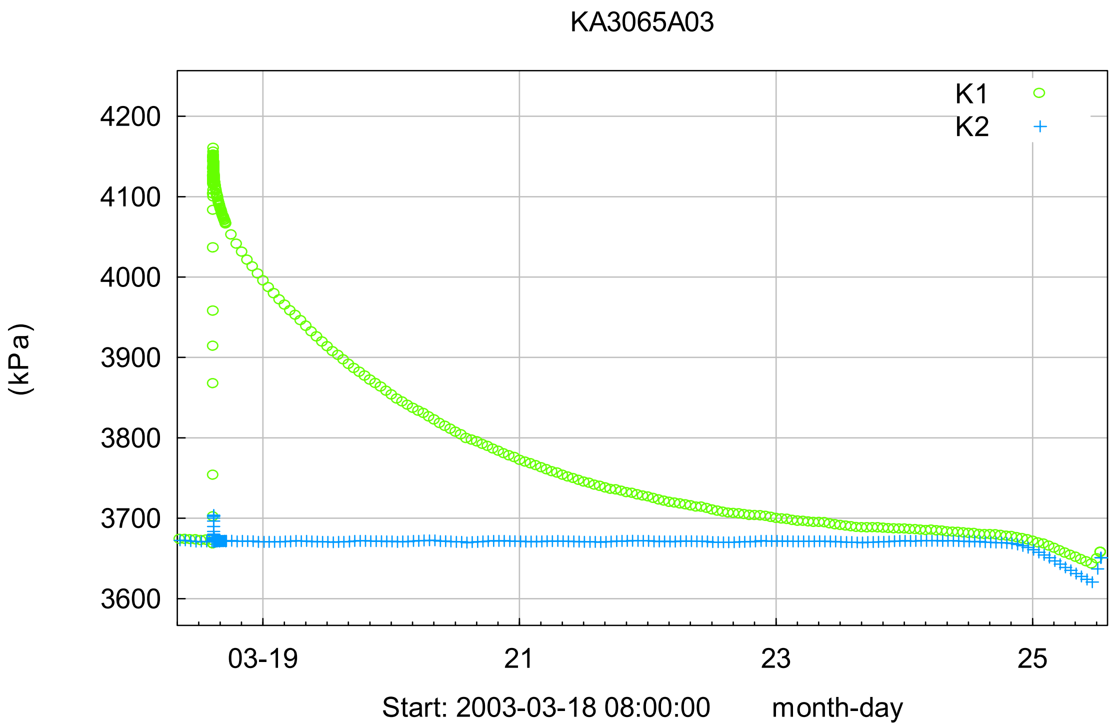


Figure 3-3. *Pressure (kPa) in borehole KA3065A03, test section (green) and guard section (blue), during pressure build-up test in test section 2003-03-18.*

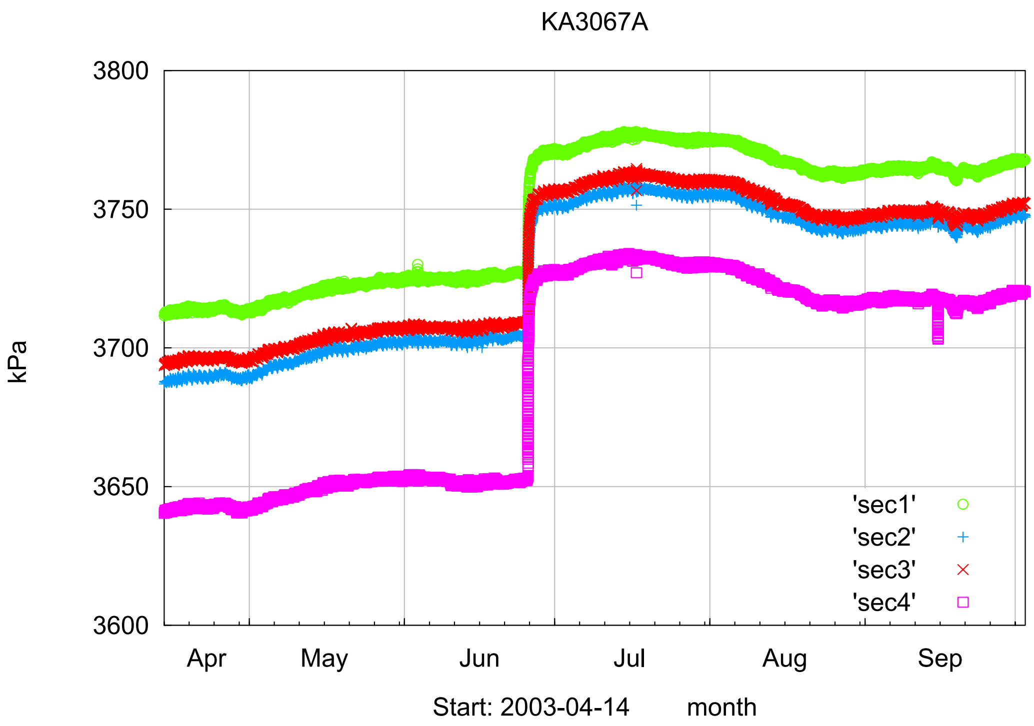


Figure 3-4. *Pressure registration (kPa) in borehole KA3067A during tunnel excavation and drilling, April to October, 2003.*

3.4 Pre-test 2 - Dilution tests

Pre-test 2 included measurements of flow rates using the tracer dilution method in three selected sections, KA3065A02:P3, KA3067A:P3 and SA3045A:P2. The measurements were performed only under natural gradient, i.e. prevailing steady-state hydraulic gradient conditions. The results are presented in Table 3-4 and the tracer dilution graphs are shown in Figure 3-5.

In Figure 3-6 the hydraulic head in the three sections mentioned above, together with borehole sections KA3065A03:P2 and KA3068A:1, is presented for a time period including Pre-test 2 and some days onwards. It shows that no disturbances occurred during the test and that the differences in head between sections KA3065A03:P2, KA3065A02:P3 and SA3045A:P2 are small, within 0.1-0.2 m.

Appendix 1 contains diagrams of the hydraulic head in the LTDE-boreholes (KA3065A02, KA3065A03, KA3067A, KA3068A and SA3045A) during the time period May 1st, 2004 until December 31st, 2004. The hydraulic gradients along the boreholes are small, in most cases the head differences between the sections are within a few meters with the lowest head in the outer section closest to the tunnel. The low hydraulic head in section 5 in borehole KA3065A03 is due to a small leakage through the casing.

The hydraulic head for some borehole sections interpreted to be intersected by Structure NW-3 and Structure NW-2 and/or NW-2´ is presented in Appendix 2. These structures are of interest for LTDE as described in Section 2.2.7. From these diagrams it can be seen that borehole sections within Structure NW-2´ (KXTT-boreholes) have lower hydraulic head than the ones within Structure NW-2 and Structure NW-3. However, the hydraulic gradients in the area of interest are small during prevailing steady-state conditions and seem to be directed towards the LTDE site and borehole KA3067A.

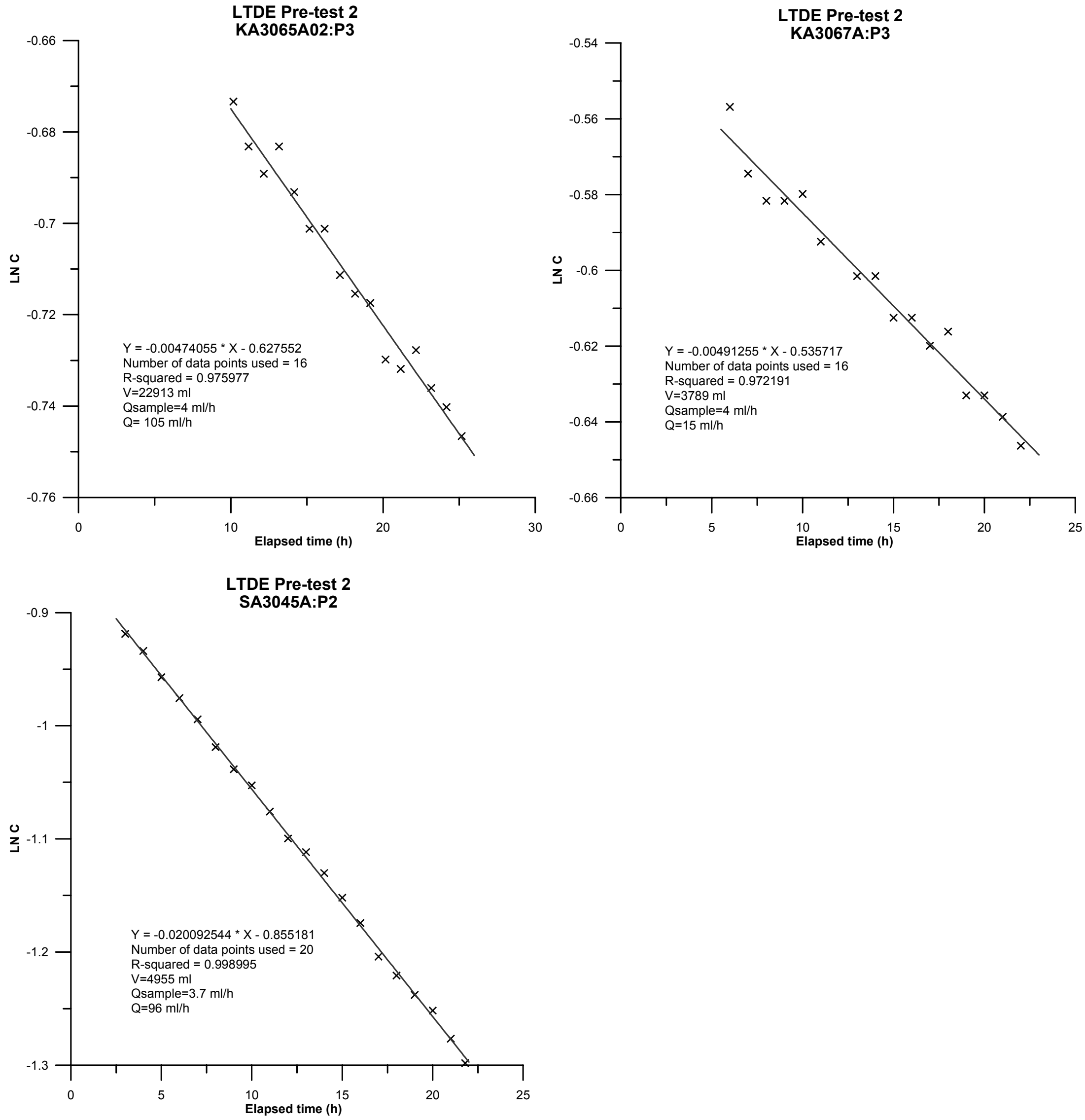


Figure 3-5. *Tracer dilution graphs (Logarithm of concentration versus time) for sections KA3065A02:P3, KA3067A:P3 and SA3045A:P2, LTDE Pre-test 2. Steeper dip of the straight-line fit implies a higher flow rate. Note that the axis scales differ.*

Table 3-4. Results of tracer dilution tests during LTDE Pre-test 2.

Test section	Structure	Section volume (ml)	$Q_{natural}$ (ml/h)
KA3065A02:P3	NW-3	22 913	105
KA3067A:P3	NW-2?	3 789	15
SA3045A:P2	NW-3	4 955	96

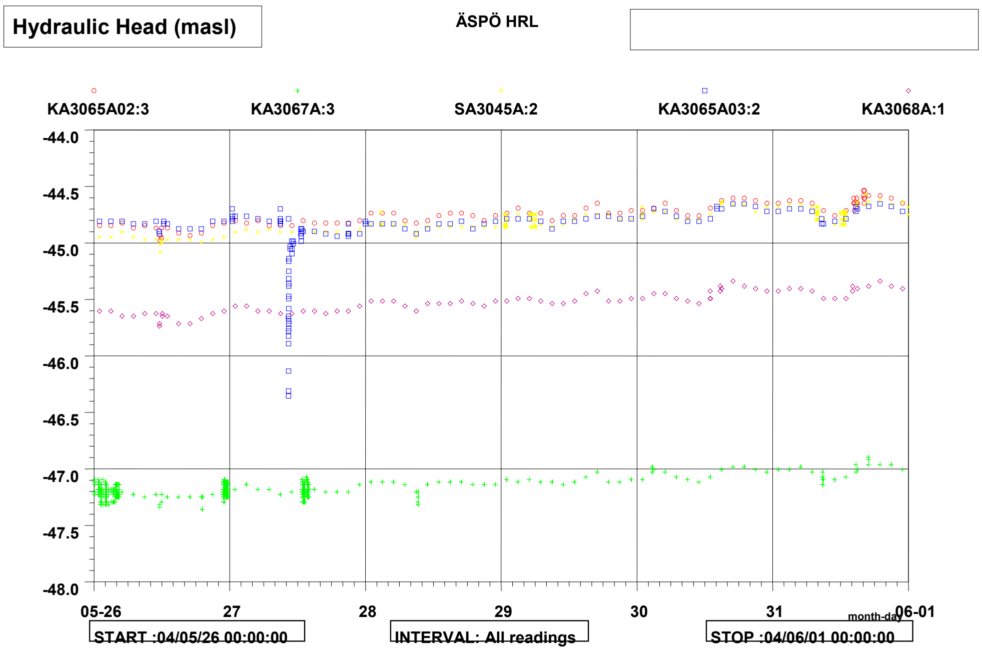


Figure 3-6. *Hydraulic head (masl) in some LTDE-borehole sections during LTDE Pre-test 2.*

3.5 Pre-test 3 and Pre-test 4 - Tracer/leakage tests

Tracer was injected as a decaying pulse in borehole section KA3065A03:P2 (inner guard section). Samples were continuously withdrawn both from the injection section and from the surrounding borehole sections KA3065A02:P3 and SA3045A:P2. A week after the tracer injection a sink was established in KA3065A02:P3 with a withdrawal rate of Q=7.2 l/min. Sampling continued in all three sections.

3.5.1 Tracer injection

The injection in borehole section KA3065A03:P2 (Structure NW-3?) was performed as a decaying pulse.

The injection concentrations presented in Figure 3-7and Table 3-5 are the actually measured ones and based on those, a flow rate was calculated from the dilution of tracer versus time.

Table 3-5. Tracer injection data and results from dilution measurement in KA3065A03:P2 during LTDE Pre-test 3 and 4 (measured values).

Inj. Section	Structure	Tracer	Section volume (ml)	Max inj. conc. (mg/l)	Inj. mass (mg)	$Q_{natural}$ (ml/h)	$Q_{stressed}$ (ml/h)
KA3065A03:P2	NW-3?	Uranine	8685	9.32	82.8	1.3	451

During Pre-test 3 and 4 the flow rate through borehole section KA3065A03:P2 (inner guard section) was determined by using the tracer dilution method. The measurement was performed both under natural gradient and during pumping of section KA3065A02:P3 (7.2 l/min). The result is presented in Table 3-5 and the tracer dilution graph is shown in Figure 3-7.

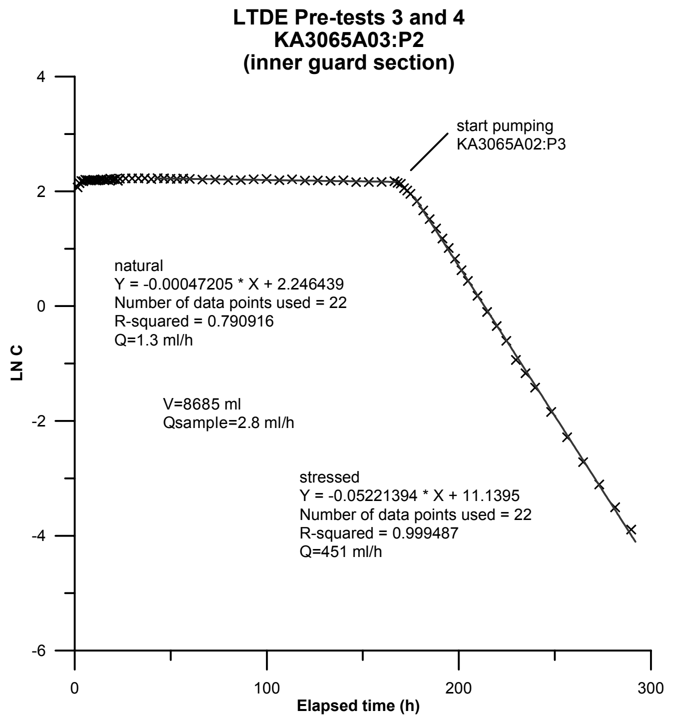


Figure 3-7. *Tracer dilution graph (Logarithm of concentration versus time) from the injection of Uranine in section KA3065A03:P2 (inner guard section), LTDE Pre-tests 3 and 4. Steeper dip of the straight-line fit implies a higher flow rate.*

3.5.2 Tracer breakthrough

Borehole sections KA3065A02:P3 (Structure NW-3) and SA3045A:P2 (Structure NW-3) were sampled for tracer breakthrough from the injection of Uranine in KA3065A03:P2 (inner guard section).

Before the injection and sampling started the borehole sections were opened for about 10-15 minutes to flush out the remaining tracer from the previous dilution tests performed in Pre-test 2. Still, the breakthrough curves show high initial concentrations in the samples slowly decreasing with time. This is probably due to contamination from the circulation and sampling equipment.

Almost immediately after the pumping in KA3065A02:P3 started, tracer breakthrough was detected in the same section, Figure 3-8. No tracer breakthrough was detected in borehole section SA3045A:P2 during the entire test, cf. Figure 3-9.

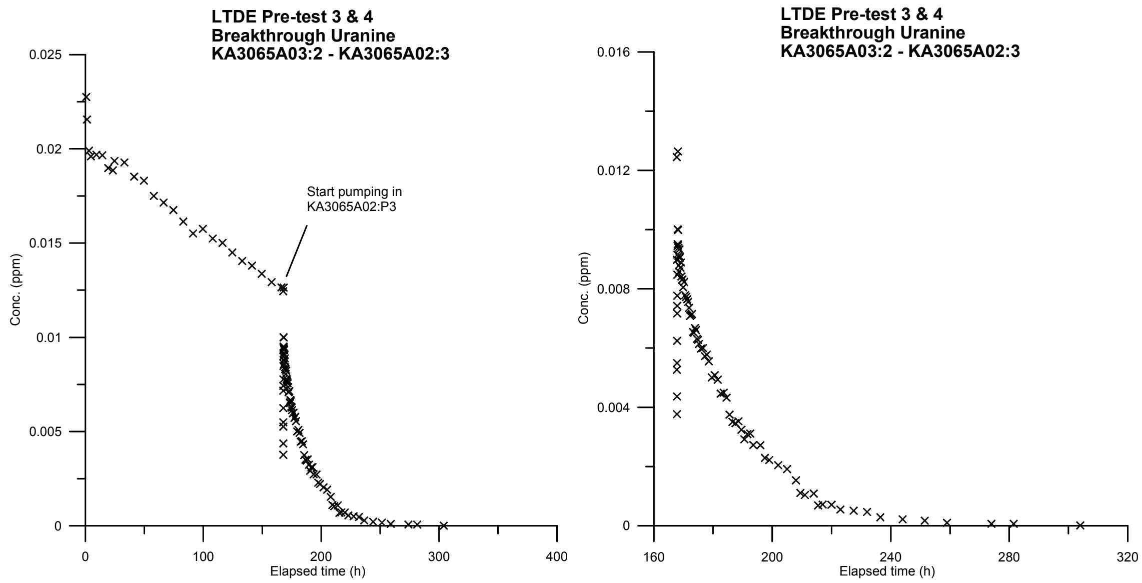


Figure 3-8. *Tracer breakthrough in KA3065A02:P3 from the injection of Uranine in section KA3065A03:P2 (inner guard section), LTDE Pre-tests 3 and 4. Entire test period to the left and pumping period to the right.*

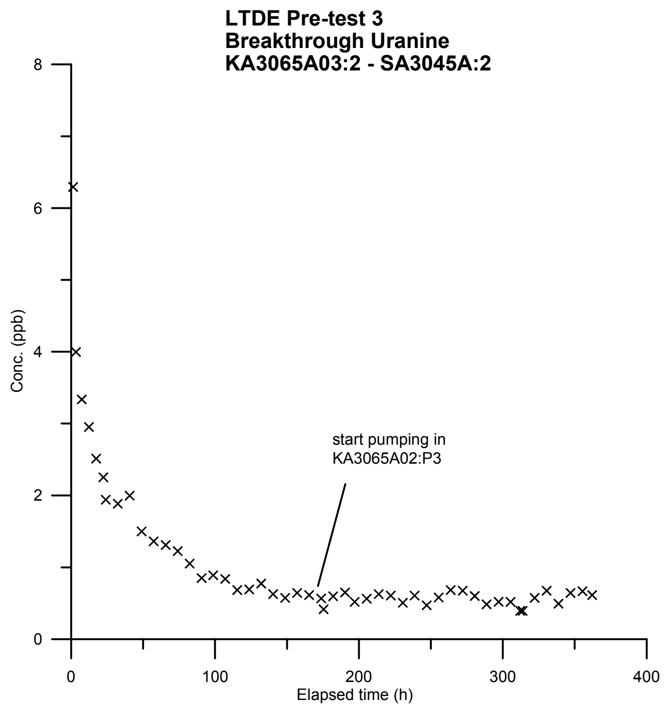


Figure 3-9. *Tracer breakthrough in SA3045A:P2 from the injection of Uranine in section KA3065A03:P2 (inner guard section), LTDE Pre-tests 3 and 4.*

Tracer mass recovery, presented in Table 3-6, was calculated by integrating the breakthrough curves for mass flux (mg/h) versus time (h) in the pumping borehole section. The injected mass was calculated by weighing the tracer solution vessel during the injection procedure. The tracer mass outflow from the injection section was close to complete (about 99.8 %) during the test time.

Table 3-6. Tracer mass recovery from injection in KA3065A03:P2 (Structure NW-3?) during LTDE Pre-test 3 to 4.

Sampling section	Structure	Sampling time after start pumping (h)	Recovery (%)
KA3065A02:P3	NW-3	136	100

3.6 Pre-test 5 and Pre-test 6 – Major interference tests

3.6.1 Pressure response matrix

The pressure response matrix for Pre-test 5 and Pre-test 6 is shown in Table 3-7. The matrix is based on the pressure response diagrams for each test. The colours and letters coding refers to the two indexes s_p/Q (drawdown normalised to pumping rate) and t_R/R^2 (response time normalised to the distance squared) according to Chapter 2.3.1.

The results of each test are discussed in more detail below.

Table 3-7. Pressure response matrix for LTDE Pre-test 5 and Pre-test 6.

Sink in Structure/Feature		NNW-4	NW-2	NW-3	NW-2?	A	NW-2',A,B,D	Structure
Borehole	**Interval (m)**	**KA3110A**	**KA3010A**	**SA3045A**	**KA3067A**	**KXTT3:2**	**KXTT5**	**/Feature**
KA3065A02:P1	21-69.95		E	G	E	M	G	
KA3065A02:P2	14-20		G	M	G	M	G	
KA3065A02:P3	7.5-13		E	G	M	M	G	NW-3
KA3065A02:P4	4-6.5		G	G	B	M	G	NW-3?
KA3065A03:P1	10.74-11.23		E	G	M	M	G	
KA3065A03:P2	10.39-10.73		E	G	M	M	G	NW-3?
KA3065A03:P3	8.98-10.23		E	E	M	M	G	NW-3?
KA3065A03:P4	4.26-7.98		G	M	B		G	
KA3065A03:P5	0-3.26		B	B			M	
KA3067A:P1	34.55-40.05		G	B	G	M	G	?
KA3067A:P2	30.55-33.55		G	M	SINK	M	G	?
KA3067A:P3	28.05-29.55		E	G	SINK	M	G	NW-2?
KA3067A:P4	6.55-27.05		E	E	B	M	G	NW-3
SA3045A:P1	9.0-20.7		M	SINK				
SA3045A:P2	6.0-8.0		E	SINK	G	M	G	NW-3
SA3045A:P3	2.5-5.0		M	G				
KA3068A:1	0-16.85	B	E	E	M	M	G	NW-3
KA2050A:P1	155-211.57		B		B		G	
KA2050A:P2	102-154		M	B	M	M	G	NW-2?
KA2050A:P3	6-101		G	G	M		M	
KA3005A:R2	46.78-50.03		B			G	M	B
KA3005A:R3	44.78-45.78		G			M	G	A
KA3005A:R4	39.03-43.78		G			M	M	A?
KA3005A:R5	6.53-38.03		G			G	G	?
KA3010A:P2	8.56-15.06		SINK	E	G	B	G	NW-2
KA3105A:P1	53.01-68.95		G	M	B		G	
KA3105A:P2	25.51-52.01	B	M	B	G		M	
KA3105A:P3	22.15-24.51	M		B	G		M	
KA3105A:P4	17.01-19.51	M		B			M	
KA3105A:P5	6.51-16.01		M					
KA3110A:P1	20.05-28.63	SINK					G	NNW-4
KA3110A:P2	6.55-19.05	SINK					M	
KXTT1:R1	17.0-28.76		G	B		G	G	NW-2'
KXTT1:R2	15.0-16.0		M			G	G	A
KXTT1:R3	7.5-11.5		B			G	M	B
KXTT1:R4	3.0-6.5		B			G	M	D
KXTT2:R1	16.55-18.3		M			G	M	?
KXTT2:R2	14.55-15.55		M			G	G	A
KXTT2:R3	11.55-13.55		B			G	B	B
KXTT2:R4	7.55-10.55		B			G	M	B
KXTT2:R5	3.05-6.55		B			G	G	D
KXTT3:R1	15.42-17.43		G			M	M	NW-2'
KXTT3:R2	12.42-14.42		G			SINK	M	A
KXTT3:R3	8.92-11.42					G	B	B
KXTT3:R4	3.17-7.92					G	M	B+D
KXTT4:R1	14.92-49.31		G	M		G	G	NW-2+NW-2'
KXTT4:R2	12.92-13.92		M			M	M	A'
KXTT4:R3	11.92-12.42		M			G	G	A
KXTT4:R4	8.42-10.92					G	M	B
KXTT4:R5	3.17-7.42					G	G	B+D
KXTT5:P1	10.81-25.85		G			M	SINK	NW-2'
KXTT5:P2	9.61-9.81		M			G	SINK	A
KXTT5:P3	6.11-8.61		M			M	SINK	B
KXTT5:P4	3.11-5.11		M			M	SINK	D

INDEX 1=sp/Q

- EXCELLENT
- HIGH
- MEDIUM
- LOW
- NO RESPONSE

INDEX 2=tr/R2

- E=EXCELLENT
- G=GOOD
- M=MEDIUM
- B=BAD

3.6.2 Sink KA3110A

The first test was performed by releasing the packers in borehole KA3110A (Structure NNW-4). Pressure responses (>1 kPa) were registered only in 4 sections in boreholes KA3068A and KA3105A. The distances were ranging between 30 and 139 m.

The magnitude of the hydraulic responses is low, less than 10 kPa and the responses are also slow, see Figure 3-10.

The flow rate was almost constant, 5.5 l/min, during the pumping period.

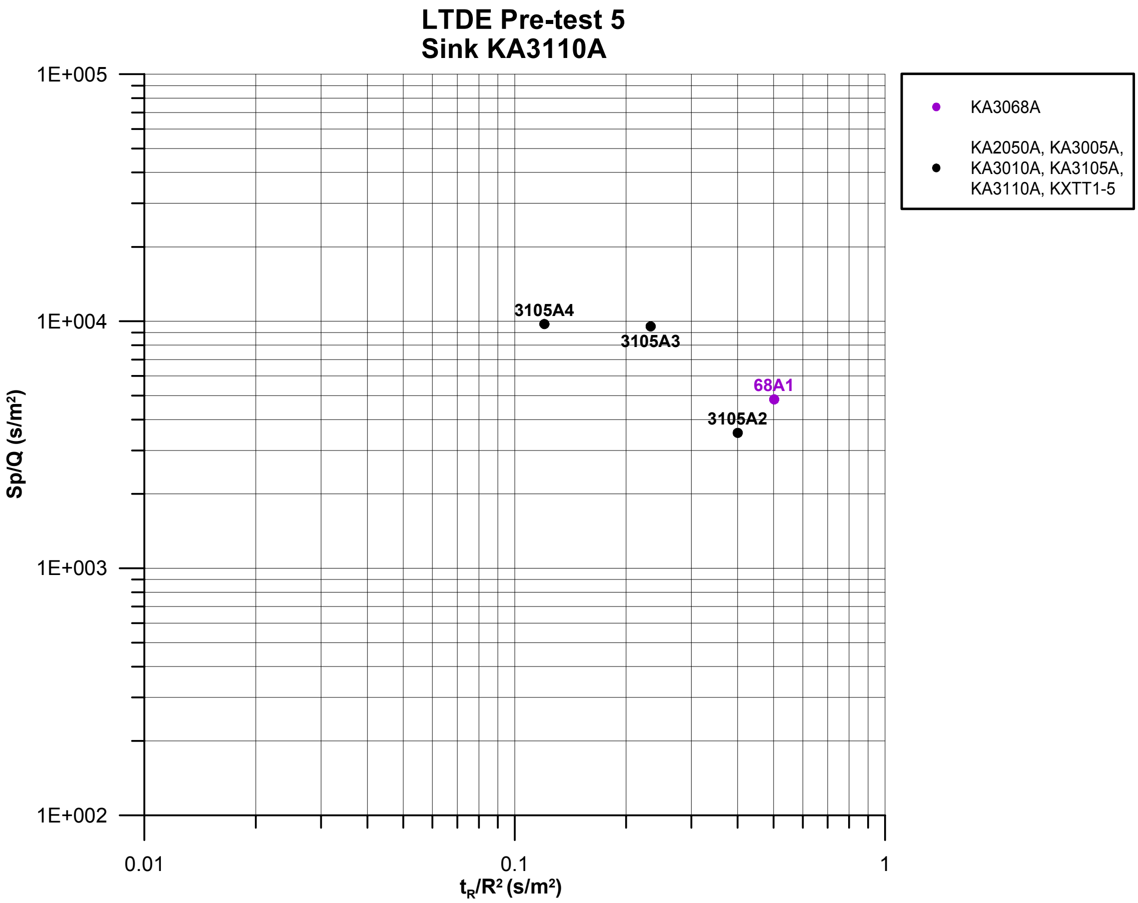


Figure 3-10. *Diagnostic plot of pressure responses during LTDE Pre-test 5 from sink in borehole KA3110A. LTDE-boreholes in colour, TRUE-1 boreholes and others in black.*

3.6.3 Sink KA3010A

This test was performed by releasing the packers in borehole KA3010A (Structure NW-2). Pressure responses (>1 kPa) were registered in all of the in total 17 sections in the LTDE-boreholes and in 28 of the 36 borehole sections outside the LTDE site. The distances were ranging between 31 and 122 m.

In most of the borehole sections within the LTDE area the responses were fast and in some cases also high (Figure 3-11). The magnitude of the hydraulic responses is typically between 70-145 kPa. The borehole sections outside the LTDE-site responded lower and slower, except KA2050A:P2 straddling the NW-2 zone.

The flow rate was almost constant, 26.5 l/min, during the pumping period.

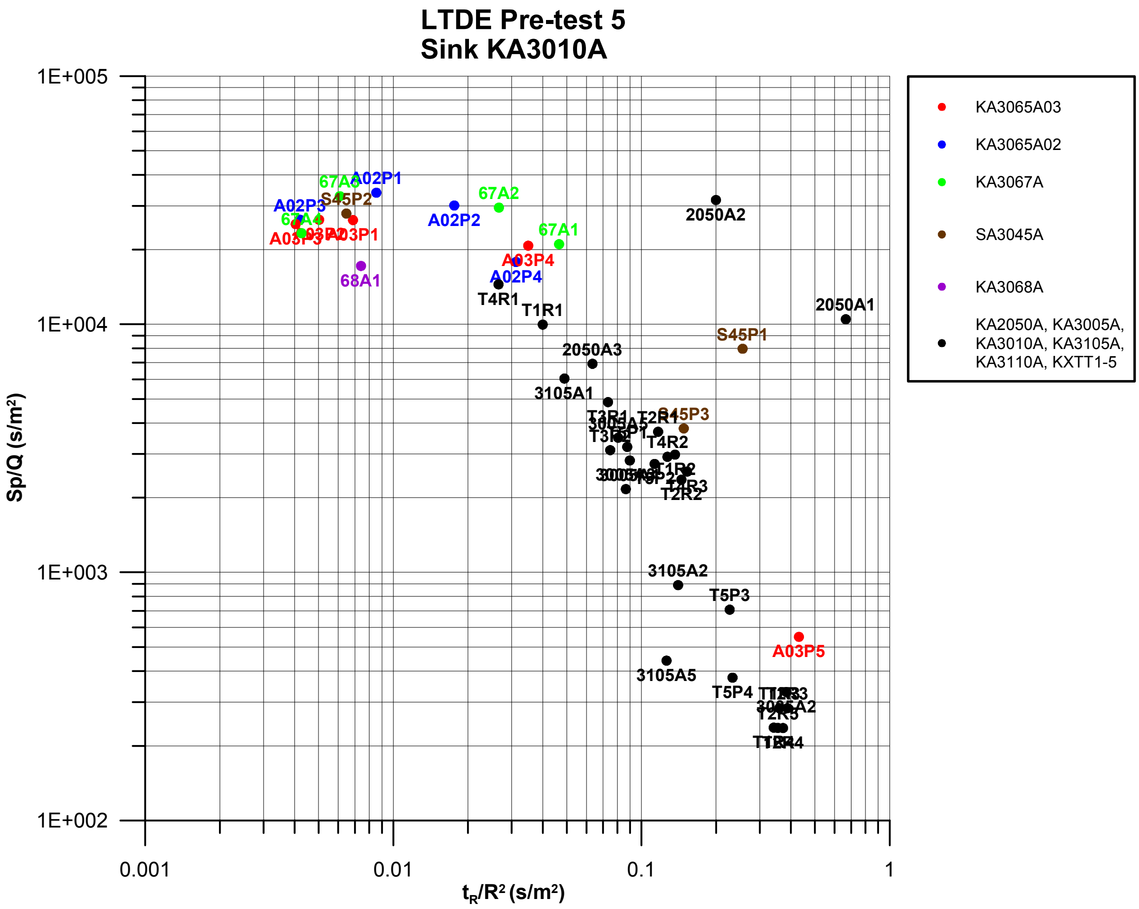


Figure 3-11. Diagnostic plot of pressure responses during LTDE Pre-test 5 from sink in borehole KA3010A. LTDE-boreholes in colour, TRUE-1 boreholes and others in black.

3.6.4 Sink SA3045A:P1+P2

A sink was established by opening the circulation tubes to sections 1 and 2 simultaneously in borehole SA3045A (Structure NW-3). Pressure responses (>1 kPa) were registered in all sections in the LTDE-boreholes and in 9 of the 37 borehole sections outside the LTDE site. The distances were ranging between 9 and 108 m.

In most of the borehole sections within the LTDE area the responses were fast and high, cf. Figure 3-12. The magnitude of the hydraulic responses is generally between 15-60 kPa. The borehole sections outside the LTDE-site responded lower and slower, except borehole KA3010A which showed the fastest response of all sections involved, even though not very high.

The flow rate was almost constant, 8.0 l/min, during the pumping period.

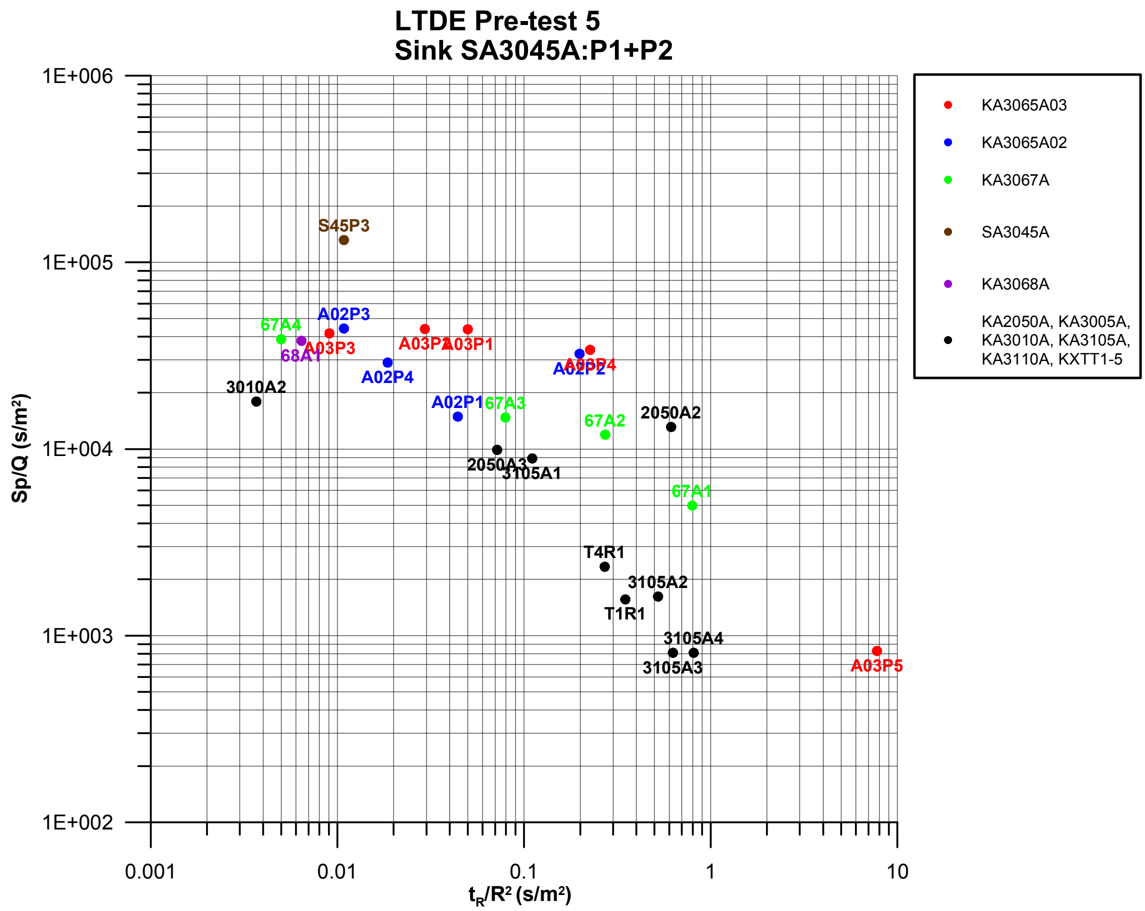


Figure 3-12. Diagnostic plot of pressure responses during LTDE Pre-test 5 from sink in borehole SA3045A sections 1 and 2. LTDE-boreholes in colour, TRUE-1 boreholes and others in black.

3.6.5 Sink KA3067A:P2+P3

A sink was established by simultaneously opening of the circulation tubes to sections 2 and 3 in borehole KA3067A (Structure NW-2?). Pressure responses (>1 kPa) were registered in 12 of 15 sections in the LTDE-boreholes and in 7 of the 37 borehole sections outside the LTDE site. The distances were ranging between 6 and 143 m.

The response pattern is quite scattered with no distinct difference between borehole sections within or outside the LTDE-site, especially not in time, see Figure 3-13. The magnitude of the hydraulic responses is generally somewhat higher for the borehole sections within the LTDE area (ranges between 15-70 kPa compared to 1-20kPa).

The flow rate was almost constant, 6.4 l/min, during the pumping period.

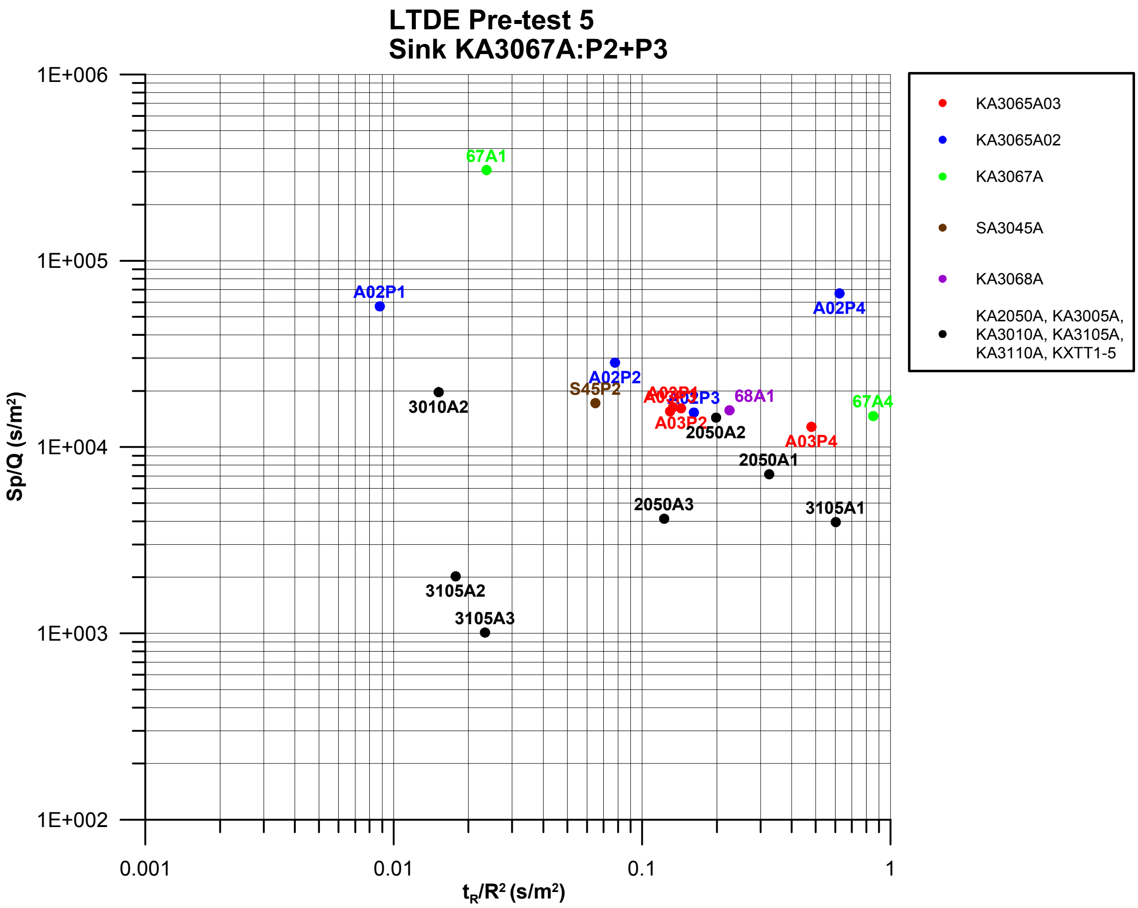


__Figure 3-13.__ Diagnostic plot of pressure responses during LTDE Pre-test 5 from sink in borehole KA3067A sections 2 and 3. LTDE-boreholes in colour, TRUE-1 boreholes and others in black.

3.6.6 Sink KXTT3:R2

In this test a sink was established by opening the circulation tubes to section 2 in borehole KXTT3 (Feature A) in the TRUE-1 site. Pressure responses (>1 kPa) were registered in 13 of 17 sections in the LTDE-boreholes and in 27 of the 36 borehole sections outside the LTDE site. The distances were ranging between 3 and 169 m.

The response pattern shows a clear difference between borehole sections within and outside the LTDE area (Figure 3-14). Sections outside LTDE, in particular in TRUE-1 boreholes, responded much higher and faster than the ones in LTDE boreholes where the responses were low and slow. The magnitude of the hydraulic responses in the TRUE-1 borehole sections is typically between 20-1800 kPa whereas the responses in the LTDE boreholes are less than 5 kPa.

The flow rate was almost constant, 3.6 l/min, during the pumping period.

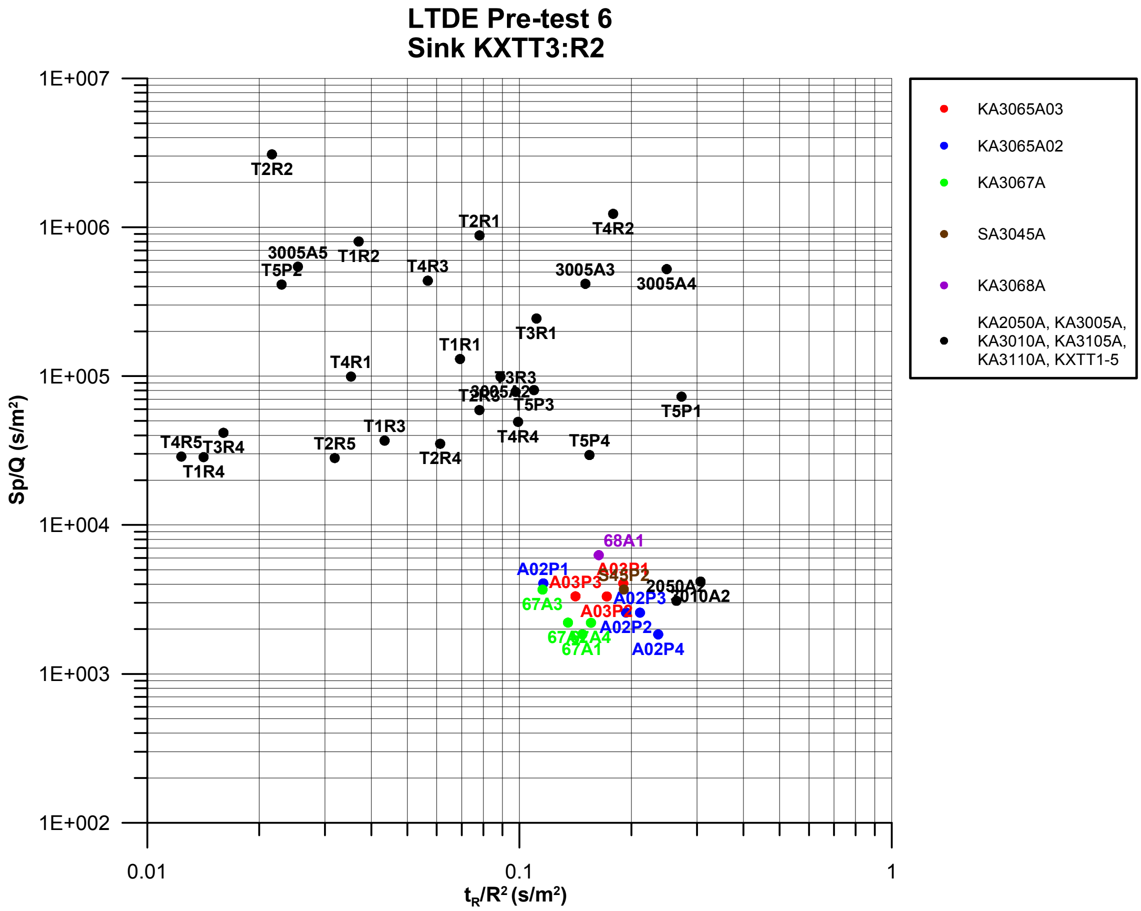


Figure 3-14. Diagnostic plot of pressure responses during LTDE Pre-test 6 from sink in borehole KXTT3 section 2. LTDE-boreholes in colour, TRUE-1 boreholes and others in black.

3.6.7 Sink KXTT5

This test was performed by releasing the packers in borehole KXTT5 (Structure NW-2′, Feature A, B, D) in the TRUE-1 site. Pressure responses (>1 kPa) were registered in 15 of 17 sections in the LTDE-boreholes and in 32 of the 33 borehole sections outside the LTDE site. The distances were ranging between 5 and 169 m.

The LTDE boreholes responded in general faster than the TRUE-1 boreholes, but the hydraulic responses in the latter were higher, cf. Figure 3-15. The magnitude of the hydraulic responses in the TRUE-1 borehole sections is generally between 350-980 kPa whereas the responses in the LTDE boreholes are 40-65 kPa.

The flow rate was constant, 100 l/min, during the pumping period.

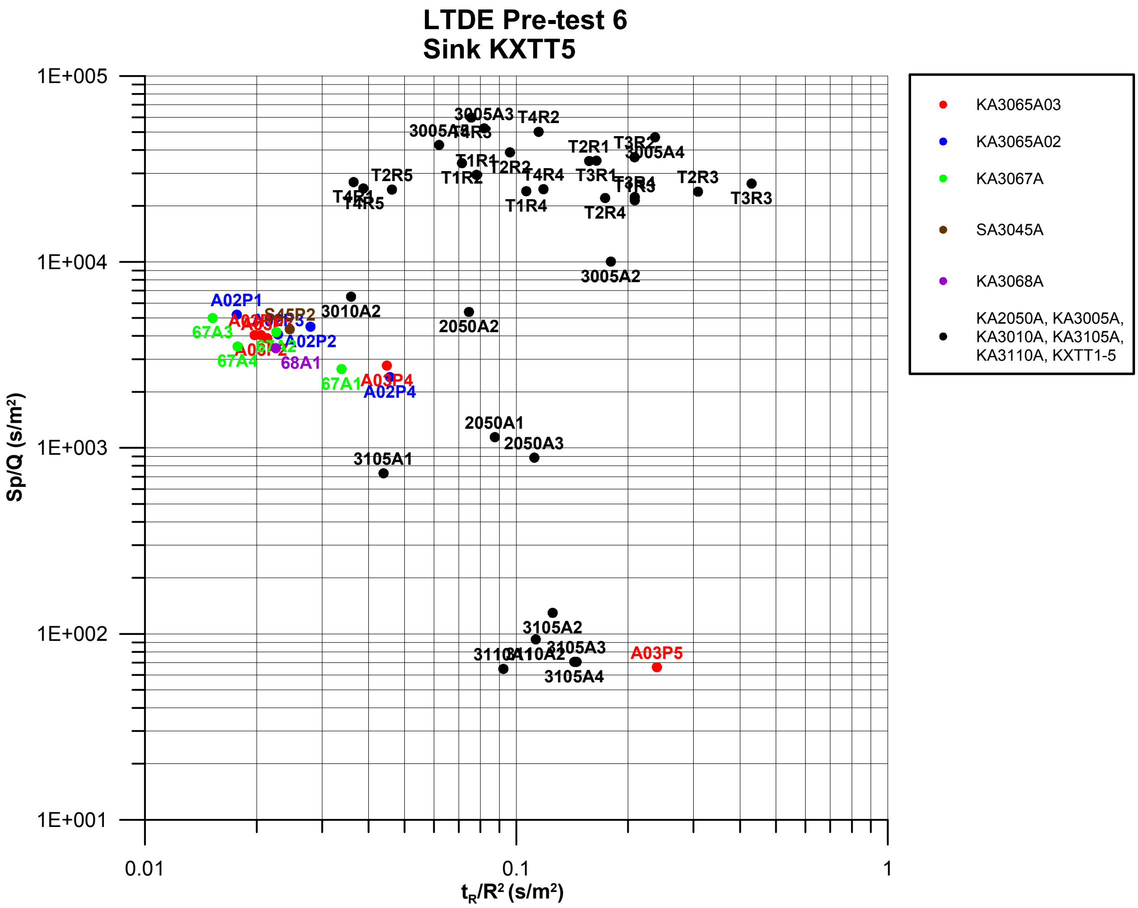


Figure 3-15. *Diagnostic plot of pressure responses during LTDE Pre-test 6 from sink in borehole KXTT5. LTDE-boreholes in colour, TRUE-1 boreholes and others in black.*

4 Discussion and conclusions

A number of pre-tests have been performed to investigate the hydraulic conditions in the experimental volume as a preparation for the main LTDE tests.

The LTDE area is surrounded by two dominating structures, NW-2 and NW-3. The interference tests showed that these structures are of vital importance for the responses in the LTDE boreholes from pumping in different surrounding boreholes. The highest and fastest responses in the LTDE boreholes occurred when boreholes KA3010A (Structure NW-2) and SA3045A (Structure NW-3) were used as sinks. The sections in the experimental borehole KA3065A03, and especially the test and inner guard sections, are also responding very well to pumping performed in the nearby pilot borehole section KA3065A02:P3. Also some of the TRUE-1 boreholes (KXTT3 and KXTT5) were used as sinks and were of interest since there are planned to be activities at the TRUE-1 site during the performance of the LTDE experiment. The responses in the LTDE boreholes were low but quite fast. However, fast responses are not considered to be such a problem for LTDE as high responses would have been. Still, caution has to be taken concerning the innermost section in borehole KXTT4, intersecting Structure NW-2.

The pressure registration in borehole KA3067A during tunnel excavation and drilling in the lower part of the tunnel (TASQ) and also in the middle of the tunnel (NASA1619A) during 2003 showed that no major disturbances in the LTDE area occurred due to these activities. However, many of the LTDE borehole sections are intersected by Structure NW-3 and possibly also Structure NW-2 why no drilling or blasting activities should be performed in these zones during the LTDE test period.

Dilution tests were performed in three borehole sections, KA3065A02:P3 (Structure NW-3), KA3067A:P3 (Structure NW-2?) and SA3045A:P2 (Structure NW-3?) in order to determine the natural groundwater flow. The result of the measurements showed a flow of about 100 ml/h in both sections within Structure NW-3 and about 15 ml/h in the section within Structure NW-2.

The differences in hydraulic head between the borehole sections in the LTDE area are in most cases within a few meters and the hydraulic gradients are small during prevailing steady-state conditions.

Looking at the hydraulic head in some borehole sections related to different structures revealed that borehole sections within Structure NW-2´ (KXTT-boreholes), which is a structure interpreted to intersect with Structure NW-2 at the TRUE-1 site, have lower hydraulic head than the ones within Structure NW-2 and Structure NW-3. However, the hydraulic gradients in the dominating zones (NW-2 and NW-3) in the area of interest are small during prevailing steady-state hydraulic conditions and seem to be directed towards the LTDE site and borehole KA3067A.

The groundwater flow was estimated also in the inner guard section, KA3065A03:P2 (Structure NW-3?), from the dilution of the tracer injected during the tracer test. The flow during unstressed conditions was very low, about 1 ml/h, but when pumping was started in KA3065A02:P3 (Structure NW-3) the flow in KA3065A03:P2 increased to 450 ml/h.

A tracer test was performed with the aim to study the possibility to recover a tracer leakage from the test section into the inner guard section in KA3065A03 by establishing a sink in borehole section KA3065A02:P3. A week after the tracer injection in the inner guard section, KA3065A03:P2 (Structure NW-3?) a sink was established in KA3065A02:P3 (Structure NW-3) using maximum possible flow (7.2 l/min). Almost immediately after the pumping in KA3065A02:P3 started, tracer breakthrough was detected in the section. A tracer recovery of 100 % was obtained after a pumping period of 136 hours. No tracer breakthrough was detected in borehole section SA3045A:P2 (Structure NW-3) during the entire test. Hence, it is possible to recover tracer from the inner guard section in KA3065A03 by establishing a sink in KA3065A02:P3.

5 References

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Winberg, A., Hermanson, J., Tullborg E-L. and Staub, I., 2003. Long-Term Diffusion Experiment. Structural model of the LTDE site and detailed description of the characteristics of the experimental volume including taget structure and intact rock section. SKB International Progress Report IPR-03-51.

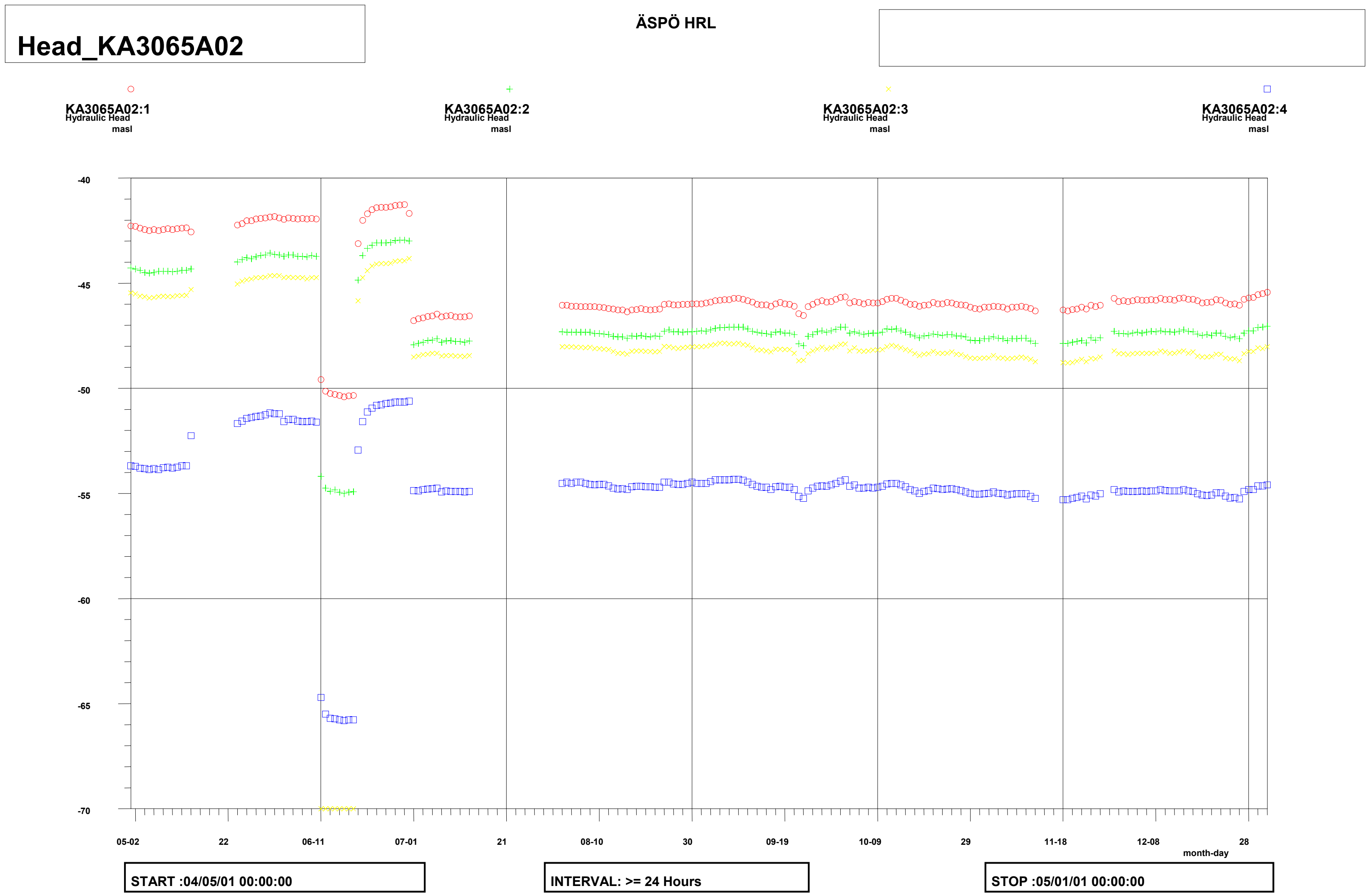
Appendices

Appendix 1. Hydraulic head in borehole KA3065A02, KA3065A03, KA3067A, KA3068A and SA3045A, respectively, 2004-05-01 – 2004-12-31.

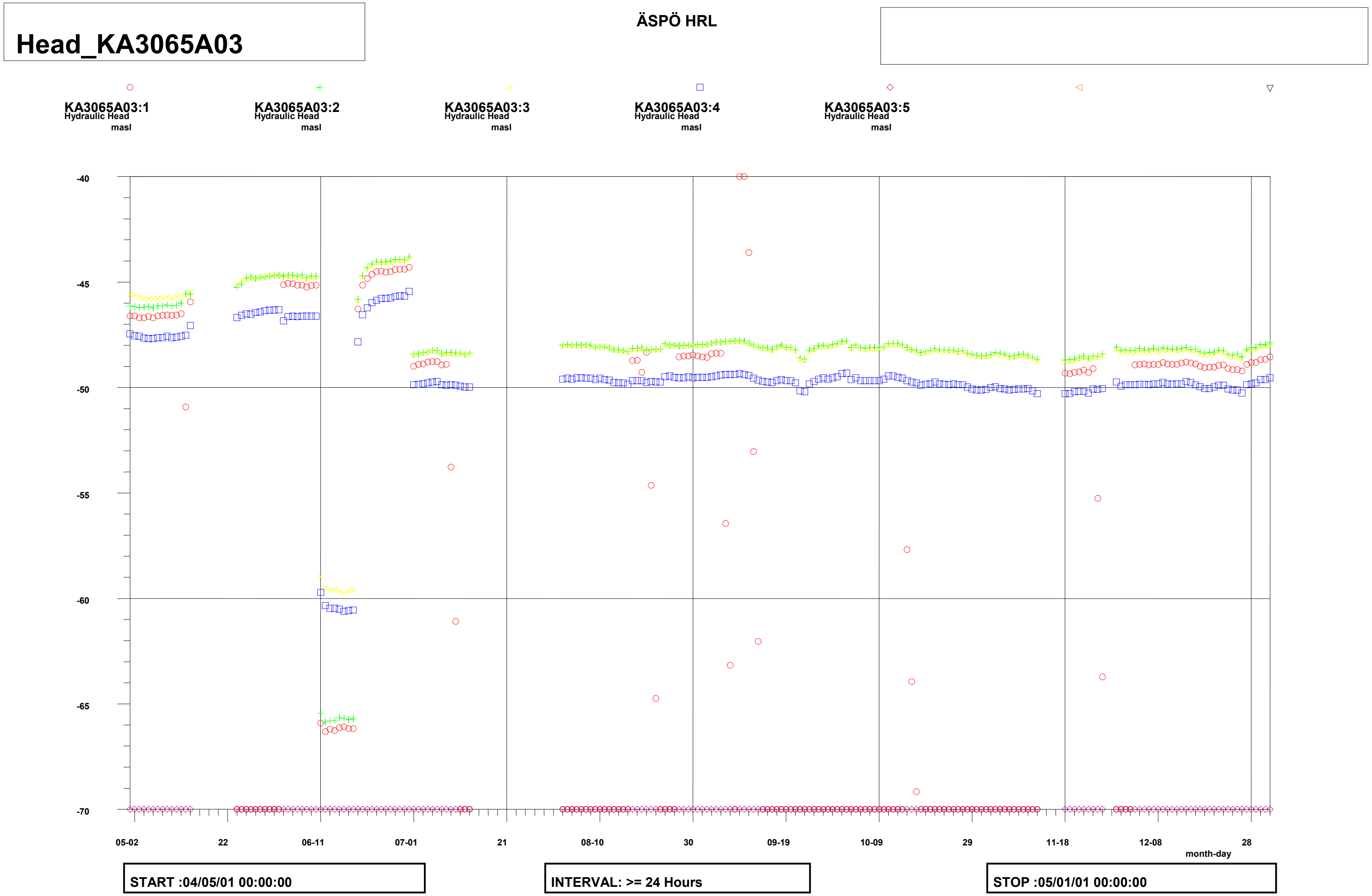
Appendix 2. Hydraulic head in borehole sections intersected by Structure NW-3 and Structure NW-2 / NW-2´, respectively, 2004-05-01 – 2004-12-31.

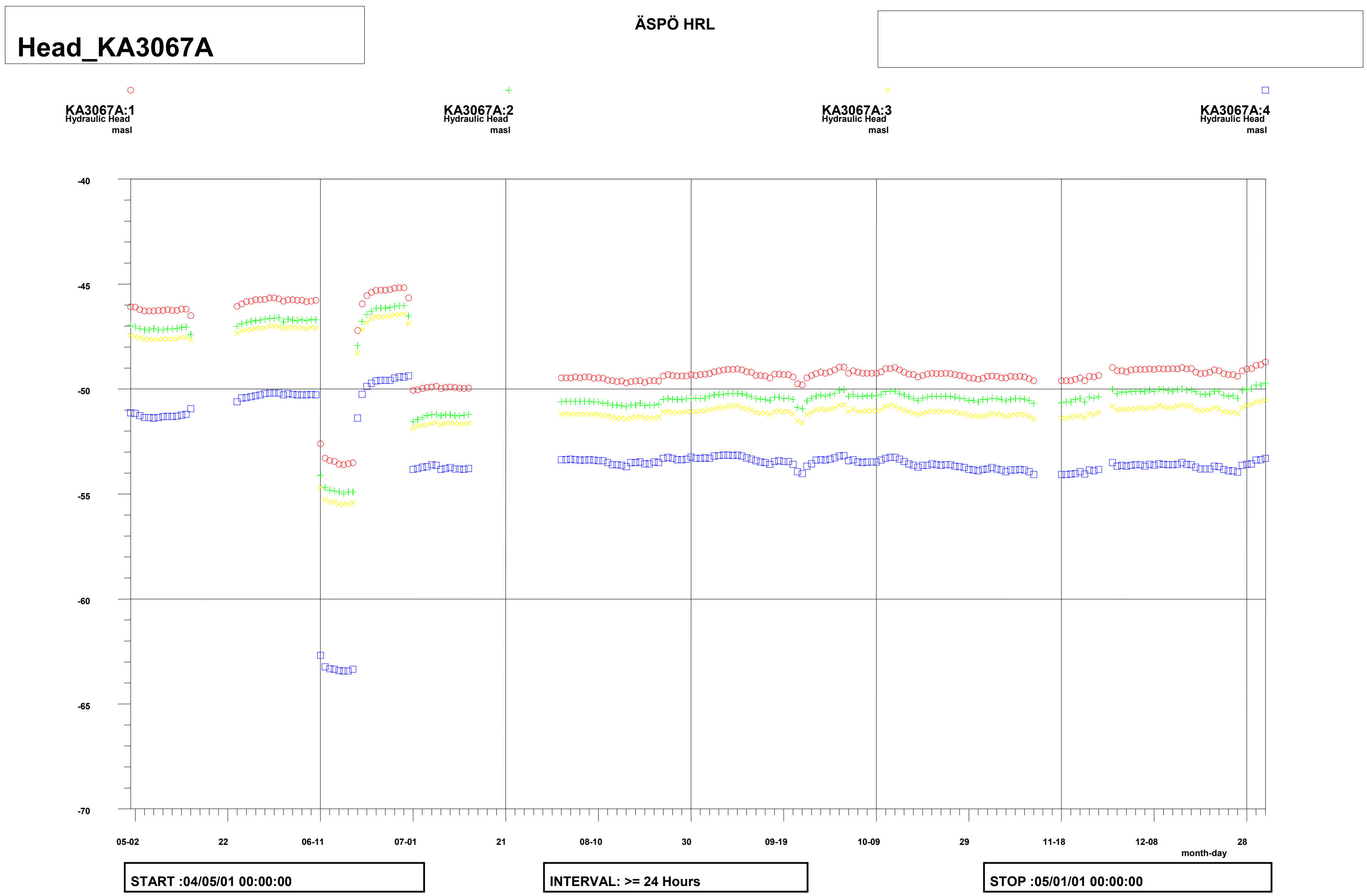
Appendix 1

Hydraulic head in borehole KA3065A02, KA3065A03, KA3067A, KA3068A and SA3045A, respectively, 2004-05-01 – 2004-12-31

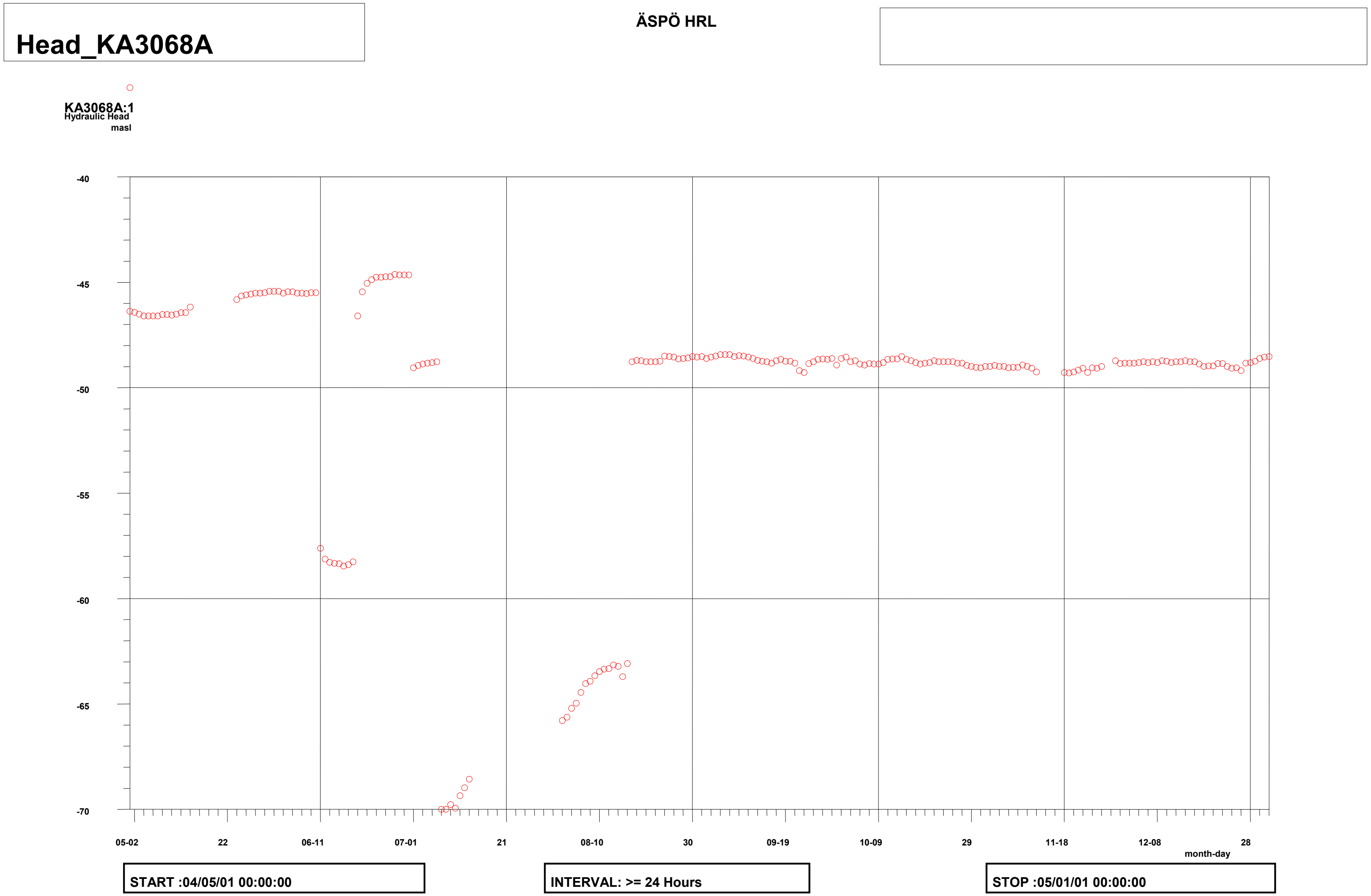


Head_KA3065A02
ÄSPÖ HRL
KA3065A02:1
Hydraulic Head
masl
KA3065A02:2
Hydraulic Head
masl
KA3065A02:3
Hydraulic Head
masl
KA3065A02:4
Hydraulic Head
masl
-40
-45
-50
-55
-60
-65
-70
05-02
22
06-11
07-01
21
08-10
30
09-19
10-09
29
11-18
12-08
28
month-day
START :04/05/01 00:00:00
INTERVAL: >= 24 Hours
STOP :05/01/01 00:00:00


Head_KA3065A03
ÄSPÖ HRL
KA3065A03:1
Hydraulic Head
masl
KA3065A03:2
Hydraulic Head
masl
KA3065A03:3
Hydraulic Head
masl
KA3065A03:4
Hydraulic Head
masl
KA3065A03:5
Hydraulic Head
masl
-40
-45
-50
-55
-60
-65
-70
05-02
22
06-11
07-01
21
08-10
30
09-19
10-09
29
11-18
12-08
28
month-day
START :04/05/01 00:00:00
INTERVAL: >= 24 Hours
STOP :05/01/01 00:00:00



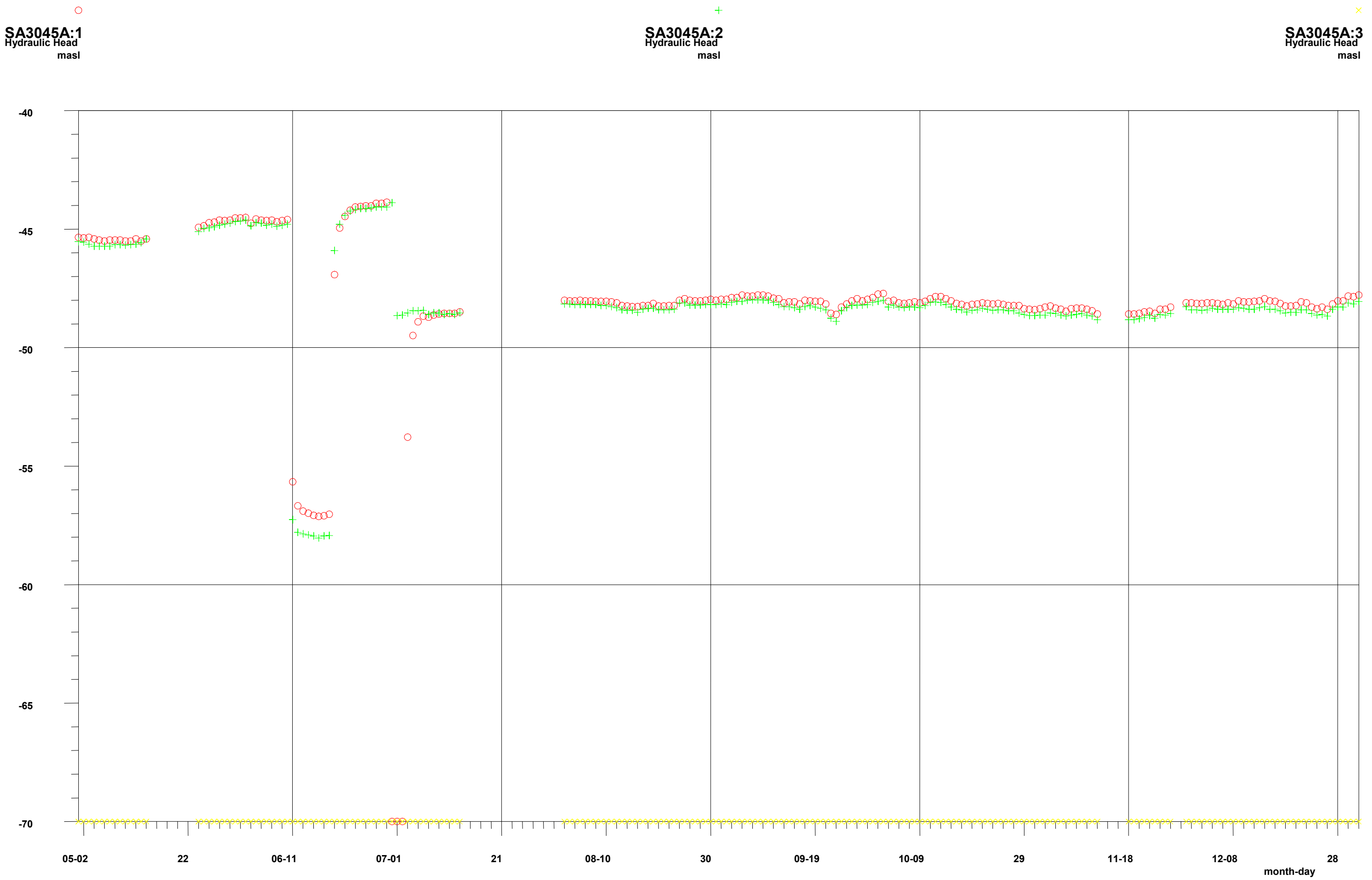
Head_KA3067A
ÄSPÖ HRL
KA3067A:1
Hydraulic Head
masl
KA3067A:2
Hydraulic Head
masl
KA3067A:3
Hydraulic Head
masl
KA3067A:4
Hydraulic Head
masl
-40
-45
-50
-55
-60
-65
-70
05-02
22
06-11
07-01
21
08-10
30
09-19
10-09
29
11-18
12-08
28
month-day
START :04/05/01 00:00:00
INTERVAL: >= 24 Hours
STOP :05/01/01 00:00:00



Head_KA3068A
ÄSPÖ HRL
KA3068A:1
Hydraulic Head
masl
-40
-45
-50
-55
-60
-65
-70
05-02
22
06-11
07-01
21
08-10
30
09-19
10-09
29
11-18
12-08
28
month-day
START :04/05/01 00:00:00
INTERVAL: >= 24 Hours
STOP :05/01/01 00:00:00

Head_SA3045A

ÄSPÖ HRL



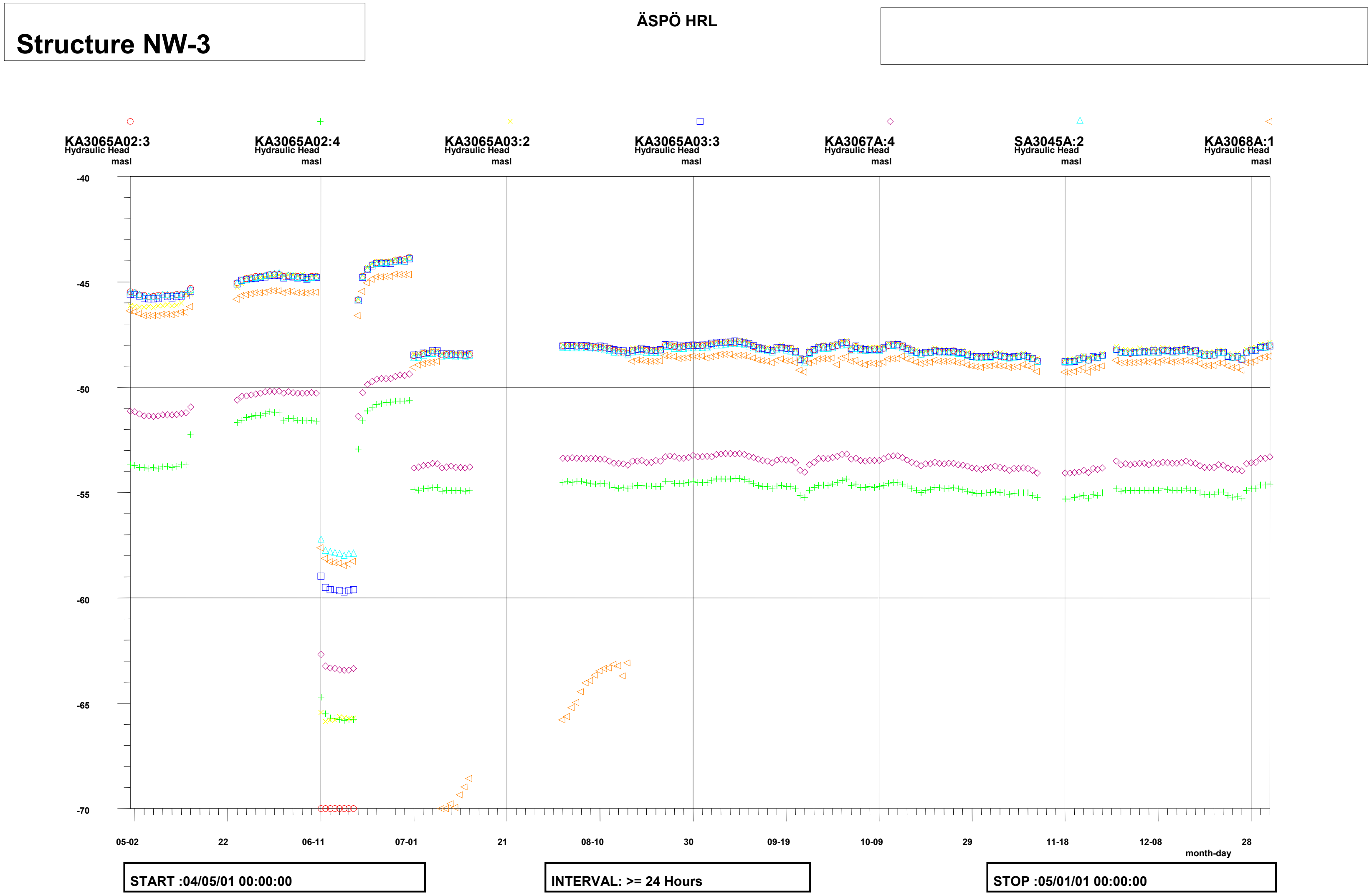
START :04/05/01 00:00:00

INTERVAL: >= 24 Hours

STOP :05/01/01 00:00:00

Appendix 2

Hydraulic head in borehole sections intersected by Structure NW-3 and Structure NW-2 / NW-2´, respectively, 2004-05-01 - 2004-12-31



Structure NW-3
ÄSPÖ HRL
KA3065A02:3 Hydraulic Head masl
KA3065A02:4 Hydraulic Head masl
KA3065A03:2 Hydraulic Head masl
KA3065A03:3 Hydraulic Head masl
KA3067A:4 Hydraulic Head masl
SA3045A:2 Hydraulic Head masl
KA3068A:1 Hydraulic Head masl
-40
-45
-50
-55
-60
-65
-70
05-02
22
06-11
07-01
21
08-10
30
09-19
10-09
29
11-18
12-08
28
month-day
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INTERVAL: >= 24 Hours
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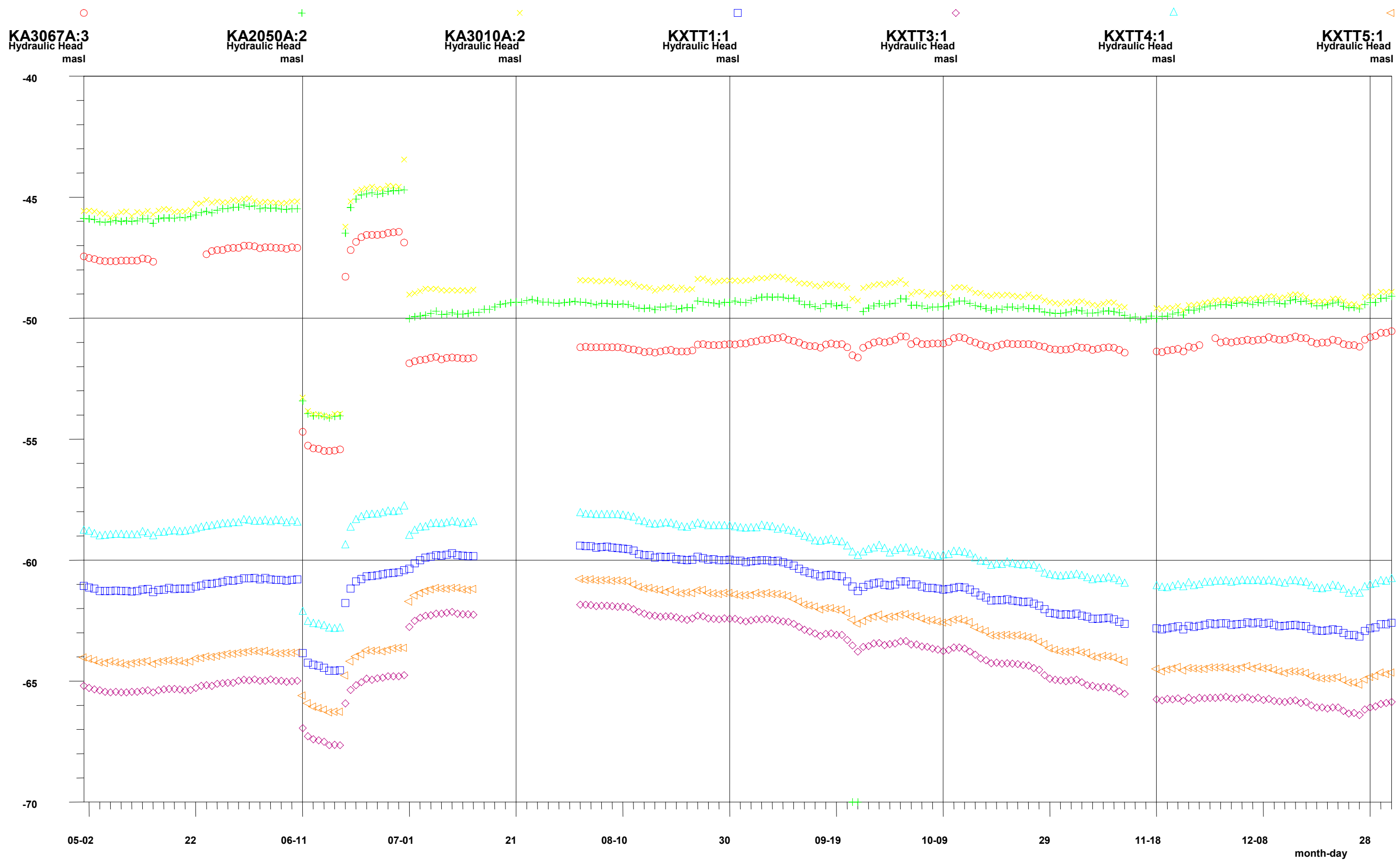
Structure NW-2 / NW-2´

ÄSPÖ HRL



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INTERVAL: >= 24 Hours

STOP :05/01/01 00:00:00