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Groundwater flow measurements in borehole KLX21B

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Abstract

This report describes the performance, evaluation and interpretation of in situ groundwater flow measurements at Laxemar area at the Oskarshamn site. The objectives of the activity were to determine the natural groundwater flow in selected fractures/fracture zones intersecting the core drilled borehole KLX21B.

Groundwater flow measurements were carried out in eight local fracture zones at borehole lengths ranging from c. 124 to c. 684 m (116 to 637 m vertical depth). The hydraulic transmissivity ranged within $T = 5.8 \cdot 10^{-8}$–$1.5 \cdot 10^{-5}$ m^2/s. The results of the dilution measurements in borehole KLX21B show that the groundwater flow varies in fracture zones during natural, i.e. undisturbed, conditions. A slight correlation is seen between borehole depth and flow rates and between depth and Darcy velocities, with the highest values in the shallowest section. The flow rate ranged from 0.009 to 15.4 ml/min and the Darcy velocity from $1.0 \cdot 10^{-9}$ to $5.7 \cdot 10^{-7}$ m/s ($8.6 \cdot 10^{-5}$–$4.9 \cdot 10^{-2}$ m/d), values that are similar to results from previously performed dilution measurements under natural gradient conditions at the Oskarshamn site. Hydraulic gradients, calculated according to the Darcy concept, are within the expected range (0.001–0.05) in six out of eight measured sections. Lowest hydraulic gradient is shown in the deepest sections. The determined groundwater flow rates are proportional to the hydraulic transmissivity although the statistical basis is weak. In one of the the sections intersecting deformation zone DZ12, the flow rate is lower than expected from the hydraulic transmissivity.

Sammanfattning

Denna rapport beskriver genomförandet, utvärderingen samt tolkningen av in situ grundvattenflödesmätningar i Laxemar, Oskarshamn. Syftet med aktiviteten var att bestämma det naturliga grundvattenflödet i enskilda sprickor och sprickzoner som skär borrhålet KLX21B.

Grundvattenflödesmätningar genomfördes i åtta lokala sprickzoner på nivåer från ca 124 till ca 684 m borrhålslängd (116 till 637 m vertikalt djup). Den hydrauliska transmissiviteten varierade inom intervallet T = $5{,}8\cdot10^{-8}$–$1{,}5\cdot10^{-5}$ m^2/s. Resultaten från utspädningsmätningarna i borrhålet KLX21B visar att grundvattenflödet varierar under naturliga, dvs. ostörda, hydrauliska förhållanden. En svag korrelation syns mellan borrhålsdjup och flödet och mellan djup och Darcy hastighet, med de högsta värdena i den grundaste sektionen. Beräknade grundvattenflöden låg inom intervallet 0,009–15,4 ml/min och Darcy hastigheterna varierade mellan $1{,}0\cdot10^{-9}$ och $5{,}7\cdot10^{-7}$ m/s ($8{,}6\cdot10^{-5}$–$4{,}9\cdot10^{-2}$ m/d), resultat vilka överensstämmer med resultat från motsvarande djup i tidigare undersökta borrhål.

Hydrauliska gradienter, beräknade enligt Darcy konceptet, ligger inom det förväntade området (0,001–0,05) i sex av åtta testade sprickor/zoner. Lägst hydraulisk gradient uppmäts i de djupaste sektionerna. Grundvattenflödet är proportionerligt mot den hydrauliska transmissiviteten, dock är det statistiska underlaget litet. I en av de djupaste sektionerna, som skär genom deformationszonen DZ12, är flödet lägre än vad den hydrauliska transmissiviteten påvisar.

Contents

1 Introduction

SKB is currently conducting a site investigation for a deep repository in Oskarshamn, according to general and site specific programmes /SKB 2001ab/. One, among several methods for site characterisation are in situ groundwater flow measurements.

This document reports the results gained by eight groundwater flow measurements with the borehole dilution probe in borehole KLX21B. The work was conducted by Geosigma AB and carried out between August and October 2007 in borehole KLX21B according to Activity Plan AP PS 400-07-059. In Table 1-1 controlling documents for performing this activity are listed. Both Activity Plans and method descriptions/instructions are SKB's internal controlling documents. Data and results were delivered to the SKB site characterization database Sicada.

Borehole KLX21B is located in the south east part of the investigation area Laxemar, Figure 1-1. KLX21B is a telescopic borehole where the part below 99 m borehole length is core drilled. KLX21B is inclined –70.86° from the horizontal plane at collaring. The borehole is in total 859 m long and cased down to 101 m. From 101 m down to 859 m the diameter is 76 mm.

Detailed information about borehole KLX21B is listed in Appendix A (excerpt from the SKB database Sicada).

Table 1-1. Controlling documents for performance of the activity.

Activity Plan	Number	Version
Grundvattenflödesmätningar i KLX21B	AP PS 400-07-059	1.0
Method documents	Number	Version
Metodbeskrivning för grundvatten-flödesmätning	SKB MD 350.001	1.0
Kalibrering av tryckgivare, temperatur-givare och flödesmätare	SKB MD 353.014	2.0
Kalibrering av fluorescensmätning	SKB MD 353.015	2.0
Kalibrering Elektrisk konduktivitet	SKB MD 353.017	2.0
Utspädningsmätning	SKB MD 353.025	2.0
Löpande och avhjälpande underhåll av Utspädningssond	SKB MD 353.065	1.0
Instruktion för rengöring av bor-rhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Instruktion för längdkalibrering vid undersökningar i kärnborrhål	SKB MD 620.010	1.0

Figure 1-1. Overview of the Oskarshamn site investigation area, showing core boreholes (purple) and percussion boreholes (blue). KLX21B in subarea Laxemar at coordinates 6366164 north and 1549715 east.

2 Objectives and scope

The objective of the activity was to determine groundwater flow under natural gradient in the Oskarshamn area.

The groundwater flow measurements were performed in fractures and fracture zones at a borehole length range of 124–684 m (116–637 m vertical depth) using the SKB borehole dilution probe. The hydraulic transmissivity in the test sections ranged between $5.8 \cdot 10^{-8}$–$1.5 \cdot 10^{-5}$ m^2/s. Groundwater flow measurements were carried out in totally eight test sections.

3 Equipment

3.1 Borehole dilution probe

The borehole dilution probe is a mobile system for groundwater flow measurements, Figure 3-1. Measurements can be made in boreholes with 56 mm or 76–77 mm diameter and the test section length can be arranged for 1, 2, 3, 4 or 5 m with an optimised special packer/dummy system and section lengths between 1 and 10 m with standard packers. The maximum measurement depth is at 1,030 m borehole length. The vital part of the equipment is the probe which measures the tracer concentration in the test section down hole and in situ. The probe is equipped with two different measurement devices. One is the Optic device, which is a combined fluorometer and light-transmission meter. Several fluorescent and light absorbing tracers can be used with this device. The other device is the Electrical Conductivity device, which measures the electrical conductivity of the water and is used for detection/analysis of saline tracers. The probe and the packers that straddle the test section are lowered down the borehole with an umbilical hose. The hose contains a tube for hydraulic inflation/deflation of the packers and electrical wires for power supply and communication/data transfer. Besides tracer dilution detection, the absolute pressure and temperature are measured. The absolute pressure is measured during the process of dilution because a change in pressure indicates that the hydraulic gradient, and thus the groundwater flow, may have changed. The pressure gauge and the temperature gauge are both positioned in the dilution probe, about seven metres from top of test section. This bias is not corrected for as only changes and trends relative to the start value are of great importance for the dilution measurement. Since the dilution method requires homogenous distribution of the tracer in the test section, a circulation pump is also installed and circulation flow rate measured.

A caliper log, attached to the dilution probe, is used to position the probe and test section at the pre-selected borehole length. The caliper detects reference marks previously made by a drill bit at exact length along the borehole, approximately every 50 m. This method makes it possible to position the test section with an accuracy of c. ± 0.10 m.

3.1.1 Measurement range and accuracy

The lower limit of groundwater flow measurement is set by the dilution caused by molecular diffusion of the tracer into the fractured/porous aquifer, relative to the dilution of the tracer due to advective groundwater flow through the test section. In a normally fractured granite, the lower limit of a groundwater flow measurement is approximately at a hydraulic conductivity, K, between $6\cdot10^{-9}$ and $4\cdot10^{-8}$ m/s, if the hydraulic gradient, I, is 0.01. This corresponds to a groundwater flux (Darcy velocity), v, in the range of $6\cdot10^{-11}$ to $4\cdot10^{-10}$ m/s, which in turn may be transformed into groundwater flow rates, Q_w, corresponding to 0.03–0.2 ml/hour through a one m test section in a 76 mm diameter borehole. In a fracture zone with high porosity, and thus a higher rate of molecular diffusion from the test section into the fractures, the lower limit is about $K = 4\cdot10^{-7}$ m/s if $I = 0.01$. The corresponding flux value is in this case $v = 4\cdot10^{-9}$ m/s and flow rate $Q_w = 2.2$ ml/hour. The lower limit of flow measurements is, however, in most cases constrained by the time available for the dilution test. The required time frame for an accurate flow determination from a dilution test is within 7–60 hours at hydraulic conductivity values greater than about $1\cdot10^{-7}$ m/s. At conductivity values below $1\cdot10^{-8}$ m/s, measurement times should be at least 70 hours for natural (undisturbed) hydraulic gradient conditions.

The upper limit of groundwater flow measurements is determined by the capability of maintaining a homogeneous mix of tracer in the borehole test section. This limit is determined by several factors, such as length of the test section, volume, distribution of the water conducting fractures and how the circulation pump inlet and outlet are designed. The practical upper measurement limit is about 2,000 ml/hour for the equipment developed by SKB.

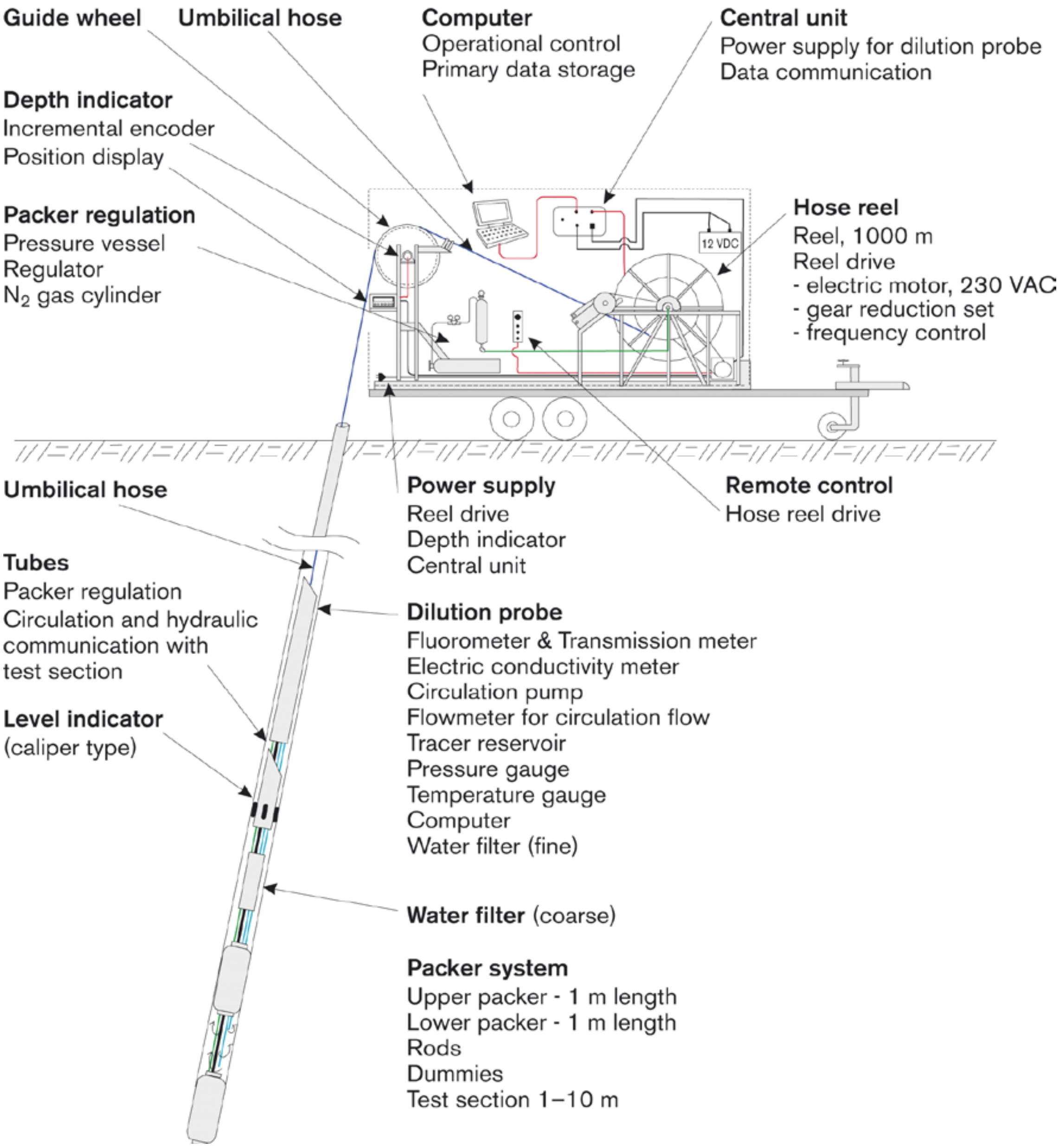

Figure 3-1. *The SKB borehole dilution probe.*

The accuracy of determined flow rates through the borehole test section is affected by various measurement errors related to, for example, the accuracy of the calculated test section volume and determination of tracer concentration. The overall accuracy when determining flow rates through the borehole test section is better than ± 30%, based on laboratory measurements in artificial borehole test sections.

The groundwater flow rates in the rock formation are determined from the calculated groundwater flow rates through the borehole test section and by using some assumption about the flow field around the borehole test section. This flow field depends on the hydraulic properties close to the borehole and is given by the correction factor α, as discussed below in Section 4.4.1. The value of α will, at least, vary within $\alpha = 2 \pm 1.5$ in fractured rock /Gustafsson 2002/. Hence, the groundwater flow in the rock formation is calculated with an accuracy of about ± 75%, depending on the flow-field distortion.

4 Execution

The measurements were performed according to AP PS 400-07-059 (SKB internal controlling document) in compliance with the methodology descriptions for the borehole dilution probe equipment – SKB MD 350.001, Metodbeskrivning för grundvattenflödesmätning, Table 1-1.

4.1 Preparations

The preparations included calibration of the fluorometer and the electric conductivity meter before arriving at the site. Briefly, this was performed by adding certain amounts of the tracer to a known test volume while registering the measured A/D-levels. From this, calibration constants were calculated and saved for future use by using the measurement application. The other sensors had been calibrated previously and calibrations were hence only checked.

Extensive functionality checks were accomplished prior to transport to the site and limited function checks were performed at the site. The equipment was cleaned to comply with SKB cleaning level 1 before lowering it into the borehole. All preparations were performed according to SKB Internal controlling documents, cf. Table 1-1.

4.2 Procedure

4.2.1 Groundwater flow measurement

In total eight groundwater flow measurements were carried out, Table 4-1.

Each measurement was performed according to the following procedure. The equipment was lowered to the correct borehole length where background values of tracer concentration and supporting parameters, pressure and temperature, were measured and logged. Then, after inflating the packers and the pressure had stabilized, tracer was injected in the test section. The tracer concentration and supporting parameters were measured and logged continuously until the tracer had been diluted to such a degree that the groundwater flow rate could be calculated.

4.3 Data handling

During groundwater flow measurement with the dilution probe, data are automatically transferred from the measurement application to a SQL database. Data relevant for analysis and interpretation are then automatically transferred from SQL to Excel via an MSSQL (ODBC) data link, set up by the operator. After each measurement the Excel data file is copied to a CD.

Table 4-1. Performed dilution (flow) measurements.

Borehole	Test section (m)[+]	Number of flowing fractures*	T (m^2/s)*	Tracer	Test period (yymmdd–yymmdd)
KLX21B	124.3–127.3 (116–119)	2–3	1.47E–05	Uranine	070827–070828
KLX21B	155.0–158.0 (146–149)	2	6.98E–07	Uranine	070828–070829
KLX21B	318.5–319.5 (297–298)	1	1.66E–07	Uranine	070919–070924
KLX21B	472.7–473.7 (440–441)	1	5.76E–08	Uranine	070905–070919
KLX21B	566.5–569.5 (529–531)	1–2	5.03E–07	Uranine	070903–070905
KLX21B	591.0–594.0 (551–554)	1–2	8.19E–07	Uranine	070829–070903
KLX21B	624.5–625.5 (582–583)	1	4.33E–06	Uranine	071008–071009
KLX21B	683.7–684.7 (637–638)	1	1.43E–07	Uranine	071005–071008

* /Sokolnicki et al. 2007/.

[+] Test section vertical depth (m b s l) is given within brackets.

4.4 Analyses and interpretation

4.4.1 The dilution method – general principles

The dilution method is an excellent tool for in situ determination of flow rates in fractures and fracture zones.

In the dilution method a tracer is introduced and homogeneously distributed into a bore-hole test section. The tracer is subsequently diluted by the ambient groundwater, flowing through the borehole test section. The dilution of the tracer is proportional to the water flow through the borehole section, Figure 4-1.

The dilution in a well-mixed borehole section, starting at time t = 0, is given by:

$$\ln(C/C_0) = -\frac{Q_w}{V} \cdot t \qquad \text{(Equation 4-1)}$$

where C is the concentration at time t (s), C_0 is the initial concentration, V is the water volume (m^3) in the test section and Q_w is the volumetric flow rate (m^3/s). Since V is known, the flow rate may then be determined from the slope of the line in a plot of ln (C/C_0), or ln C, versus t.

An important interpretation issue is to relate the measured groundwater flow rate through the borehole test section to the rate of groundwater flow in the fracture/fracture zone straddled by the packers. The flow-field distortion must be taken into consideration, i.e. the degree to which the groundwater flow converges and diverges in the vicinity of the borehole test section. With a correction factor, α, which accounts for the distortion of the flow lines due to the presence of the borehole, it is possible to determine the cross-sectional area perpendicular to groundwater flow by:

$$A = 2 \cdot r \cdot L \cdot \alpha \qquad \text{(Equation 4-2)}$$

where A is the cross-sectional area (m^2) perpendicular to groundwater flow, r is borehole radius (m), L is the length (m) of the borehole test section and α is the correction factor. Figure 4-2 schematically shows the cross-sectional area, A, and how flow lines converge and diverge in the vicinity of the borehole test section.

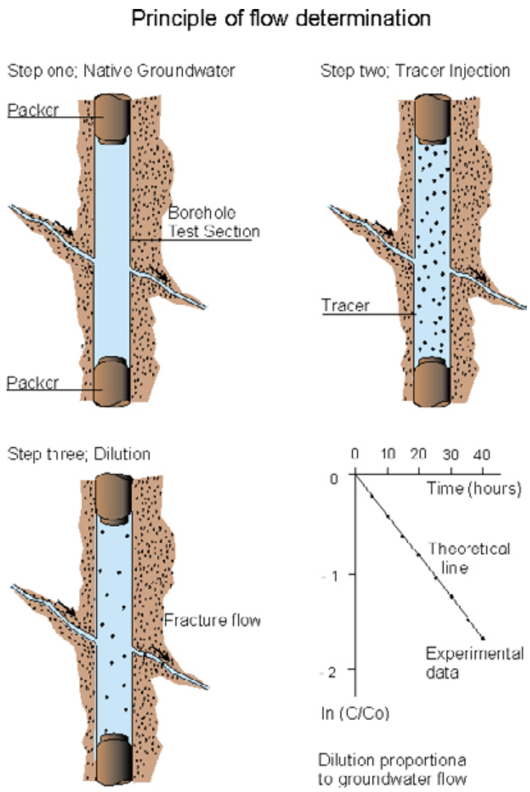

Figure 4-1. *General principles of dilution and flow determination.*

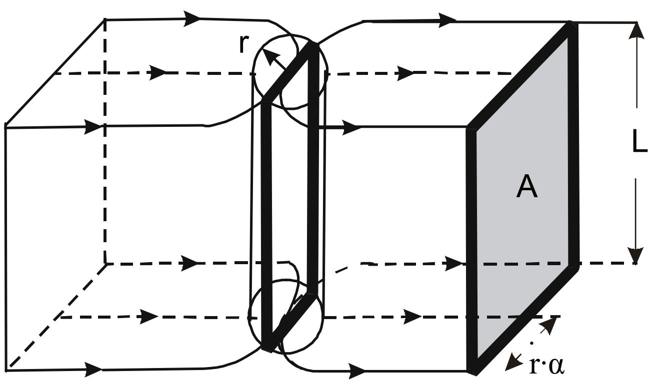

Figure 4-2. *Diversion and conversion of flow lines in the vicinity of a borehole test section.*

Assuming laminar flow in a plane parallel fissure or a homogeneous porous medium, the correction factor α is calculated according to Equation (4-3), which often is called the formula of Ogilvi /Halevy et al. 1967/. Here it is assumed that the disturbed zone, created by the presence of the borehole, has an axis-symmetrical and circular form.

$$\alpha = \frac{4}{1 + (r/r_d) + (K_2/K_1)(1 - (r/r_d)^2)} \qquad \text{(Equation 4-3)}$$

where r_d is the outer radius (m) of the disturbed zone, K_1 is the hydraulic conductivity (m/s) of the disturbed zone, and K_2 is the hydraulic conductivity of the aquifer. If the drilling has not caused any disturbances outside the borehole radius, then $K_1 = K_2$ and $r_d = r$ which will result in $\alpha = 2$. With $\alpha = 2$, the groundwater flow within twice the borehole radius will converge through the borehole test section, as illustrated in Figures 4-2 and 4-3.

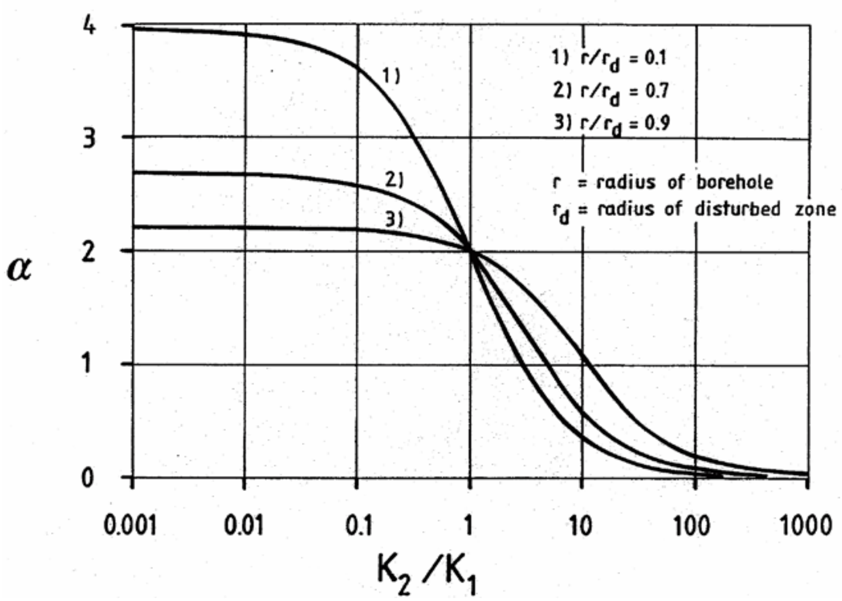

Figure 4-3. *The correction factor, α, as a function of K_2/K_1 at different radial extent (r/r_d) of the disturbed zone (skin zone) around the borehole.*

If there is a disturbed zone around the borehole the correction factor α is given by the radial extent and hydraulic conductivity of the disturbed zone. If the drilling has caused a zone with a lower hydraulic conductivity in the vicinity of the borehole than in the fracture zone, e.g. positive skin due to drilling debris and clogging, the correction factor α will decrease. A zone of higher hydraulic conductivity around the borehole will increase α. Rock stress redistribution, when new boundary conditions are created by the drilling of the borehole, may also change the hydraulic conductivity around the borehole and thus affect α. In Figure 4-3, the correction factor, α, is given as a function of K_2/K_1 at different normalized radial extents of the disturbed zone (r/r_d). If the fracture/fracture zone and groundwater flow are not perpendicular to the borehole axis, this also has to be accounted for. At a 45 degree angle to the borehole axis the value of α will be about 41% larger than in the case of perpendicular flow. This is further discussed in /Gustafsson 2002/ and /Rhén et al. 1991/.

In order to obtain the Darcy velocity in the undisturbed rock the calculated groundwater flow, Q_w is divided by A, Equation 4-4.

$$v = Q_w / A \qquad \text{(Equation 4-4)}$$

The hydraulic gradient is then calculated as

$$I = v/K \qquad \text{(Equation 4-5)}$$

where K is the hydraulic conductivity.

4.4.2 The dilution method – evaluation and analysis

The first step of evaluation included studying a graph of the measured concentration versus time data. In next step background concentration, i.e. any tracer concentration in the groundwater before tracer injection, was subtracted from the measured concentrations. Thereafter $\ln(C/C_0)$ was plotted versus time. In most cases that relationship was linear and the proportionality constant was then calculated by performing a linear regression. In the cases where the relationship between $\ln(C/C_0)$ and time was non-linear, a sub-interval was chosen in which the relationship was linear.

The value of $\ln(C/C_0)/t$ obtained from the linear regression was then used to calculate Q_w according to Equation (4-1).

The hydraulic gradient, I, was calculated by combining Equations (4-2), (4-4) and (4-5), and choosing $\alpha = 2$. The hydraulic conductivity, K, in Equation (4-5) was obtained from previously performed Posiva Flow Log measurements (PFL) /Sokolnicki et al. 2007/.

4.5 Nonconformities

Interruptions in the data transfer were a recurrent problem. This was caused by potential drops in the electric power supply due to a malfunctioned electrical (canbus) circuit or unexplainable interruptions in communication with the probe. A thunderstorm caused a broken circuit card in the Central unit at ground surface. The circuit card had to be repaired with further delays as a consequence. During the repair of the circuit card the dilution measurement was continued in the test section at c. 473 m but data transfer from the borehole probe was not possible. Data from before and after the interruption were used for evaluation.

The borehole water was found to have high particle content and chemical composition that caused clogging of the optical measurement device at the section at c. 684 m borehole length. To get rid of high particle content borehole water in the section, water was pumped from the section to the borehole. Circulation and further rinsing with expanded packers also increased the cleansing of the borehole water in the section. These actions took some time and delayed the measurements.

5 Results

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan number (AP PS 400-07-059). Only data in SKB's databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

5.1 Dilution measurements

Figure 5-1 exemplifies a typical dilution curve in a fracture zone straddled by the test section at 591.0–594.0 m borehole length (551–554 m vertical depth) in borehole KLX21B. In the first phase, the background value is recorded. The packers are inflated and background recorded further for about 25 minutes. In phase two, Uranine tracer is injected, and after mixing a start concentration (C_0) of about 0.94 mg/l is achieved. In phase three the dilution is measured for about 113 hours. Thereafter the packers are deflated and the remaining tracer flows out of the test section. Figure 5-2 shows the measured pressure during the dilution measurement. Since the pressure gauge is positioned about seven metres from top of test section there is a bias from the pressure in the test section which is not corrected for, as only changes and trends relative to the start value are of great importance for the dilution measurement. Figure 5-3 is a plot of the ln (C/C_0) versus time data and linear regression best fit to data showing a good fit with correlation R^2 = 0.9981. The standard deviation, STDAV, shows the mean divergence of the values from the best fit line and is calculated from

$$\text{STDAV} = \sqrt{\frac{n\sum x^2 - \left(\sum x\right)^2}{n(n-1)}}$$

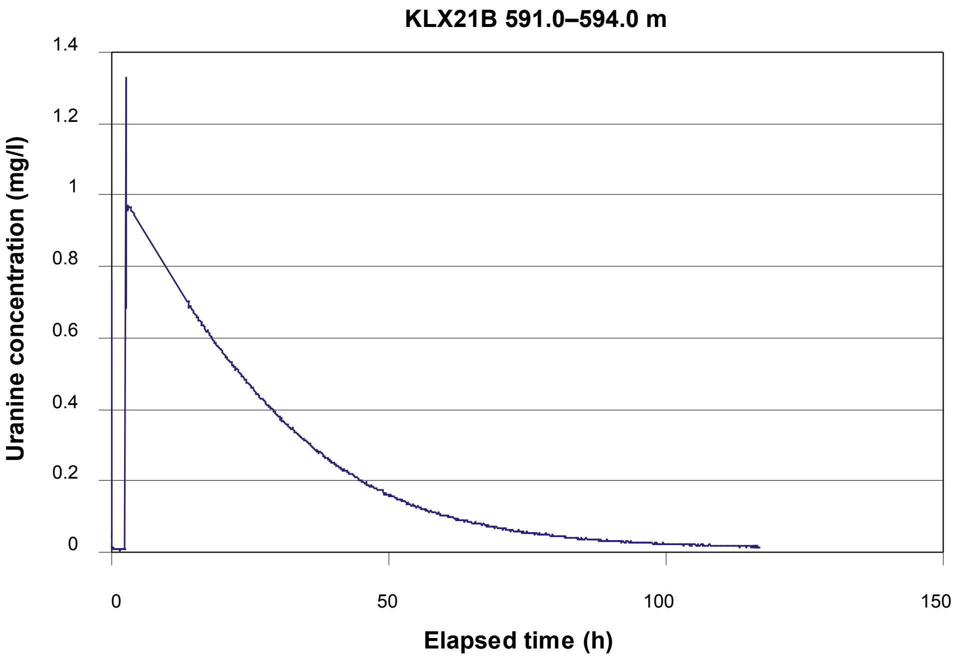

Figure 5-1. *Dilution measurement in borehole KLX21B, section 591.0–594.0 m. Uranine concentration versus time.*

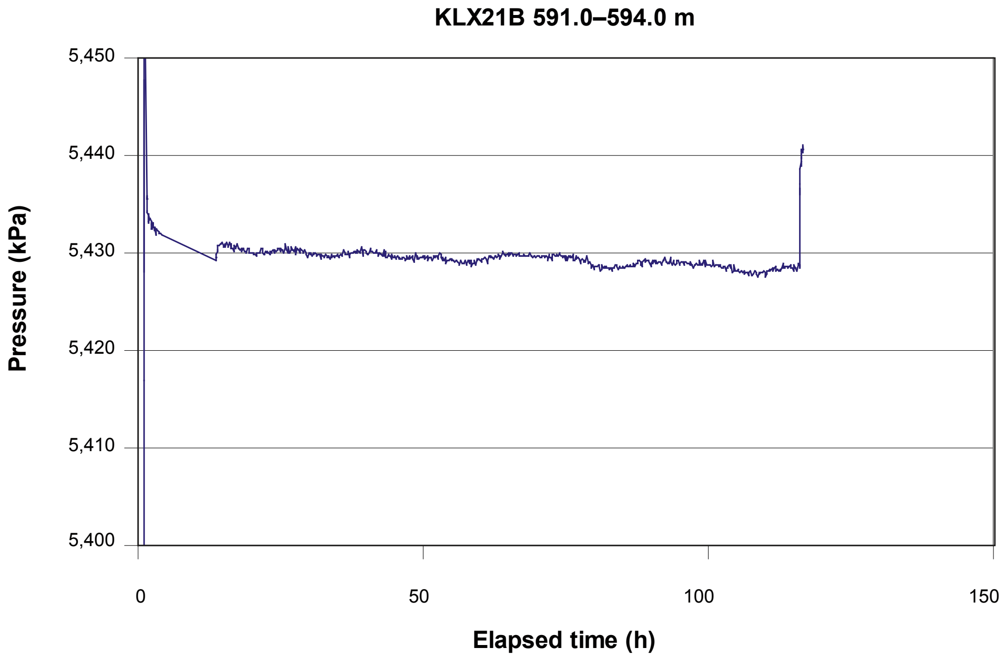

Figure 5-2. *Measured pressure during dilution measurement in borehole KLX21B, section 591.0–594.0 m.*

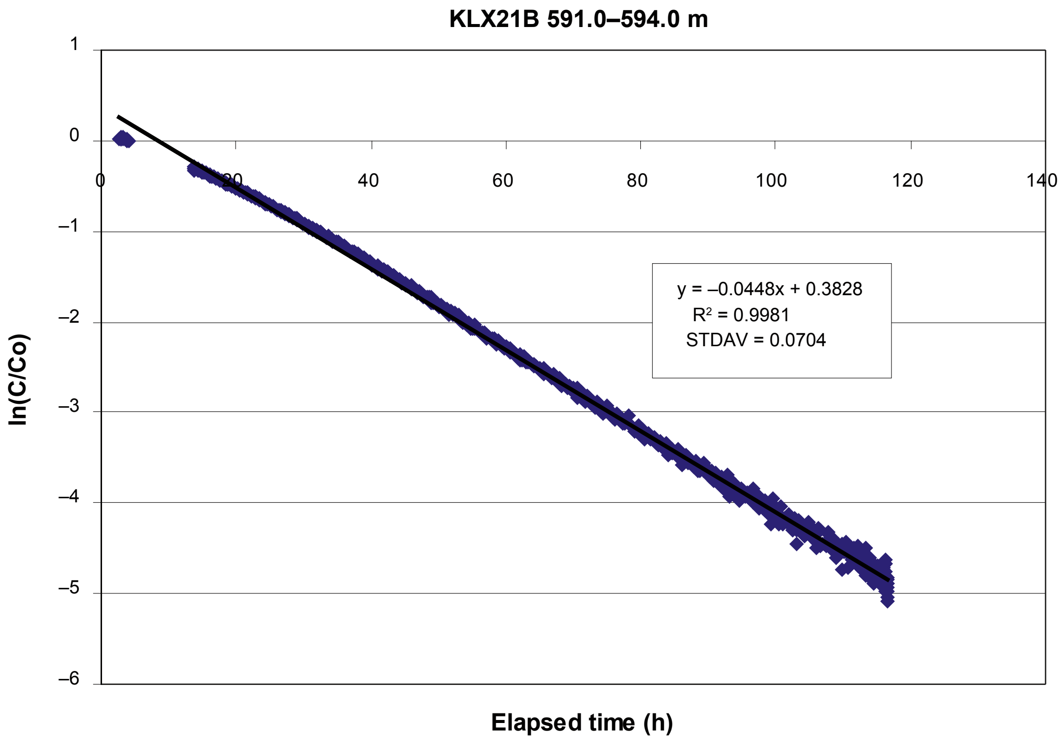

Figure 5-3. *Linear regression best fit to data from dilution measurement in borehole KLX21B, section 591.0–594.0 m.*

Calculated groundwater flow rate, Darcy velocity and hydraulic gradient are presented in Table 5-1 together with the results from all other dilution measurements carried out in borehole KLX21B.

The dilution measurements were carried out with the dye tracer Uranine. Uranine normally has a low background concentration and the tracer can be injected and measured in concentrations far above the background value, which gives a large dynamic range and accurate flow determinations.

Details of all dilution measurements, with diagrams of dilution versus time and the supporting parameters pressure, temperature and circulation flow rate are presented in Appendix B1–B8.

5.1.1 KLX21B, section 124.3–127.3 m

This dilution measurement was carried out with the dye tracer Uranine in a test section with two-three flowing fractures. The complete test procedure can be followed in Figure 5-4. Background concentration (0.01 mg/l) is measured for about 10 minutes with inflated packers. Thereafter the Uranine tracer is injected in three steps, and after mixing it finally reaches a start concentration of 1.19 mg/l above background. Dilution is measured for about eight hours. The packers are then deflated. Hydraulic pressure is stable (Appendix B1). The final evaluation was made on the 7 to 15 hours part of the dilution curve. The regression line fits well to the slope of the dilution with a correlation coefficient of $R^2 = 0.9986$ for the best fit line (Figure 5-5). The groundwater flow rate, calculated from the best fit line, is 15.4 ml/min. Calculated hydraulic gradient is 0.115 and Darcy velocity $5.7 \cdot 10^{-7}$ m/s. The hydraulic gradient is large and may be caused by local effects, where the measured fracture constitutes a hydraulic conductor between other fractures with different hydraulic heads. Or, the large gradient may be calculated due to wrong estimate of the correction factor, α, and/or the hydraulic conductivity of the fracture.

According to evaluated injection test in section 123.0–143.0 m the flow regime is defined as a PRF (Pseudo-radial flow regime) for the injection phase, which suggest a uniform flow in one plane. The recovery phase is defined as a radial flow regime with wellbore storage. The pressure response and the recovery of the pulse test indicates high transmissivity /Enachescu et al. 2007/, but do not explain the high hydraulic gradient in the section. However, in the injection test section there are 6 fractures lying outside the dilution test section with added T-value $5.5 \cdot 10^{-6}$ m^2/s /Sokolnicki et al. 2007/.

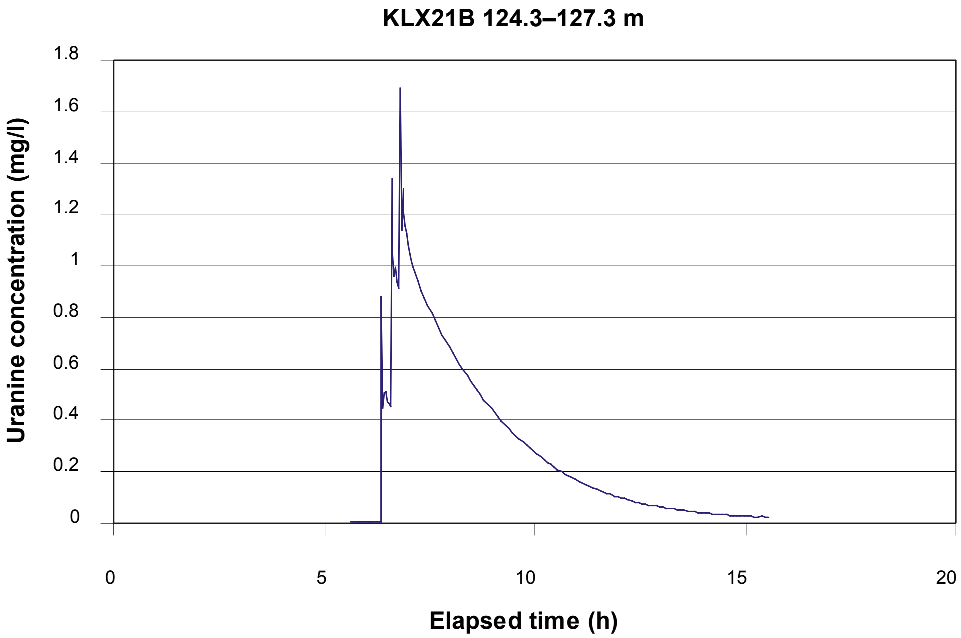

Figure 5-4. Dilution measurement in borehole KLX21B, section 124.3–127.3 m. Uranine concentration versus time.

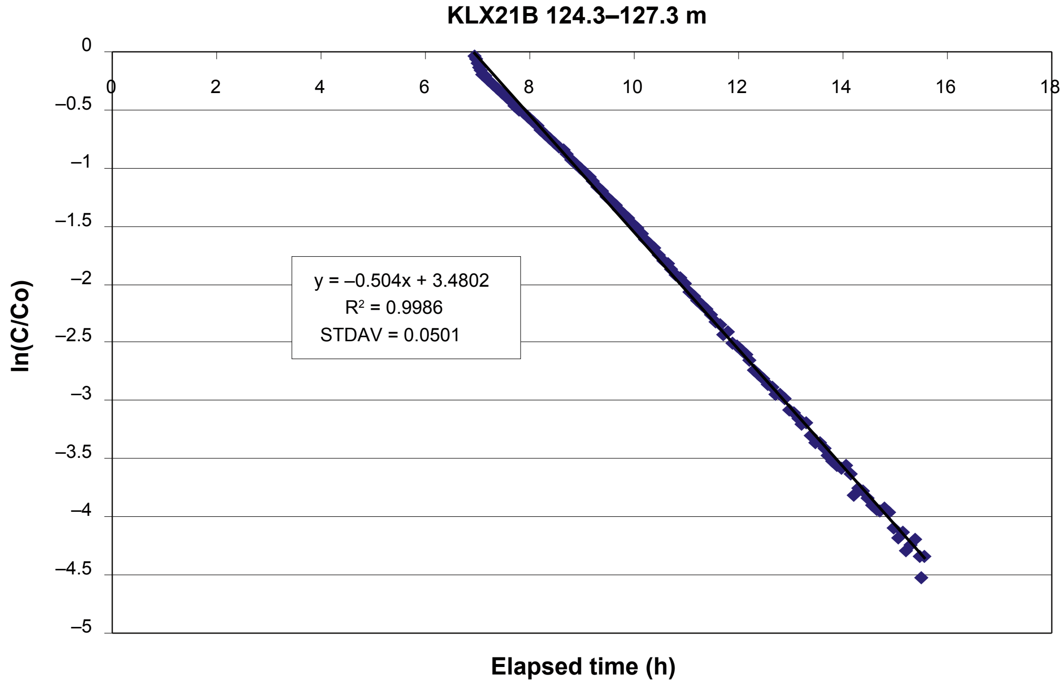

Figure 5-5. *Linear regression best fit to data from dilution measurement in borehole KLX21B, section 124.3–127.3 m.*

5.1.2 KLX21B, section 155.0–158.0 m

This dilution measurement was carried out with the dye tracer Uranine in a test section with two flowing fractures. The background measurement, tracer injection and dilution can be followed in Figure 5-6. Background concentration (0.01 mg/l) is measured for about 25 minutes with inflated packers. The Uranine tracer is injected and after mixing it reaches a start concentration of 0.94 mg/l above background. Dilution is measured for about 18 hours, thereafter the packers are deflated. Hydraulic pressure is stable (Appendix B2). Groundwater flow is determined from the 2–20 hours part of the dilution measurement. The correlation coefficient of the best fit line is $R^2 = 0.9883$ (Figure 5-7), and the groundwater flow rate, calculated from the best fit line, is 0.21 ml/min. Calculated hydraulic gradient is 0.032 and Darcy velocity $7.5 \cdot 10^{-9}$ m/s.

According to evaluated injection test measurement in section 143.0–163.0 m the flow regime is defined as a PRF for the injection phase, which suggests a uniform flow in one plane. The recovery phase is defined as a radial flow regime with wellbore storage. An unusually large skin factor may be caused by turbulent flow in the formation. The pressure response and the recovery of the pulse test indicate high transmissivity. /Enachescu et al. 2007/. However, in the injection test section there are 4 fractures lying outside the dilution test section with added T-value $1.9 \cdot 10^{-6}$ m²/s /Sokolnicki et al. 2007/.

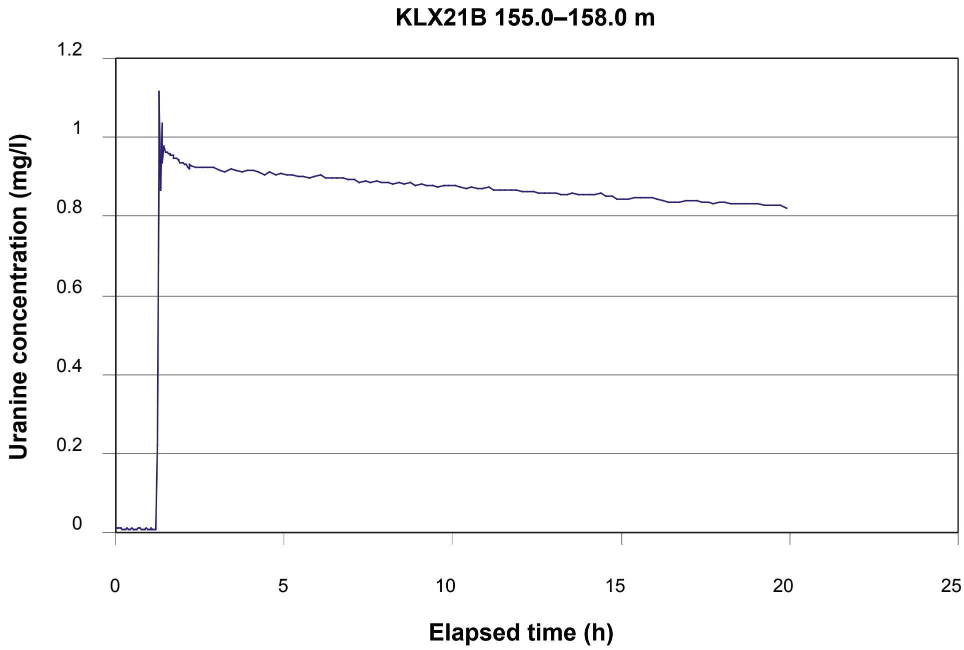

Figure 5-6. *Dilution measurement in borehole KLX21B, section 155.0–158.0 m. Uranine concentration versus time.*

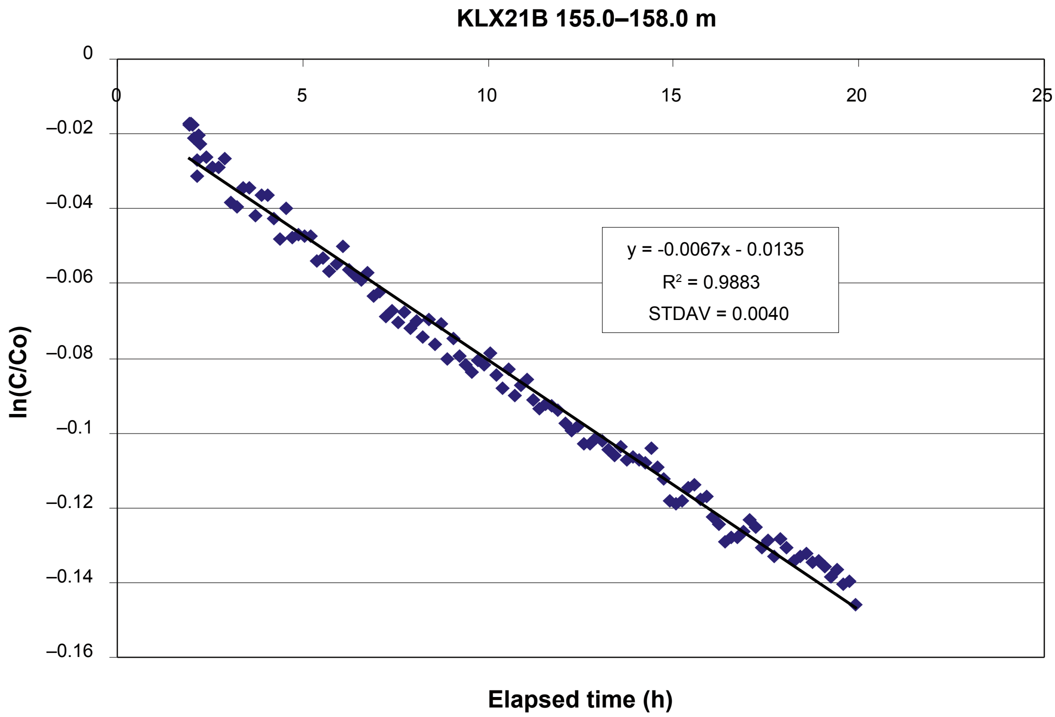

Figure 5-7. *Linear regression best fit to data from dilution measurement in borehole KLX21B, section 155.0–158.0 m.*

5.1.3 KLX21B, section 318.5–319.5 m

This dilution measurement was carried out in a test section with a single flowing fracture. The background measurement, tracer injection and dilution can be followed in Figure 5-8. Background concentration (0.01 mg/l) is measured for about 15 minutes with inflated packers. The Uranine tracer is injected and after mixing it reaches a start concentration of 0.98 mg/l above background. Dilution is measured for about 117 hours. Thereafter the packers are deflated and the remaining tracer flows out of the test section. Hydraulic pressure shows small diurnal pressure variations due to earth tidal effects (Appendix B3). The final evaluation was made from 2 to 119 hours of elapsed time. The regression line fits well to the slope of the dilution, and the correlation coefficient for the best fit line is good, $R^2 = 0.9984$ (Figure 5-9). The groundwater flow rate, calculated from the best fit line, is 0.062 ml/min. Calculated hydraulic gradient is 0.041 and Darcy velocity $6.8 \cdot 10^{-9}$ m/s.

According to evaluated injection test measurement in section 303.0–323.0 m the flow regime is defined as a PRF with a two composite model for the injection phase, which suggests a uniform flow in one plane. Sign of increase of transmissivity at some distance of the borehole is observed. The recovery phase is defined as a, radial flow regime with wellbore storage with a two composite model. The pressure response and the recovery of the pulse test indicate a medium formation transmissivity /Enachescu et al. 2007/. However, in the injection test section there are 2 fractures lying outside the dilution test section with added T-value $1.1 \cdot 10^{-8}$ m^2/s /Sokolnicki et al. 2007/.

5.1.4 KLX21B, section 472.7–473.7 m

This dilution measurement was carried out with the dye tracer Uranine in a test section with a single flowing fracture. The background measurement, tracer injection and dilution can be followed in Figure 5-10. Background concentration (0.01 mg/l) is measured for about 10 minutes with inflated packers. Thereafter the Uranine tracer is injected and after mixing it finally reaches a start concentration of 1.33 mg/l above background. Dilution is measured for about 320 hours. Thereafter the packers are deflated and the remaining tracer flows out of the test section. Hydraulic pressure shows small diurnal pressure variations due to earth tidal effects (Appendix B4). A broken circuit card gives a gap in the data transfer. The evaluation is made using both the 60–76 hours part of the dilution measurement before the interruption and the 239–309 hours part when the repaired circuit card is reinstalled. The correlation coefficient of the best fit line is $R^2 = 0.9888$ (Figure 5-11), and the groundwater flow rate, calculated from the best fit line, is 0.009 ml/min. Calculated hydraulic gradient is 0.018 and Darcy velocity $1.0 \cdot 10^{-9}$ m/s.

According to evaluated injection test measurement in section 473.0–478.0 m the flow regime is defined as a PRF for the injection phase, which suggests a uniform flow in one plane. The recovery phase is defined as a radial flow regime with wellbore storage. The pressure response and the recovery of the pulse test indicate a medium formation transmissivity /Enachescu et al. 2007/. The injection test section does not have any fractures lying outside the dilution test section /Sokolnicki et al. 2007/.

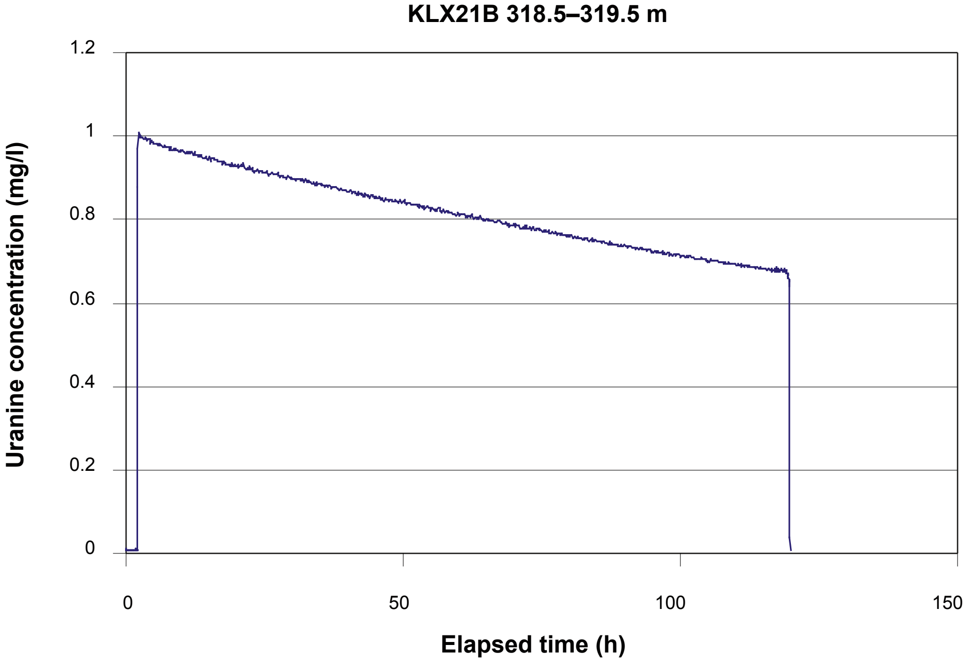

Figure 5-8. *Dilution measurement in borehole KLX21B, section 318.5–319.5 m. Uranine concentration versus time.*

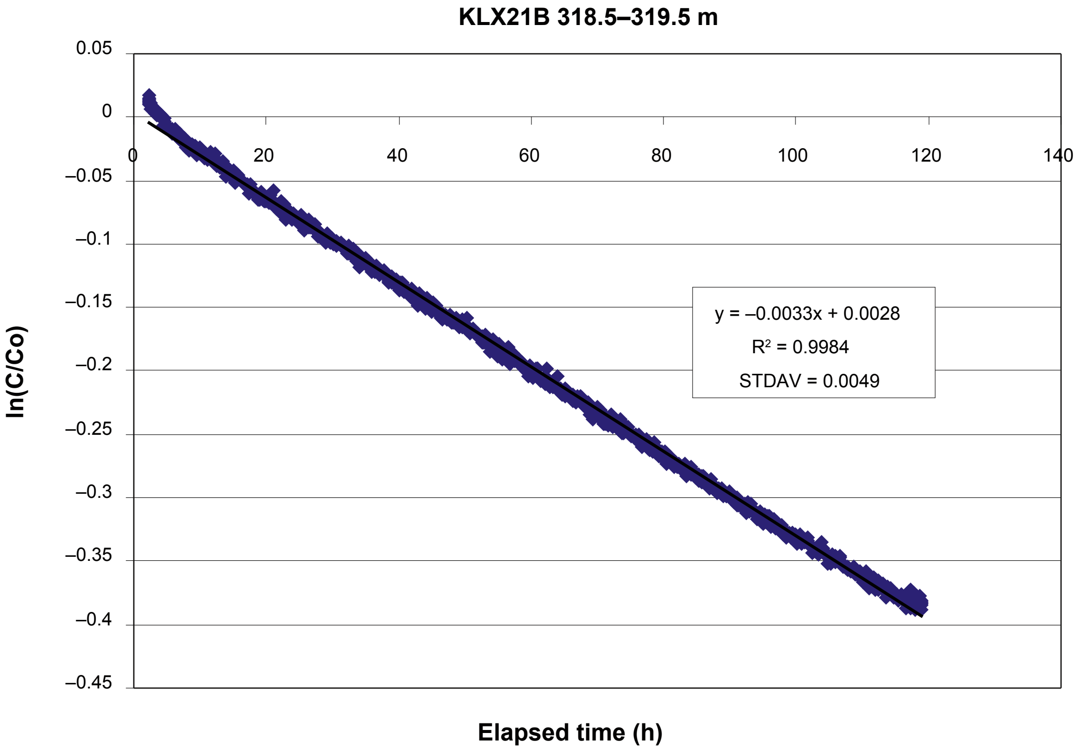

Figure 5-9. *Linear regression best fit to data from dilution measurement in borehole KLX21B, section 318.5–319.5 m.*

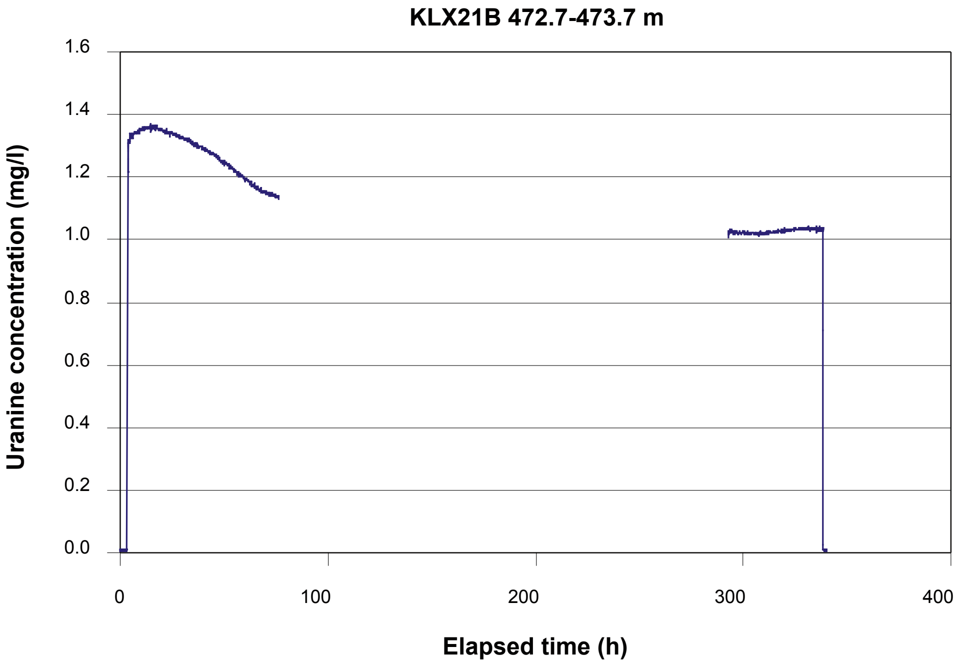

Figure 5-10. *Dilution measurement in borehole KLX21B, section 472.7–473.7 m. Uranine concentration versus time.*

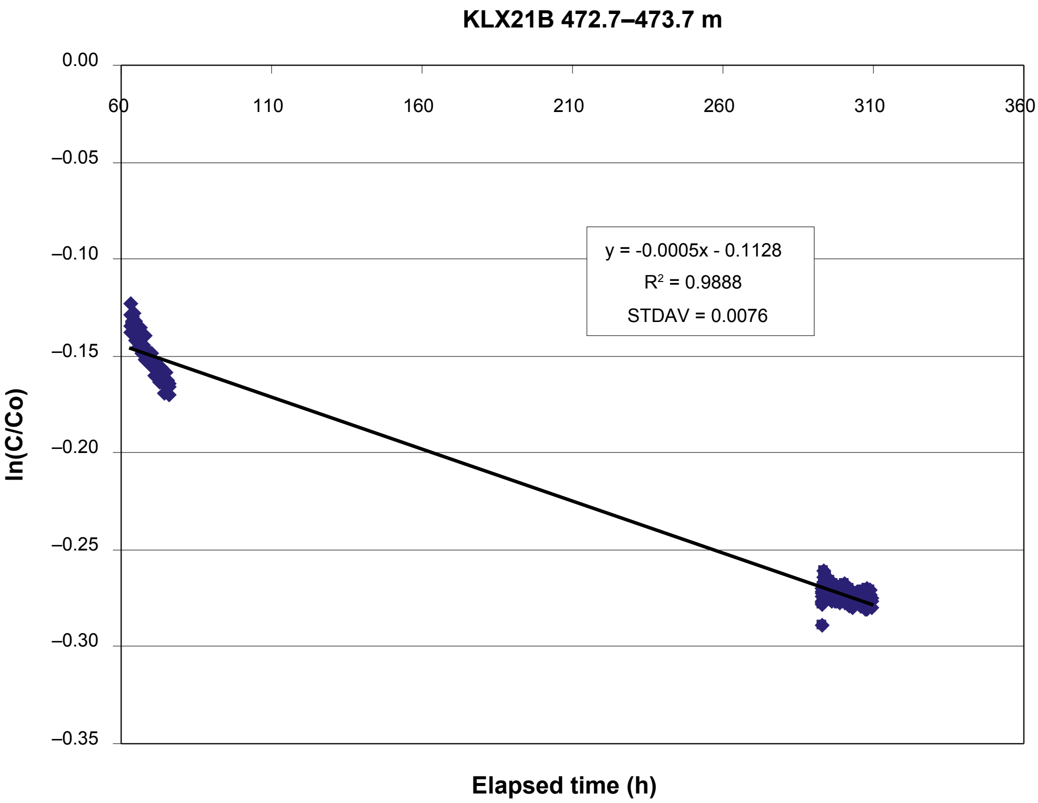

Figure 5-11. *Linear regression best fit to data from dilution measurement in borehole KLX21B, section 472.7–473.7 m.*

5.1.5 KLX21B, section 566.5–569.5 m

This dilution measurement was carried out with the dye tracer Uranine in a test section with one or two flowing fractures. The background measurement, tracer injection and dilution can be followed in Figure 5-12. Background concentration (0.01 mg/l) is measured for about 20 minutes with inflated packers. Thereafter the Uranine tracer is injected and after mixing it finally reaches a start concentration of 0.92 mg/l above background. Dilution is measured for about 38 hours. Thereafter the packers are deflated. Hydraulic pressure shows small diurnal pressure variations due to earth tidal (Appendix B5). The groundwater flow is determined from the 1–39 hours part of the dilution measurement. The correlation coefficient of the best fit line is $R^2 = 0.9953$ (Figure 5-13), and the groundwater flow rate, calculated from the best fit line, is 0.12 ml/min. Calculated hydraulic gradient is 0.025 and Darcy velocity $4.3 \cdot 10^{-9}$ m/s.

According to evaluated injection test measurement in section 563.0–583.0 m the flow regime is defined as a PRF for the injection phase, which suggests uniform flow in one plane. The recovery phase is defined as a, radial flow regime with wellbore storage with a two composite model. The pressure response and the recovery of the pulse test indicate a. high formation transmissivity /Enachescu et al. 2007/. The injection test section do not have any fractures lying outside the dilution test section /Sokolnicki et al. 2007/.

5.1.6 KLX21B, section 591.0–594.0 m

This dilution measurement was carried out with the dye tracer Uranine in a test section with one or two flowing fractures. The background measurement, tracer injection and dilution can be followed in Figure 5-14. Background concentration (0.01 mg/l) is measured for about 20 minutes with inflated packers. Thereafter the Uranine tracer is injected and after mixing it finally reaches a start concentration of 0.93 mg/l above background. Dilution is measured for about 113 hours. Thereafter the packers are deflated. Hydraulic pressure shows small diurnal pressure variations due to earth tidal (Appendix B6). Groundwater flow is determined from the 3–78 hours part of the dilution measurement. The correlation coefficient of the best fit line is $R^2 = 0.9981$ (Figure 5-15), and the groundwater flow rate, calculated from the best fit line, is 1.37 ml/min. Calculated hydraulic gradient is 0.184 and Darcy velocity $5.0 \cdot 10^{-8}$ m/s. The hydraulic gradient is large and may be caused by local effects, where the measured fracture constitutes a hydraulic conductor between other fractures with different hydraulic heads. Or, the large gradient may be calculated due to wrong estimate of the correction factor, α, and/or the hydraulic conductivity of the fracture. Pressure responses in the borehole outside the test section are indicated in the Pipe String System measurement in section 588.0–593.0 m, which can explain the high flow rate and large hydraulic gradient.

According to evaluated injection te st measurement in section 583.0–603.0 m the flow regime is defined as a PRF for the injection phase, which suggests a uniform flow in one plane. The recovery phase is defined as a radial flow regime with wellbore storage. An increase of pressure in the section below during the injection phase indicates a minor flow through the fracture system of the formation. The pressure response and the recovery of the pulse test indicate a high formation transmissivity /Enachescu et al. 2007/. However,in the injection test section there is 1 fracture lying outside, but close to the dilution test section, at c. 595.2 m with added T-value $3.4 \cdot 10^{-7}$ m^2/s /Sokolnicki et al. 2007/.

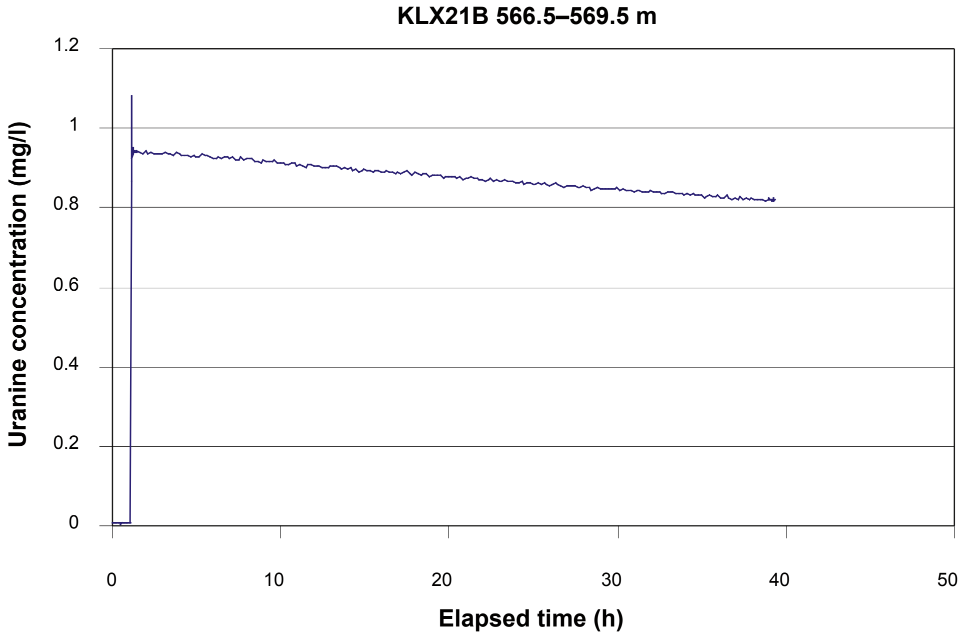

Figure 5-12. Dilution measurement in borehole KLX21B, section 566.5–569.5 m. Uranine concentration versus time.

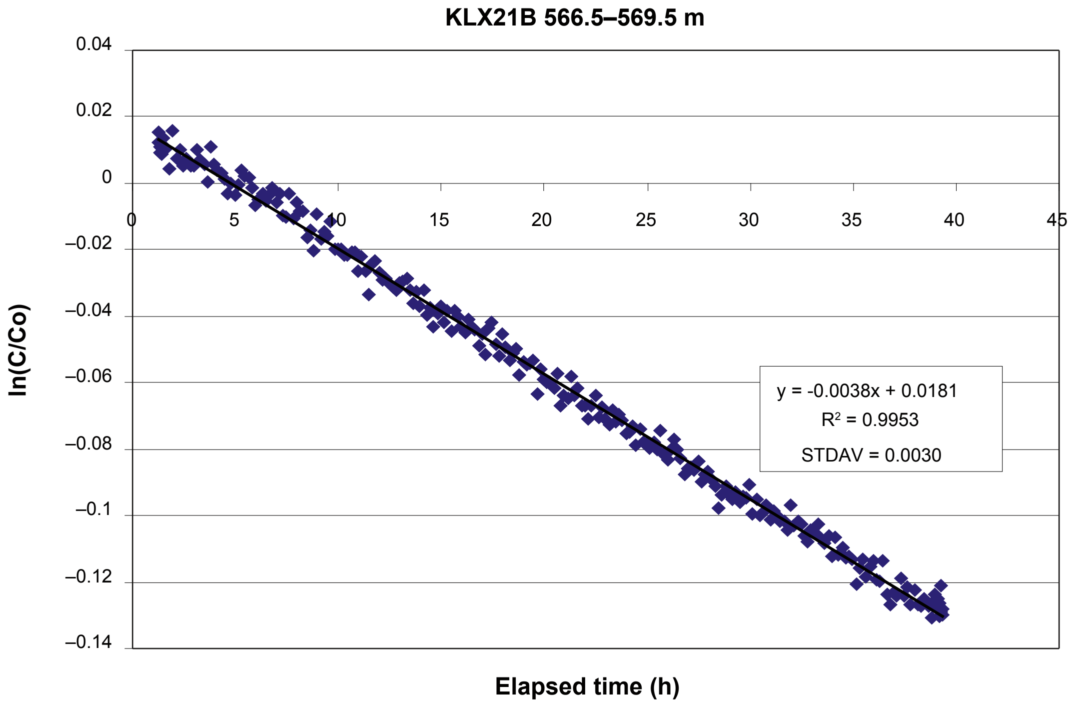

Figure 5-13. Linear regression best fit to data from dilution measurement in borehole KLX21B, section 566.5–569.5 m.

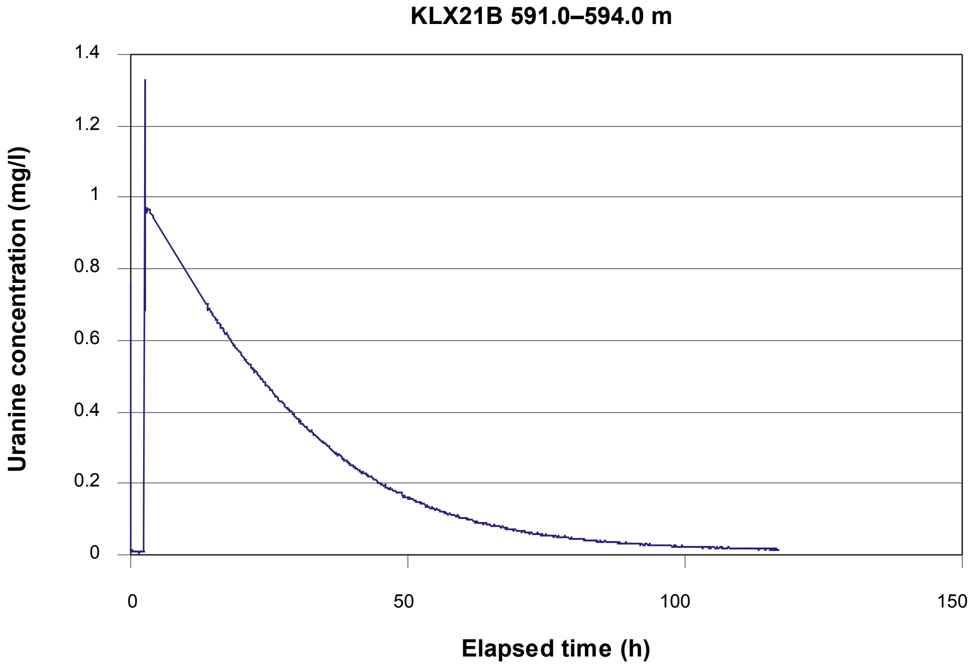

Figure 5-14. *Dilution measurement in borehole KLX21B, section 591.0–594.0 m. Uranine concentration versus time.*

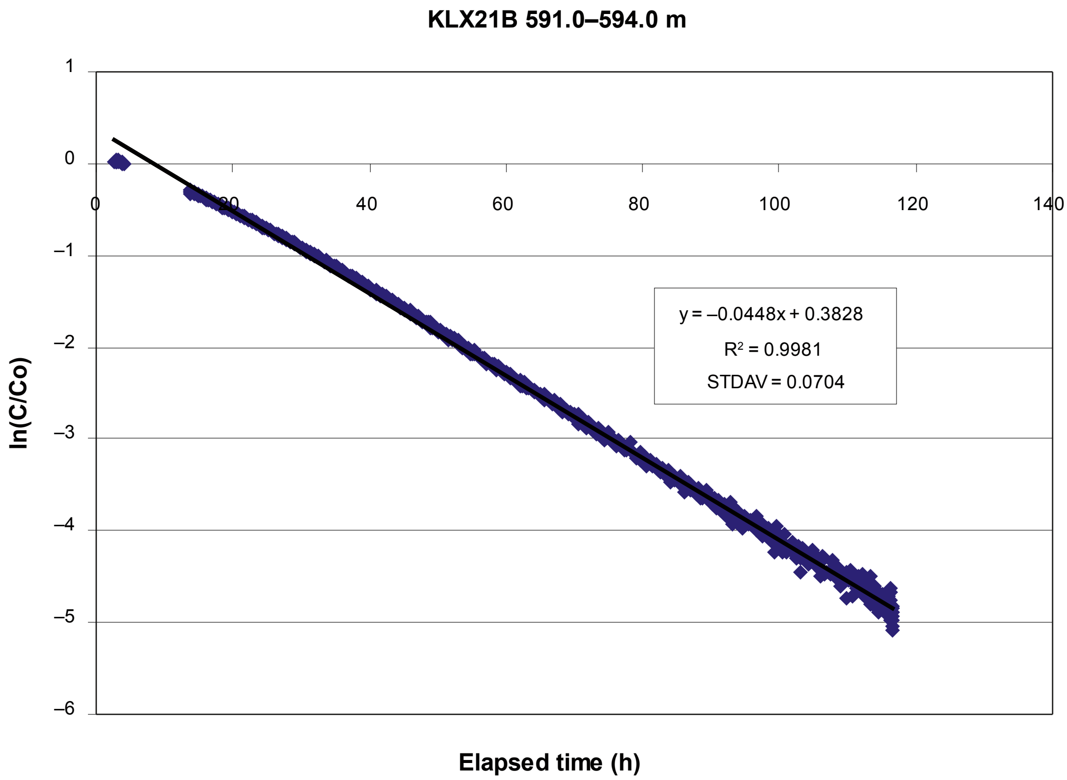

Figure 5-15. *Linear regression best fit to data from dilution measurement in borehole KLX21B, section 591.0–594.0 m.*

5.1.7 KLX21B, section 624.5–625.5 m

This dilution measurement was carried out with the dye tracer Uranine in a test section with a single flowing fracture. The background measurement, tracer injection and dilution can be followed in Figure 5-16. Background concentration (0.01 mg/l) is measured for about 15 minutes with inflated packers. Thereafter the Uranine tracer is injected in three steps and after mixing it finally reaches a start concentration of 1.05 mg/l above background. Dilution is measured for about 20 hours. Thereafter the packers are deflated and the remaining tracer flows out of the test section. Hydraulic pressure is stabile (Appendix B7). The groundwater flow is determined from the 2–22 hours part of the dilution measurement. The correlation coefficient of the best fit line is $R^2 = 0.9948$ (Figure 5-17), and the groundwater flow rate, calculated from the best fit line, is 0.17 ml/min. Calculated hydraulic gradient is 0.004 and Darcy velocity $1.8 \cdot 10^{-8}$ m/s.

According to evaluated injection test measurement in section 623.0–628.0 m the flow regime is defined as a PRF with a two composite model for the injection phase, which suggests a uniform flow in one plane. The recovery phase is defined as a radial flow regime with wellbore storage with a two composite model. A hydraulic connection to the bottom zone is assumed to be related to some flow through fractures in the formation. The pressure response and the recovery of the pulse test indicate a high formation transmissivity /Enachescu et al. 2007/. The injection test section does not have any fractures lying outside the dilution test section /Sokolnicki et al. 2007/.

5.1.8 KLX21B, section 683.7–684.7 m

This dilution measurement was carried out with the dye tracer Uranine in a test section with a single flowing fracture. The background measurement, tracer injection and dilution can be followed in Figure 5-18. Background concentration (0.01 mg/l) is measured for about 30 minutes with inflated packers. Thereafter the Uranine tracer is injected in two steps and after mixing it finally reaches a start concentration of 0.90 mg/l above background. Dilution is measured for about 75 hours. Thereafter the packers are deflated and the remaining tracer flows out of the test section. Hydraulic pressure is stable (Appendix B8). Groundwater flow is determined on the 219–266 hours part in the second attempt of dilution measurement after pumping to rinse the section from high particle content borehole water. The correlation coefficient of the best fit line is $R^2 = 0.9695$ (Figure 5-19), and the groundwater flow rate, calculated from the best fit line, is 0.023 ml/min. Calculated hydraulic gradient is 0.017 and Darcy velocity $2.5 \cdot 10^{-9}$ m/s.

According to evaluated injection test measurement in section 683.0–688.0 m the flow regime is defined as a PRF with a two composite model for the injection phase, which suggests a uniform flow in one plane. The recovery phase is defined as a radial flow regime with wellbore storage. A hydraulic connection to the bottom zone is assumed to be related to a flow through fractures in the formation. Sign of increase of transmissivity at some distance of the borehole is observed. The pressure response and the recovery of the pulse test indicate a medium formation transmissivity /Enachescu et al. 2007/. The injection test section does not have any fractures lying outside the dilution test section /Sokolnicki et al. 2007/.

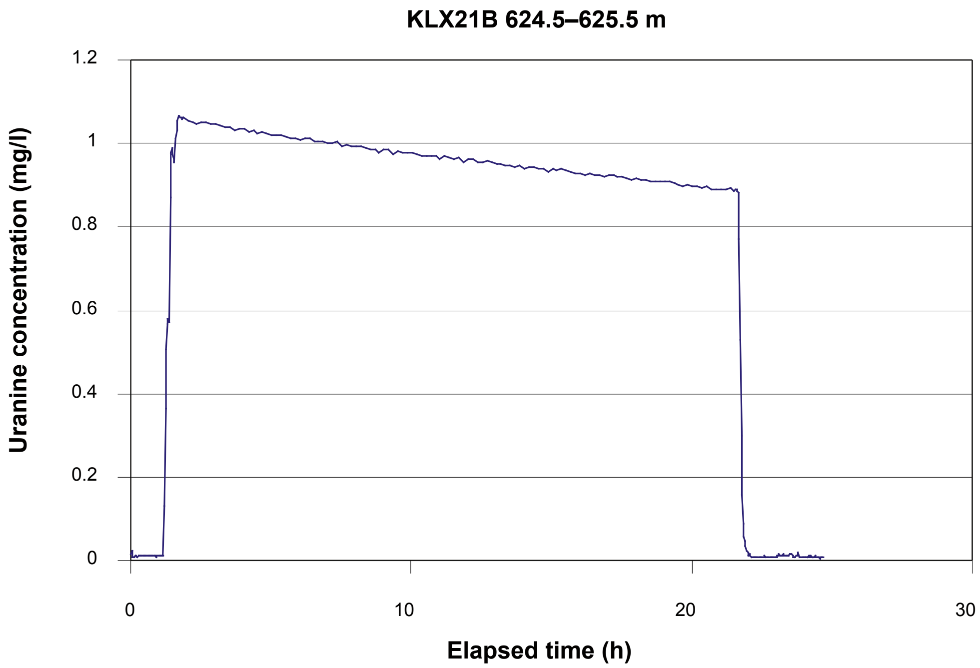

Figure 5-16. *Dilution measurement in borehole KLX21B, section 624.5–625.5 m. Uranine concentration versus time.*

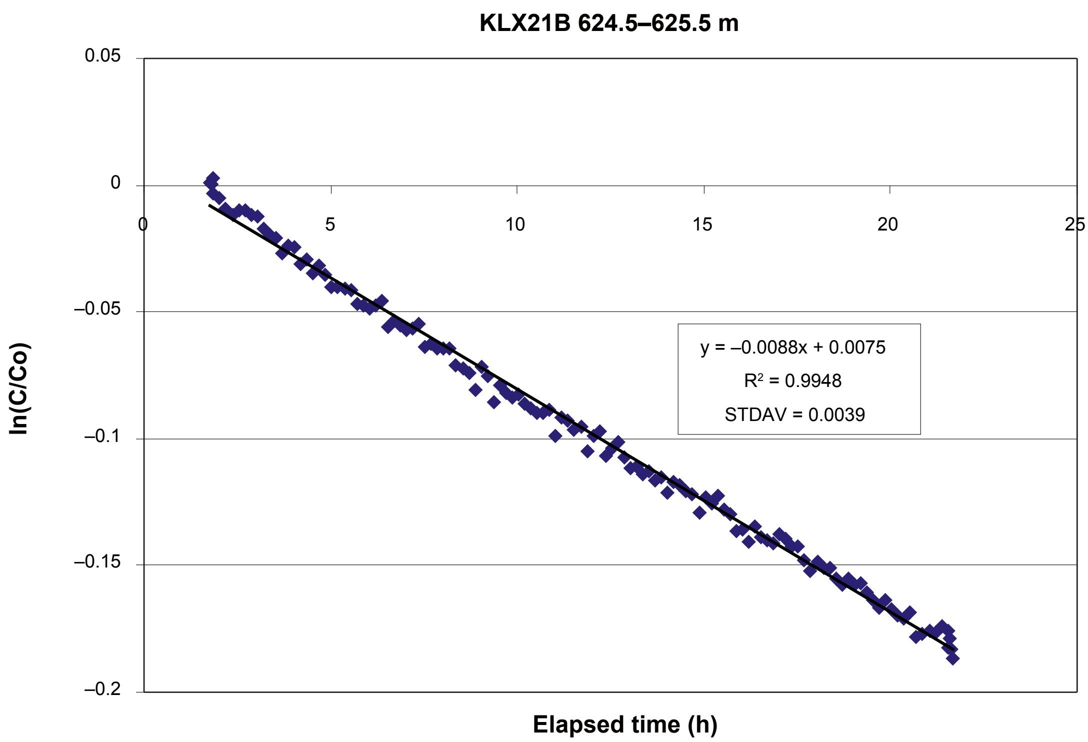

Figure 5-17. *Linear regression best fit to data from dilution measurement in borehole KLX21B, section 624.5–625.5 m.*

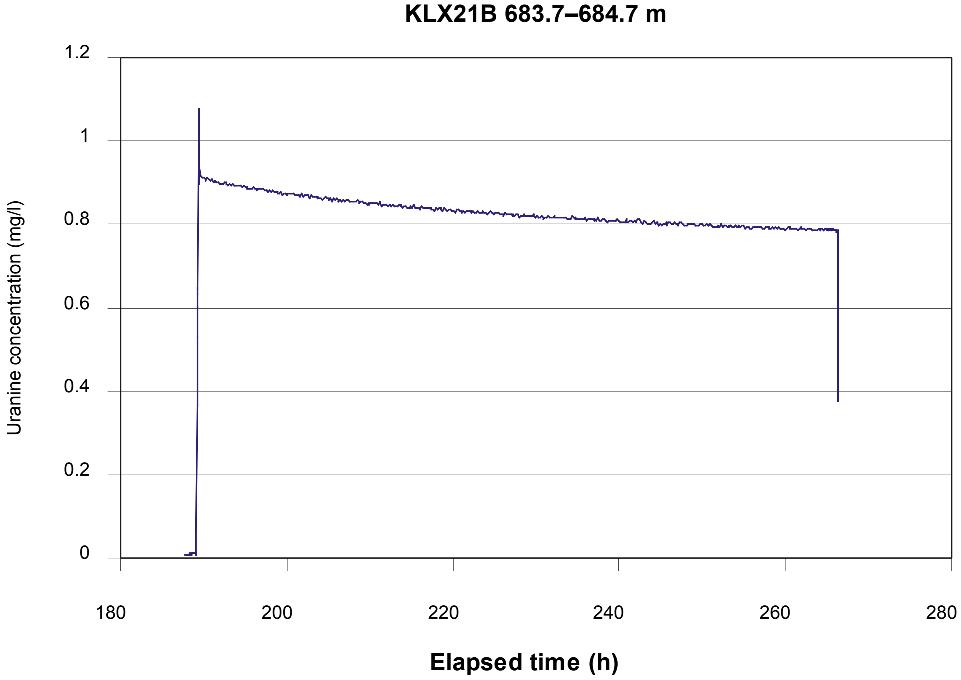

Figure 5-18. *Dilution measurement in borehole KLX21B, section 693.7–684.7 m. Uranine concentration versus time.*

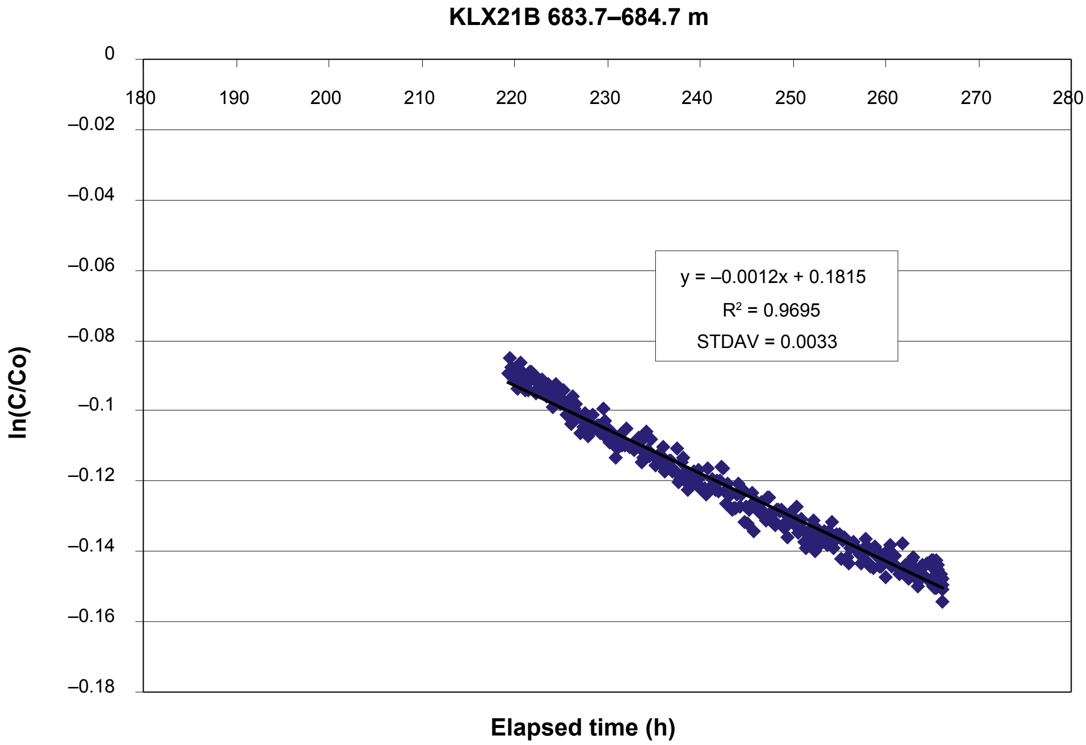

Figure 5-19. *Linear regression best fit to data from dilution measurement in borehole KLX21B, section 683.7–684.7 m.*

5.1.9 Summary of dilution results

Calculated groundwater flow rates, Darcy velocities and hydraulic gradients from all dilution measurements carried out in borehole KLX21B are presented in Table 5-1.

The results show that the groundwater flow varies during natural, i.e. undisturbed, conditions, with flow rates from 0.009 to 15.4 ml/min and Darcy velocities from $1.0 \cdot 10^{-9}$ to $5.7 \cdot 10^{-7}$ m/s. In this borehole a slight correlation is shown between depth and flow rates and depth and Darcy velocities. The highest flow rate and Darcy velocity were measured in the shallowest section at c. 124 m. The lowest flow rate and Darcy velocity were measured in the single fracture at c. 473 m borehole length, see Figures 5-20 and 5-21.

Correlation between flow rate and transmissivity is fairly good as shown in Figure 5-23, with the highest flow rate in the section with the highest transmissivity. In the section intersecting deformation zone DZ12 at c. 624 m borehole length the flow rate is somewhat lower than expected from the transmissivity. Hydraulic gradients, calculated according to the Darcy concept, are lowest in the deepest sections and highest in the shallowest sections se Figure 5-22. Exception is the section at c. 591 m borehole length where the gradient is high in spite of the depth.

Table 5-1. Groundwater flow rates, Darcy velocities and hydraulic gradients for all measured sections in borehole KLX21B.

Borehole	Test section (m)[+]	Number of flowing fractures*	T* (m^2/s)	Q (ml/min)	Q (m^3/s)	Darcy velocity (m/s)	Hydraulic gradient	Flow regime according to the Pipe String System** (Injection phase above, recovery below)
KLX21B	124.3–127.3 (116–119)	2–3	1.47E–05	15.431	2.6E–07	5.7E–07	0.115	PRF PRF–WBS
KLX21B	155.0–158.0 (146–149)	2	6.98E–07	0.205	3.4E–09	7.5E–09	0.032	PRF PRF–WBS
KLX21B	318.5–319.5 (297–298)	1	1.66E–07	0.062	1.0E–09	6.8E–09	0.041	PRF, two composite model PRF–WBS, two composite model
KLX21B	472.7–473.7 (440–441)	1	5.76E–08	0.009	1.6E–10	1.0E–09	0.018	PRF PRF–WBS
KLX21B	566.5–569.5 (529–531)	1–2	5.03E–07	0.116	1.9E–09	4.3E–09	0.025	PRF PRF–WBS two composite model
KLX21B	591.0–594.0 (551–554)	1–2	8.19E–07	1.372	2.3E–08	5.0E–08	0.184	PRF PRF–WBS
KLX21B	624.5–625.5 (582–583)	1	4.33E–06	0.165	2.8E–09	1.8E–08	0.004	PRF two composite model PRF–WBS two composite model
KLX21B	683.7–684.7 (637–638)	1	1.43E–07	0.023	3.8E–10	2.5E–09	0.017	PRF two composite model PRF–WBS

* /Sokolnicki et al. 2007/.

**/Enachescu et al. 2007/.

[+] Test section vertical depth (m b s l) is given within brackets.

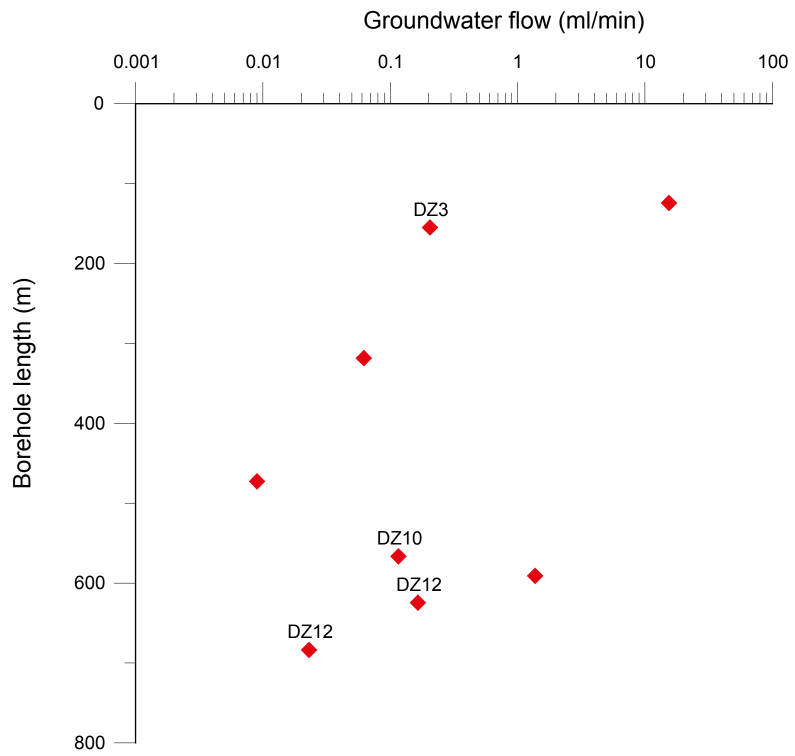

Figure 5-20. *Groundwater flow rate versus borehole length during natural hydraulic gradient conditions. Results from dilution measurements in fracture zones in borehole KLX21B. Labels DZ3, DZ10, and DZ12 refer to minor fracture zone notation /Carlsten et al. 2007/.*

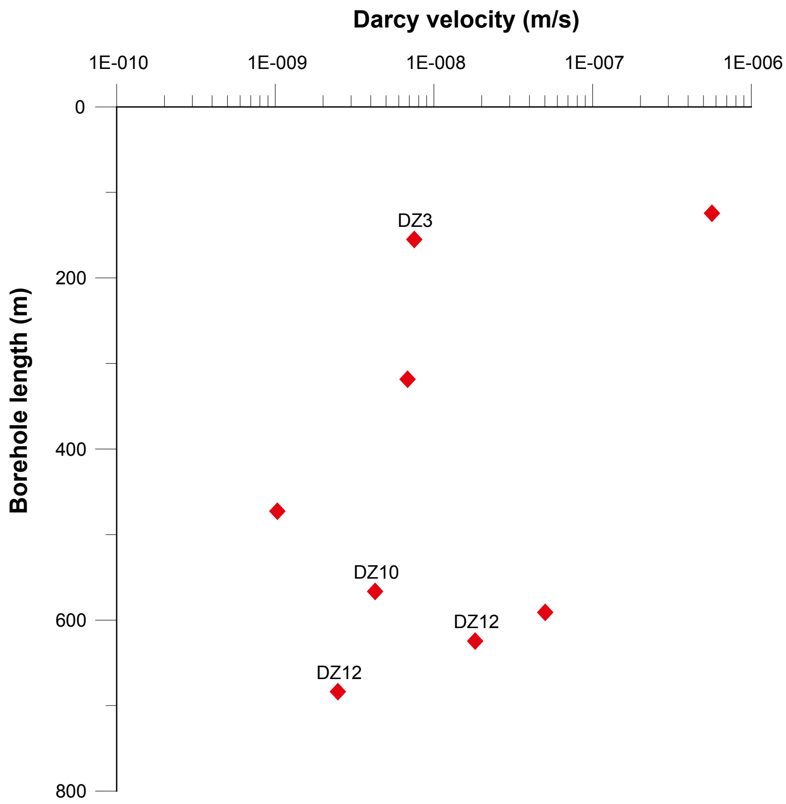

Figure 5-21. *Darcy velocity versus borehole length during natural hydraulic gradient conditions. Results from dilution measurements in fracture zones in borehole KLX21B. Labels DZ3, DZ10, and DZ12 refer to minor fracture zone notation /Carlsten et al. 2007/.*

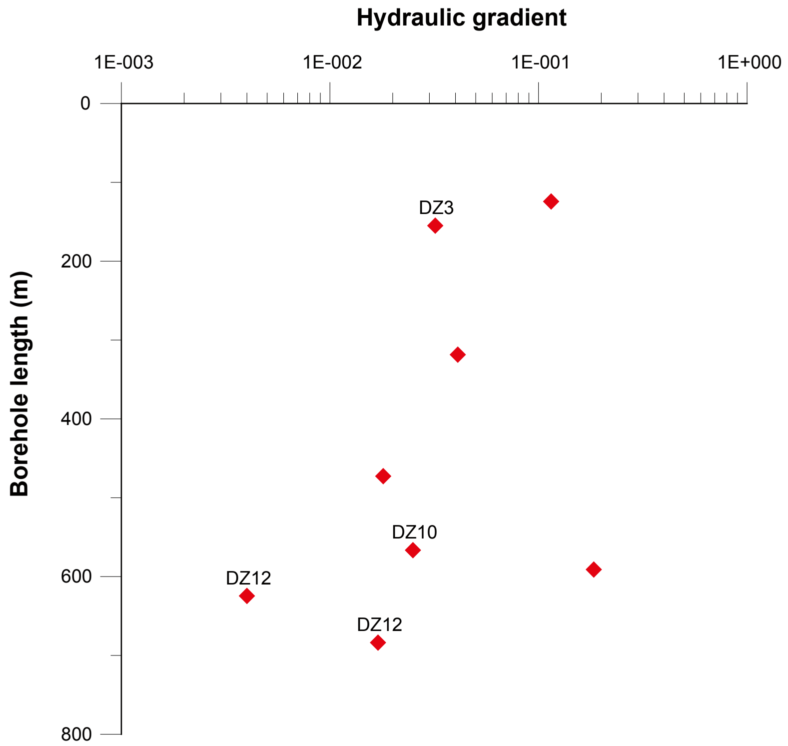

***Figure 5-22.** Hydraulic gradient versus borehole length during natural hydraulic gradient condition. Results from dilution measurements in fracture zones in borehole KLX21B. Labels DZ3, DZ10, and DZ12 refer to minor fracture zone notation /Carlsten et al. 2007/.*

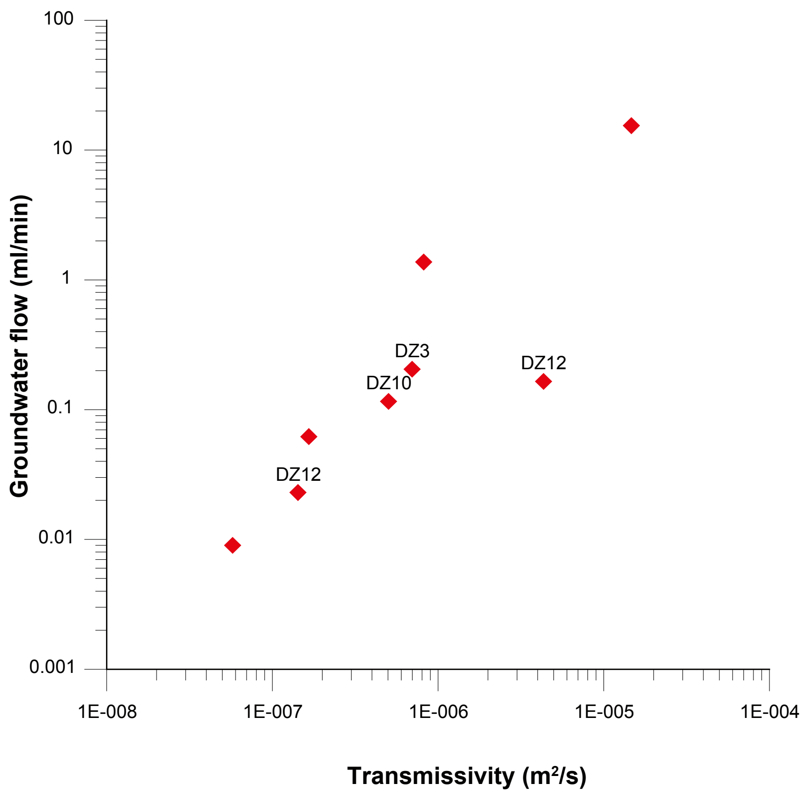

***Figure 5-23.** Groundwater flow rate versus transmissivity /Sokolnicki et al. 2007 and this report/ during undisturbed, i.e. natural hydraulic gradient conditions. Results from dilution measurements in fracture zones in borehole KLX21B. Labels DZ3, DZ10, and DZ12 refer to minor fracture zone notation /Carlsten et al. 2007/.*

6 Discussion and conclusions

The dilution measurements were carried out in selected fracture zones in borehole KLX21B at levels from c. 124 to 684 m borehole length (116 to 637 m vertical depth), where hydraulic transmissivity ranged within $T = 5.8 \cdot 10^{-8}$–$1.5 \cdot 10^{-5}$ m^2/s. In the studied sections two rock units are determined, RU1 at 100.8–670.5 m borehole length and RU2 at 670.5–706.0 m borehole length. RU1 are totally dominated by Ävrö granite and RU2 are totally dominated by fine-grained diorite. The borehole intersects some minor local deformation zones that are identified by SKB's single hole interpretation (SHI) of cored boreholes as seen in Table 6-1 /Carlsten et al. 2007/.

The results of the dilution measurements in borehole KLX21B show that the groundwater flow varies considerably during natural conditions, with flow rates from 0.009 to 15.4 ml/min and Darcy velocities from $1.0 \cdot 10^{-9}$ to $5.7 \cdot 10^{-7}$ m/s ($8.6 \cdot 10^{-5}$–$4.9 \cdot 10^{-2}$ m/d). These results are in accordance with previous dilution measurements carried out in boreholes KSH02, KLX02, KLX03, KLX18A and KLX11A. In these boreholes hydraulic transmissivity in the test sections was within $T = 1.3 \cdot 10^{-8}$–$1.8 \cdot 10^{-5}$ m^2/s and flow rate ranged from 0.02 to 4.2 ml/min and Darcy velocity from $9.3 \cdot 10^{-10}$ to $1.2 \cdot 10^{-7}$ m/s ($8.0 \cdot 10^{-5}$–$1.0 \cdot 10^{-2}$ m/d) /Gustafsson and Nordqvist 2005, Gustafsson et al. 2006a, Thur et al. 2006, 2007b/.

Table 6-1. Intersected zones, groundwater flow rates, Darcy velocities and hydraulic gradients for all measured sections in boreholes KLX21B.

Borehole	Test section (m)+	Rock types and Zones**	Number of flowing fractures*	T* (m^2/s)	Q (ml/min)	Q (m^3/s)	Darcy velocity (m/s)	Hydraulic gradient
KLX21B	124.3–127.3 (116–119)	RU1, Ävrö granite	2–3	1.47E–05	15.43	2.6E–07	5.7E–07	0.115
KLX21B	155.0–158.0 (146–149)	RU1, Ävrö granite	2	6.98E–07	0.21	3.4E–09	7.5E–09	0.032
		DZ3						
KLX21B	318.5–319.5 (297–298)	RU1, Ävrö granite	1	1.66E–07	0.06	1.0E–09	6.8E–09	0.041
KLX21B	472.7–473.7 (440–441)	RU1, Ävrö granite	1	5.76E–08	0.01	1.6E–10	1.0E–09	0.018
KLX21B	566.5–569.5 (529–531)	RU1, Ävrö granite	1–2	5.03E–07	0.12	1.9E–09	4.3E–09	0.025
		DZ10						
KLX21B	591.0–594.0 (551–554)	RU1, Ävrö granite	1–2	8.19E–07	1.37	2.3E–08	5.0E–08	0.184
KLX21B	624.5–625.5 (582–583)	RU1, Ävrö granite	1	4.33E–06	0.17	2.8E–09	1.8E–08	0.004
		DZ12						
KLX21B	683.7–684.7 (637–638)	RU2, fine–grained dioritoid	1	1.43E–07	0.02	3.8E–10	2.5E–09	0.017
		DZ12						

* /Sokolnicki et al. 2007/.

** /Carlsten et al. 2007/.

+ Test section vertical depth (m b s l) is given within brackets.

Groundwater flow rates and Darcy velocities calculated from dilution measurements in borehole KLX21B are also within the range that can be expected based on experience from previously preformed dilution measurements under natural gradient conditions at other sites in Swedish crystalline rock /Gustafsson and Andersson 1991, Gustafsson and Morosini 2002, Gustafsson and Nordqvist 2005, Gustafsson et al. 2005, 2006ab, Thur et al. 2006, 2007ab/.

In KLX21B the lowest flow rate and Darcy velocity were measured in the single fracture at c. 473 m borehole length. Flow rate and Darcy velocity is also low in the test section at c. 684 m borehole length in deformation zone DZ12 .The highest flow rate and Darcy velocity were measured in the section at c. 124 m borehole length at the top of the borehole. The determined groundwater flow rates are proportional to the hydraulic transmissivity, although the section at c. 624 m borehole length, intersecting deformation zone DZ12, show lower flow rate than the hydraulic transmissivity is indicating. A slight correlation is shown between borehole length and flow rate and between depth and Darcy velocity.

Hydraulic gradients in KLX21B, calculated according to the Darcy concept, are within the expected range (0.001–0.05) in six out of eight measured test sections. In the section at c. 124 and c. 591 m borehole lengths the hydraulic gradients are considered to be large. In section 591 m hydraulic injection testing with the Pipe String System showed some pressure change in the adjacent section that might suggest a short-cut between fractures with different hydraulic head that would explain the high flow rate and large hydraulic gradient. Also wrong estimations of the correction factor, α, and/or the hydraulic conductivity of the fracture could explain the large hydraulic gradients.

7 References

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Appendix A

Borehole data KLX21B
SICADA - Information about KLX21B

Title	**Value**
	Information about cored borehole KLX21B (2007-08-24).
Comment:	No comment exists.

BOREHOLE LENGTH:

Signed/Approved By	Length(m)	Reference Level
Lars-Eric Samuelsson	858.78	Top of casing (center)

DRILLING PERIODS:

Signed/Approved By	From Date	To Date	Secup(m)	Seclow(m)	Drilling Type
Lars-Eric Samuelsson	2006-09-20	2006-09-25	0.30	99.41	Percussion drilling
Lars-Eric Samuelsson	2006-10-12	2006-11-29	99.41	858.78	Core drilling

STARTING POINT COORDINATE:

Signed/Approved By	Length(m)	Northing(m)	Easting(m)	Elevation	Coord System
Lars-Eric Samuelsson	0.00	6366164.00	1549715.10	10.68	RT90-RHB70
Lars-Eric Samuelsson	3.00	6366163.30	1549714.41	7.84	RT90-RHB70

STARTING POINT ANGLES:

Signed/Approved By	Length(m)	Bearing	Inclination (- = down)	Coord System
Lars-Eric Samuelsson	0.00	225.05	-70.86	RT90-RHB70

BOREHOLE DIAMETERS:

Signed/Approved By	Secup(m)	Seclow(m)	Hole Diam(m)
Lars-Eric Samuelsson	0.30	6.35	0.340
Lars-Eric Samuelsson	6.35	11.85	0.248
Lars-Eric Samuelsson	11.85	99.30	0.198
Lars-Eric Samuelsson	99.30	99.41	0.158
Lars-Eric Samuelsson	99.41	100.00	0.086
Lars-Eric Samuelsson	100.00	100.85	0.086
Lars-Eric Samuelsson	100.85	858.78	0.076

CORE DIAMETERS:

Signed/Approved By	Secup(m)	Seclow(m)	Core Diam(m)
Lars-Eric Samuelsson	99.41	100.00	0.072
Lars-Eric Samuelsson	100.00	858.78	0.050

CASING DIAMETERS:

Signed/Approved By	Secup(m)	Seclow(m)	Case In(m)	Case Out(m)	Comment
Lars-Eric Samuelsson	0.00	11.85	0.200	0.208	
Lars-Eric Samuelsson	0.30	6.35	0.311	0.323	

CONE DIMENSIONS:

Signed/Approved By	Secup(m)	Seclow(m)	Cone In(m)	Cone Out(m)
Lars-Eric Samuelsson	96.15	99.15	0.100	0.104
Lars-Eric Samuelsson	99.15	100.85	0.080	0.084

GROVE MILLING:

Signed/Approved By	Length(m)	Trace Detectable
Lars-Eric Samuelsson	110.00	Yes
Lars-Eric Samuelsson	150.00	Yes
Lars-Eric Samuelsson	200.00	Yes
Lars-Eric Samuelsson	250.00	Yes
Lars-Eric Samuelsson	300.00	Yes
Lars-Eric Samuelsson	350.00	Yes
Lars-Eric Samuelsson	400.00	Yes
Lars-Eric Samuelsson	450.00	Yes
Lars-Eric Samuelsson	500.00	Yes
Lars-Eric Samuelsson	550.00	Yes
Lars-Eric Samuelsson	600.00	Yes
Lars-Eric Samuelsson	650.00	Yes
Lars-Eric Samuelsson	700.00	Yes
Lars-Eric Samuelsson	750.00	Yes
Lars-Eric Samuelsson	800.00	Yes
Lars-Eric Samuelsson	830.00	Yes

INSTALLED SECTIONS:

Signed/Approved By	Section No	Start Date	Secup(m)	Seclow(m)

SECTION INFORMATION:

Signed/Approved By	Status
N/A	Packers are released.

VALVE INFORMATION:

Signed/Approved By	Status
	(No valve installation/removal.)

End of additional information.

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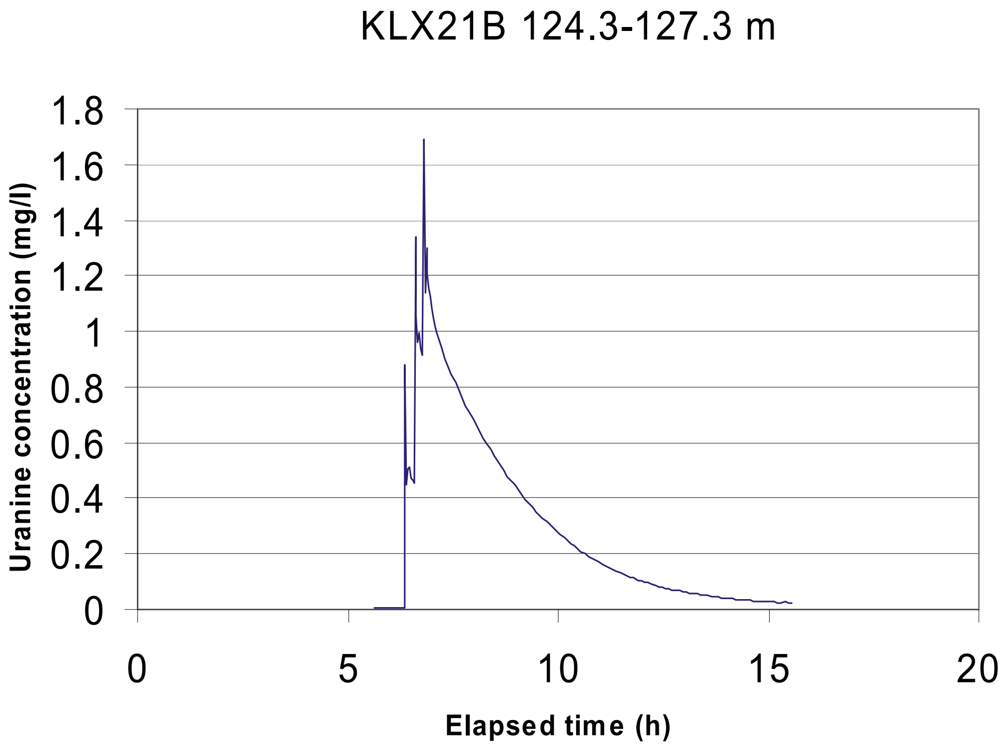
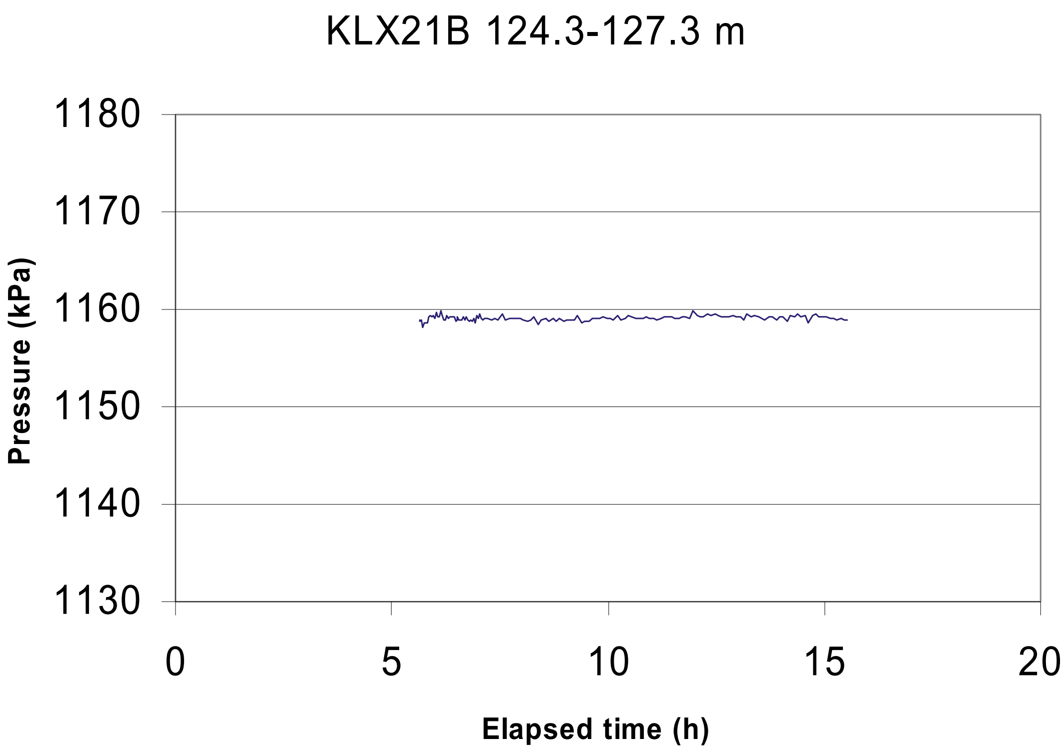
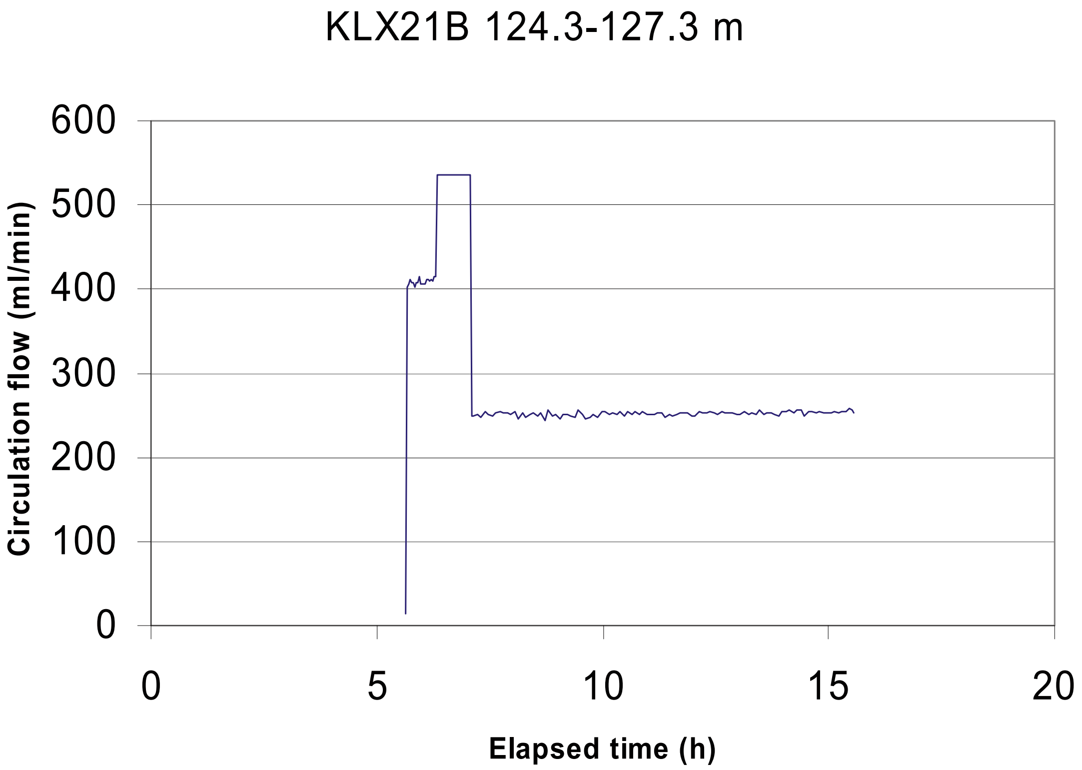
Dilution measurement KLX21B 124.3–125.3 m






KLX21B 124.3-127.3 m
Circulation flow (ml/min)
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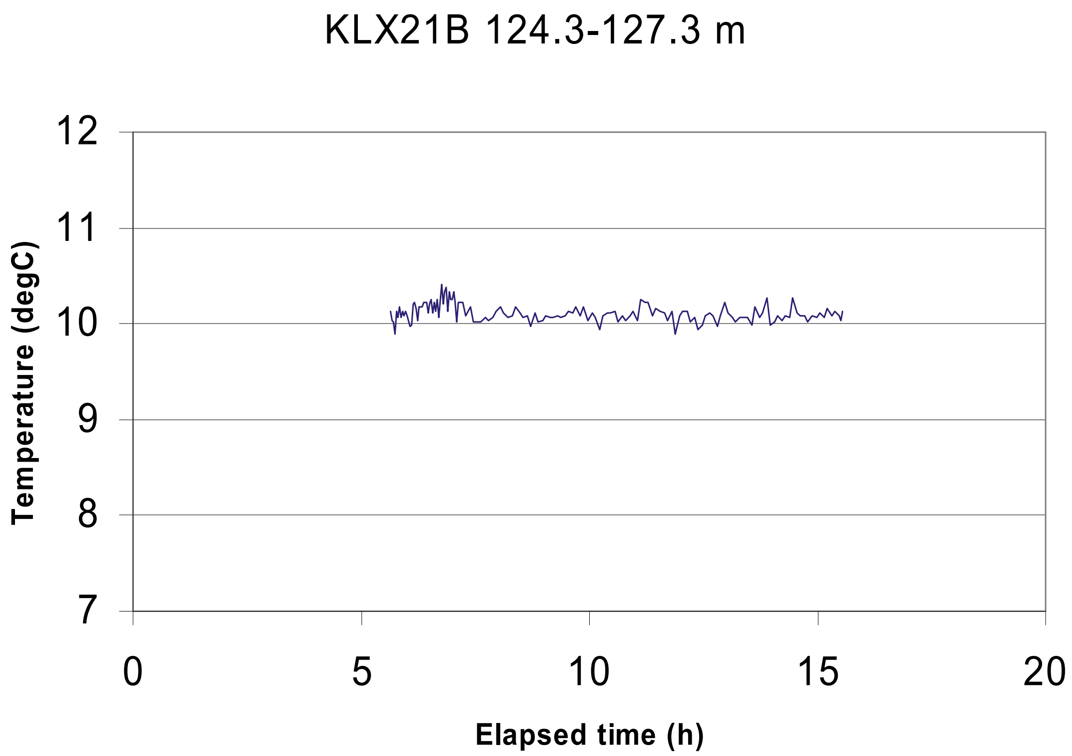
500
400
300
200
100
0
0
5
10
15
20
Elapsed time (h)


KLX21B 124.3-127.3 m
Temperature (degC)
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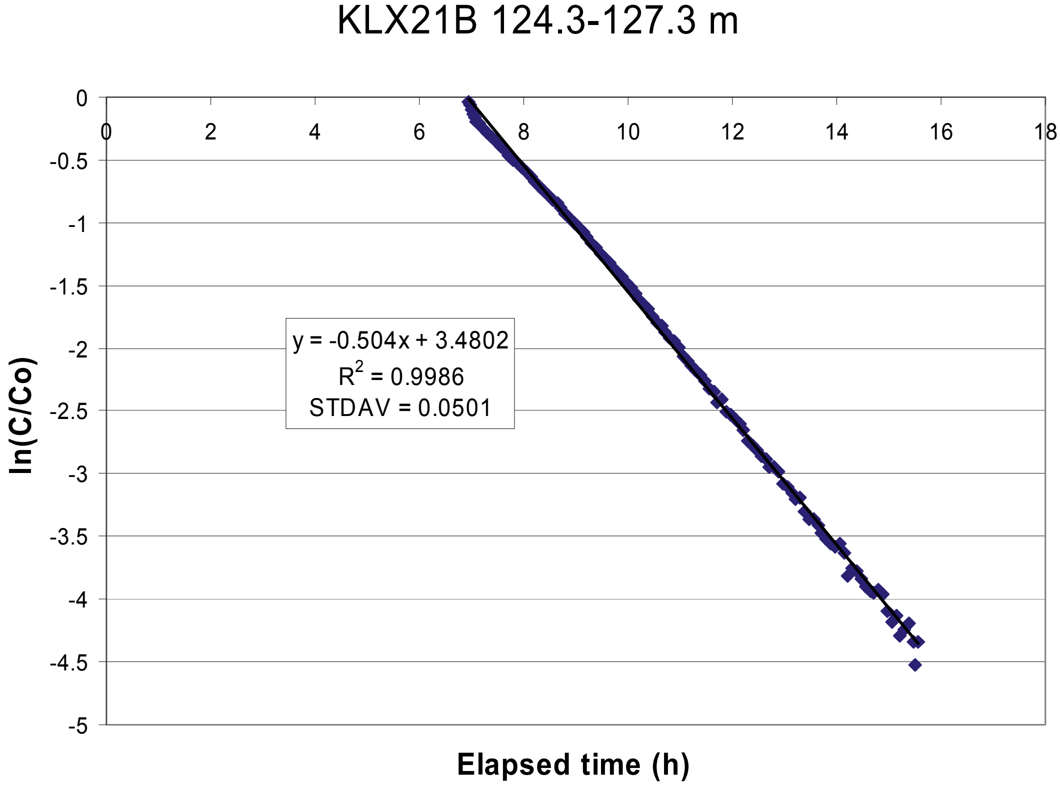
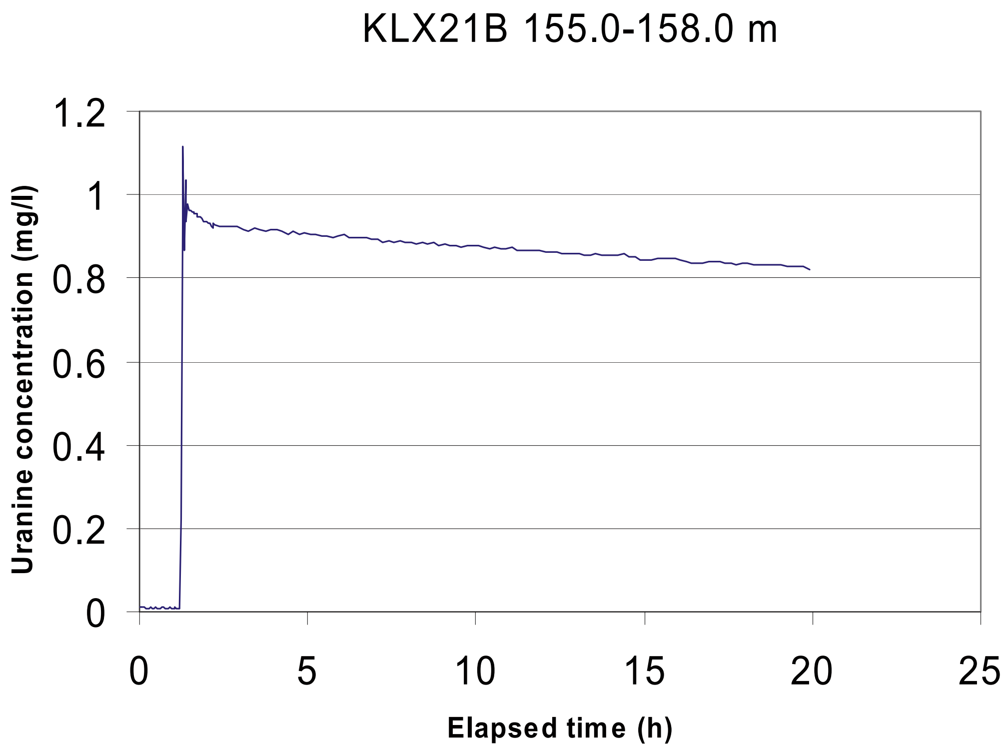
11
10
9
8
7
0
5
10
15
20
Elapsed time (h)

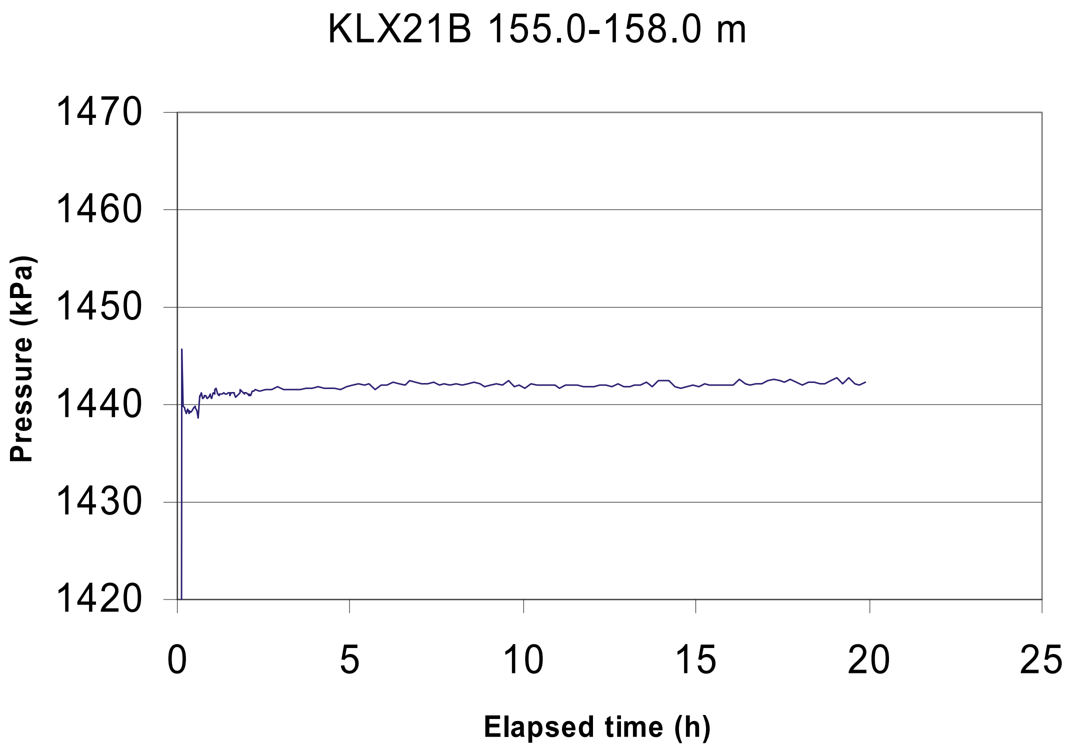


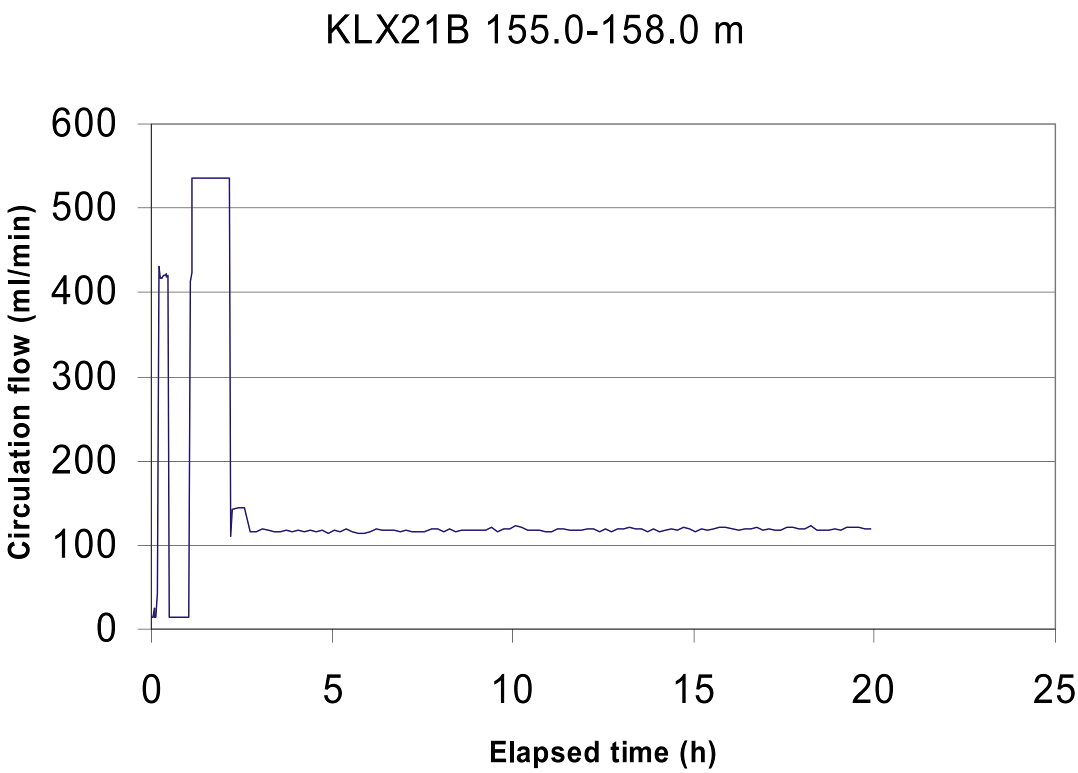
Part of dilution curve (h)	V (ml)	ln(C/Co)/t	Q (ml/h)	Q (ml/min)	Q (m3/s)	R2-value
7 ~15	1837	-0.504	925.85	15.431	2.57E-07	0.9986

Part of dilution curve (h)	K (m/s)	Q (m3/s)	A (m2)	v(m/s)	I
7 ~15	4.91E-06	2.57E-07	0.4548	5.65E-07	0.115

Dilution measurement KLX21B 155.0–158.0 m






KLX21B 155.0-158.0 m
Circulation flow (ml/min)
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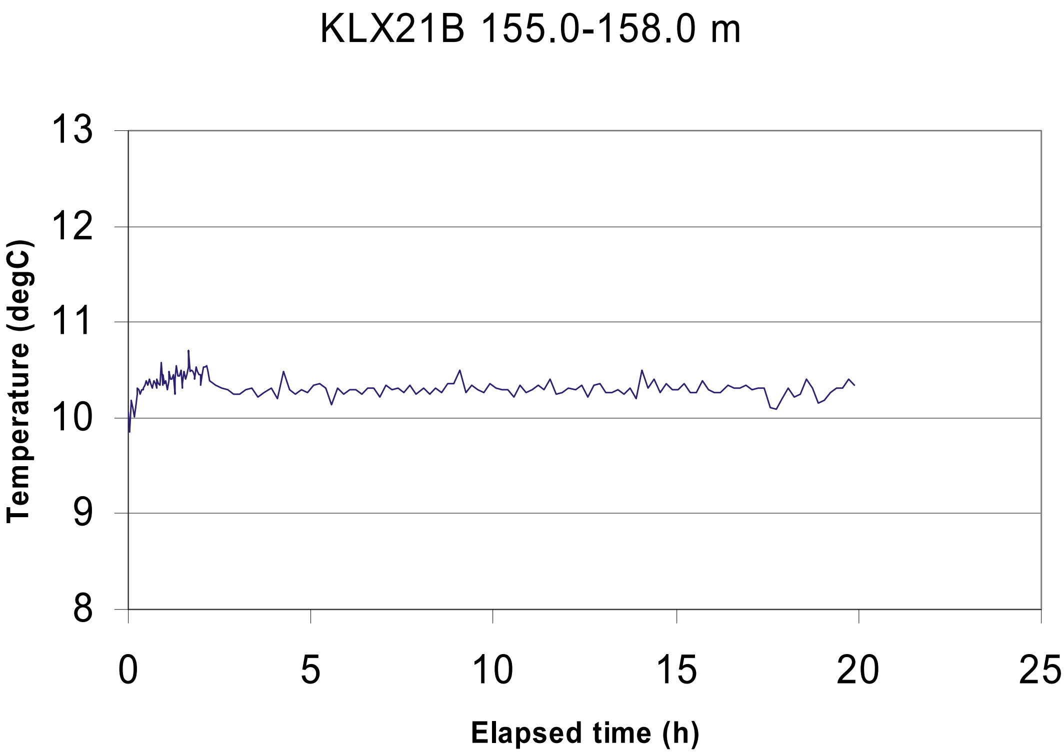
100
200
300
400
500
600
0
5
10
15
20
25
Elapsed time (h)


KLX21B 155.0-158.0 m
Temperature (degC)
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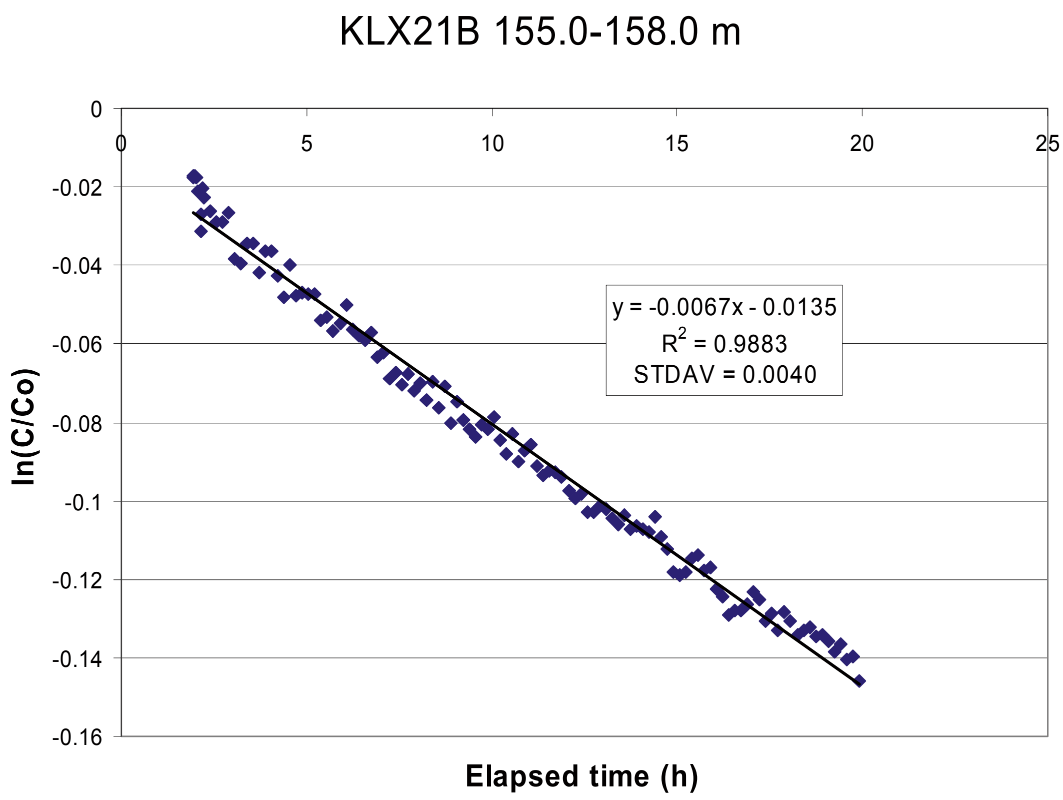
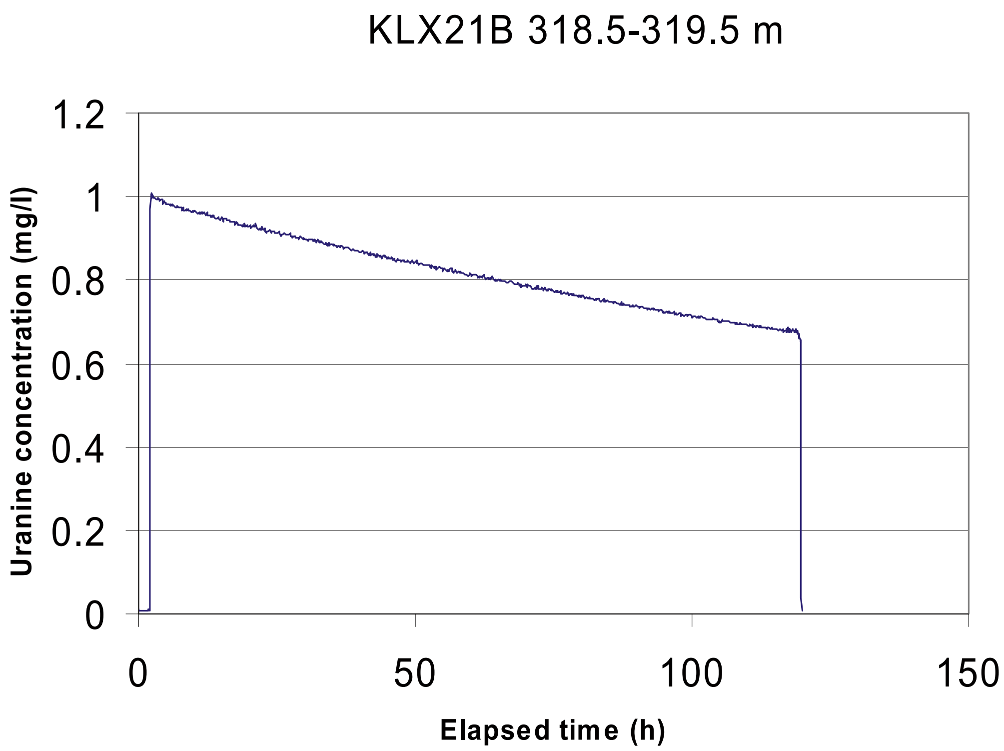
9
10
11
12
13
0
5
10
15
20
25
Elapsed time (h)

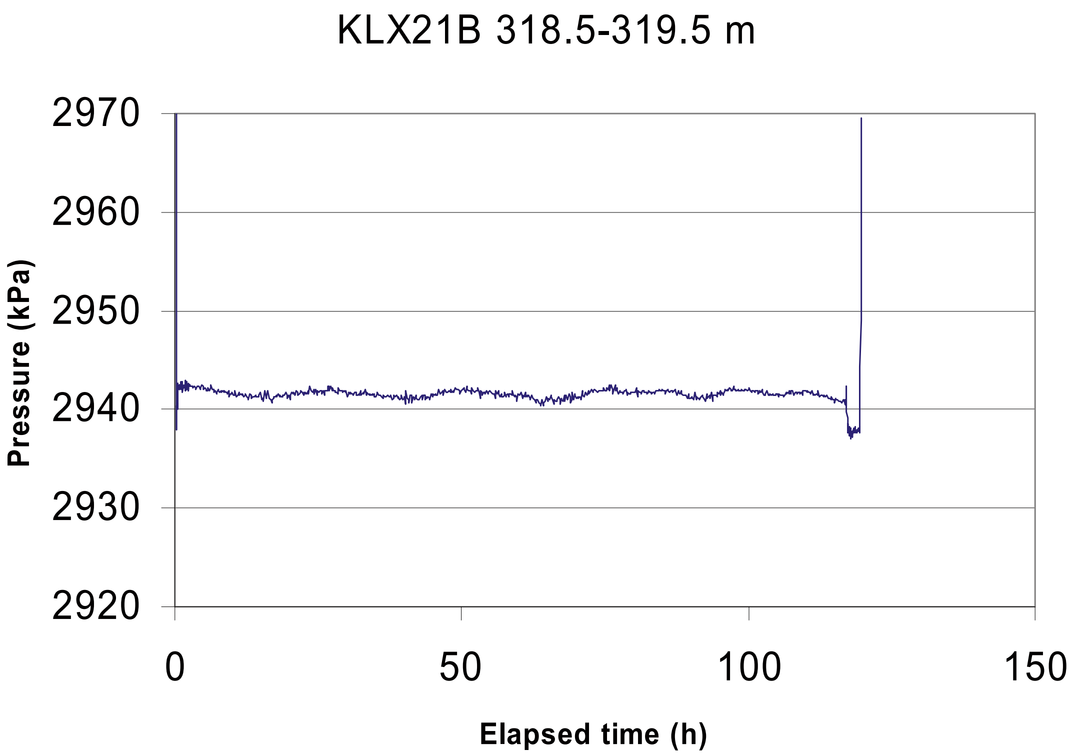


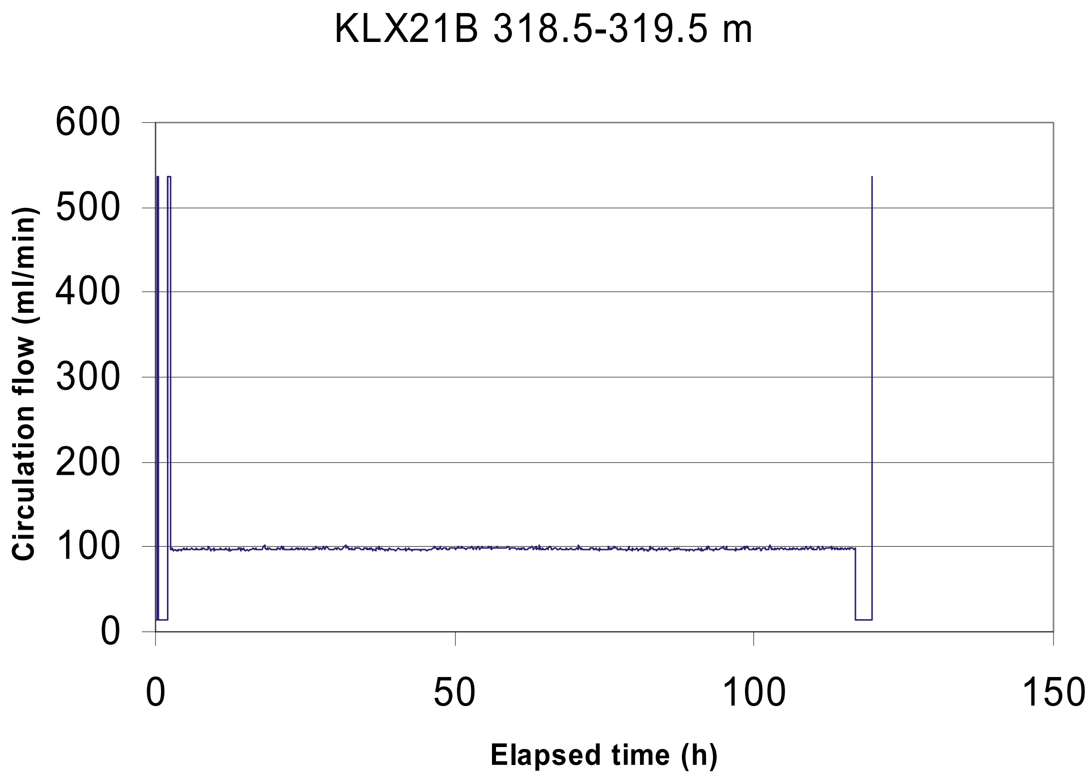
Part of dilution curve (h)	V (ml)	ln(C/Co)/t	Q (ml/h)	Q (ml/min)	Q (m3/s)	R2-value
2 ~20	1837	-0.0067	12.31	0.205	3.42E-09	0.9883

Part of dilution curve (h)	K (m/s)	Q (m3/s)	A (m2)	v(m/s)	I
2 ~20	2.33E-07	3.42E-09	0.4548	7.52E-09	0.032

Dilution measurement KLX21B 318.5–319.5 m






KLX21B 318.5-319.5 m
Circulation flow (ml/min)
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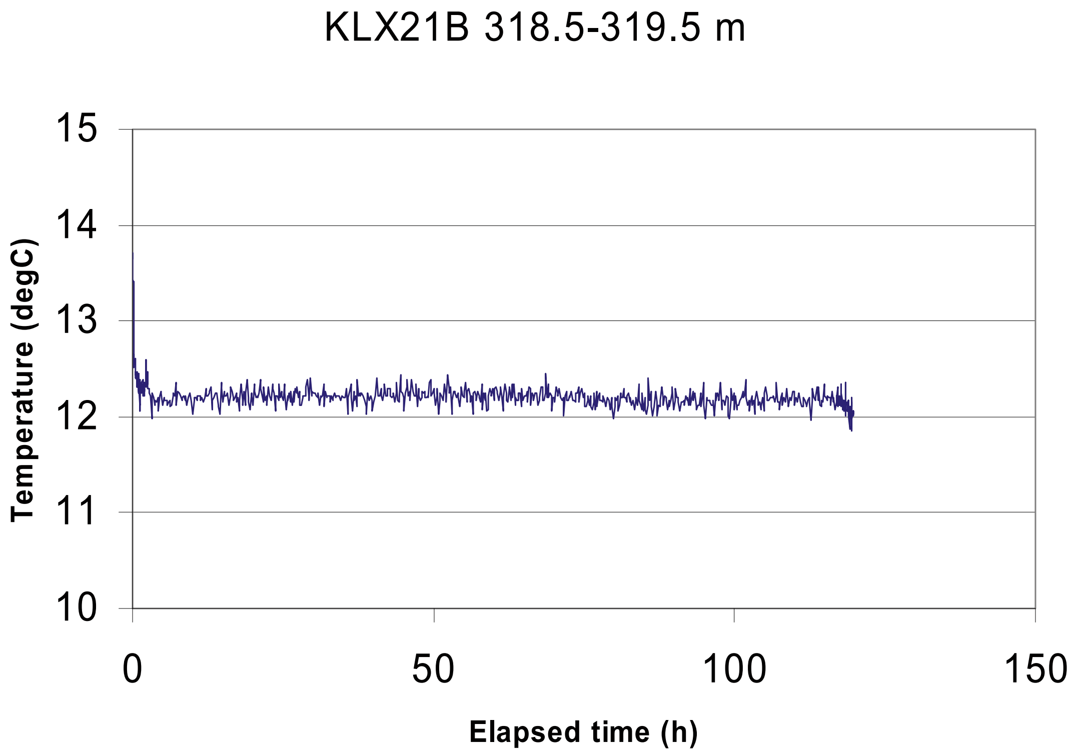
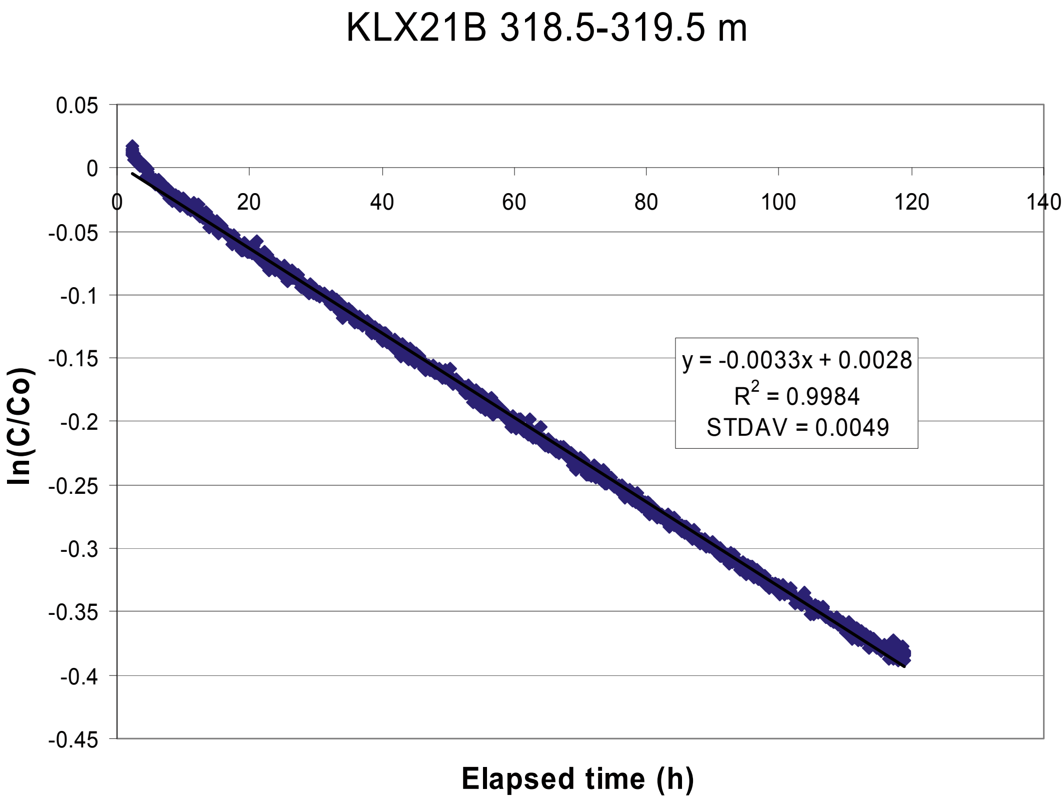
500
400
300
200
100
0
0
50
100
150
Elapsed time (h)

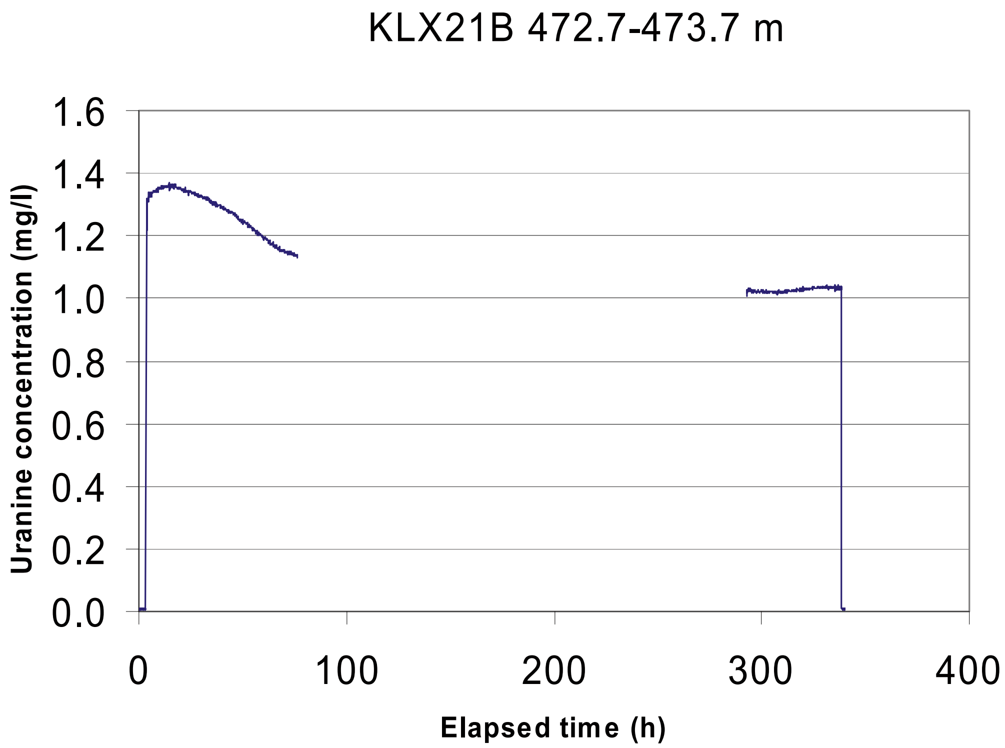

KLX21B 318.5-319.5 m
Temperature (degC)
15
14
13
12
11
10
0
50
100
150
Elapsed time (h)

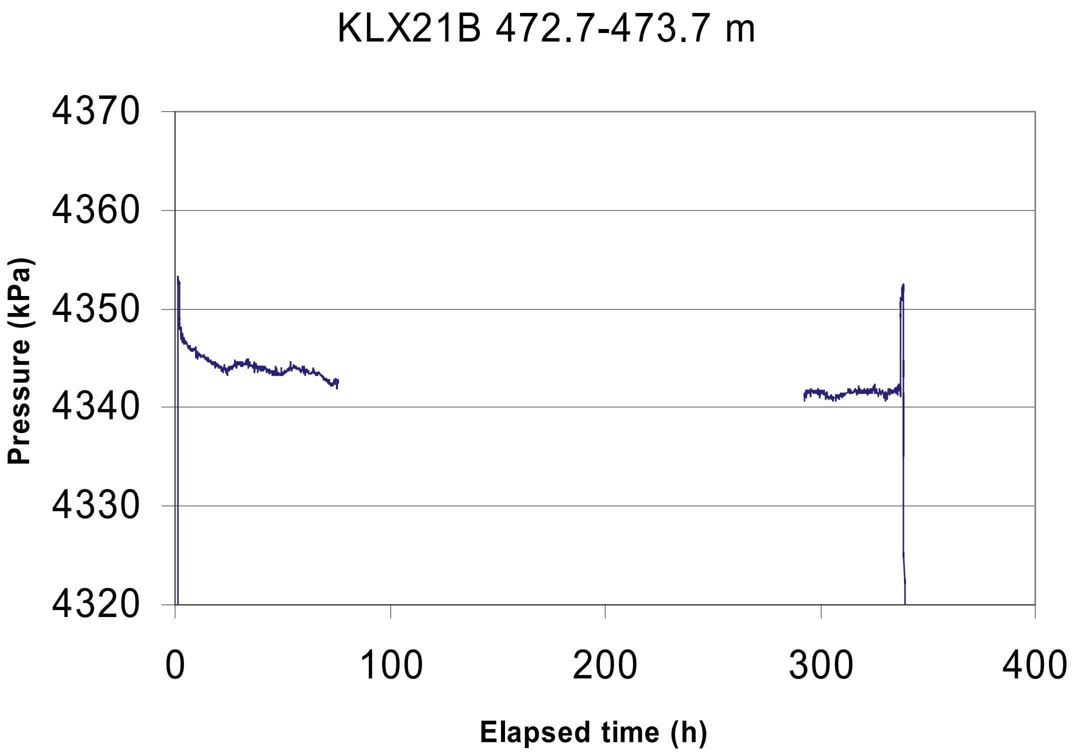


Part of dilution curve (h)	V (ml)	ln(C/Co)/t	Q (ml/h)	Q (ml/min)	Q (m3/s)	R2-value
2 - 119	1126	-0.0033	3.72	0.062	1.03E-09	0.9984

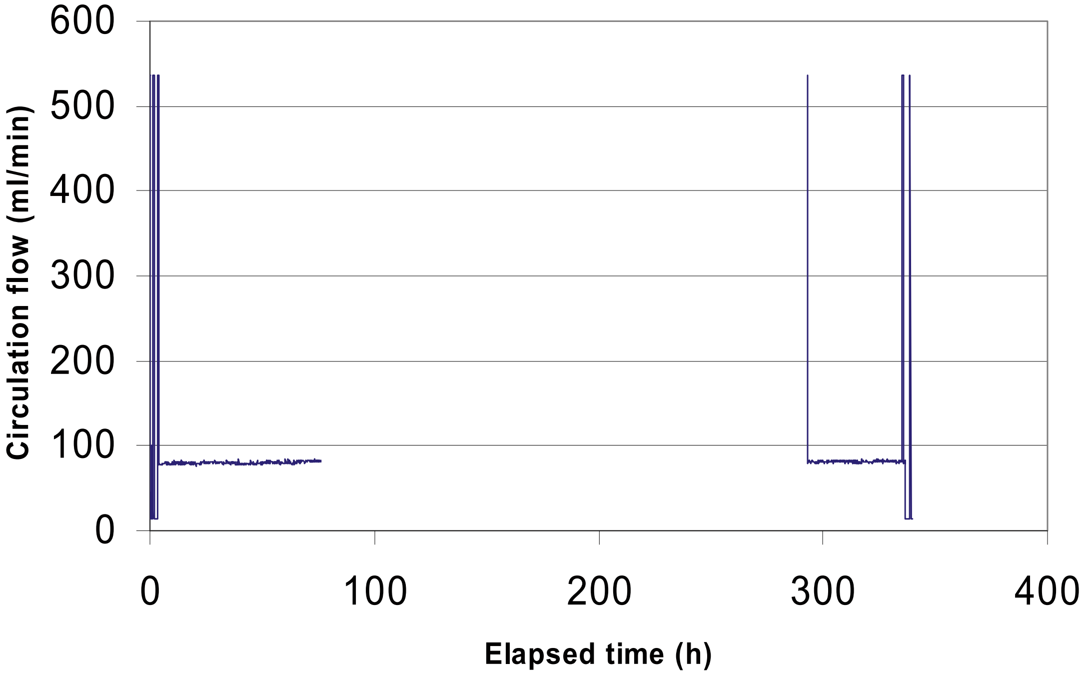
Part of dilution curve (h)	K (m/s)	Q (m3/s)	A (m2)	v(m/s)	I
2 - 119	1.66E-07	1.03E-09	0.1516	6.81E-09	0.041

Dilution measurement KLX21B 472.7–473.7 m

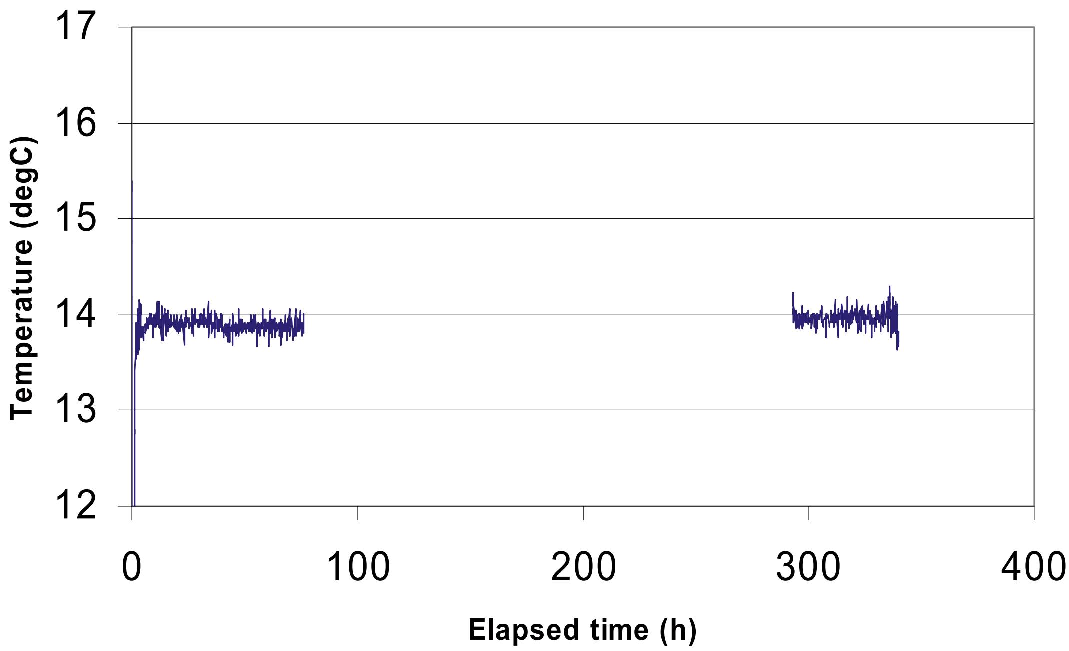


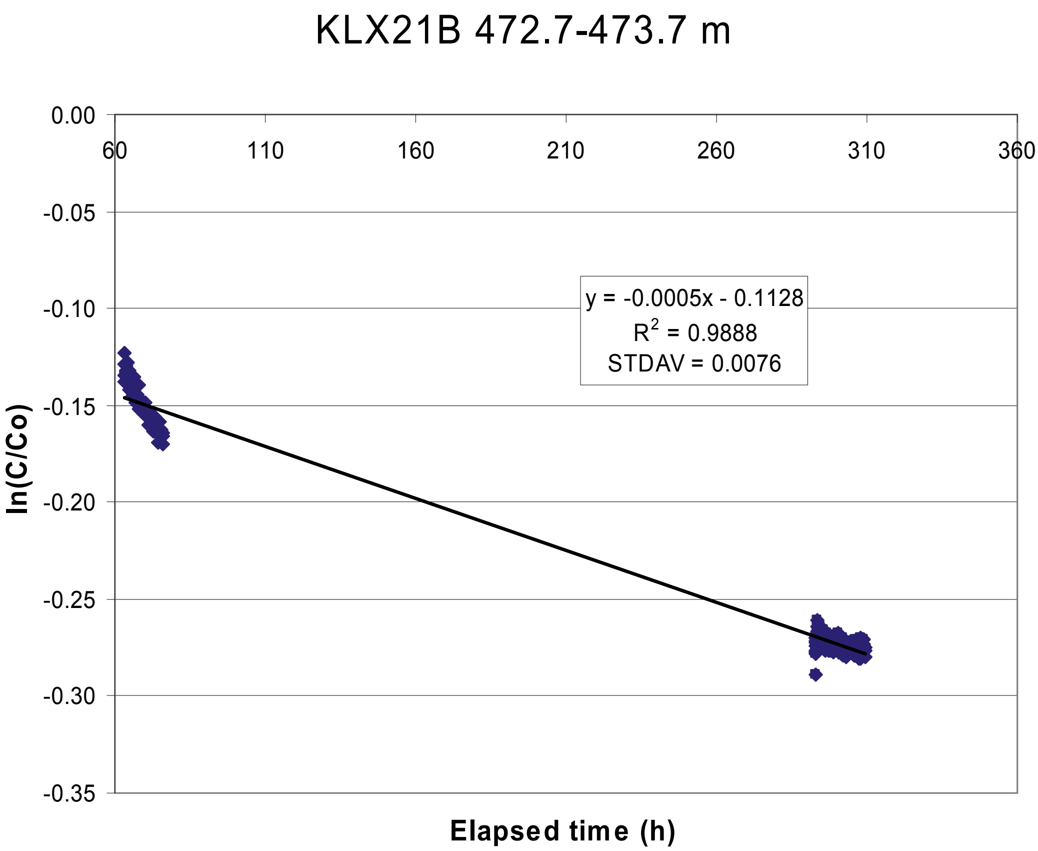


KLX21B 472.7-473.7 m



KLX21B 472.7-473.7 m

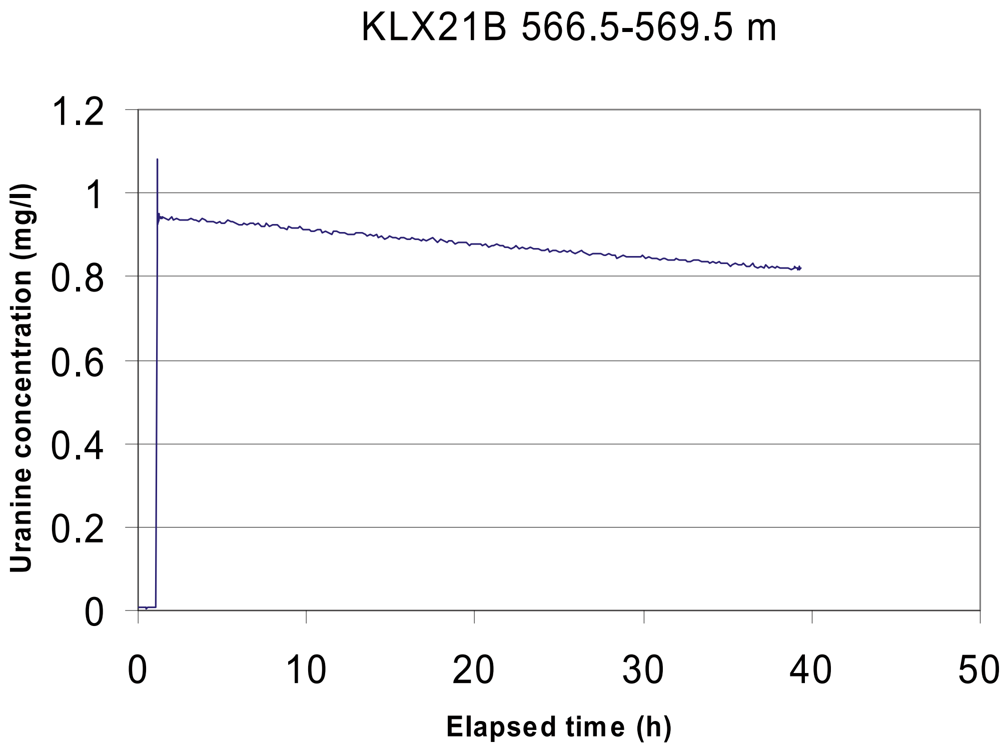


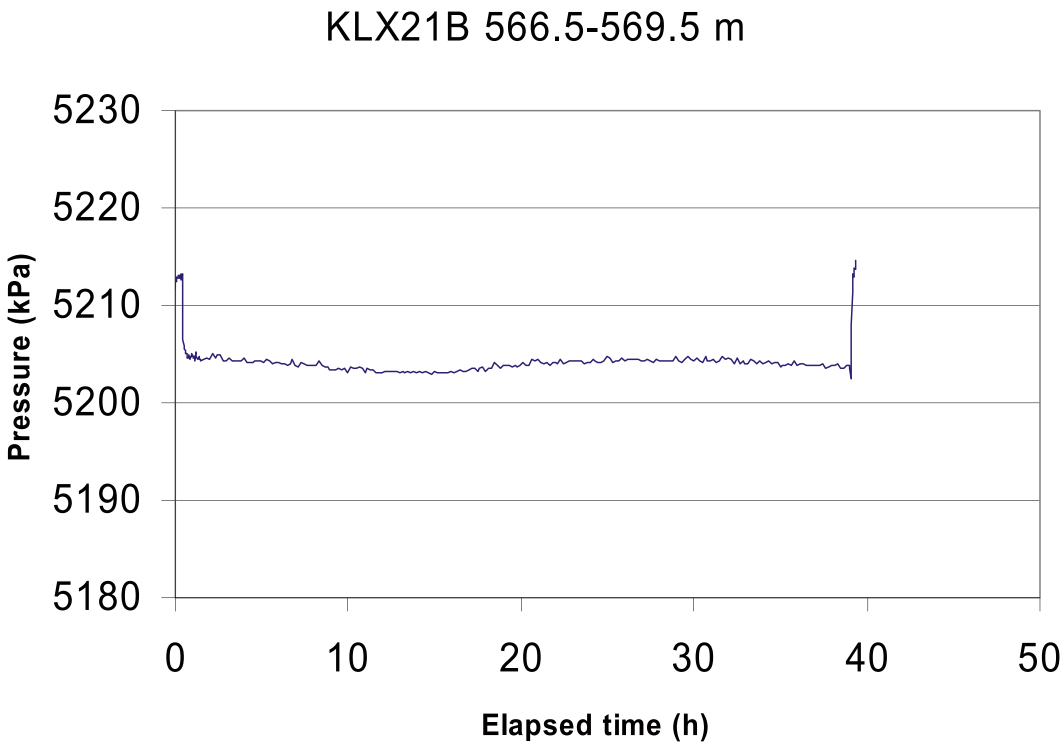


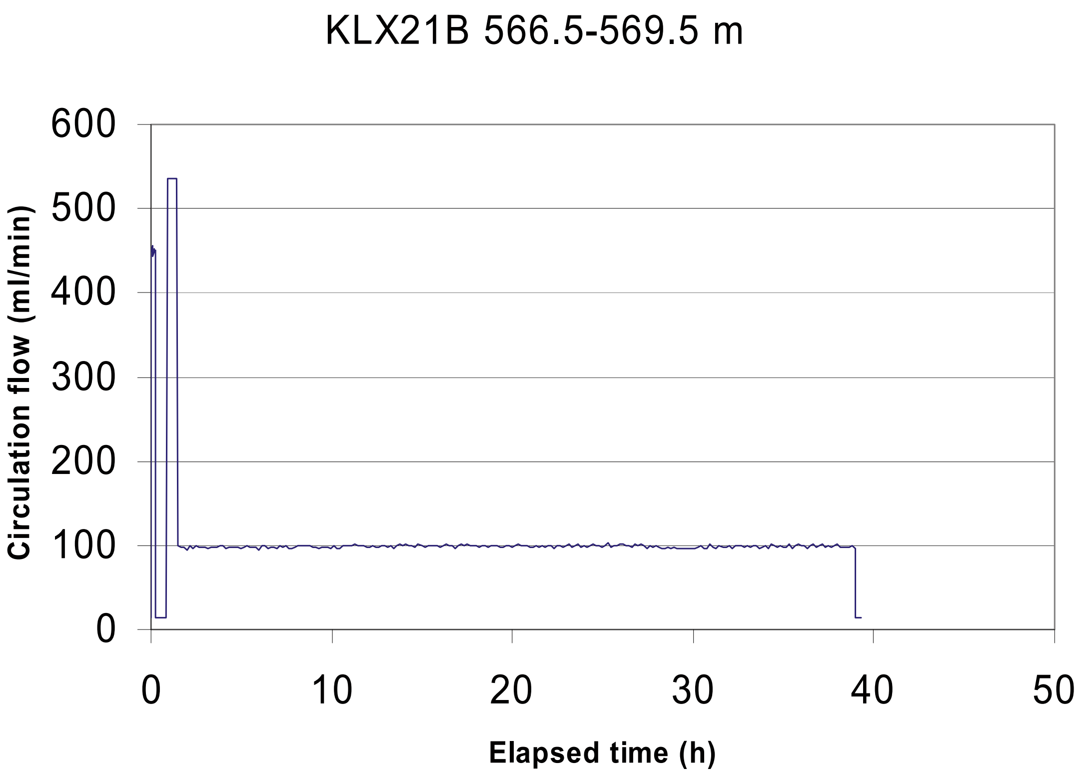
Part of dilution curve (h)	V (ml)	ln(C/Co)/t	Q (ml/h)	Q (ml/min)	Q (m3/s)	R2-value
60-76 & 293-309	1126	-0.0005	0.56	0.009	1.56E-10	0.9888

Part of dilution curve (h)	K (m/s)	Q (m3/s)	A (m2)	v(m/s)	I
60-76 & 293-309	5.76E-08	1.56E-10	0.1516	1.03E-09	0.018

Dilution measurement KLX21B 566.5–569.5 m






KLX21B 566.5-569.5 m
Circulation flow (ml/min)
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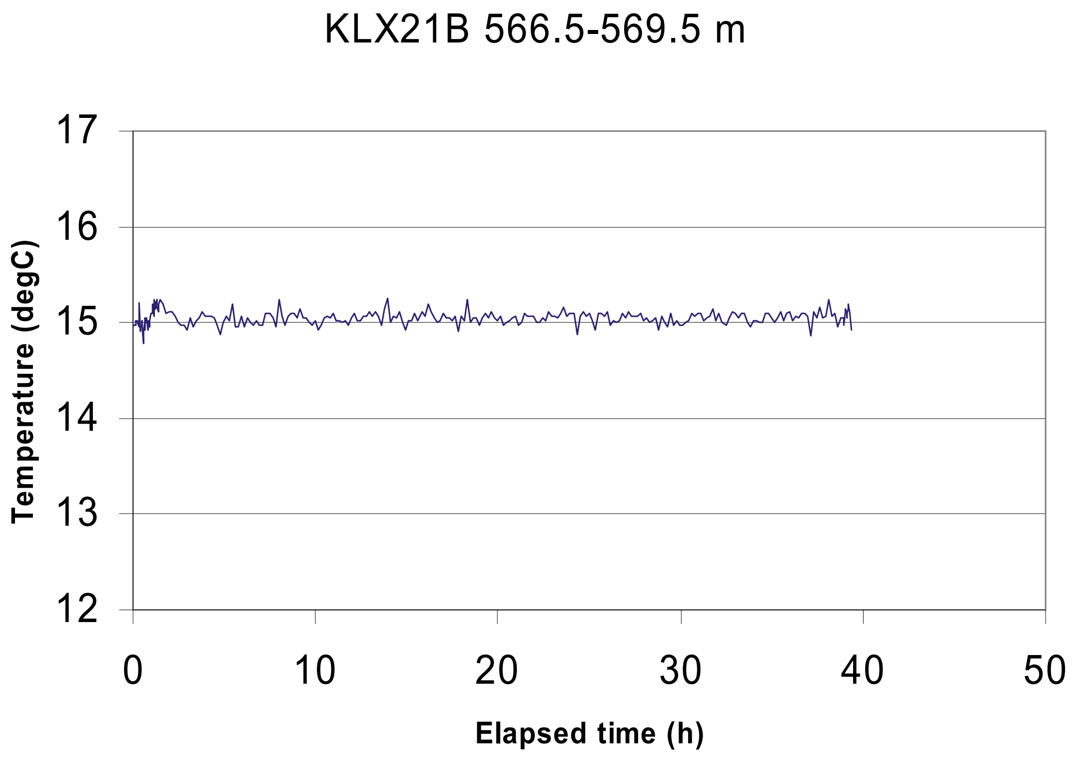
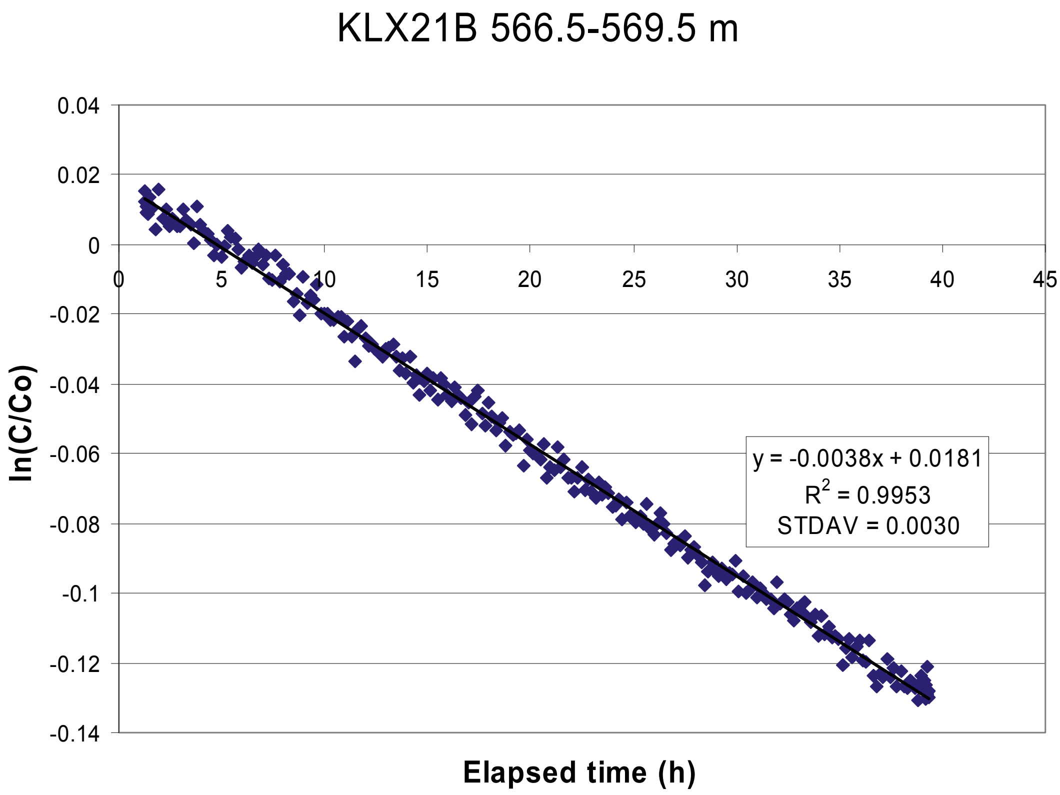
500
400
300
200
100
0
0
10
20
30
40
50
Elapsed time (h)

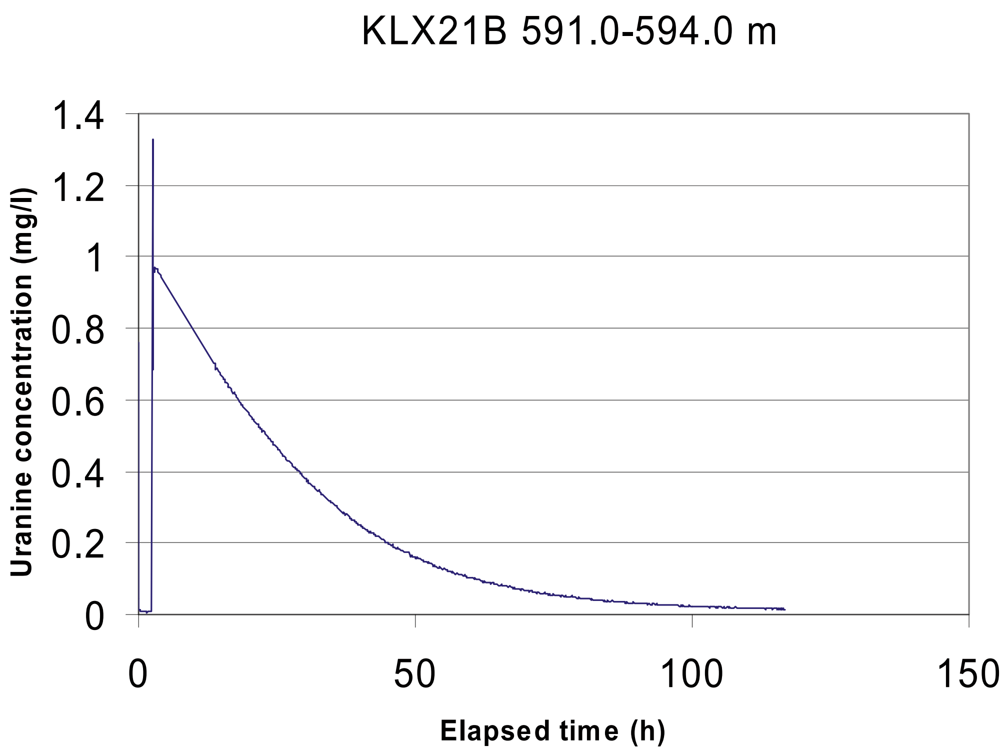

KLX21B 566.5-569.5 m
Temperature (degC)
17
16
15
14
13
12
0
10
20
30
40
50
Elapsed time (h)

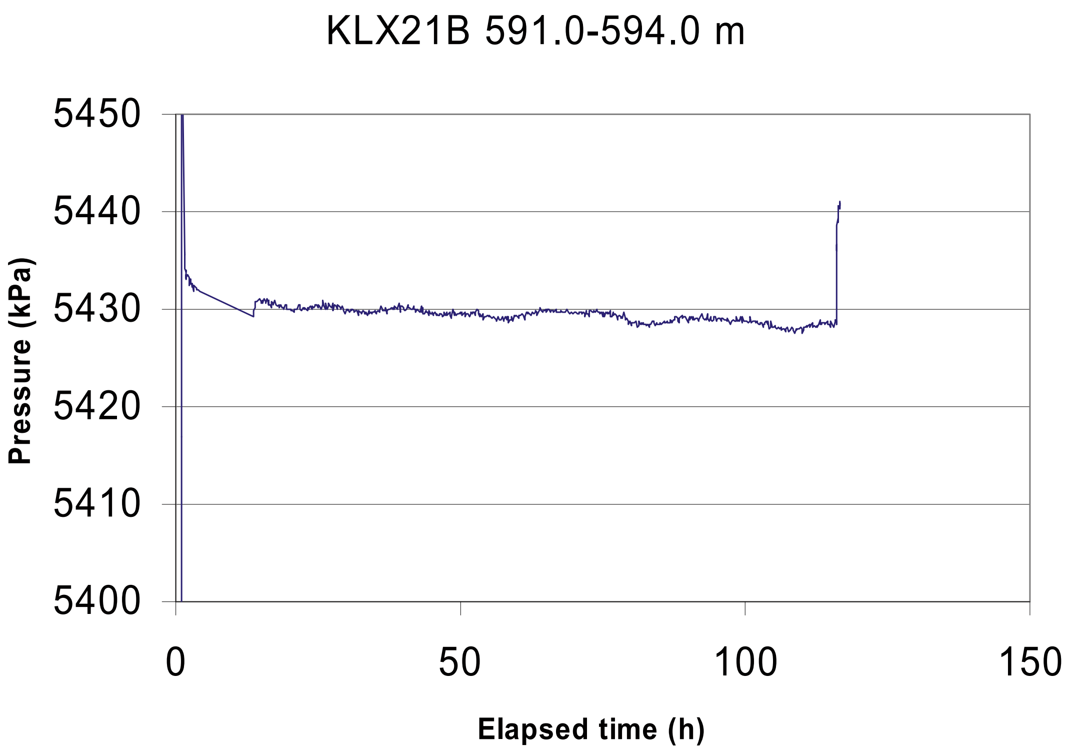


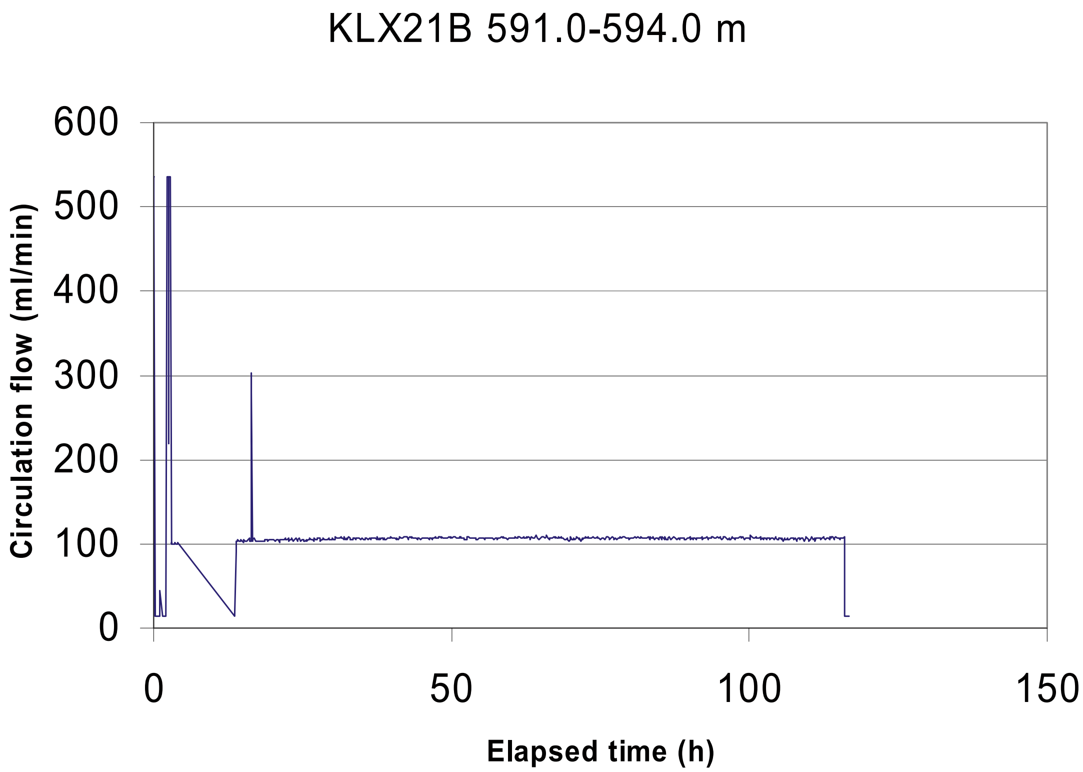
Part of dilution curve (h)	V (ml)	ln(C/Co)/t	Q (ml/h)	Q (ml/min)	Q (m3/s)	R2-value
1 ~39	1837	-0.0038	6.98	0.116	1.94E-09	0.9953

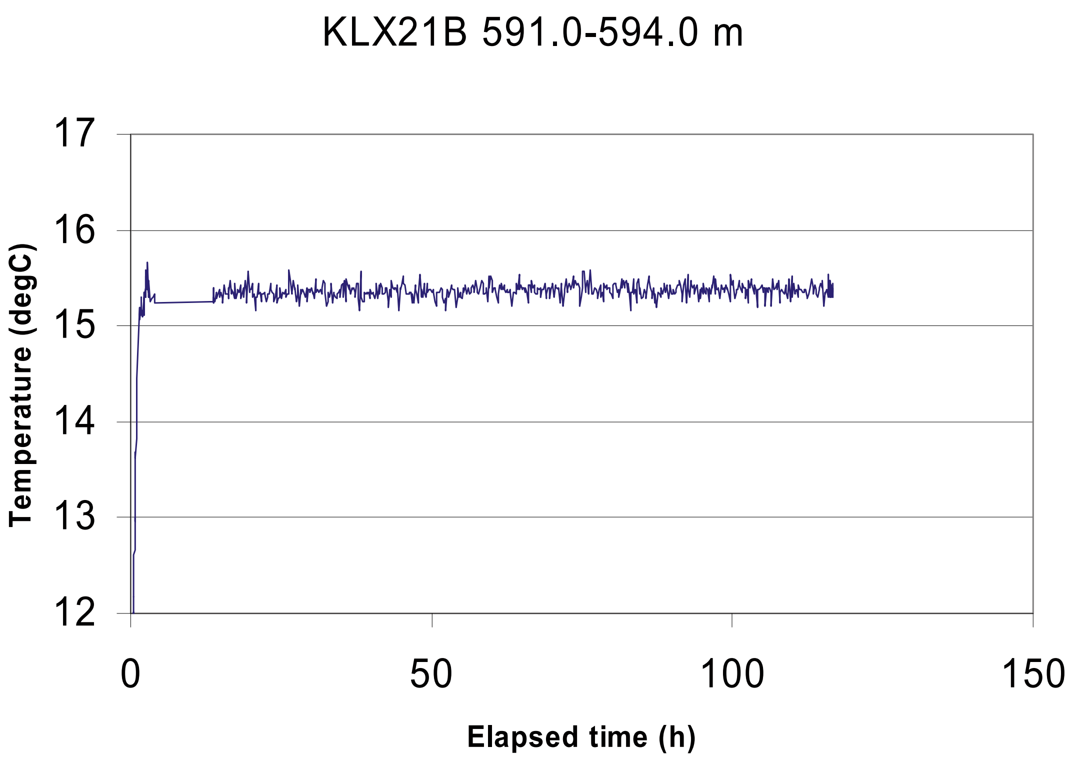
Part of dilution curve (h)	K (m/s)	Q (m3/s)	A (m2)	v(m/s)	I
1 ~39	1.68E-07	1.94E-09	0.4548	4.26E-09	0.025

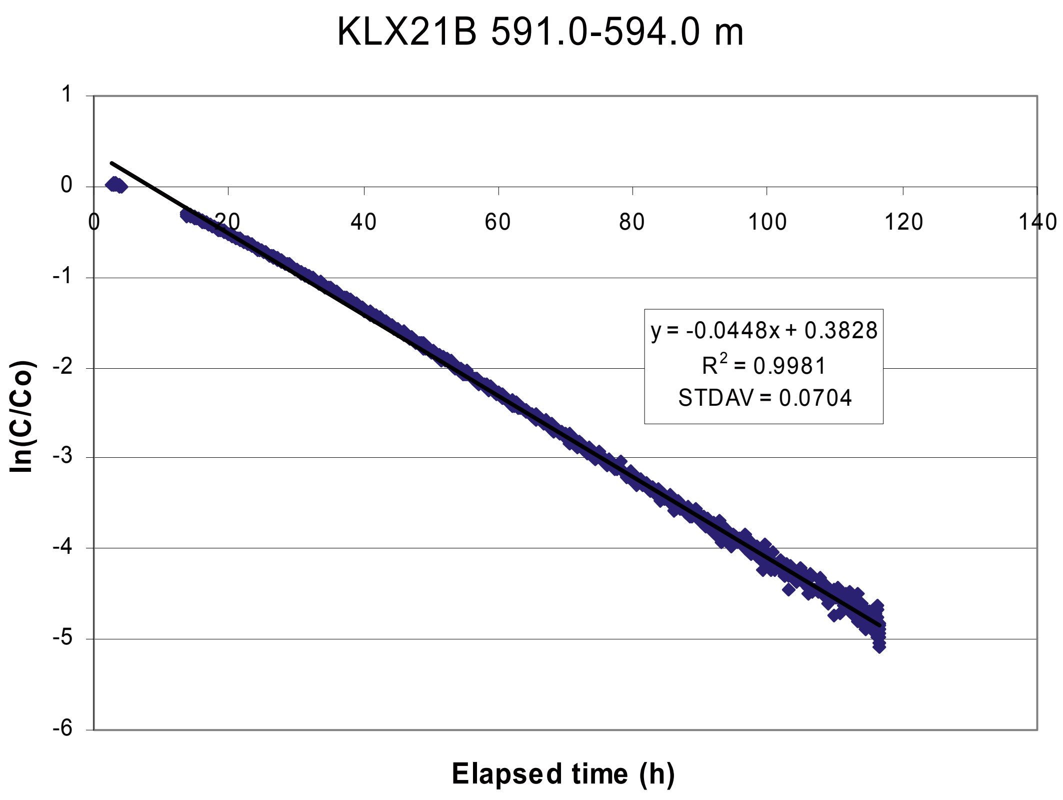
Dilution measurement KLX21B 591.0–594.0 m






KLX21B 591.0-594.0 m
600
500
400
300
200
100
0
Circulation flow (ml/min)
0
50
100
150
Elapsed time (h)

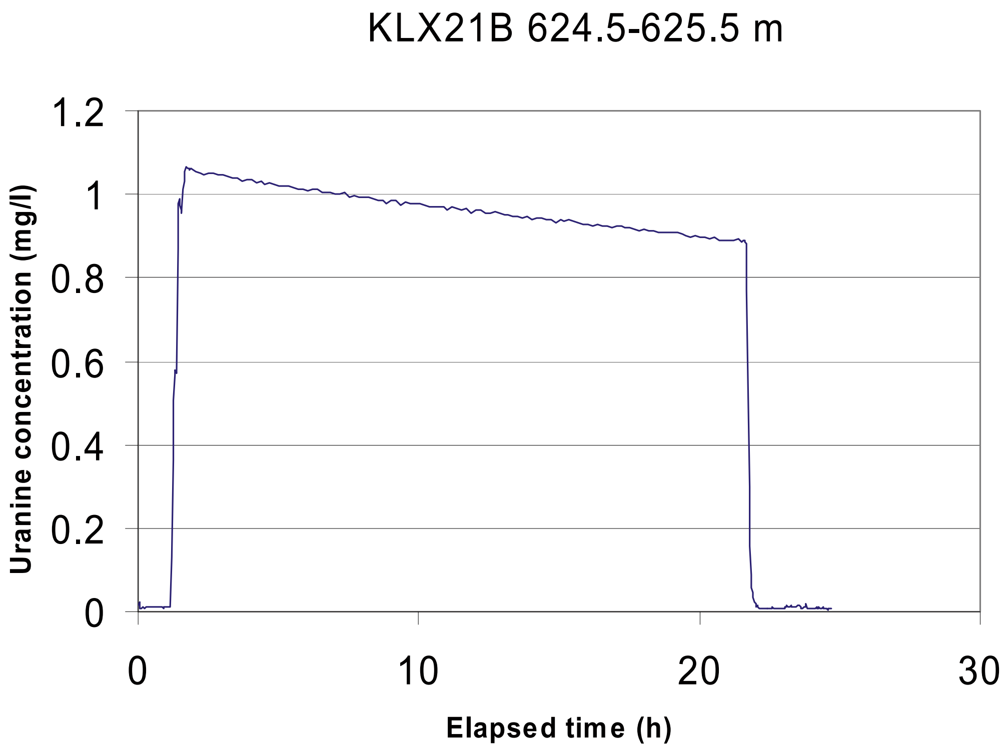

KLX21B 591.0-594.0 m
17
16
15
14
13
12
Temperature (degC)
0
50
100
150
Elapsed time (h)

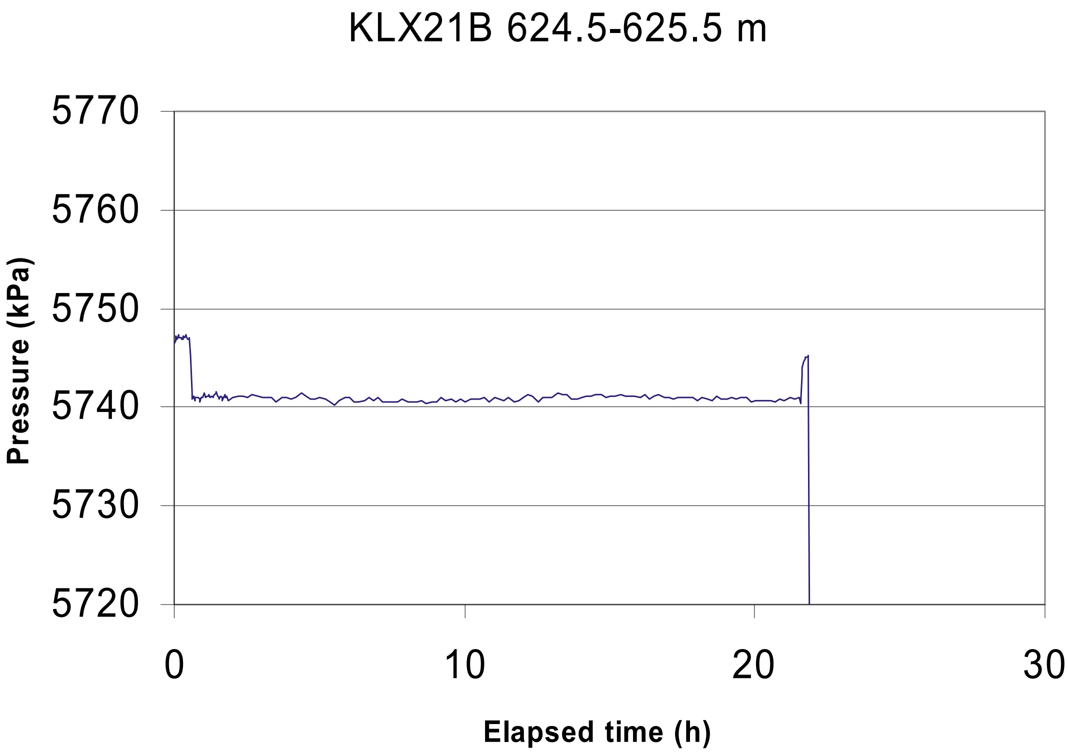


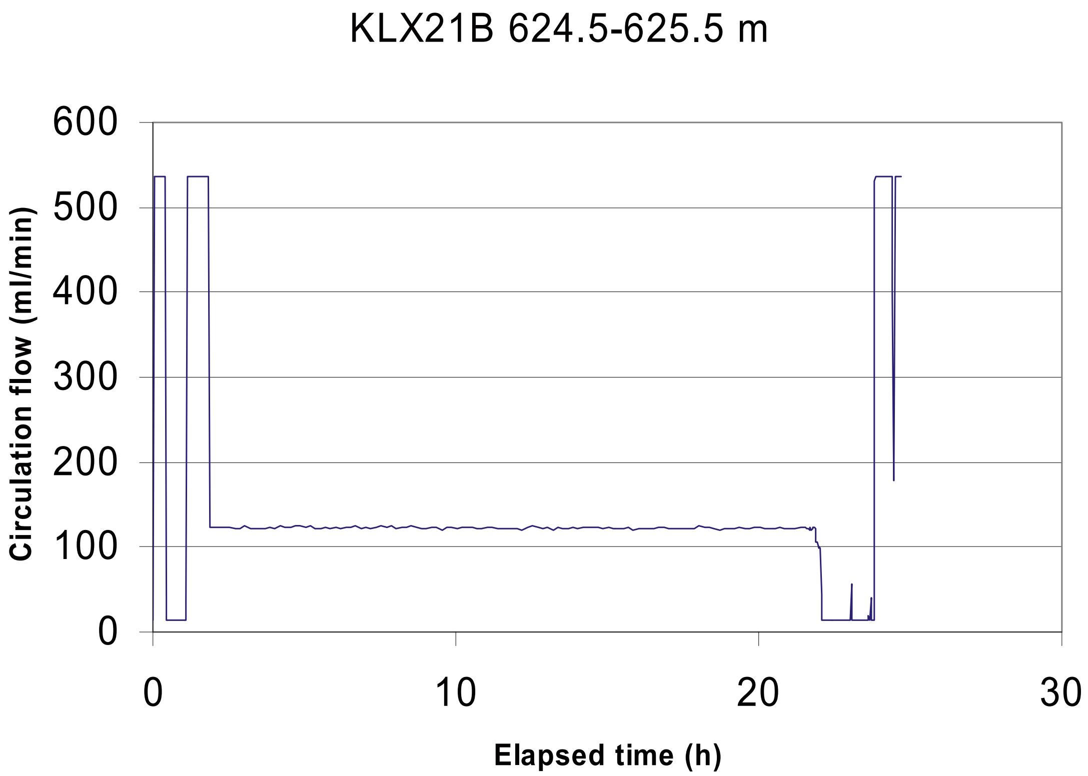
Part of dilution curve (h)	V (ml)	ln(C/Co)/t	Q (ml/h)	Q (ml/min)	Q (m3/s)	R2-value
3 ~78	1837	-0.0448	82.30	1.372	2.29E-08	0.9981

Part of dilution curve (h)	K (m/s)	Q (m3/s)	A (m2)	v(m/s)	I
3 ~78	2.73E-07	2.29E-08	0.4548	5.03E-08	0.184

Dilution measurement KLX21B 624.5–625.5 m






KLX21B 624.5-625.5 m
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400
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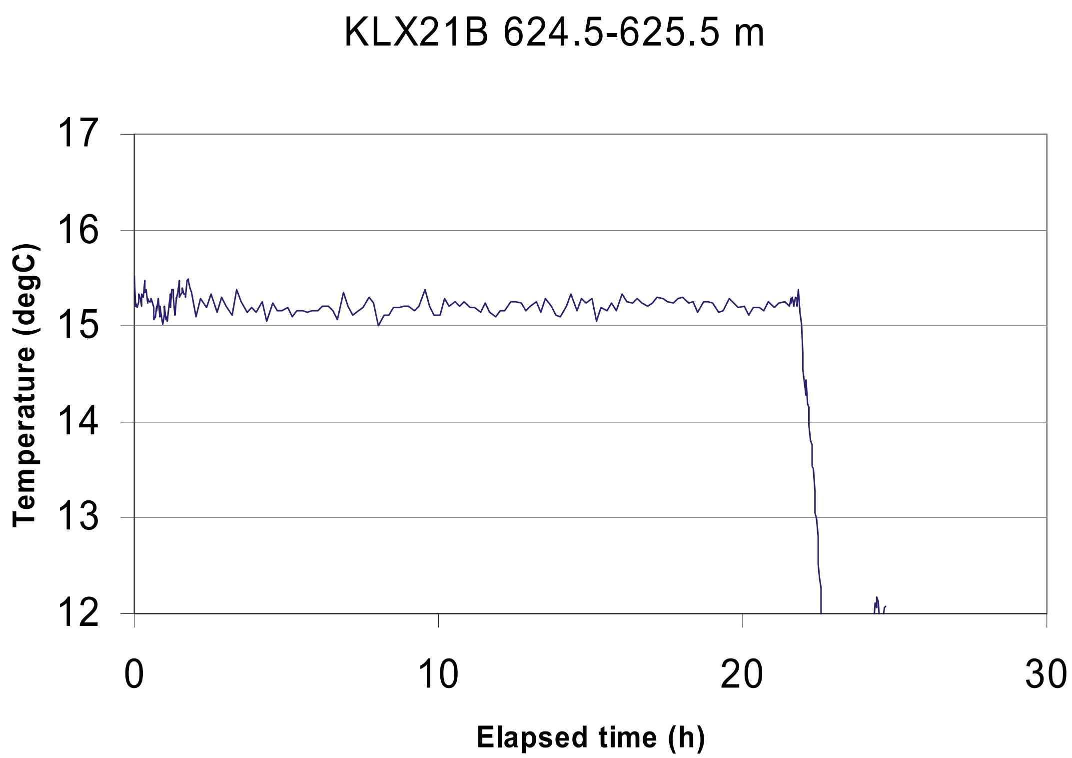
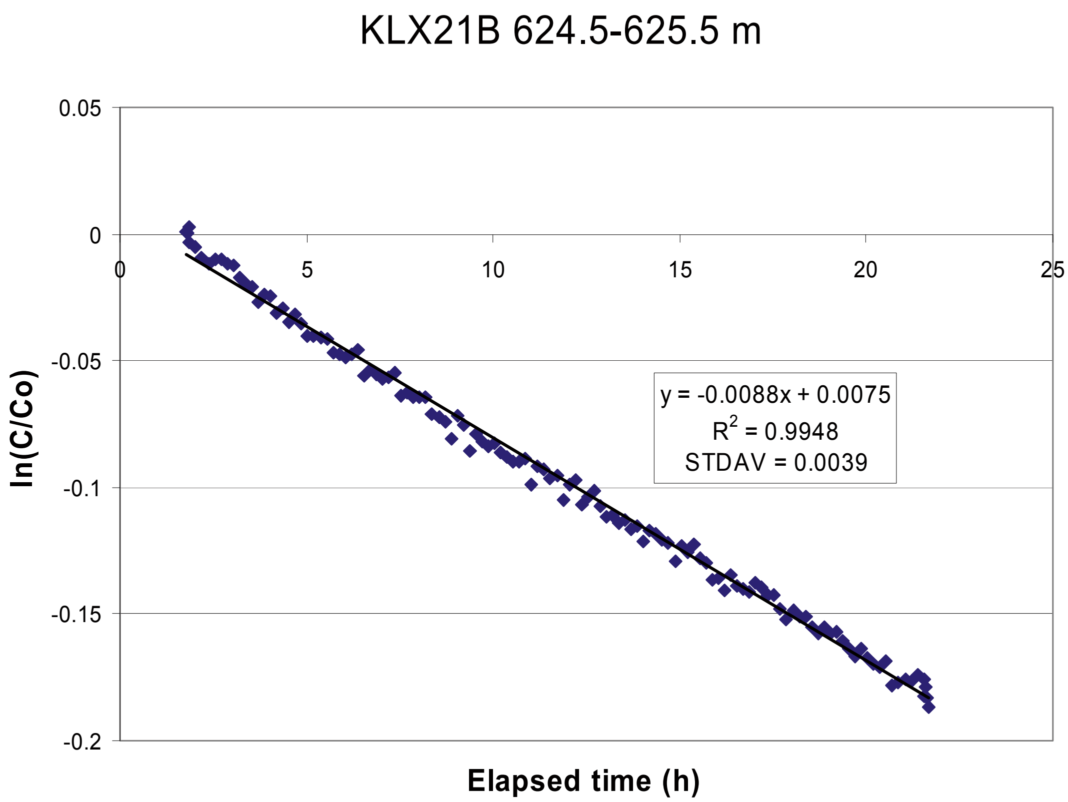
200
100
0
Circulation flow (ml/min)
0
10
20
30
Elapsed time (h)

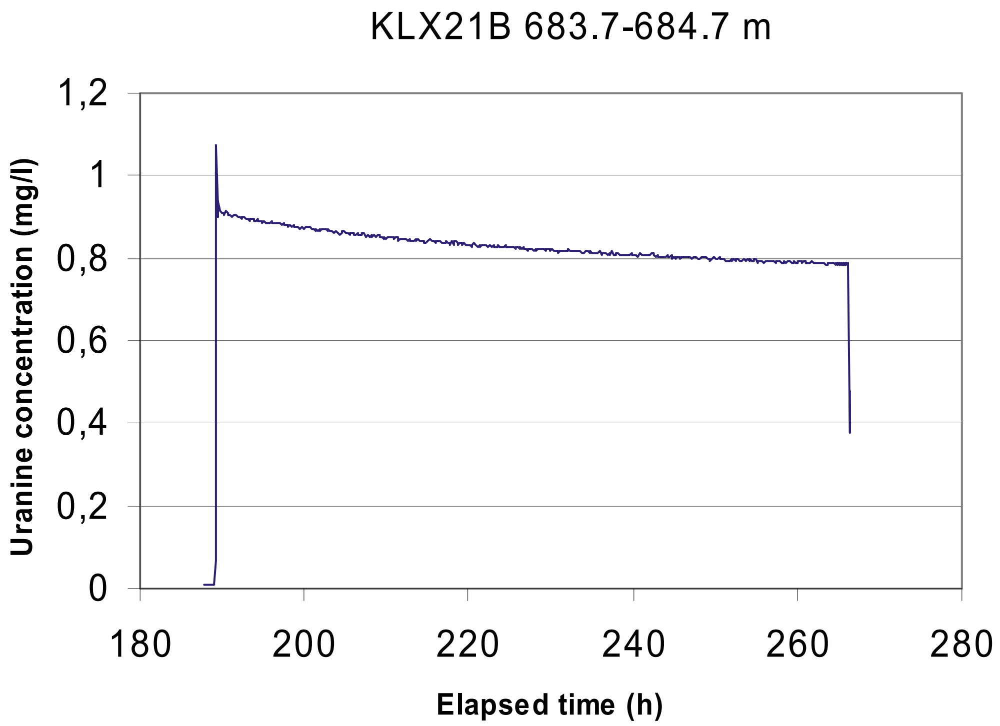

KLX21B 624.5-625.5 m
17
16
15
14
13
12
Temperature (degC)
0
10
20
30
Elapsed time (h)

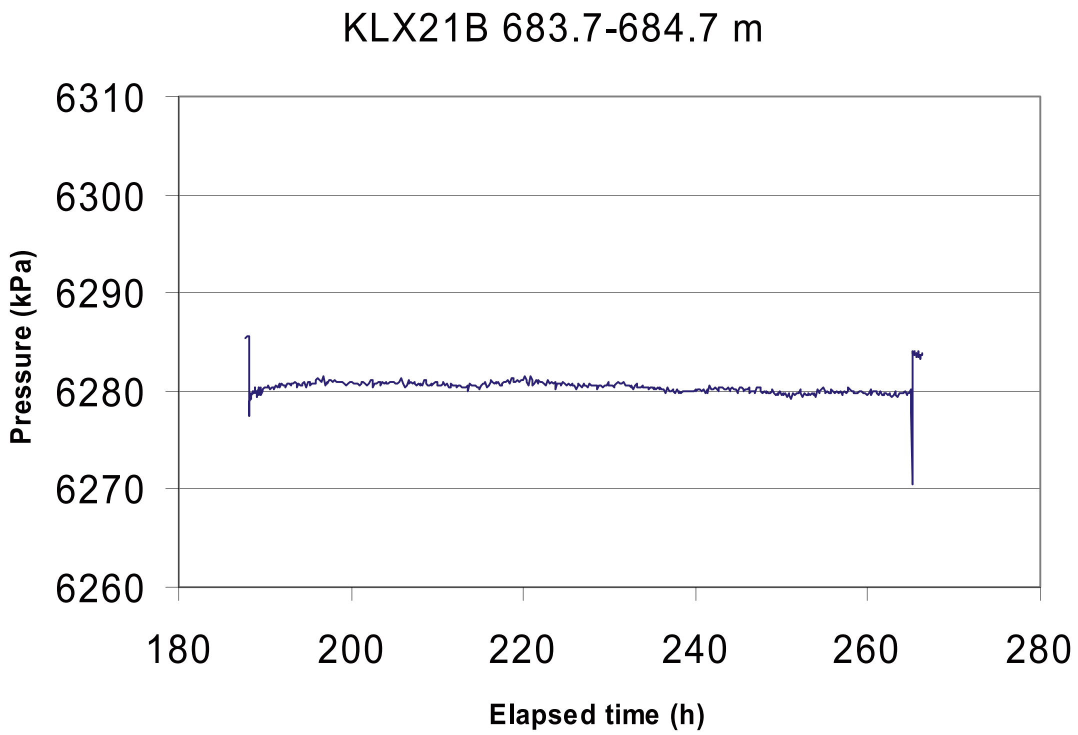


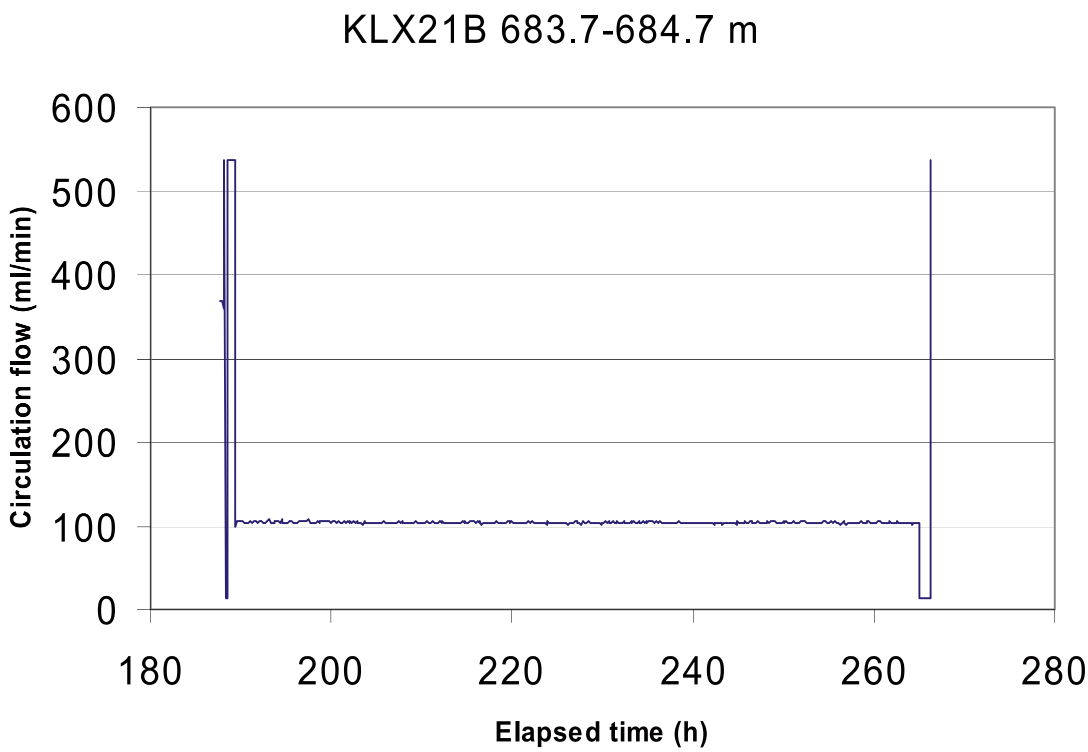
Part of dilution curve (h)	V (ml)	ln(C/Co)/t	Q (ml/h)	Q (ml/min)	Q (m3/s)	R2-value
2~22	1126	-0.0088	9.91	0.165	2.75E-09	0.9948

Part of dilution curve (h)	K (m/s)	Q (m3/s)	A (m2)	v(m/s)	I
2~22	4.33E-06	2.75E-09	0.1516	1.82E-08	0.004

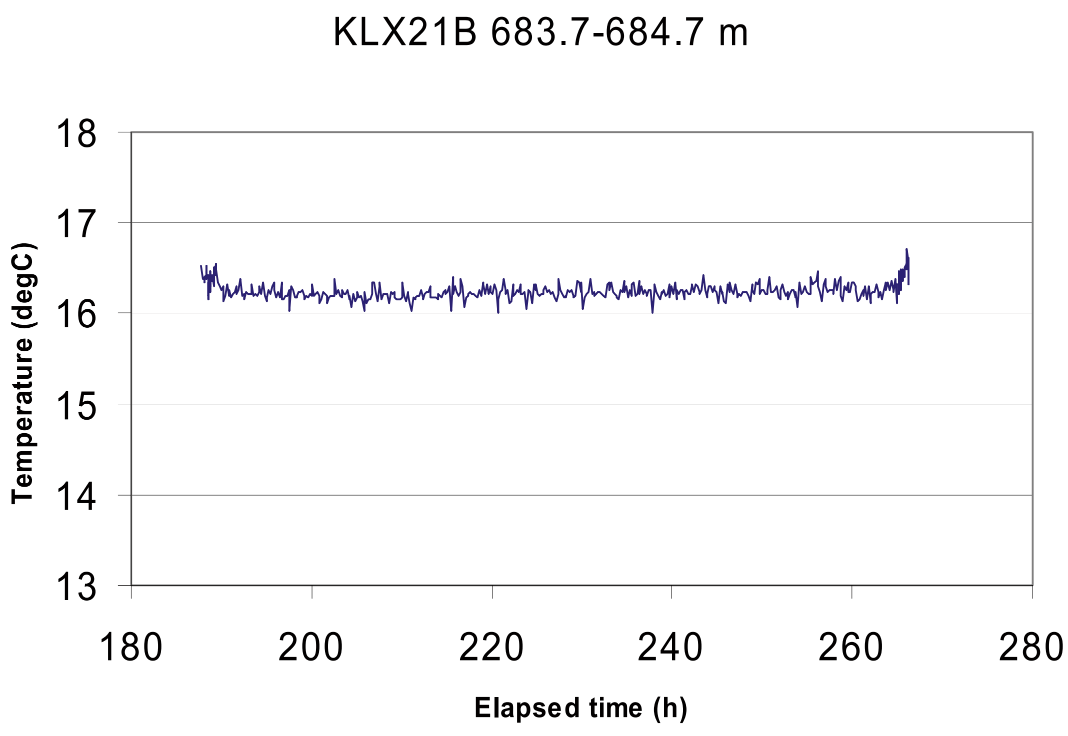
Dilution measurement KLX21B 683.7–684.7 m



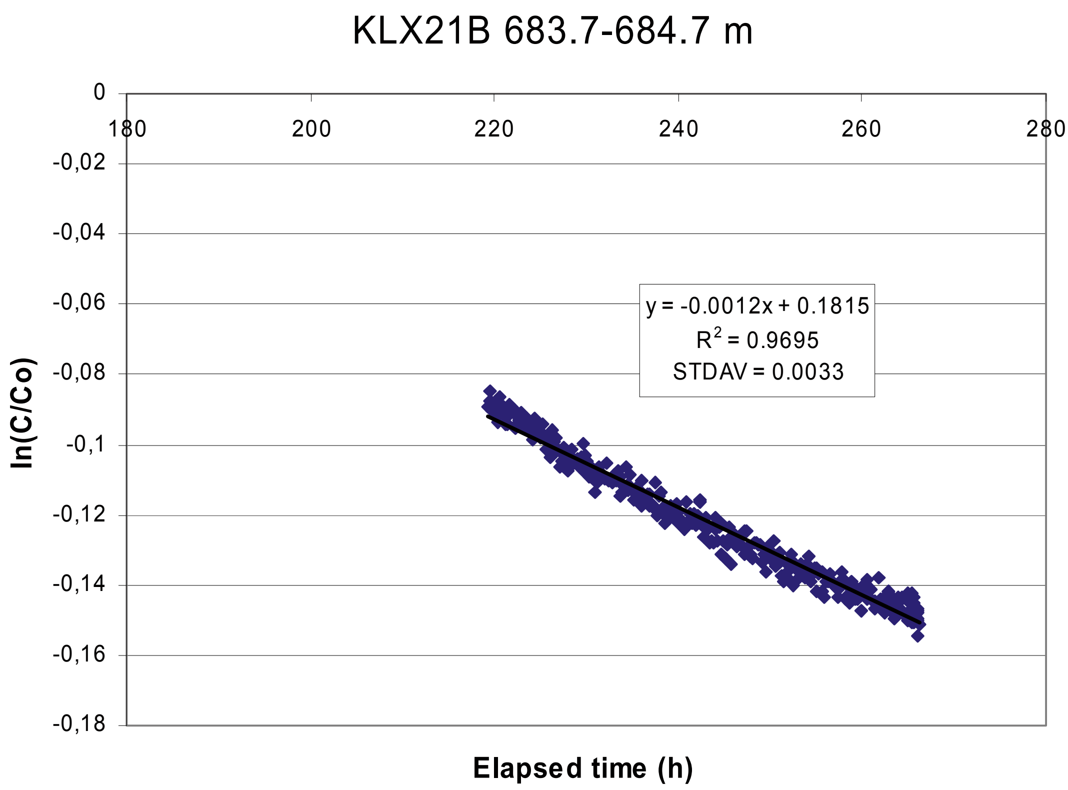




KLX21B 683.7-684.7 m
600
500
400
300
200
100
0
Circulation flow (ml/min)
180
200
220
240
260
280
Elapsed time (h)



KLX21B 683.7-684.7 m
18
17
16
15
14
13
Temperature (degC)
180
200
220
240
260
280
Elapsed time (h)



Part of dilution curve (h)	V (ml)	ln(C/Co)/t	Q (ml/h)	Q (ml/min)	Q (m3/s)	R2-value
219-266	1126	-0,0012	1,35	0,023	3,75E-10	0,9695

Part of dilution curve (h)	K (m/s)	Q (m3/s)	A (m2)	v(m/s)	I
219-266	1,43E-07	3,75E-10	0,1516	2,48E-09	0,017