P-10-03

Oskarshamn site investigation

Groundwater flow measurements in permanently installed boreholes

Test campaign no. 5, 2009

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Abstract

This report describes the performance and evaluation of groundwater flow measurements in 28 borehole sections in permanently installed boreholes within the site investigation at Oskarshamn (Simpevarp, Ävrö and Laxemar). The objective was to determine groundwater flow rates in a selection of borehole sections instrumented for this purpose. This is the fifth test campaign performed in the monitoring program.

The groundwater flow rates were determined through dilution measurements during ambient hydraulic conditions. Measured flow rates vary from 0.03 to 80 ml/min with Darcy velocities ranging from $7.2 \cdot 10^{-11}$ to $6.4 \cdot 10^{-7}$ m/s. Hydraulic gradients were calculated according to the Darcy concept and range from 0.001 to 4.

Sammanfattning

Denna rapport beskriver genomförandet och utvärderingen av grundvattenflödesmätningar i 28 borrhålssektioner i permanent installerade borrhål i Oskarshamnsområdet (Simpevarp, Ävrö och Laxemar). Syftet var att bestämma grundvattenflödet i ett urval av för ändamålet instrumenterade borrhålssektioner. Denna mätning var den femte som genomfördes i moniteringsprogrammet.

Grundvattenflödet i de utvalda borrhålssektionerna mättes med utspädningsmetoden under naturliga ostörda förhållanden. Uppmätta grundvattenflöden ligger i intervallet 0,03 till 80 ml/min med beräknade Darcy-hastigheter mellan $7,2 \cdot 10^{-11}$ till $6,4 \cdot 10^{-7}$ m/s. Den hydrauliska gradienten beräknades till mellan 0,001 och 4.

Contents

1 Introduction

This document reports the results obtained from groundwater flow measurements in permanently installed boreholes, test campaign no. 5, 2009. This is one of the activities performed within the site investigation program at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-09-006. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

Most of the field work was performed during September and October 2009 and the test campaign included a total of 28 borehole sections. A map showing the investigation site at Oskarshamn and the boreholes is presented in Figure 1-1.

The original results are stored in the primary data base Sicada and are traceable by the activity plan number.

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

Activity plan	Number	Version
Monitering av grundvattenflöde, 2009.	AP PS 400-09-006	1.0
Method descriptions	**Number**	**Version**
Mätsystembeskrivning (MSB) – Handhavande del:	SKB MD 368.010	1.0
System för hydrologisk och metrologisk datainsamling. Vattenprovtagning och utspädningsmätning i observationshål.		

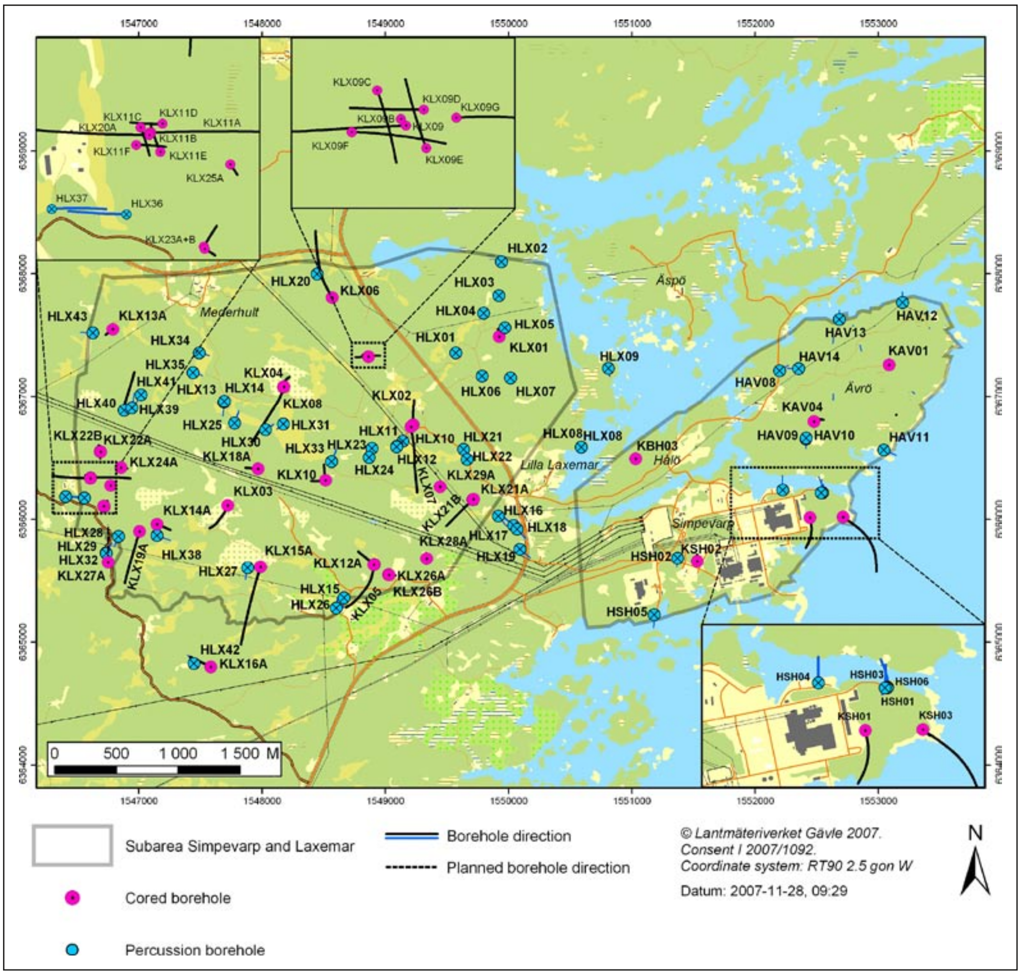

Figure 1-1. General overview of Oskarshamn site investigation area.

2 Objective and scope

The objective of this activity was to determine the groundwater flow in permanently installed borehole sections. These boreholes are located in the site investigation area adjacent to the Oskarshamn nuclear plant. A total of 28 instrumented borehole sections were included in this campaign, cf Table 2-1, which is the fifth campaign performed within the monitoring program.

The groundwater flow in the selected borehole sections was determined through dilution measurements during ambient hydraulic conditions.

Table 2-1. Borehole sections used for groundwater flow measurements in Oskarshamn, test campaign no. 5, 2009.

Borehole/section	Borehole length (m)	Transmissivity (m^2/s)	Measurement period (YYMMDD–YYMMDD)
HLX14:1	96–116	5.7E-05*	090908–090914
HLX20:2	71–80	8.7E-06*	090831–090904
HLX28:2	70–90	3.7E-04*	090929–091005
HLX35:2	120–130	2.3E-04*	090929–091005
HLX39:1	187–199	1.4E-04*	090922–090928
HLX43:1	135–146	4.6E-05*	090923–090928
KAV01:3	391–434	1.5E-05***	090916–090921
KLX02:2	1,145–1,164	3.2E-07**	090901–090907
KLX02:5	452–494	1.0E-07**	090901–090907
KLX03:1	965–971	4.5E-07***	090929–091005
KLX03:4	729–751	4.7E-06***	090929–091005
KLX04:2	870–897	1.4E-07***	090908–090914
KLX04:5	507–530	2.0E-06***	090908–090914
KLX06:3	554–570	5.2E-06***	090901–090907
KLX06:6	256–275	2.0E-05***	090901–090907
KLX07A:2	753–780	9.3E-06***	091006–091014
KLX08:3	626–683	5.8E-07***	090907–090914
KLX08:4	594–625	3.8E-07***	090908–090914
KLX10A:2	689–710	4.4E-08***	090916–090922
KLX10A:5	351–368	7.6E-07***	090917–090922
KLX13A:2	490–507	3.8E-07***	090923–090928
KLX15A:3	623–640	9.0E-07***	091006–091010
KLX15A:6	260–272	3.7E-06***	091006–091010
KLX17A:2	419–434	1.5E-05***	090922–090928
KLX17A:6	180–219	1.1E-06***	090922–090928
KLX18A:3	472–489	5.4E-08***	091006–091010
KSH02:1	955–963	5.4E-07**	090917–090922
KSH02:4	411–439	1.1E-06**	090916–090922

* From flow logging /1–2/.

** From injection tests /3–5/.

*** From differential flow logging /6–19/.

3 Equipment

The boreholes involved in the tests are instrumented with one to eight packers sealing off two to nine borehole sections. In Figure 3-1 a drawing of the instrumentation in core boreholes is presented. All isolated borehole sections are connected to the HMS-system for pressure monitoring. In general the sections intended for tracer tests are equipped with three polyamide tubes. Two are used for injection, sampling and circulation in the borehole section and one is used for pressure monitoring.

The tracer dilution tests were performed using four to five identical equipment set-ups, i.e. allowing four to five sections to be measured simultaneously. The tracer used was Amino-G Acid from Aldrich-Chemie. A schematic drawing of the tracer test equipment is shown in Figure 3-2. The basic idea is to have a continuous internal circulation in the borehole section in order to maintain a homogeneous tracer concentration in the borehole section. The circulation also makes it possible to sample the tracer concentration outside the borehole in order to monitor the dilution of the tracer with time.

Circulation is controlled via a down-hole pump with variable speed and measured using a flow meter. Tracer injections are made with a peristaltic pump and sampling is made by continuously extracting a small volume of water from the system through another peristaltic pump (constant leak) to a fractional sampler.

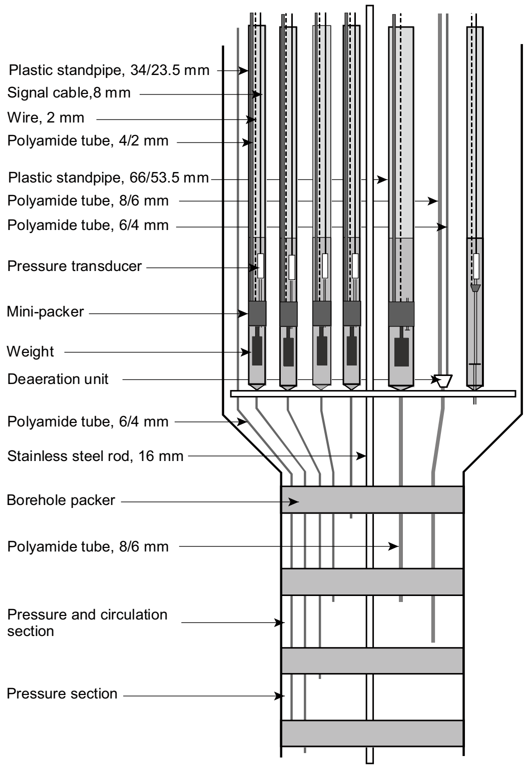

Figure 3-1. *An example of a permanently instrumented core borehole including one circulation section.*

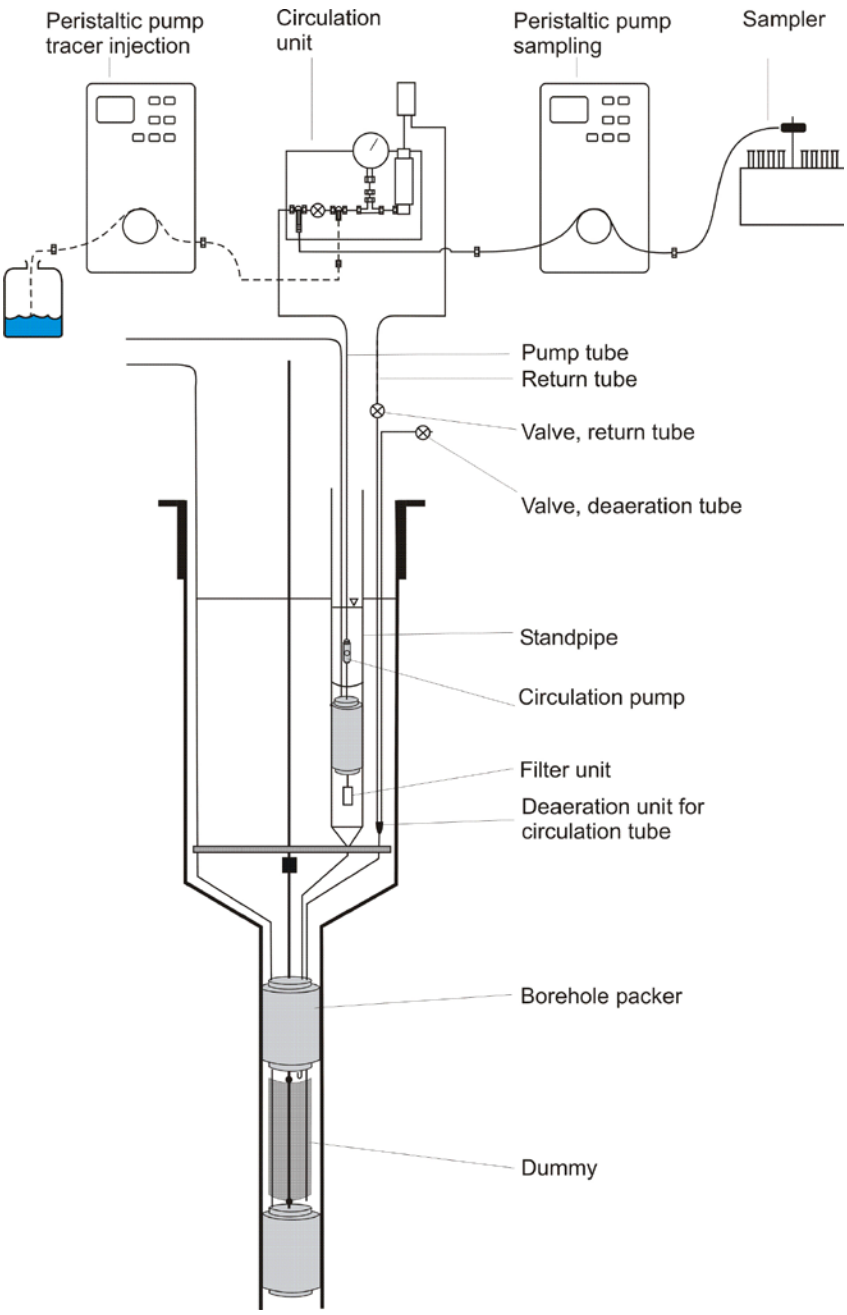

Figure 3-2. *Schematic drawing of the equipment used in tracer dilution measurements.*

4 Execution

4.1 General

In the dilution method a tracer is introduced and homogeneously distributed into a borehole section. The tracer is subsequently diluted by the ambient groundwater flow through the section. The dilution of the tracer is proportional to the water flow through the borehole section and the groundwater flow rate is estimated from the decreasing tracer concentration with time, Figure 4-1.

4.2 Preparations

Before the field work started, a tracer stock solution of the fluorescent dye tracer Amino-G Acid (1,000 mg/l) was mixed and the field equipment was checked and calibrated.

4.3 Execution of field work

Tracer dilution tests were performed in 28 borehole sections, which are listed in Table 4-1. The table also includes all other sections instrumented for tracer dilution tests and the geologic character of the sections. Some sections were excluded as they were used as monitoring sections in a long-term pumping test (LPT) /20/ and some were excluded for other reasons (low priority).

The tests were made by injecting a finite volume of tracer solution (Amino-G Acid 1,000 mg/l) in the selected borehole section. The injection flow rate was adjusted so that the entire tracer solution volume would be injected over a time interval equal to the time it takes to circulate one section volume.

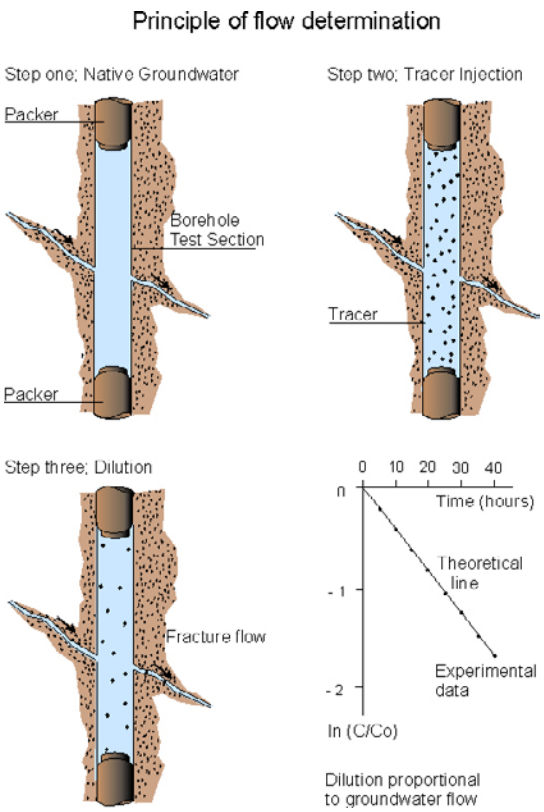

Figure 4-1. *General principles of dilution and flow determination.*

Table 4-1. Borehole sections used for groundwater flow measurements at Oskarshamn site investigation. Sections with grey shade are not measured as a part of this activity.

Borehole/section	Depth (m)	No of fractures*	Geologic character**	Comments
HLX14:1	96–116	–	Deformation Zone EW007A	
HLX20:2	71–80	–	Deformation Zone EW002A	
HLX28:2	70–90	–	Deformation Zone HLX28_DZ1	
HLX32:2	20–30	–	Deformation Zone NW042A	Measured during LPT /20/
HLX35:2	120–130	–	Deformation Zone EW007A	
HLX37:1	150–200	–	Deformation Zone NS001C	Measured during LPT /20/
HLX38:3	28–40	–	Deformation Zone NS059A	Measured during LPT /20/
HLX39:1	187–199	–	Deformation Zone EW900B	
HLX43:1	135–146	–	Possible Deformation ZoneZ	
KAV01:3	391–434	30	Deformation Zone NE012A	
KLX01:3	171–190	–	Possible Deformation Zone	Not prioritised
KLX02:2	1,145–1,164	–	Possible Deformation Zone	
KLX02:5	452–494	4	Possible Deformation Zone	
KLX03:1	965–971	2	Possible Deformation Zone	
KLX03:4	729–751	6	Deformation Zone EW946A	
KLX04:2	870–897	2	Deformation Zone NW928A	
KLX04:5	507–530	2	Fracture domain FSM_EW007	
KLX05:3	625–633	1	Single fracture in Fracture Domain FSM_NE005	Not possible to circulate
KLX05:7	241–255	4	Fracture Domain FSM_NE005	Not prioritised
KLX06:3	554–570	2	No Deformation Zone	
KLX06:6	256–275	9	Deformation Zone NW052A	
KLX07A:2	753–780	15	Deformation Zone KLX07A_DZ12	
KLX08:3	626–683	13	Fracture domain FSM_EW007	
KLX08:4	594–625	4	Fracture domain FSM_EW007	
KLX10A:2	689–710	3	Deformation Zone EW946A	
KLX10A:5	351–368	10	Fracture domain FSM_EW007	
KLX11A:3	573–586	7	Fracture domain FSM_W	Measured during LPT /20/
KLX11A:7	256–272	4	Fracture domain FSM_W	Measured durinfg LPT /20/
KLX12A:2	535–545	3	Fracture domain FSM_NE005	Not prioritised
KLX13A:2	490–507	8	Deformation Zone EW128A	
KLX15A:3	623–640	3	Fracture domain FSM_C	
KLX15A:6	260–272	7	Fracture domain FSM_C	
KLX17A:2	419–434	7	Fracture domain FSM_W	
KLX17A:6	180–219	11	Deformation Zone EW900B	
KLX18A:3	472–489	8	Fracture domain FSM_C	
KLX19A:3	509–517	6	Deformation Zone KLX19A_DZ5-8 dolerite	Measured during LPT /20/
KLX20A:2	260–296	17	Fracture domain FSM_W	Measured during LPT /20/
KLX20A:5	103–144	22	Fracture domain FSM_W	Measured during LPT /20/
KLX21B:3	558–572	2	Deformation Zone KLX21B_DZ10-12	Not prioritised
KLX27A:1	640–651	3	Fracture domain FSM_W	Measured during LPT /20/
KLX27A:6	220–259	7	Deformation Zone NW042A	Measured during LPT /20/
KSH01A:4	532–572	9	Possible Deformation Zone	Not prioritised
KSH01A:7	238–277	12	Possible Deformation Zone	Not prioritised
KSH02:1	955–963	1	Single fracture, no Deformation Zone	
KSH02:4	411–439	5	No Deformation Zone	

* No of fractures from POSIVA Flow Log (PFL). Data from Sicada.

** Geologic interpretation from /21/.

Further, the injection flow rate and tracer concentration were selected so that a starting concentration of approximately 1 mg/l in the borehole section would be obtained. Using the equipment described in Chapter 3, the tracer solution in the borehole section was continuously circulated and sampled. Circulation was maintained during the entire test and the sampler was set to change tubes every two hours.

4.4 Analysis and interpretation

The samples were analysed for tracer concentrations at the Geosigma Laboratory using a Jasco FP 777 Spectrofluorometer.

4.4.1 Tracer dilution calculations

Flow rates were calculated from the decay of tracer concentration over time through dilution by the ambient groundwater flow. The so-called "dilution curves" were plotted as the natural logarithm of concentration versus time cf /22/. Theoretically, a straight-line relationship exists between the natural logarithm of the relative tracer concentration (c/c_0) and time (t):

$$\ln (c/c_0) = -(Q_{bh}/V) \cdot t \qquad (4\text{-}1)$$

where Q_{bh} (m^3/s) is the groundwater flow rate through the borehole section and V (m^3) is the mixing volume including the borehole section and the tubing in the circulation system. By plotting ln (c/c_0) versus t, and by knowing the mixing volume V, Q_{bh} may be obtained from the straight-line slope. If c_0 is constant, it is sufficient to use ln c in the plot.

The sampling procedure with a constant flow rate of approximately 0.100 ml/min also creates a dilution of tracer. The sampling flow rate is therefore subtracted from the value obtained from (4-1).

The flow Q_{bh} may be translated into a Darcy velocity by taking into account the distortion of the flow caused by the borehole and the angle between the borehole and flow direction. In practise, a 90º angle between the borehole axis and the flow direction is assumed and the relation between the flow in the rock the Darcy velocity v (m/s) and the measured flow through the borehole section Q_{bh} can be expressed as:

$$Q_{bh} = v \cdot L_{bh} \cdot 2r_{bh} \cdot \alpha \qquad (4\text{-}2)$$

where L_{bh} is the length of the borehole section (m), r_{bh} is the borehole radius (m) and α is the factor accounting for the distortion of flow caused by the borehole.

Hydraulic gradients may be estimated from Darcy's law where the gradient I is calculated as the function of the Darcy velocity v with the conductivity K:

$$I = \frac{v}{K} = \frac{Q_{bh} \cdot L_{bh}}{\alpha \cdot A \cdot T_{bh}} = \frac{Q_{bh} \cdot L_{bh}}{2 \cdot d_{bh} \cdot L_{bh} \cdot T_{bh}} \qquad (4\text{-}3)$$

where T_{bh} is the transmissivity of the section, A the cross section area between the packers and d_{bh} the borehole diameter.

The factor α is commonly given the value 2 in the calculations, which is the theoretical value for a homogeneous porous media. Since the rock is mostly heterogeneous and the angle between the groundwater flow and borehole axis in the section not always is 90º, the calculation of the hydraulic gradient should be regarded as a rough estimate.

4.5 Nonconformities

- The mobile diesel electric power stations affected the frequency of the sampler. When the sampler was set up to change tubes every 120 minutes the actual sampling interval varied between approximately 114 and 124 minutes. This was compensated for in the evaluation.
- The mobile electric power station at HLX35 stopped after about 17 hours, reason unknown. It was re-started after one hour and this short stop should not affect the results.

- The sampling hose was tangled in the tube sampler in KLX04:5. Due to this, some tubes were not filled. This should not affect the results.
- Due to an erroneously adjusted tube sampler in KLX06:3 some sample tubes in the beginning of the period were not filled. This should not affect the results.
- To avoid work during the weekend, sampling in HLX20:2 was stopped after about 90 hours, which was 6 hours before the minimum limit of a 4 day sampling period established in the AP. The results from the evaluation, however, were not reliable, probably due to tracer contamination of the samples and thereby excluded from this report.
- Due to the start of the moose-hunting period in the area, measurements in KLX15A:3 and KLX15A:6 were terminated 5 and 7 hours, respectively before the limit of 4 days. This should not affect the results.

5 Results

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan number (AP PS 400-09-006). Only data in 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. However, such revision of the database will not necessarily result in a revision of this report although the normal procedure is that major data revisions entail a revision of P-reports. Minor data revisions are normally presented as supplements available at www.skb.se.

The results obtained within this activity are groundwater flow rates in 27 borehole sections during natural conditions. Borehole section HLX20:1 was omitted as described in Section 4.5. The calculated groundwater flow rate together with transmissivity and measurement volume gives the Darcy velocity and hydraulic gradient for the section as additional results, see Table 5-1.

In Figure 5-6 an example of a typical tracer dilution curve is shown, in this case for HLX14:1. The flow rate is calculated from the slope of the straight-line fit. The results show that the groundwater flow during natural undisturbed conditions varied from 0.03 to 80 ml/min in the measured sections with Darcy velocities ranging from $7.2 \cdot 10^{-11}$ to $6.4 \cdot 10^{-7}$ m/s. Hydraulic gradients are calculated according to the Darcy concept and range from 0.001 to 4.

Tracer dilution graphs together with straight-line fits for each borehole section are presented in Appendix 1. The straight-line fits to the experimental data are generally good with regression coefficients (R-squared) between 0.725 and 0.999 for 23 of 27 borehole sections. For four of the borehole sections, data is substantially scattered with regression coefficient values ranging between 0.050 and 0.452.

Table 5-1. Results from groundwater flow measurements in permanently installed boreholes test campaign no. 5, 2009.

Borehole/section	Borehole length (m)	Transmissivity (m^2/s)	Volume (ml)	Measured flow (ml/min)	Darcy velocity (m/s)	Hydraulic gradient
HLX14:1	96–116	5.7E-05*	84,950	80	2.4E-07	0.084
HLX28:2	70–90	3.7E-04*	46,055	27	8.2E-08	0.0044
HLX35:2	120–130	2.3E-04*	38,460	39	2.3E-07	0.010
HLX39:1	187–199	1.4E-04*	66,982	1.9	9.6E-09	0.0008
HLX43:1	135–146	4.6E-05*	42,820	4.6	2.5E-08	0.0060
KAV01:3	391–434	1.5E-05***	47,757	61	8.4E-08	0.24
KLX02:2	1,145–1,164	3.2E-07**	90,589	0.93	2.9E-09	0.17
KLX02:5	452–494	1.0E-07**	70,197	2.2	3.1E-09	1.3
KLX03:1	965–971	4.5E-07***	65,598	0.25	2.5E-09	0.033
KLX03:4	729–751	4.7E-06***	66,610	1.8	4.8E-09	0.023
KLX04:2	870–897	1.4E-07***	83,344	0.03	7.2E-11	0.014
KLX04:5	507–530	2.0E-06***	54,119	0.51	1.3E-09	0.015
KLX06:3	554–570	5.2E-06***	52,881	1.1	3.9E-09	0.012
KLX06:6	256–275	2.0E-05***	35,861	6.8	2.1E-08	0.020
KLX07A:2	753–780	9.3E-06***	77,028	15	3.3E-08	0.095
KLX08:3	626–683	5.8E-07***	103,491	3.0	3.1E-09	0.31
KLX08:4	594–625	3.8E-07***	68,440	22	4.2E-08	3.4
KLX10A:2	689–710	4.4E-08***	66,620	0.36	1.9E-09	0.89
KLX10A:5	351–368	7.6E-07***	39,875	24	1.6E-07	3.5
KLX13A:2	490–507	3.8E-07***	51,210	0.33	2.1E-09	0.096
KLX15A:3	623–640	9.0E-07***	57,606	33	2.1E-07	4.0
KLX15A:6	260–272	3.7E-06***	29,384	70	6.4E-07	2.0
KLX17A:2	419–434	1.5E-05***	44,880	4.0	2.9E-08	0.029
KLX17A:6	180–219	1.1E-06***	50,800	0.72	2.0E-09	0.075
KLX18A:3	472–489	5.4E-08***	49,343	2.0	1.3E-08	4.0
KSH02:1	955–963	5.4E-07**	67,328	0.16	2.3E-09	0.034
KSH02:4	411–439	1.1E-06**	54,136	0.35	1.4E-09	0.034

* From flow loggings /1–2/.

** From injection tests /3–5/.

*** From differential flow logging /6–19/.

A comparison between test campaign no. 1, 2005 /23/, test campaign no. 2, 2006 /24/, test campaign no. 3, 2007 /25/, test campaign no. 4, 2008 /26/ and test campaign no. 5, 2009 is shown in Table 5-2. In this comparison results from the dilution measurements for the LPT project /20/ is included (within brackets) as well. As seen in Table 5-2, the flow rate in the borehole sections displays increasing, decreasing or constant trends over time. These results and trends are shown in Figure 5-3, Figure 5-4 and Figure 5-5. Some of the sections, for instance HLX43:1 and KLX08:4, shows a varying hydraulic gradient over time at a ratio of 113 and 22 respectively and seven sections has maximum ratios above 10. The reasons for these fluctuations are not fully understood but some of the sections in campaign no. 5 might still have been affected by the long-term pumping (LPT) conducted in borehole HLX28 between 090119 and 090526. The pumping rate was about 300 l/min and had a large influence on groundwater levels in some flow directions. During the pre-test to the LPT, some of the sections (see Table 5-2 below), was measured in the summer 2009 and the results from this measurement was then used in campaign 4.

A hydraulic gradient above 0.1 is unlikely to exist in a flat topography area like Laxemar. Notable is that 9 out of 12 sections having a transmissivity below 1 E-06 m^2/s, show hydraulic gradients above 0.1 compared to only 2 out of 15 sections having a transmissivity above 1 E-06 m^2/s, see Table 5.1. The relationship between transmissivity and hydraulic gradient was also noted in a separate study /27/ where also other sources of error such as convergence factors and fracture orientations are discussed.

Groundwater levels during the test period are shown for the selected boreholes in Appendix 2. The groundwater levels are generally decreasing during the measurement period which was in late summer in 2009, a relatively dry period. The previous test campaigns have been conducted between November and February. Generally the groundwater levels can have a big effect on the flow rate and the differences between the summer period and the winter with rain and snowfall are factors that might have affected the results. One example is section KLX08:4 whose flow rate increased over 40 times from 2008 to 2009 and which might have been affected by a decreasing groundwater level. The result from KLX08:4 however is a bit uncertain as seen in Appendix 1 since the dilution graph is very unstable. The changes in flow rate are plotted in Figure 5-1.

As seen in Figure 5-1 the change between 2008 and 2009 is generally small but some of the sections have changed with a factor 5 to 10. The shallower sections display a somewhat higher but not significant ratio of change. The outlier with a ratio of 40 is from section KLX08:4 which result is seen as a bit uncertain as discussed above.

In order to explain the diverging results of the flow rate in some sections, some comparisons were made. It is noticeable that the boreholes with a varying flow ratio exceeding 10 are all situated in the eastern part of Laxemar subarea. These sections are: HLX43:1, KLX02:2, KLX04:2, KLX05:7, KLX08:4, KLX15A:6 and KLX18A:3. To see if there are any long-term correlations between depth and flow changes the logarithm of the ratio of change was plotted against the mean depth of each section and is seen in Figure 5-2. There is no clear relation between the two variables even though the shallower sections display a somewhat higher ratio of the present flow changes similar to the one seen in Figure 5-1.

Table 5-2. Results from groundwater flow measurements in permanently installed boreholes. Comparison between test campaign no. 1, 2005, no. 2, 2006, no. 3, 2007, no. 4, 2008 and no. 5, 2009. Values within brackets from LPT measurements 2008 and 2009.

Borehole/ section	Measured flow (ml/min)					Darcy velocity (m/s)					Hydraulic gradient				
	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009
HLX14:1				11	80				3.4E-08	2.4E-07				0.012	0.084
HLX20:2			0.57	0.31	–			3.8E-09	2.1E-09	–			0.0039	0.0020	–
HLX27:1			2.60					1.3E-08					0.0041		
HLX28:2			11		27			3.4E-08		8.2E-08			0.0018		0.0044
HLX32:2			15	8.3	7.1			8.7E-08	[4.9E-08]	[4.2E-08]			0.13	0.071	0.061
HLX35:2			73	71	39			4.4E-07	4.2E-07	2.3E-07			0.019	0.019	0.010
HLX37:1				2.5	1.8				[3.0E-09]	[2.2E-09]				0.0030	0.0020
HLX37:3			1.2					4.8E-09					0.0049		
HLX38:3				4.6	0.94				[2.3E-08]	[4.7E-09]				0.0050	0.0010
HLX39:1			1.4		1.9			7.1E-09		9.6E-09			0.00060		0.00082
HLX43:1			83	0.7	4.6			4.5E-07	4.0E-09	2.5E-08			0.11	0.0010	0.0060
KAV01:3	61	42	68		61	2.1E-07	1.4E-07	1.7E-07		8.4E-08	0.59	0.40	0.48		0.24
KLX01:3	5.9	4.1	4.8			3.4E-08	2.4E-08	2.8E-08			0.018	0.013	0.015	0.015	
KLX02:2	2.1	0.77	0.72	0.20	0.93	1.2E-08	4.4E-09	4.1E-09	1.2E-09	2.9E-09	0.71	0.26	0.24	0.071	0.17
KLX02:5	3.1	2.5	1.6	3.1	2.2	8.0E-09	6.6E-09	4.2E-09	8.0E-09	3.1E-09	3.4	2.8	1.8	3.4	1.3
KLX03:1		0.93	0.20	0.77	0.25		1.7E-08	3.7E-09	1.4E-08	2.5E-09		0.23	0.049	0.19	0.033
KLX03:4		0.65	0.40	1.7	1.8		3.2E-09	2.0E-09	8.7E-09	4.8E-09		0.015	0.0095	0.041	0.023
KLX04:2	0.73	0.70	0.57		0.03	3.0E-09	2.8E-09	2.3E-09		7.2E-11	0.58	0.54	0.45		0.014
KLX04:5	0.67	0.55	0.70		0.51	3.2E-09	2.6E-09	3.4E-09		1.3E-09	0.036	0.029	0.038		0.015
KLX05:3		0.25					3.4E-09					4.9			
KLX05:7		0.58	0.22	14			4.6E-09	1.7E-09	1.1E-07			0.034	0.013	0.81	
KLX06:3	0.88	0.78	0.82		1.1	6.1E-09	5.4E-09	5.6E-09		3.9E-09	0.019	0.016	0.017		0.012
KLX06:6	2.2	2.0	1.7		6.8	1.3E-08	1.2E-08	9.7E-09		2.1E-08	0.012	0.011	0.0090		0.020
KLX07A:2		18	19	17	15		7.2E-08	7.9E-08	6.9E-08	3.3E-08		0.21	0.23	0.20	0.095
KLX08:3			26	3.5	3.0			5.0E-08	5.8E-08	3.1E-09			4.9	0.65	0.31
KLX08:4			0.75	0.54	22			2.7E-09	1.9E-09	4.2E-08			0.22	0.15	3.4
KLX10A:2		2.3	0.60	0.27	0.36		1.2E-08	3.1E-09	4.5E-09	1.9E-09		5.7	1.5	0.66	0.89
KLX10A:5		18	19	13	24		1.2E-07	1.2E-07	8.2E-08	1.6E-07		2.7	2.7	1.8	3.5
KLX11A:3			3.2	2.6	1.1			2.7E-08	[2.2E-08]	[9.6E-09]			0.023	0.019	0.0080
KLX11A:7			0.67	0.70	0.38			4.6E-09	[4.8E-09]	[2.6E-09]			0.0029	0.0030	0.0020
KLX12A:2			0.17	0.60				1.8E-09	6.5E-09				0.14	0.51	
KLX13A:2				0.62	0.33				4.0E-09	2.1E-09				0.18	0.096
KLX15A:3			18	44	33			1.2E-07	2.9E-07	2.1E-07			2.3	5.5	4.0
KLX15A:6			3.0	30	70			2.7E-08	2.8E-07	6.4E-07			0.087	0.90	2.0
KLX17A:2				5.6	4.0				4.1E-08	2.9E-08				0.040	0.029
KLX17A:6				0.65	0.72				1.8E-09	2.0E-09				0.066	0.075
KLX18A:3			0.28	15	2.0			1.9E-09	1.0E-07	1.3E-08			0.59	31	4.0
KLX19A:3			1.2	0.61	0.36			1.6E-08	[8.3E-09]	[5.0E-09]			0.13	0.065	0.039
KLX20A:2			0.70	0.69	5.2			2.1E-09	[2.3E-09]	[1.7E-08]			0.034	0.037	0.28
KLX20A:5			4.2	6.3	6.3			1.1E-08	[1.7E-08]	[1.7E-08]			0.055	0.085	0.085
KLX21B:3				170					1.3E-06					36	
KLX27A:1				0.32	0.067				[3.1E-09]	[6.6E-10]				0.010	0.0020
KLX27A:6				4.2	4.6				[1.2E-08]	[1.3E-08]				1.2	1.3
KSH01A:4	9.0	7.4	4.6			2.5E-08	2.0E-08	1.2E-08			2.9	2.3	1.4		
KSH01A:7	1.9	2.0	1.6			5.3E-09	5.6E-09	4.4E-09			0.13	0.14	0.11		
KSH02:1	0.82	0.55	0.10		0.16	1.1E-08	7.6E-09	1.3E-09		2.3E-09	0.16	0.11	0.019		0.034
KSH02:4	0.65	0.33	0.18		0.35	2.6E-09	1.3E-09	6.9E-10		1.4E-09	0.065	0.032	0.017		0.034

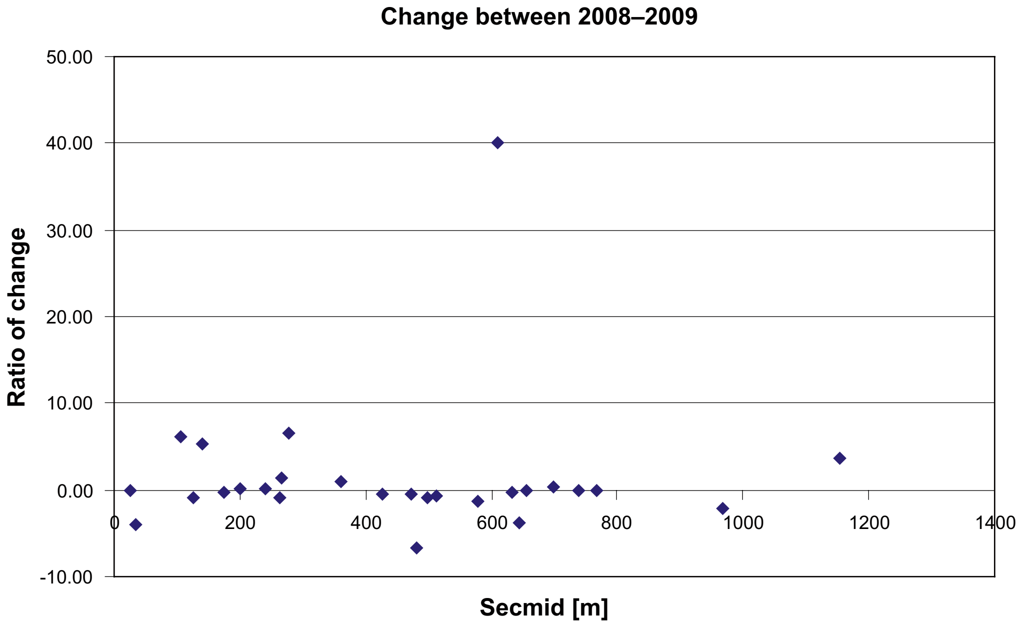

Figure 5-1. *Comparison of the ratio ([2009–2008]/min[2008:2009]) between tested flow rates 2008 and 2009 plotted against mean depth for all sections measured in these two test campaigns.*

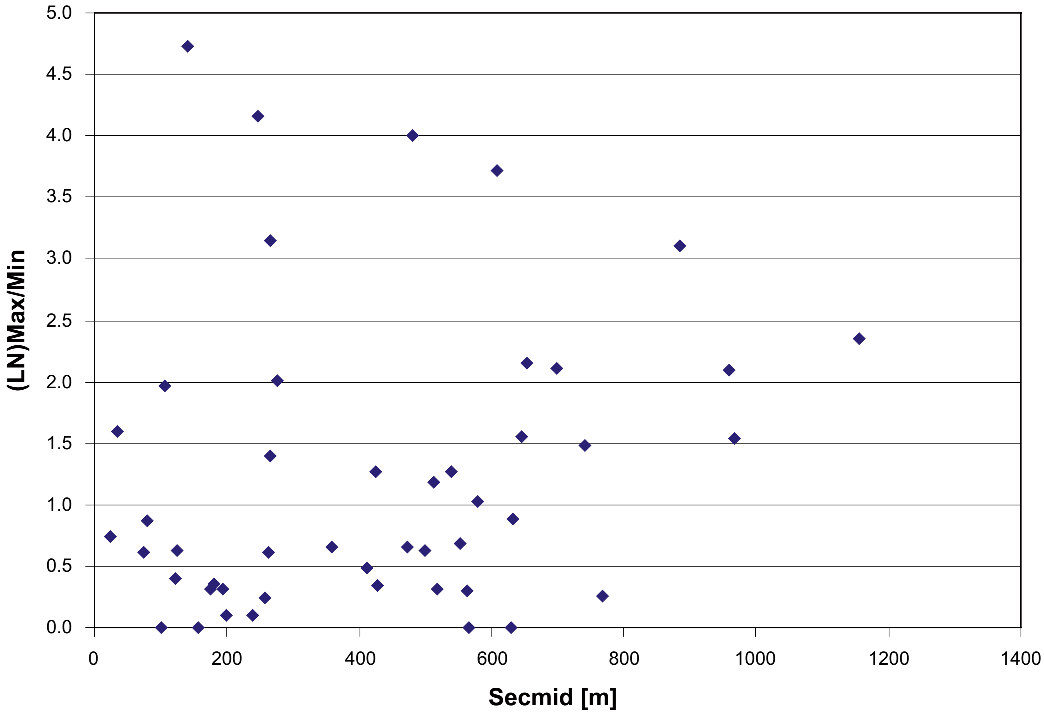

Figure 5-2. *Comparison of the logarithm of the ratio between tested max and min flow rates plotted against mean depth for all sections measured in at least two test campaigns.*

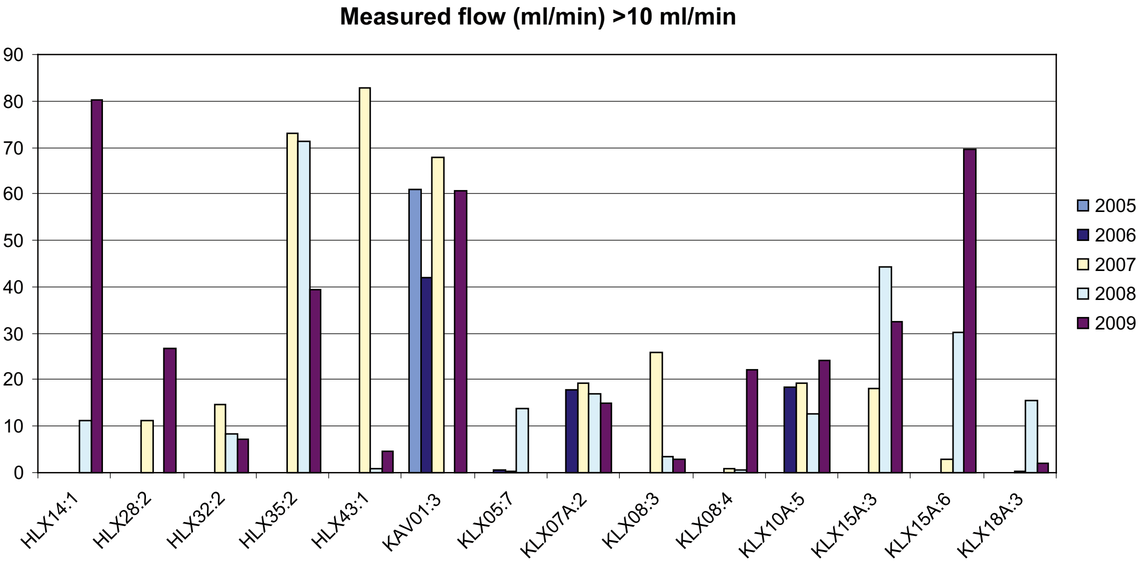

Figure 5-3. *Comparison of flow rates determined from all measurement campaigns performed for borehole sections having flow rates above 10 ml/min.*

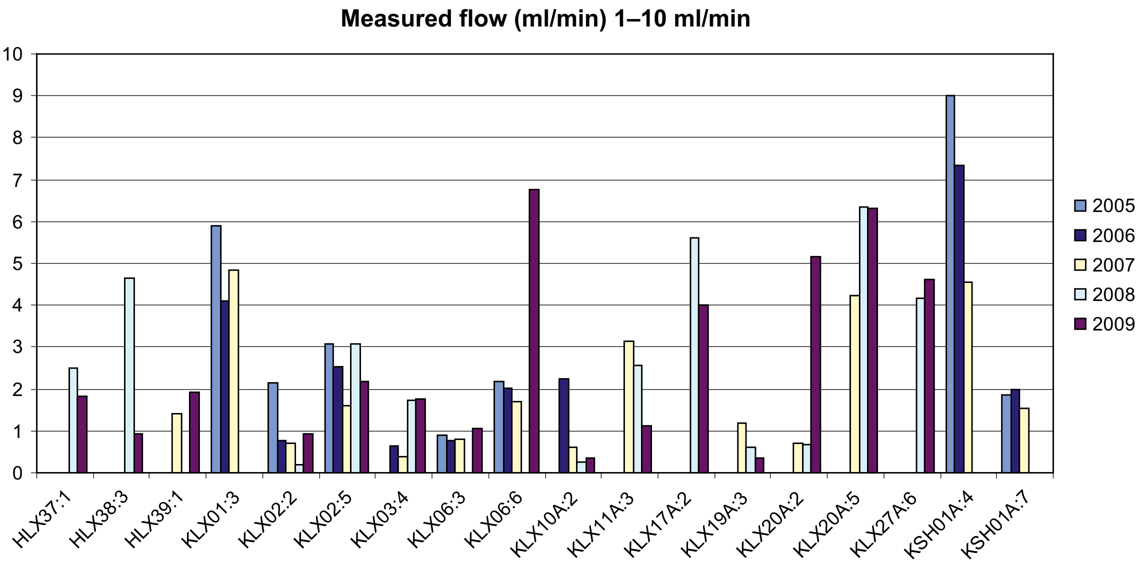

Figure 5-4. *Comparison of flow rates determined from all measurement campaigns for borehole sections having flow rates in the range 1–10 ml/min.*

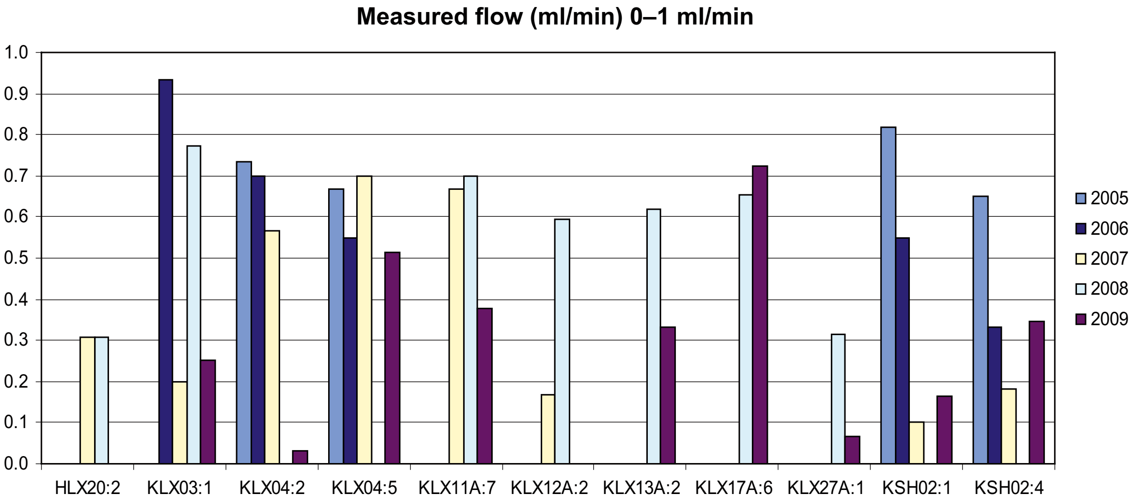

Figure 5-5. *Comparison of flow rates determined from all measurement campaigns for borehole sections having flow rates in the range 0–1 ml/min.*

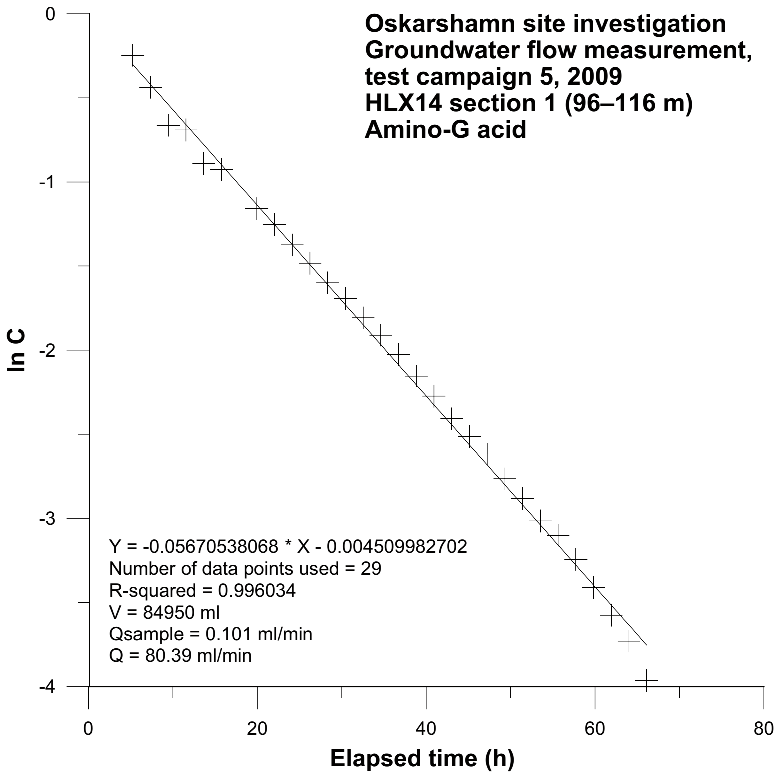

Figure 5-6. *Example of a tracer dilution graph for borehole HLX14:1, including straight – line fit.*

6 References

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/25/ **Thur P, 2008.** Groundwater flow measurements in permanently installed boreholes. Test campaign no. 3. 2007. Oskarshamn site investigation. SKB P-08-31, Svensk Kärnbränslehantering AB.

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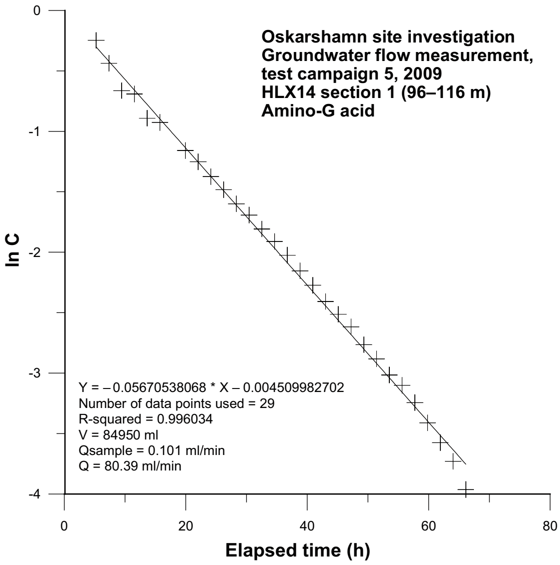
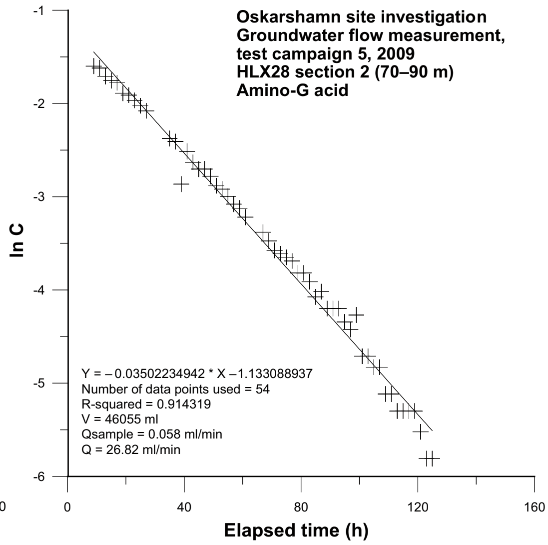
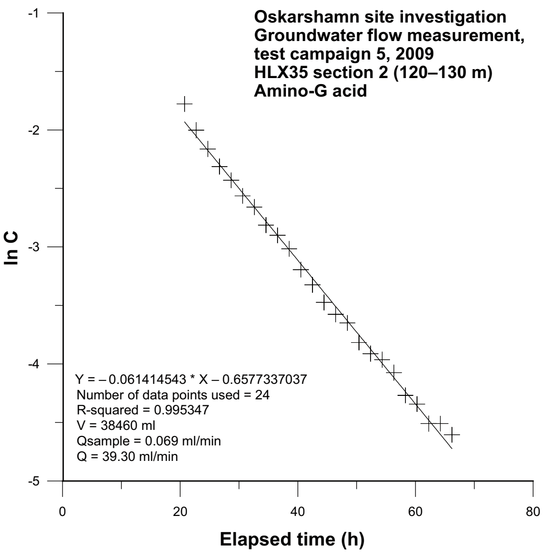
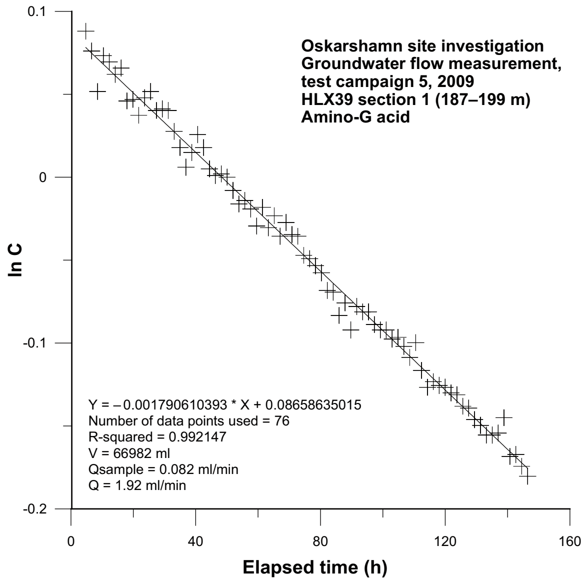
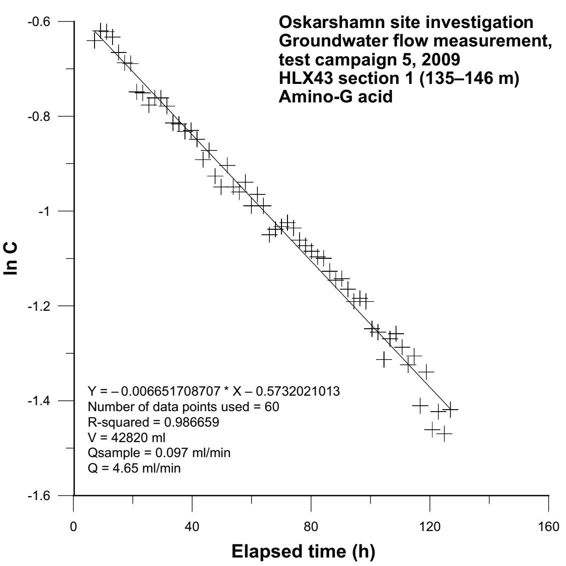
Tracer dilution graphs







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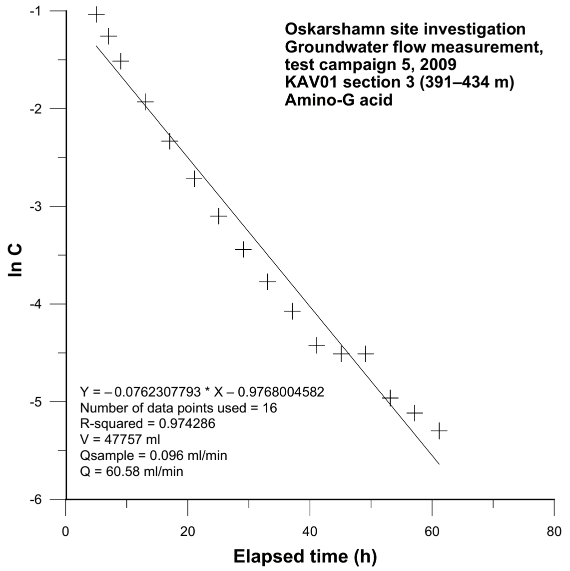
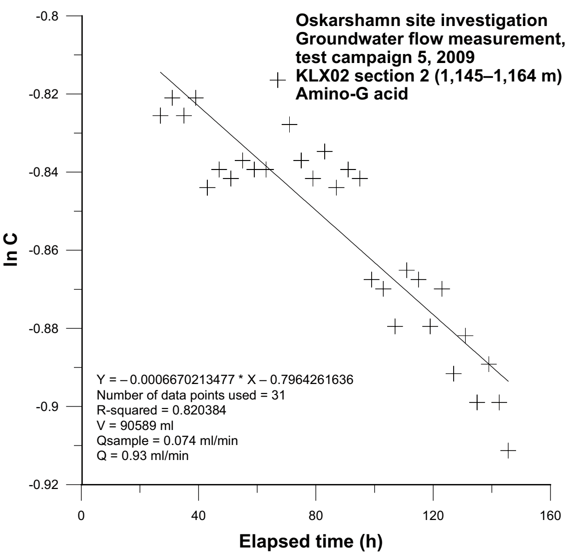
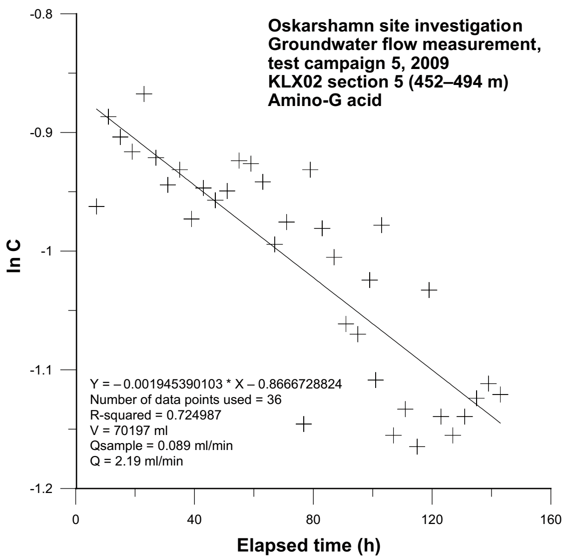
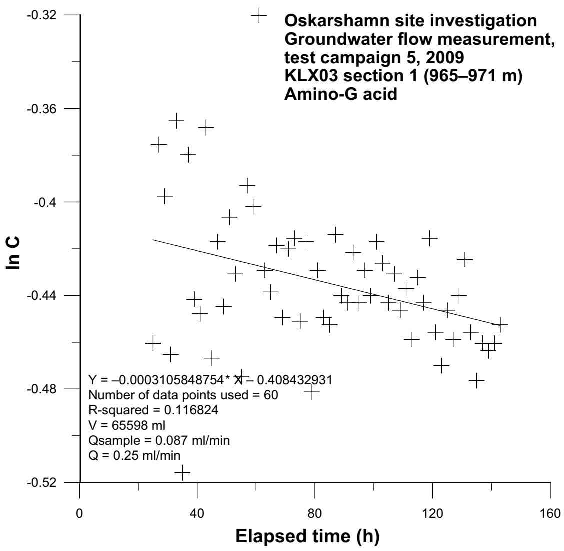
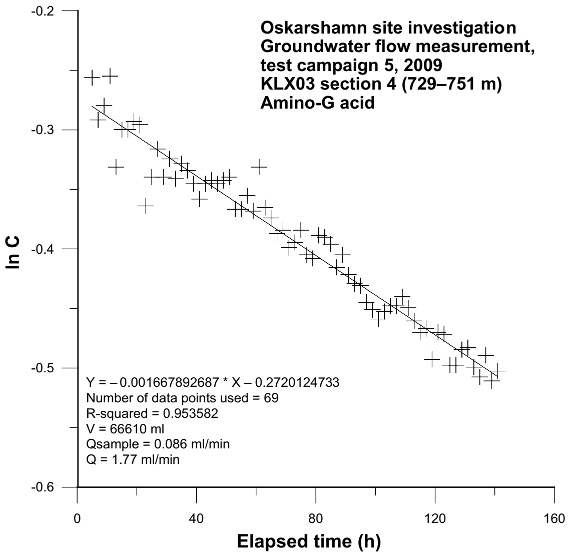
Groundwater flow measurement,
test campaign 5, 2009
HLX43 section 1 (135–146 m)
Amino-G acid
Y = – 0.006651708707 * X – 0.5732021013
Number of data points used = 60
R-squared = 0.986659
V = 42820 ml
Qsample = 0.097 ml/min
Q = 4.65 ml/min
ln C
Elapsed time (h)

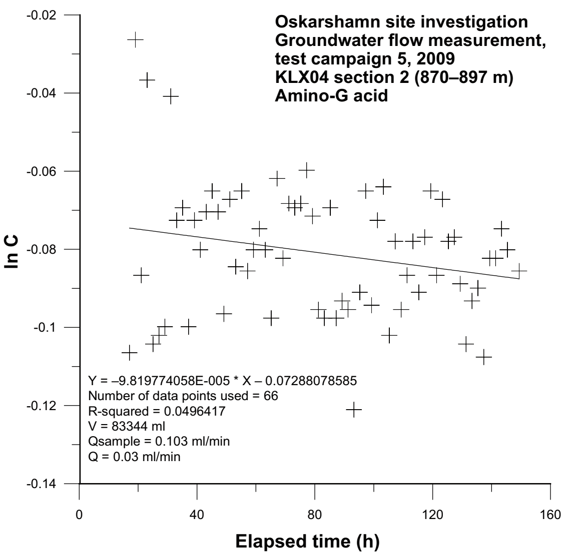

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KAV01 section 3 (391–434 m)
Amino-G acid
Y = – 0.0762307793 * X – 0.9768004582
Number of data points used = 16
R-squared = 0.974286
V = 47757 ml
Qsample = 0.096 ml/min
Q = 60.58 ml/min
ln C
Elapsed time (h)

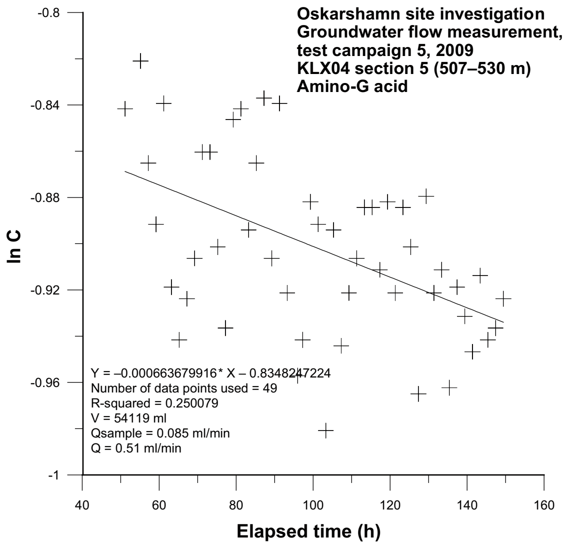

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX02 section 2 (1,145–1,164 m)
Amino-G acid
Y = – 0.0006670213477 * X – 0.7964261636
Number of data points used = 31
R-squared = 0.820384
V = 90589 ml
Qsample = 0.074 ml/min
Q = 0.93 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX02 section 5 (452–494 m)
Amino-G acid
Y = – 0.001945390103 * X – 0.8666728824
Number of data points used = 36
R-squared = 0.724987
V = 70197 ml
Qsample = 0.089 ml/min
Q = 2.19 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX03 section 1 (965–971 m)
Amino-G acid
Y = –0.0003105848754* X – 0.408432931
Number of data points used = 60
R-squared = 0.116824
V = 65598 ml
Qsample = 0.087 ml/min
Q = 0.25 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX03 section 4 (729–751 m)
Amino-G acid
Y = –0.001667892687 * X – 0.2720124733
Number of data points used = 69
R-squared = 0.953582
V = 66610 ml
Qsample = 0.086 ml/min
Q = 1.77 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX04 section 2 (870–897 m)
Amino-G acid
Y = –9.819774058E-005 * X – 0.07288078585
Number of data points used = 66
R-squared = 0.0496417
V = 83344 ml
Qsample = 0.103 ml/min
Q = 0.03 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX04 section 5 (507–530 m)
Amino-G acid
Y = –0.000663679916* X – 0.8348247224
Number of data points used = 49
R-squared = 0.250079
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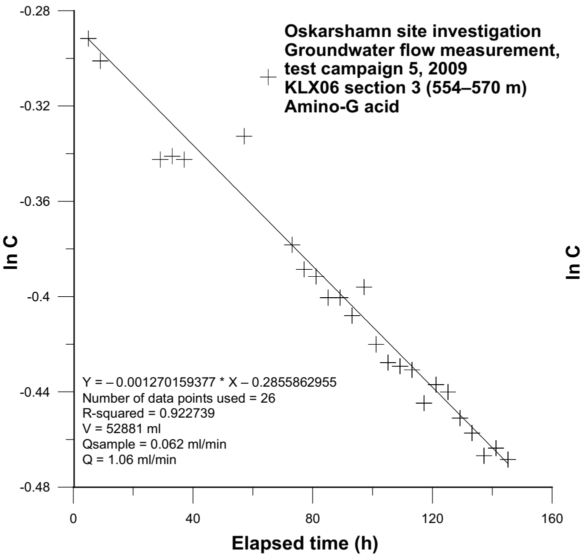
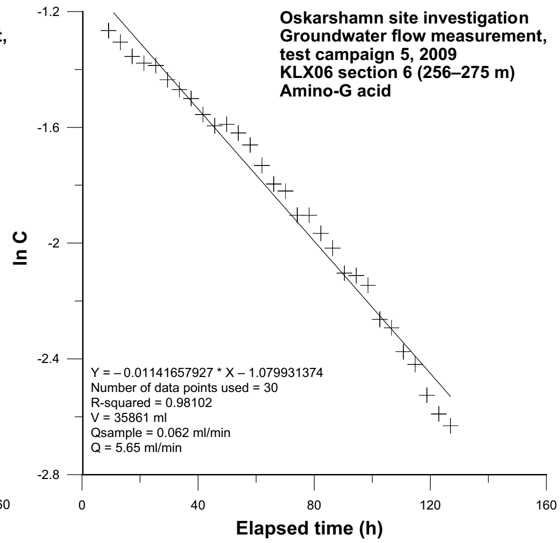
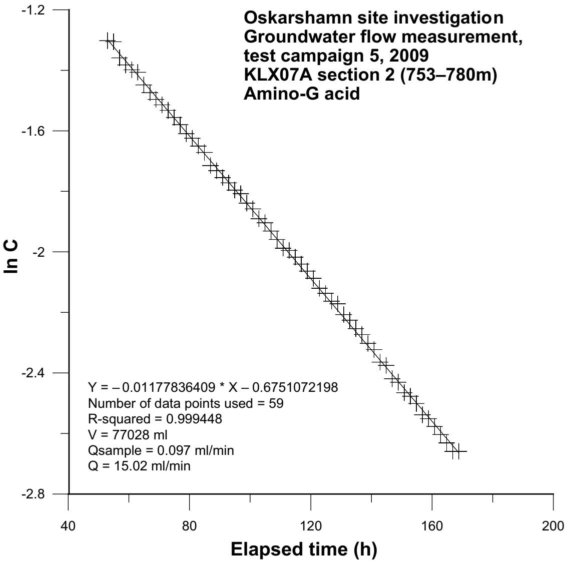
Qsample = 0.085 ml/min
Q = 0.51 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX06 section 3 (554–570 m)
Amino-G acid
Y = – 0.001270159377 * X – 0.2855862955
Number of data points used = 26
R-squared = 0.922739
V = 52881 ml
Qsample = 0.062 ml/min
Q = 1.06 ml/min
ln C
Elapsed time (h)
-0.28
-0.32
-0.36
-0.4
-0.44
-0.48
0
40
80
120
160


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX06 section 6 (256–275 m)
Amino-G acid
Y = – 0.01141657927 * X – 1.079931374
Number of data points used = 30
R-squared = 0.98102
V = 35861 ml
Qsample = 0.062 ml/min
Q = 5.65 ml/min
ln C
Elapsed time (h)
-1.2
-1.6
-2
-2.4
-2.8
0
40
80
120
160


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX07A section 2 (753–780m)
Amino-G acid
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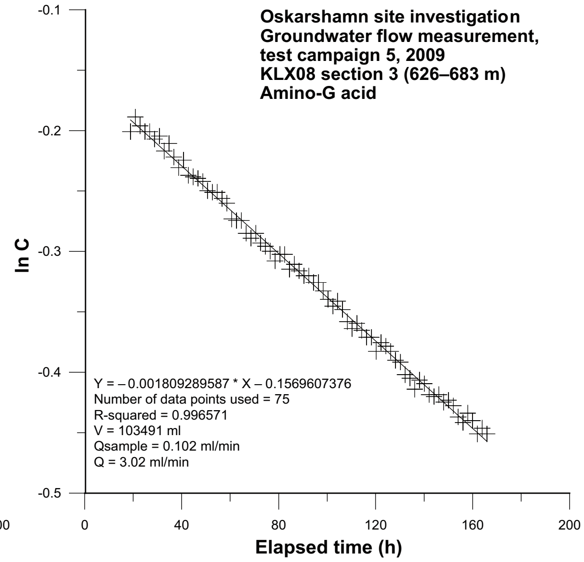
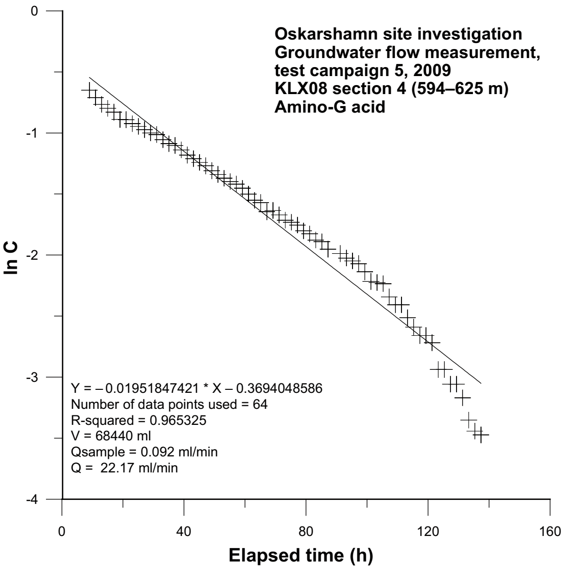
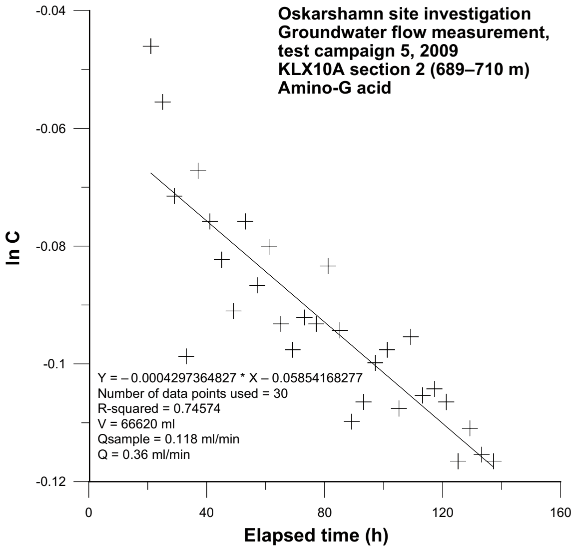
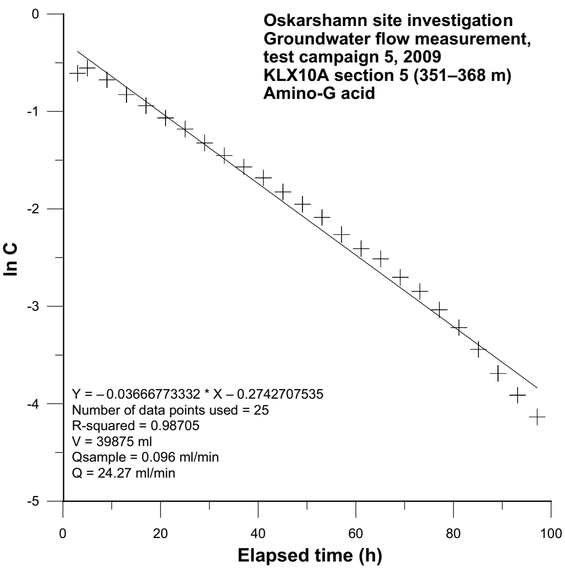
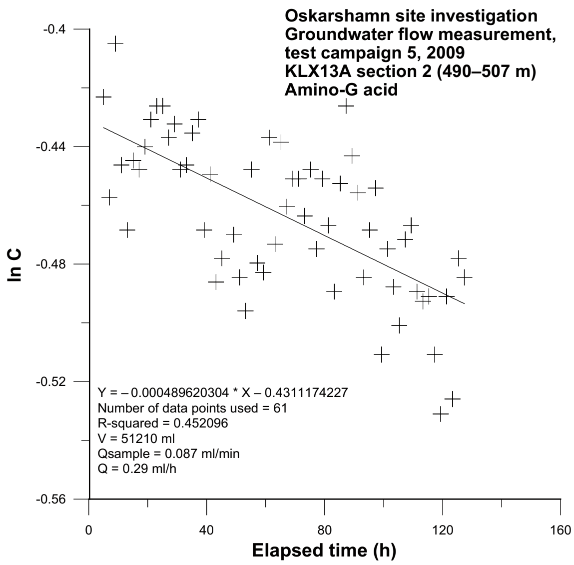
Number of data points used = 59
R-squared = 0.999448
V = 77028 ml
Qsample = 0.097 ml/min
Q = 15.02 ml/min
ln C
Elapsed time (h)
-1.2
-1.6
-2
-2.4
-2.8
40
80
120
160
200

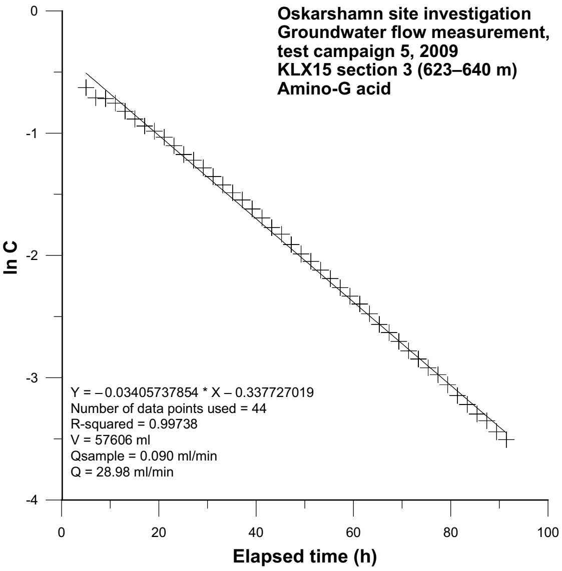

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX08 section 3 (626–683 m)
Amino-G acid
Y = – 0.001809289587 * X – 0.1569607376
Number of data points used = 75
R-squared = 0.996571
V = 103491 ml
Qsample = 0.102 ml/min
Q = 3.02 ml/min
ln C
Elapsed time (h)
-0.1
-0.2
-0.3
-0.4
-0.5
0
40
80
120
160
200

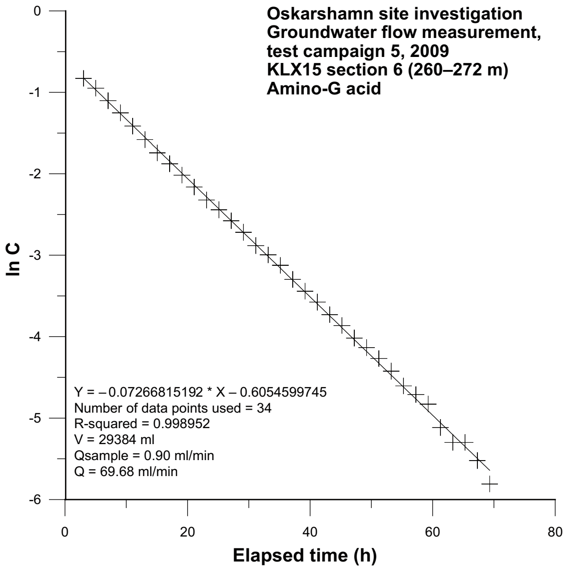

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX08 section 4 (594–625 m)
Amino-G acid
Y = – 0.01951847421 * X – 0.3694048586
Number of data points used = 64
R-squared = 0.965325
V = 68440 ml
Qsample = 0.092 ml/min
Q = 22.17 ml/min
ln C
Elapsed time (h)
0
-1
-2
-3
-4
0
40
80
120
160

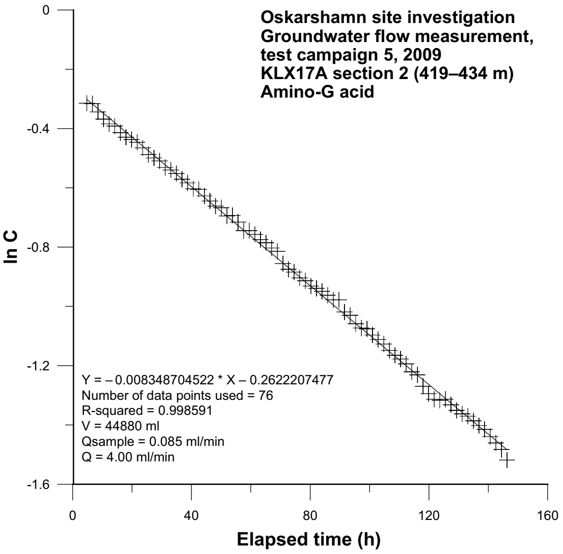

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX10A section 2 (689–710 m)
Amino-G acid
Y = – 0.0004297364827 * X – 0.05854168277
Number of data points used = 30
R-squared = 0.74574
V = 66620 ml
Qsample = 0.118 ml/min
Q = 0.36 ml/min
ln C
Elapsed time (h)
-0.04
-0.06
-0.08
-0.1
-0.12
0
40
80
120
160

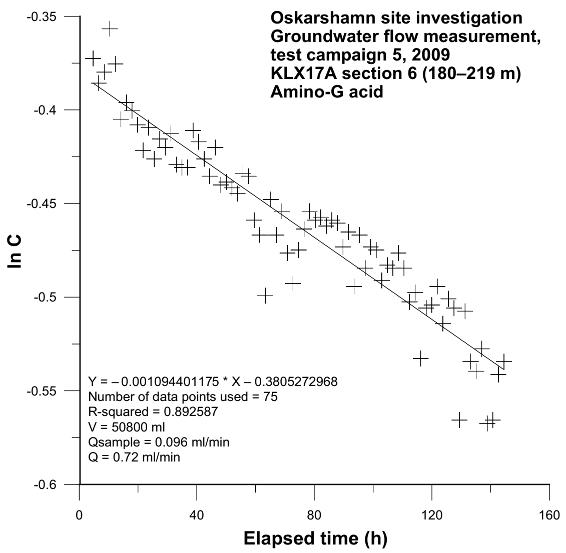

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX10A section 5 (351–368 m)
Amino-G acid
Y = – 0.03666773332 * X – 0.2742707535
Number of data points used = 25
R-squared = 0.98705
V = 39875 ml
Qsample = 0.096 ml/min
Q = 24.27 ml/min
ln C
Elapsed time (h)
0
-1
-2
-3
-4
-5
0
20
40
60
80
100

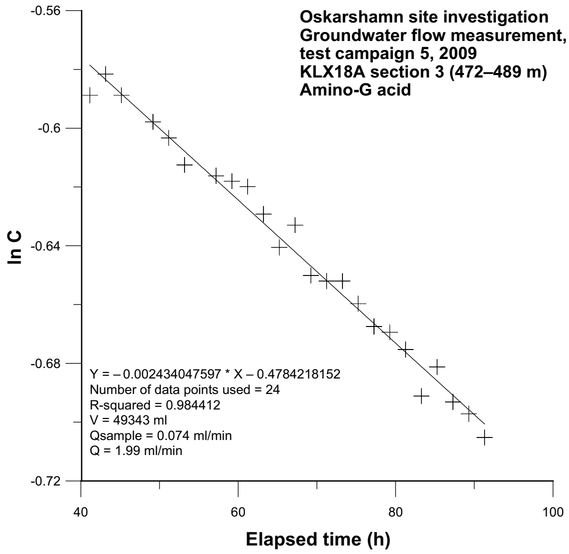

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX13A section 2 (490–507 m)
Amino-G acid
Y = – 0.000489620304 * X – 0.4311174227
Number of data points used = 61
R-squared = 0.452096
V = 51210 ml
Qsample = 0.087 ml/min
Q = 0.29 ml/h
ln C
Elapsed time (h)
-0.4
-0.44
-0.48
-0.52
-0.56
0
40
80
120
160

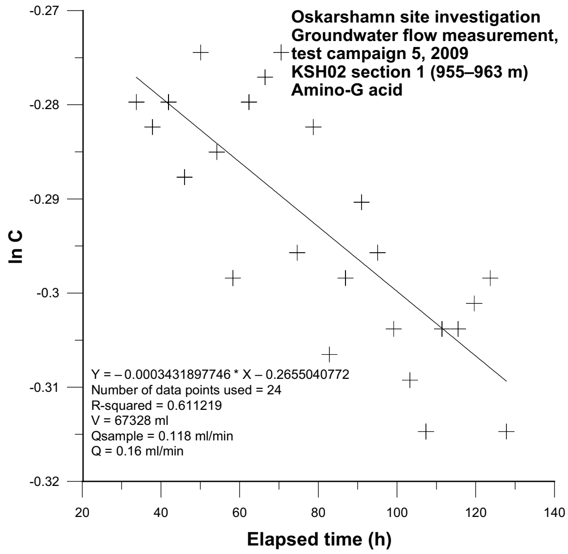

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX15 section 3 (623–640 m)
Amino-G acid
Y = – 0.03405737854 * X – 0.337727019
Number of data points used = 44
R-squared = 0.99738
V = 57606 ml
Qsample = 0.090 ml/min
Q = 28.98 ml/min
ln C
Elapsed time (h)
0
-1
-2
-3
-4
0
20
40
60
80
100

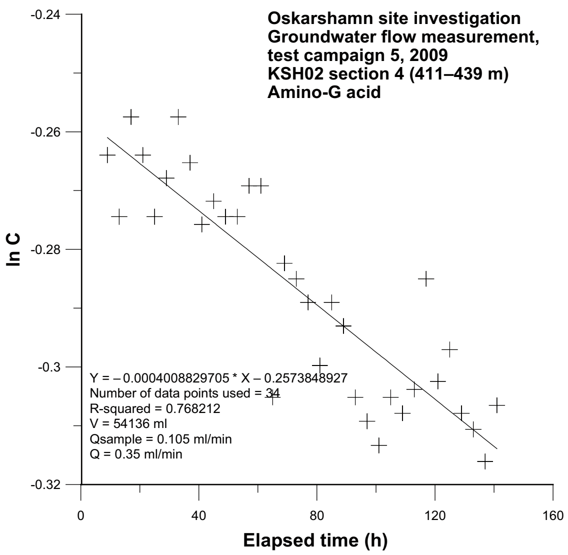

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX15 section 6 (260–272 m)
Amino-G acid
Y = – 0.07266815192 * X – 0.6054599745
Number of data points used = 34
R-squared = 0.998952
V = 29384 ml
Qsample = 0.90 ml/min
Q = 69.68 ml/min
ln C
Elapsed time (h)
0
-1
-2
-3
-4
-5
-6
0
20
40
60
80


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX17A section 2 (419–434 m)
Amino-G acid
Y = – 0.008348704522 * X – 0.2622207477
Number of data points used = 76
R-squared = 0.998591
V = 44880 ml
Qsample = 0.085 ml/min
Q = 4.00 ml/min
ln C
Elapsed time (h)
0
-0.4
-0.8
-1.2
-1.6
0
40
80
120
160


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX17A section 6 (180–219 m)
Amino-G acid
Y = – 0.001094401175 * X – 0.3805272968
Number of data points used = 75
R-squared = 0.892587
V = 50800 ml
Qsample = 0.096 ml/min
Q = 0.72 ml/min
ln C
Elapsed time (h)
-0.35
-0.4
-0.45
-0.5
-0.55
-0.6
0
40
80
120
160

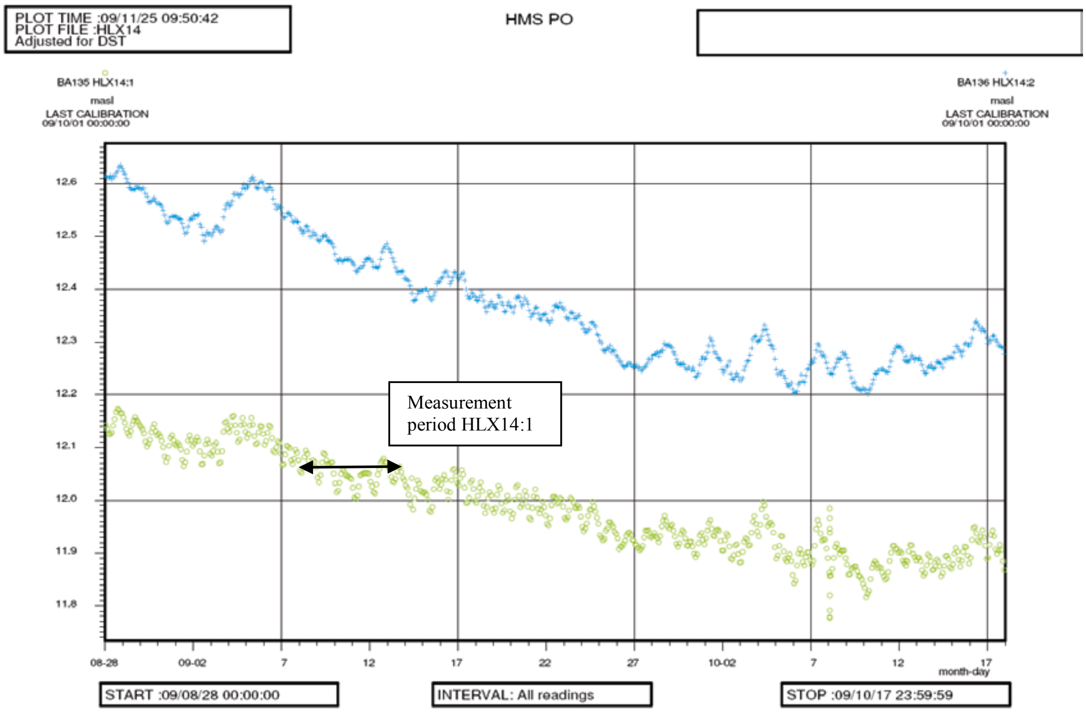

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KLX18A section 3 (472–489 m)
Amino-G acid
Y = – 0.002434047597 * X – 0.4784218152
Number of data points used = 24
R-squared = 0.984412
V = 49343 ml
Qsample = 0.074 ml/min
Q = 1.99 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KSH02 section 1 (955–963 m)
Amino-G acid
Y = – 0.0003431897746 * X – 0.2655040772
Number of data points used = 24
R-squared = 0.611219
V = 67328 ml
Qsample = 0.118 ml/min
Q = 0.16 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 5, 2009
KSH02 section 4 (411–439 m)
Amino-G acid
Y = – 0.0004008829705 * X – 0.2573848927
Number of data points used = 34
R-squared = 0.768212
V = 54136 ml
Qsample = 0.105 ml/min
Q = 0.35 ml/min
ln C
Elapsed time (h)

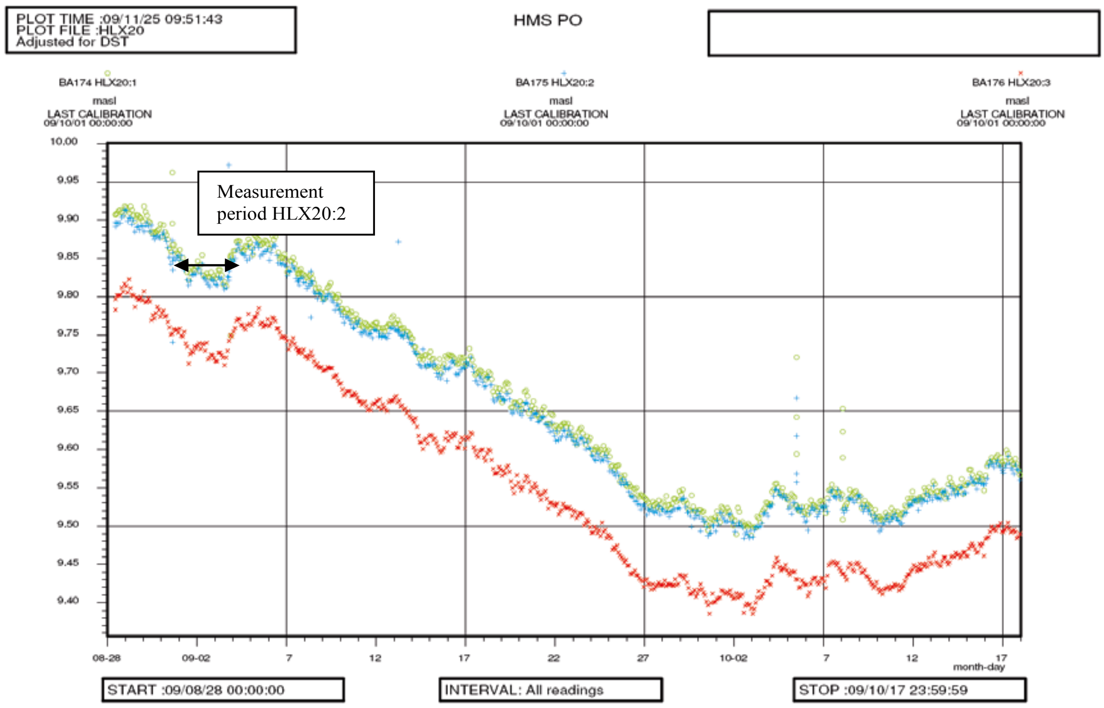
Groundwater levels (metres above sea level)

HLX14



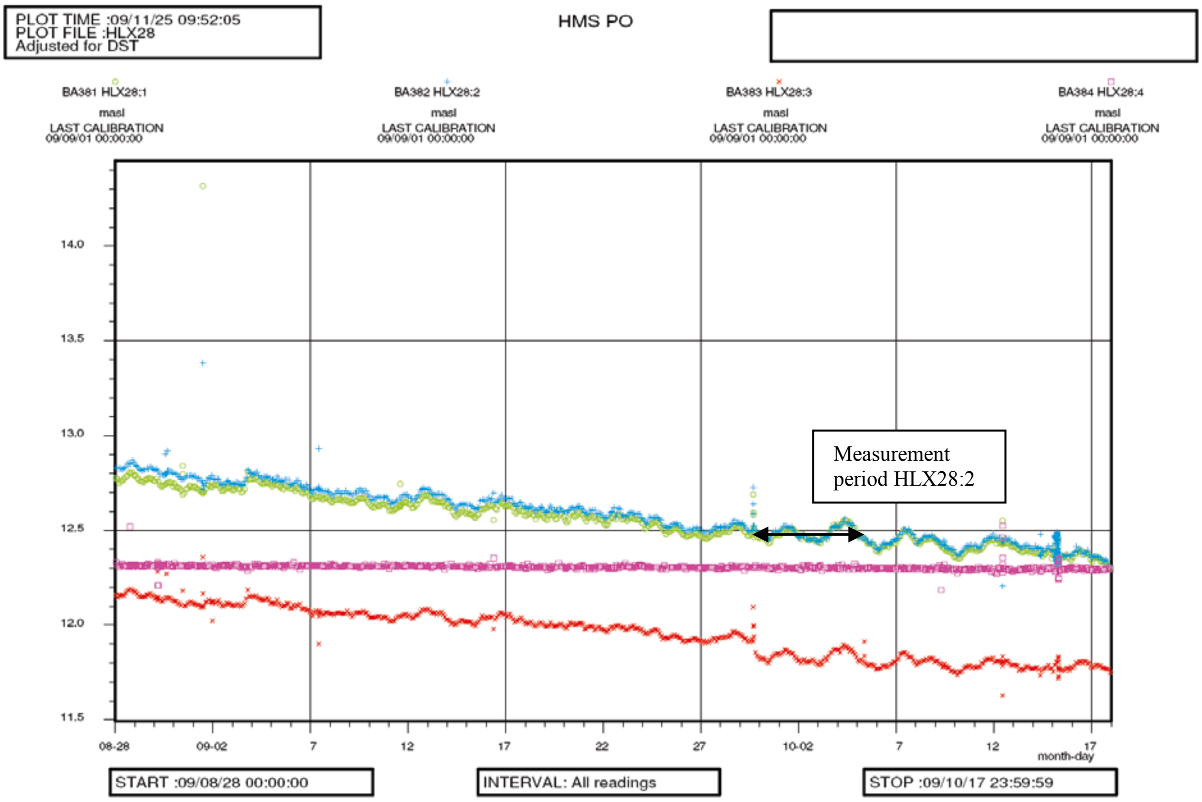
Measured section: HLX14:1 (green)

HLX20



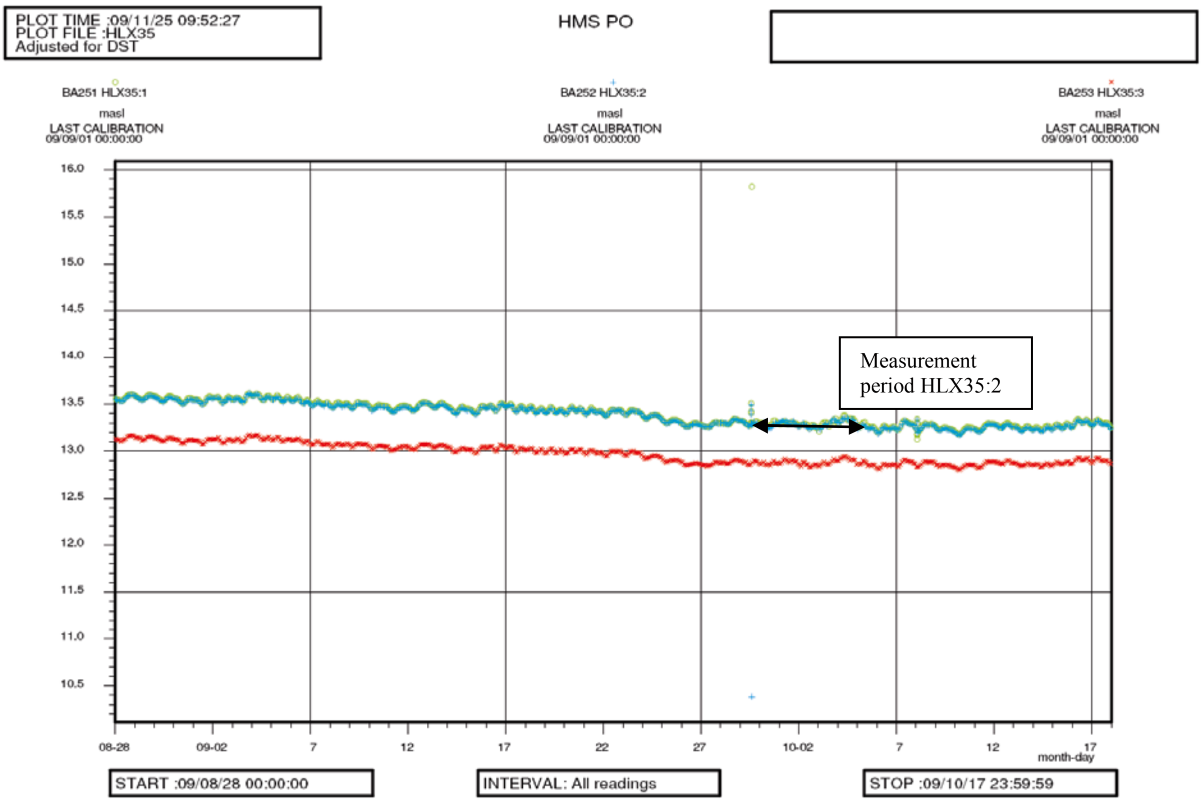
Measured section: HLX20:2 (blue)

HLX28



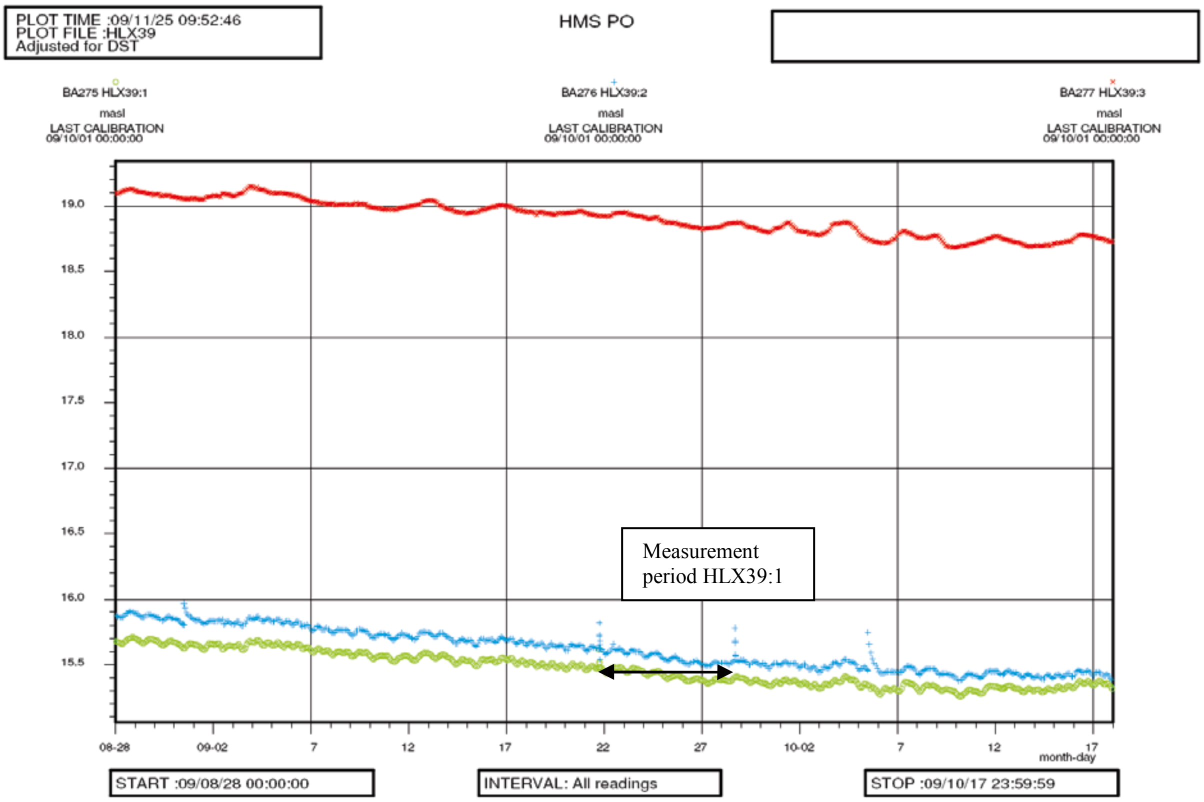
Measured section: HLX28:2 (blue)

HLX35



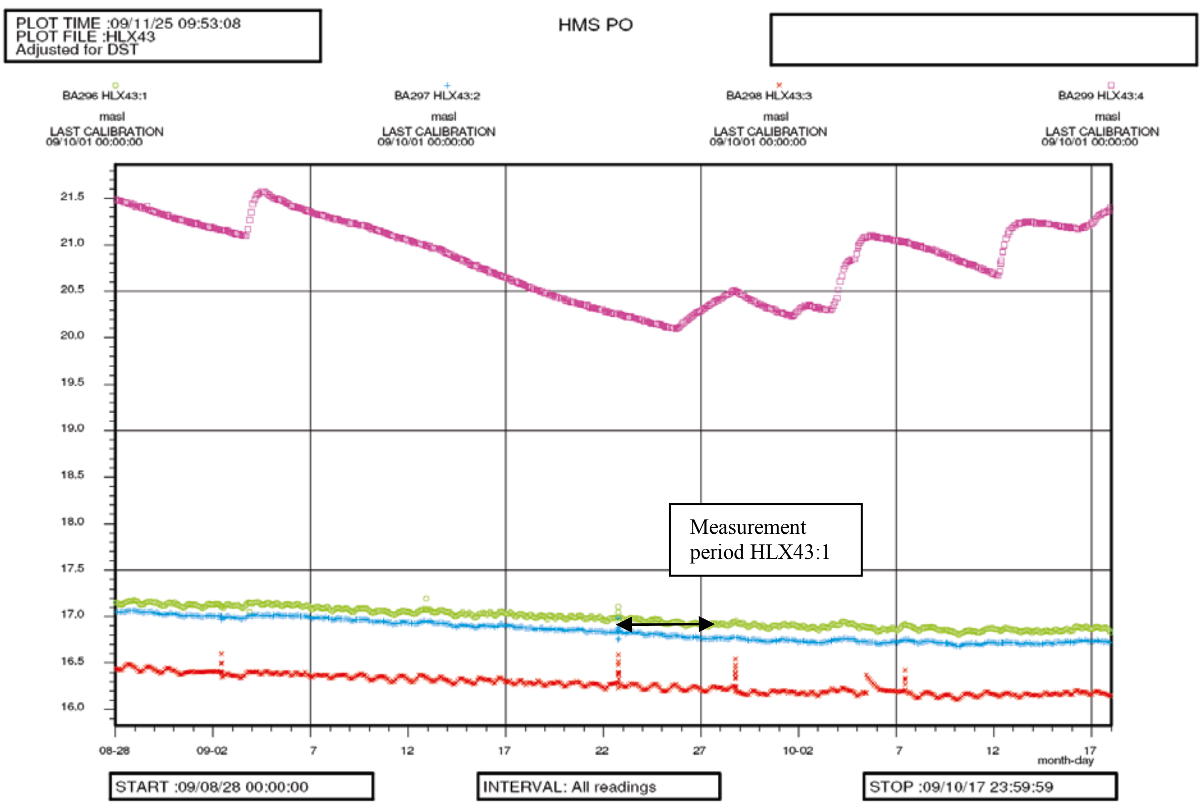
Measured sections: HLX35:2 (blue)

HLX39



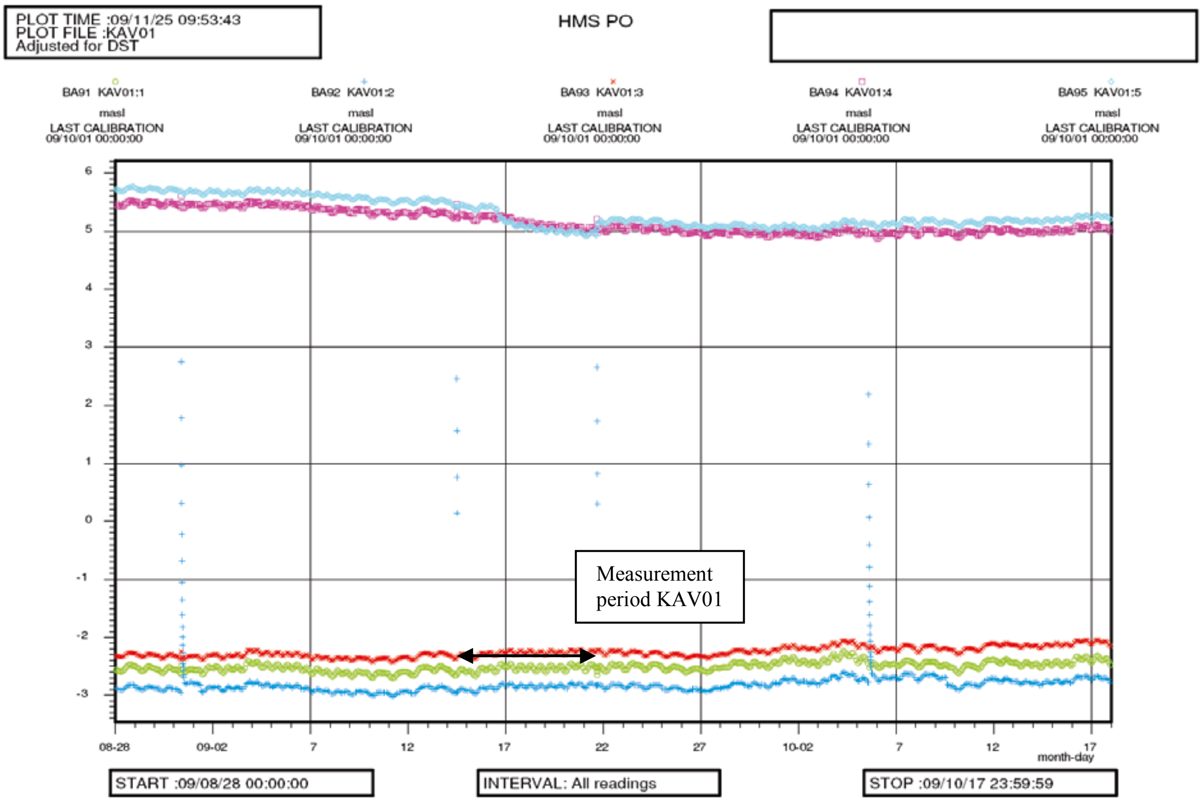
Measured sections: HLX35:2 (green)

HLX43



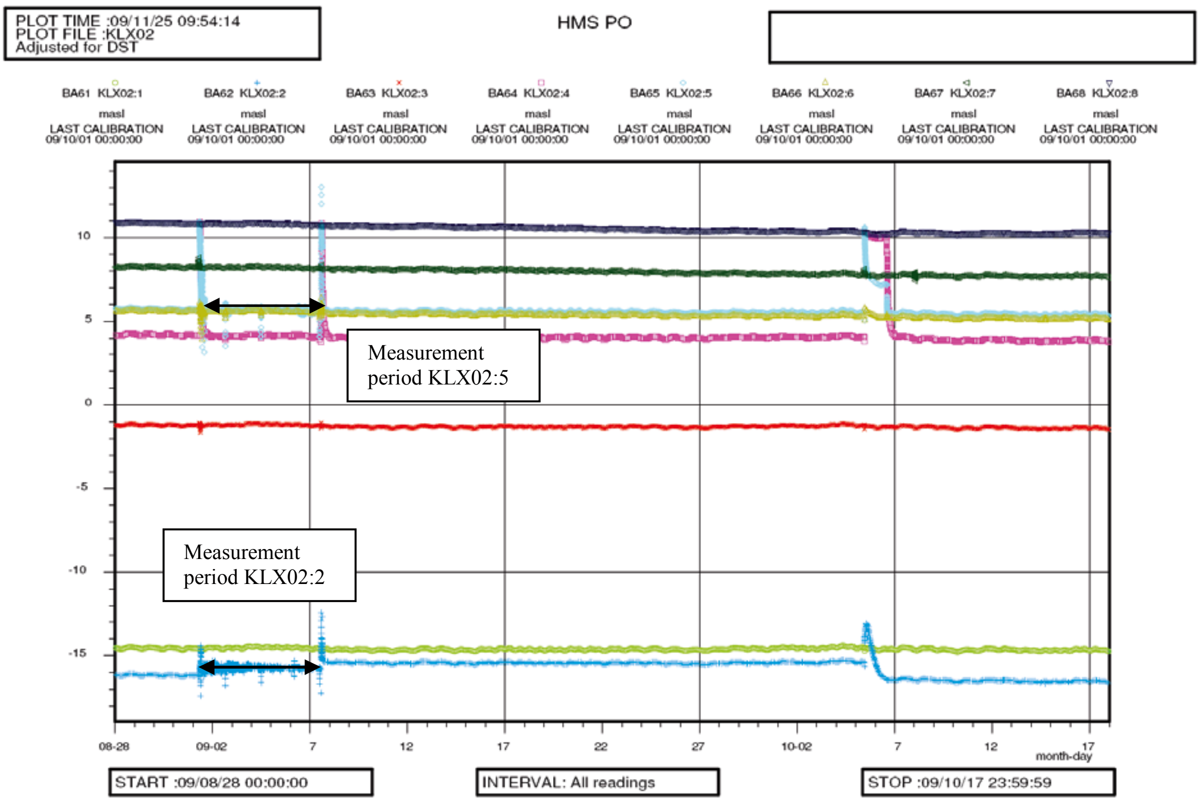
Measured section: HLX43:1 (green)

KAV01



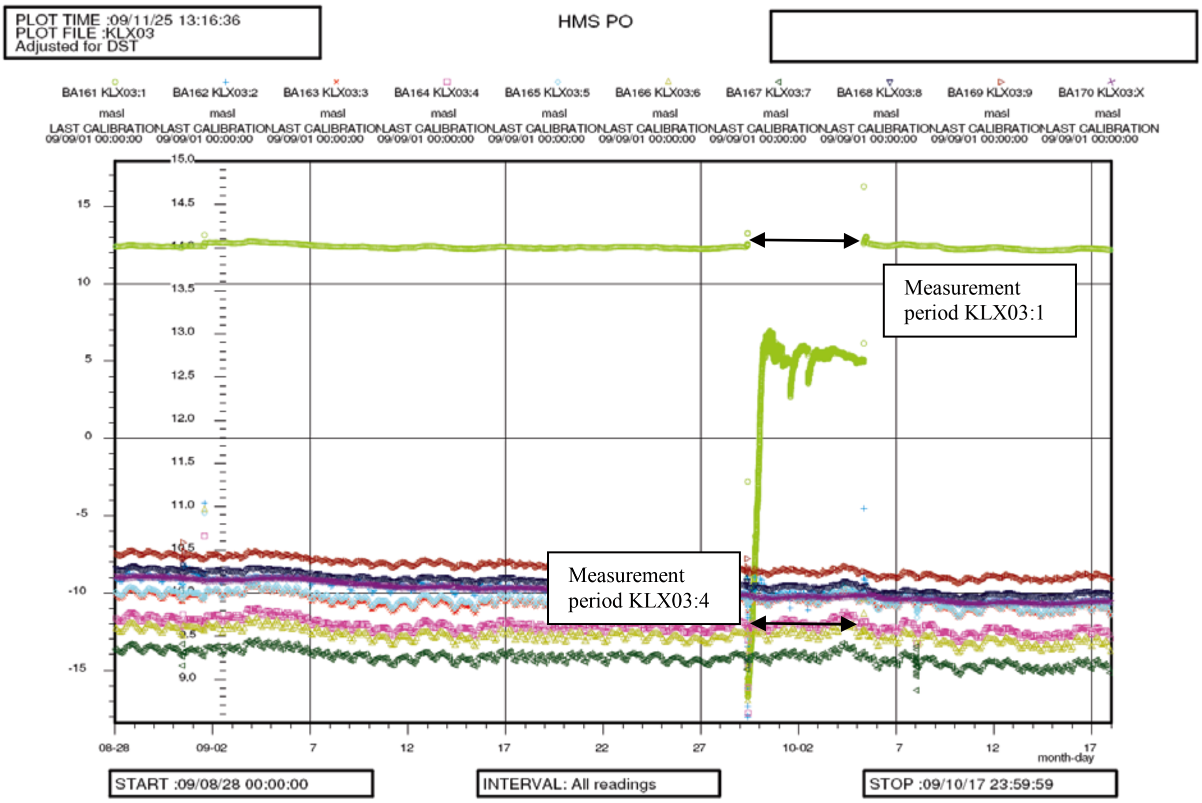
Measured section: KAV01:3 (red)

KLX02



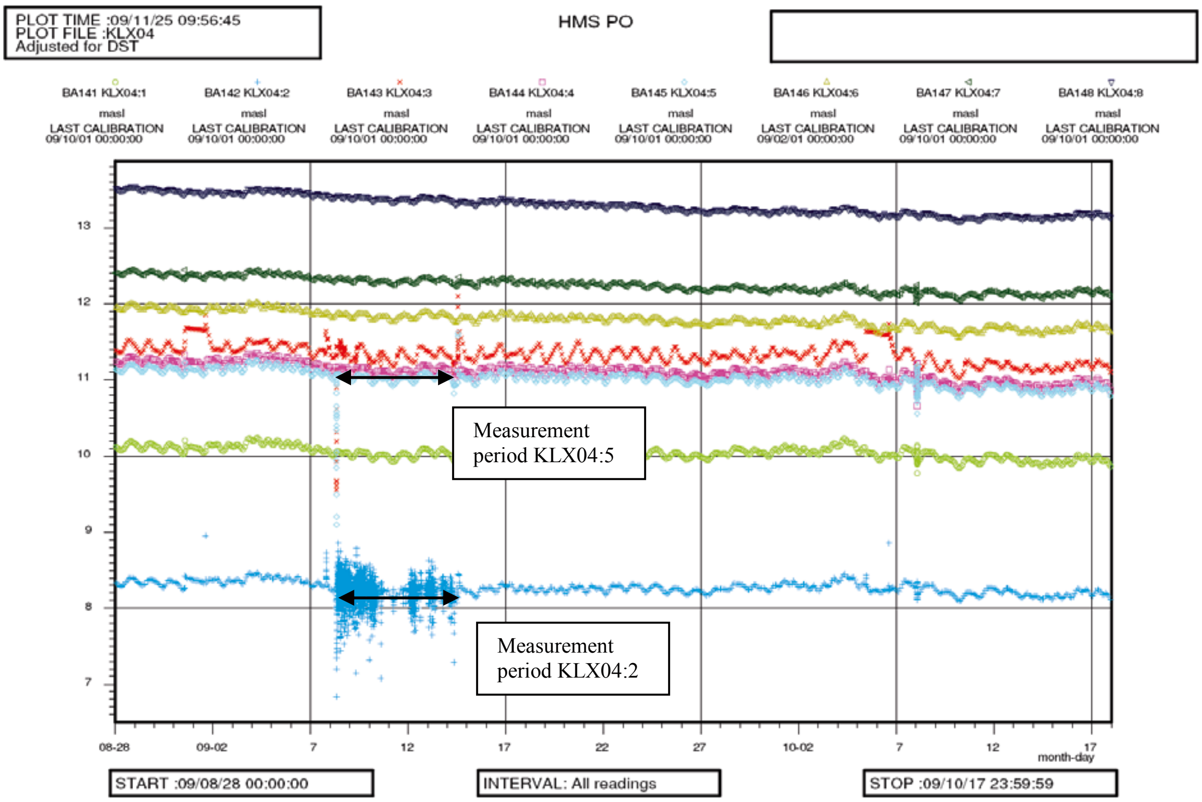
Measured sections: KLX02:2 (blue) and KLX02:5 (turquoise)

KLX03



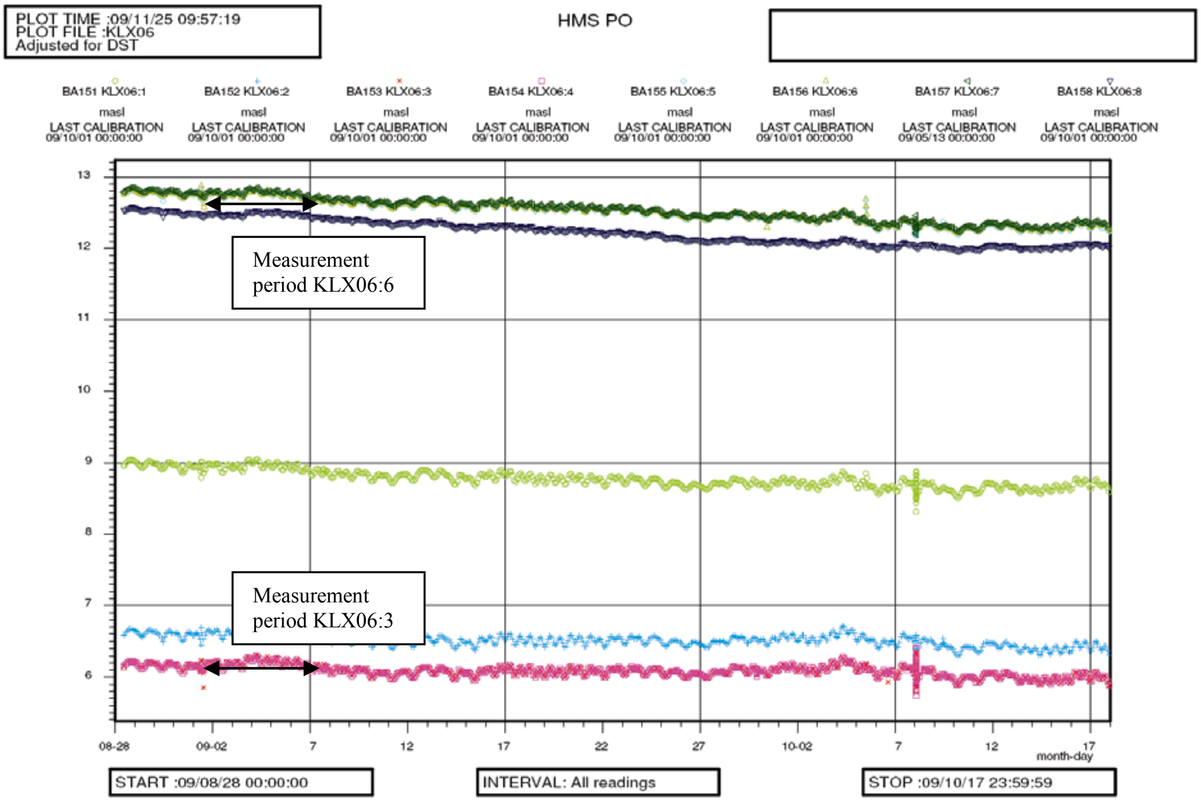
Measured sections: KLX03:1 (green) and KLX03:4 (pink)

KLX04



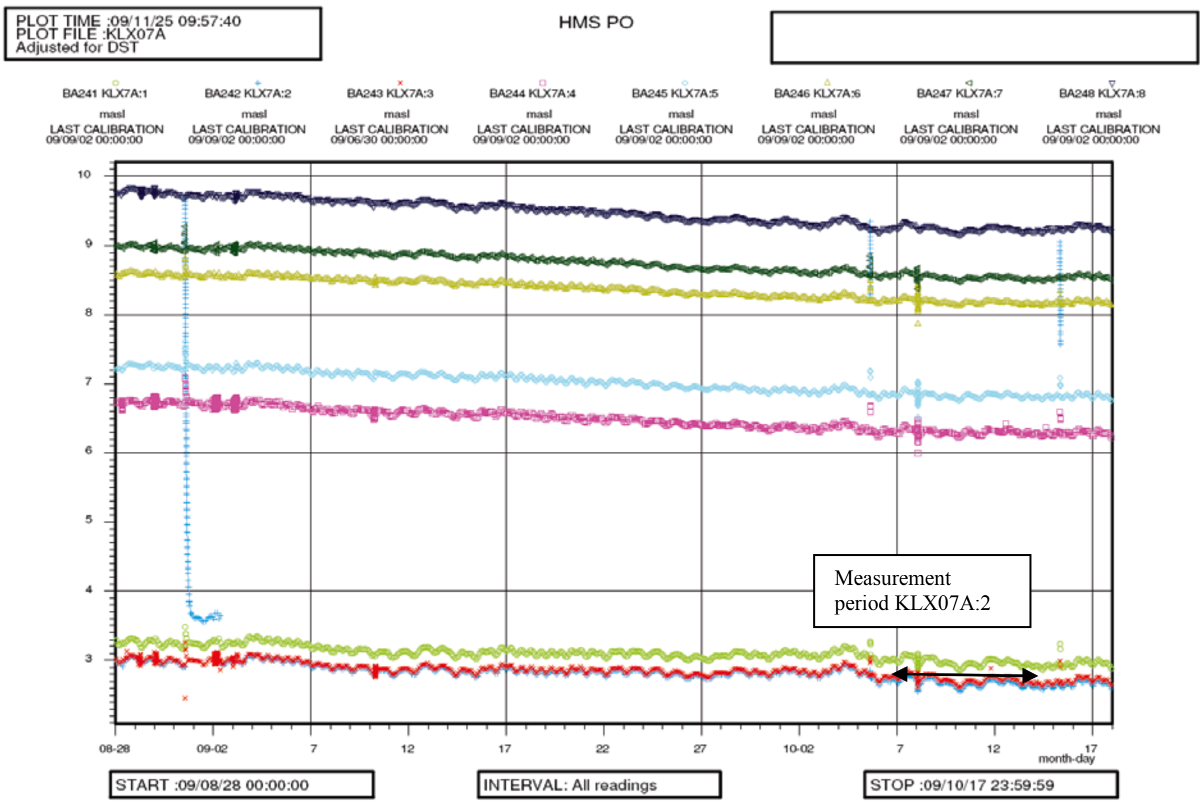
Measured sections: KLX04:2 (blue) and KLX04:5 (turquoise)

KLX06



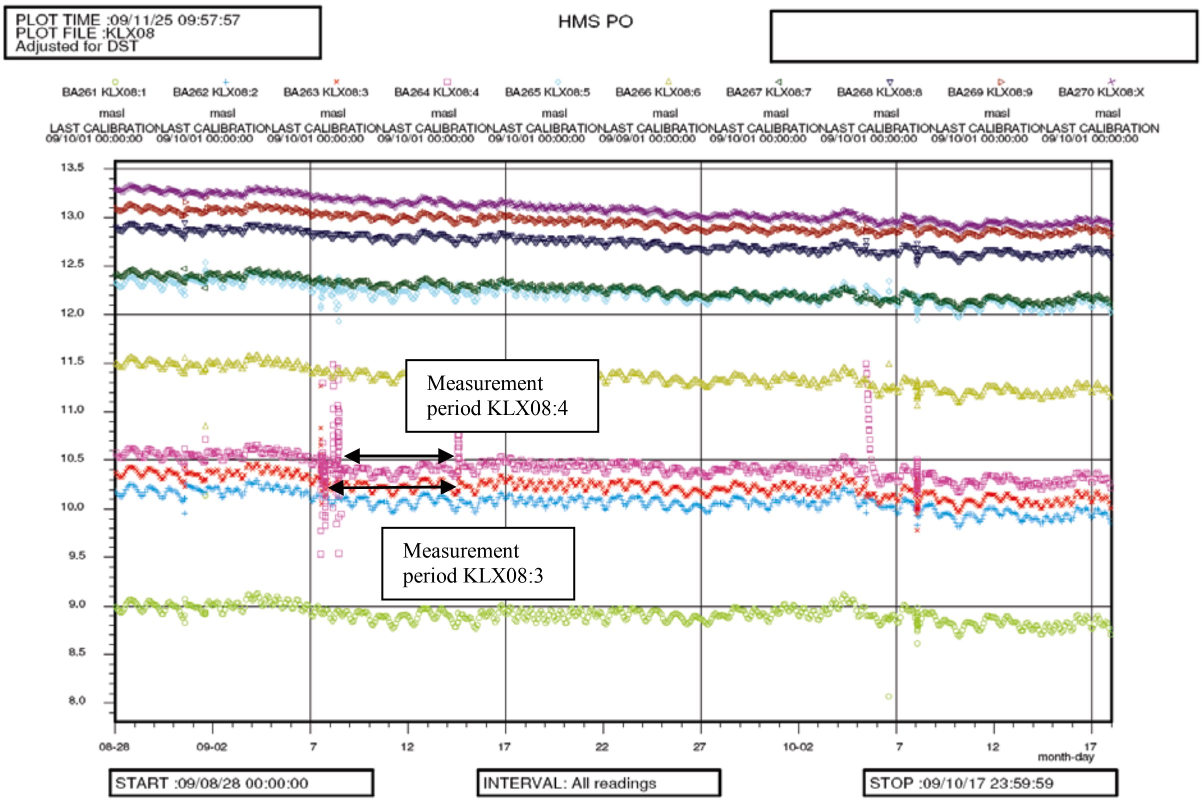
Measured sections: KLX06:3 (red) and KLX06:6 (beige).

KLX07A



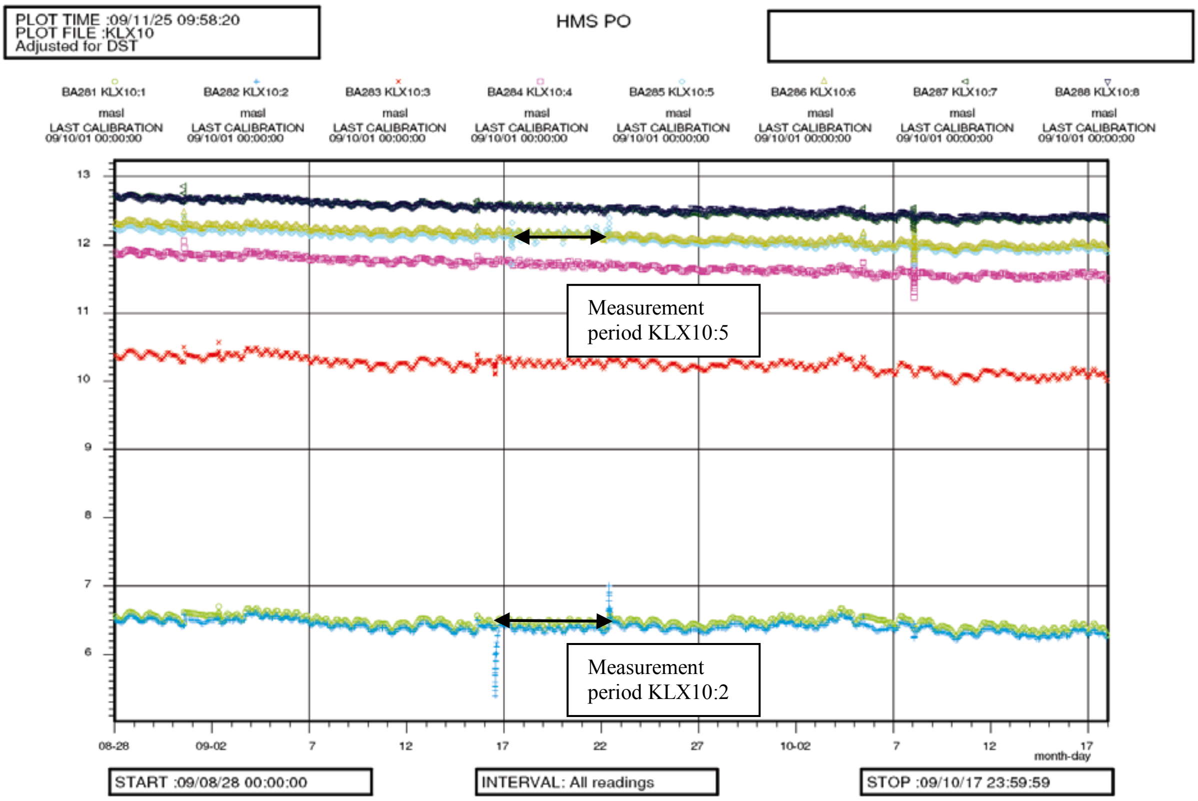
Measured section: KLX07A:2 (blue)

KLX08



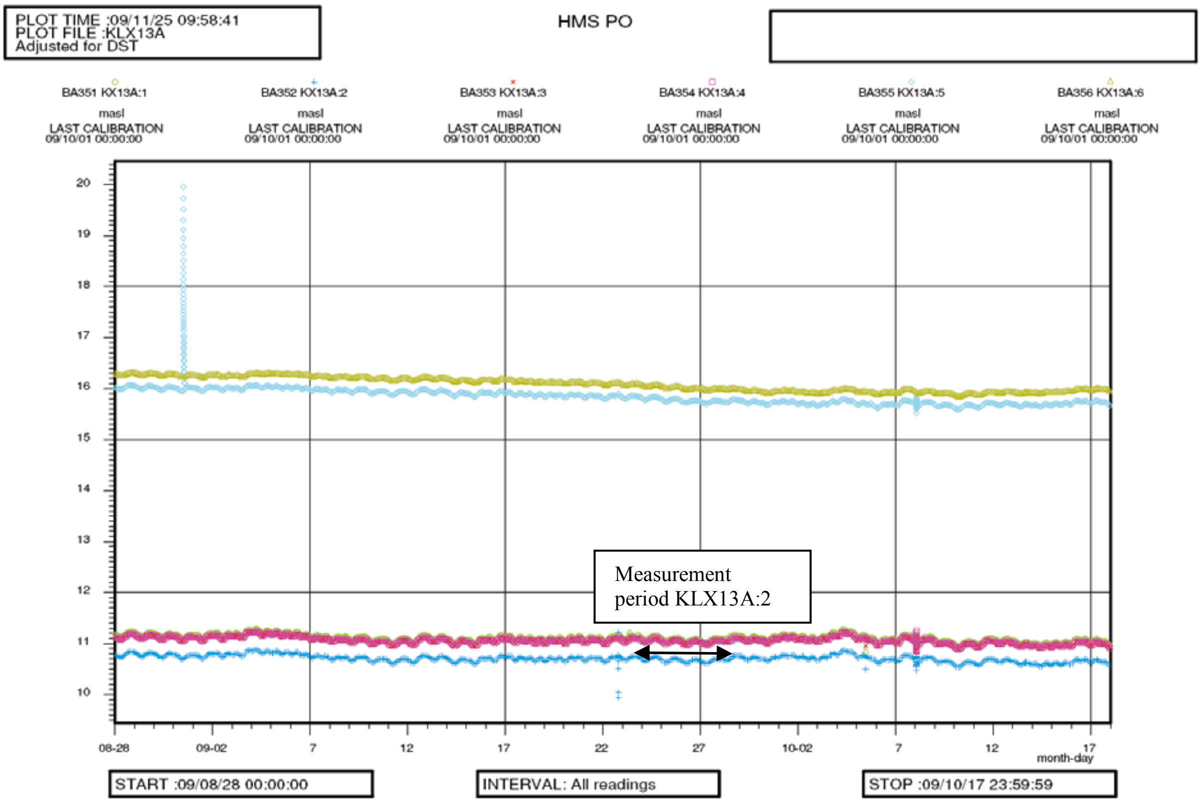
Measured sections: KLX08:3 (red) and KLX08:4 (pink)

KLX10A



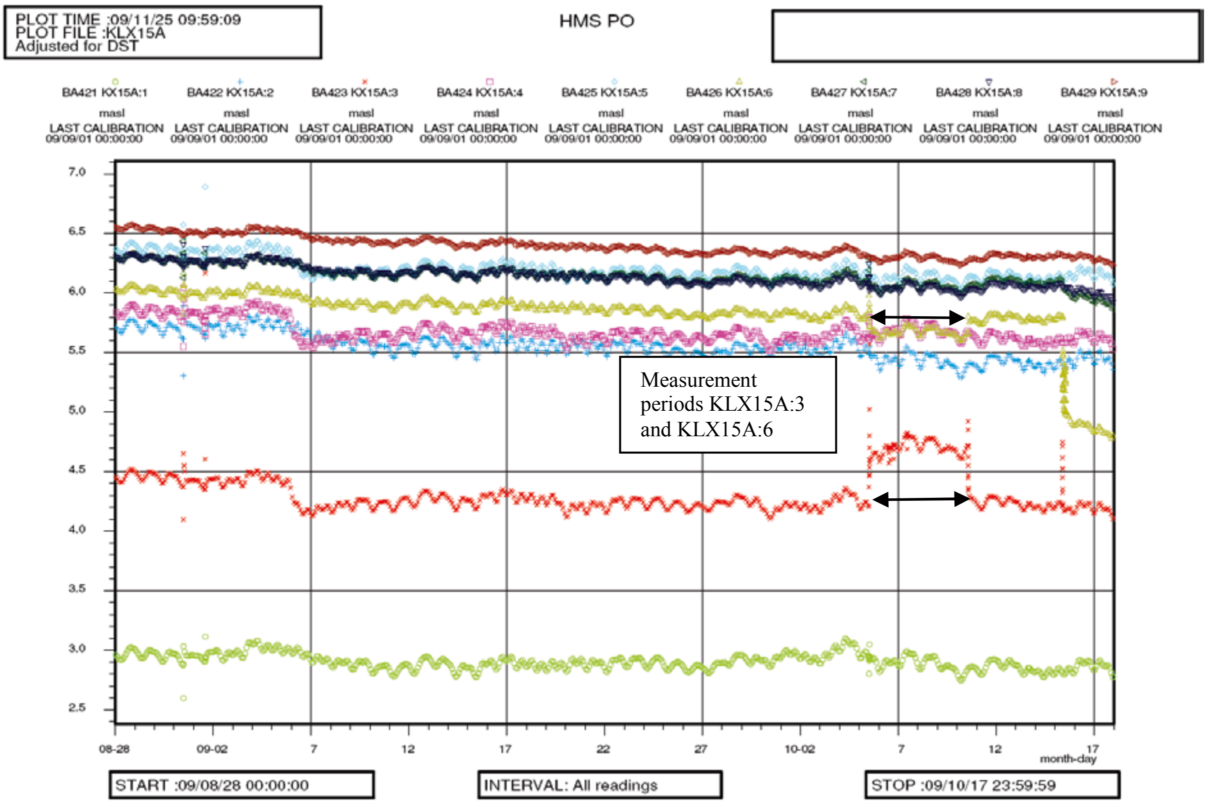
Measured sections: KLX10A:2 (blue) and KLX10A:5 (turquoise)

KLX13A



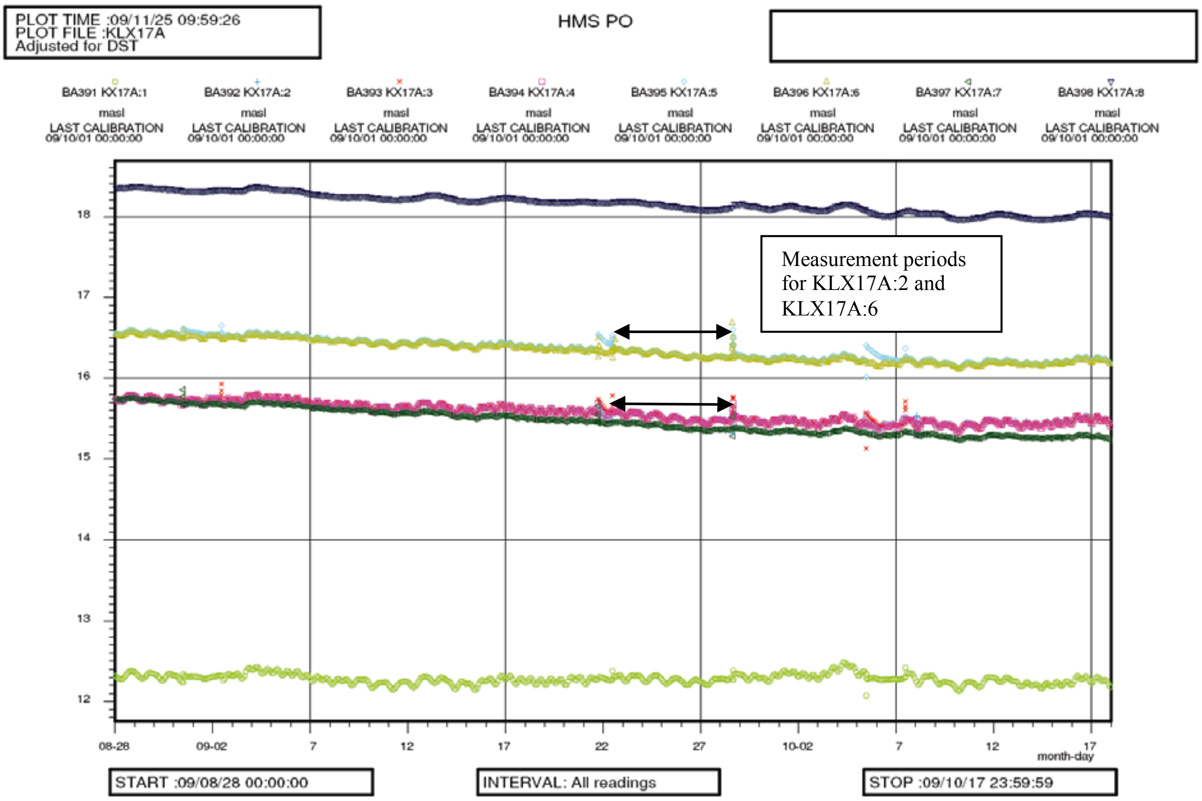
Measured section: KLX13A:2 (blue)

KLX15A



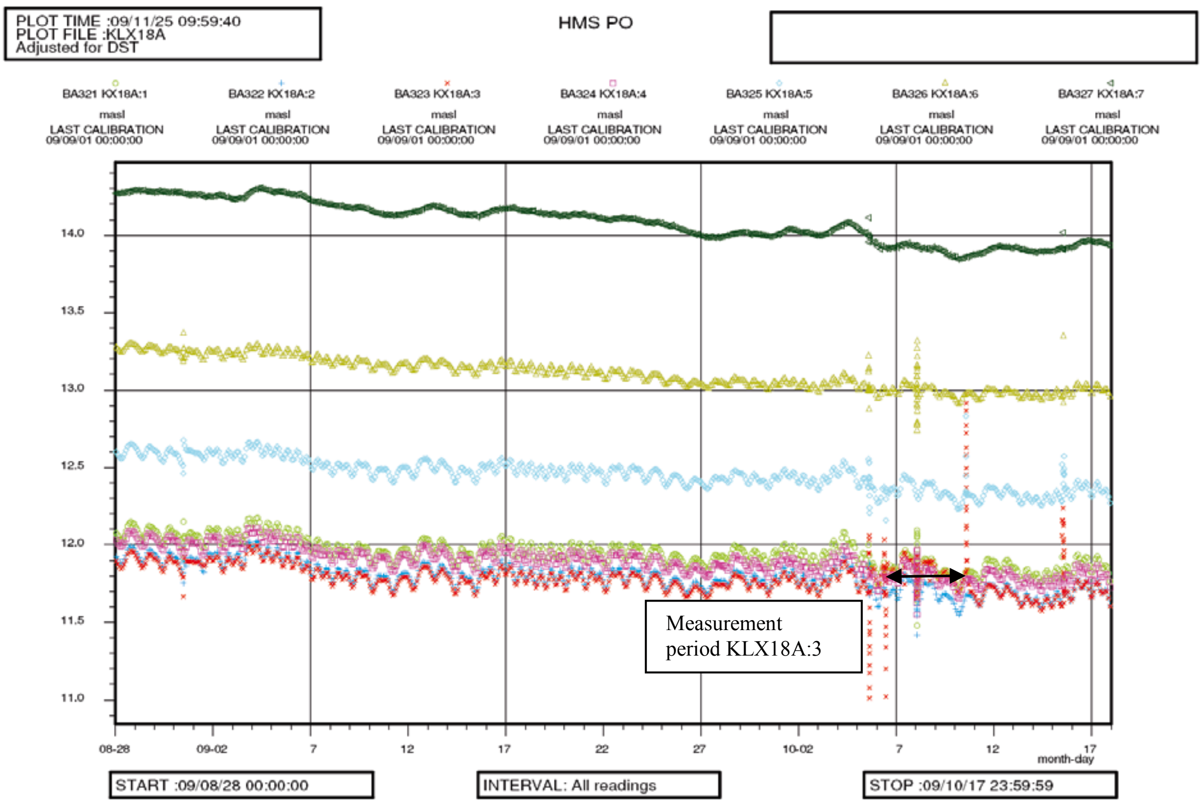
Measured sections: KLX15A:3 (red) and KLX15A:6 (beige)

KLX17A



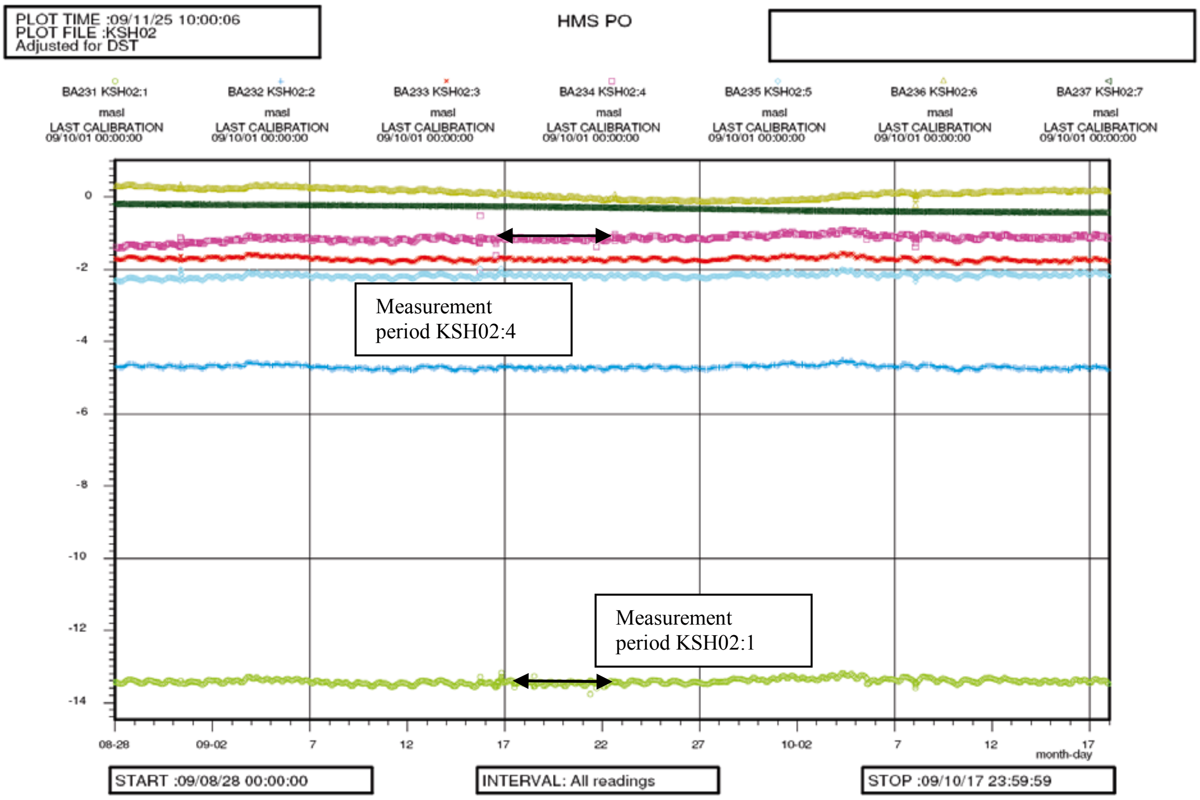
Measured section: KLX17A:2 (blue) and KLX17A:6 (beige)

KLX18A



Measured section: KLX18A:3 (red)

KSH02



Measured sections: KSH02:1 (green) and KSH02:4 (pink).