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Oskarshamn site investigation

Groundwater flow measurements in permanently installed boreholes

Test campaign no. 4, 2008

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Abstract

This report describes the performance and evaluation of measurements of ground water flow in 23 borehole sections in permanently installed boreholes within the site investigation at Oskarshamn. The objective was to determine the groundwater flow in a selection of borehole sections instrumented for this purpose. This is the fourth test campaign performed within the monitoring program and is planned to be repeated once every year.

The groundwater flow in the selected borehole sections was determined through dilution measurements during natural undisturbed conditions. Measured flow rates vary from 0.20 to 170 ml/min in the included sections with calculated Darcy velocities ranging from $1.2\cdot10^{-9}$ to $1.3\cdot10^{-6}$ m/s. Hydraulic gradients are calculated according to the Darcy concept and ranging from 0.001 to 37.

Sammanfattning

Denna rapport beskriver genomförandet och utvärderingen av grundvattenflödesmätningar i 23 borrhålssektioner i permanent installerade borrhål i Oskarshamnsområdet. Syftet var att bestämma grundvattenflödet i ett urval av för ändamålet instrumenterade borrhålssektioner. Denna mätning är den fjärde som genomförts i moniteringsprogrammet och mätningarna är planerade att återupprepas en gång per år.

Grundvattenflödet i de utvalda borrhålssektionerna bestämdes genom utspädningsmätningar under naturliga ostörda förhållanden. Uppmätta grundvattenflöden varierar mellan 0,20 till 170 ml/min i de inkluderade sektionerna, med beräknade Darcy-hastigheter mellan $1{,}2 \cdot 10^{-9}$ till $1{,}3 \cdot 10^{-6}$ m/s. Hydrauliska gradienter beräknades enligt Darcy metoden och varierar mellan 0,001 och 37.

Contents

1 Introduction

This document reports the results gained by the groundwater flow measurements in permanently installed boreholes, test campaign no. 4, 2008, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-08-020. In Table 1-1, controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

The major field work, including 19 sections, was performed in November and December 2008 whereas 4 sections were measured in June 2009. This break was necessary due to a large test pumping performed in the beginning of 2009. A map showing the investigation site at Oskarshamn including 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, 2008	AP PS 400-08-020	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.		

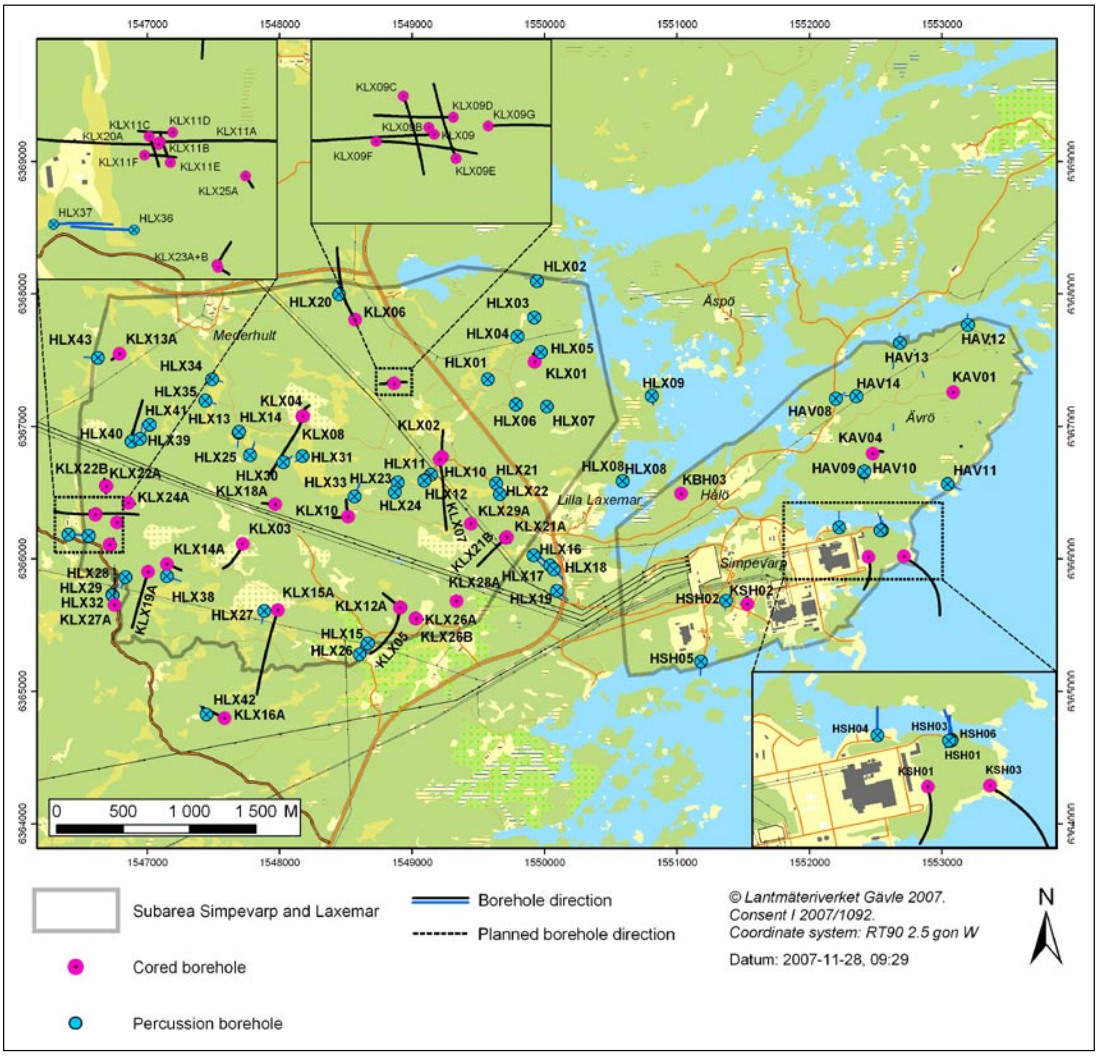


Figure 1-1. General overview over Oskarshamn site investigation area.

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 subarea Laxemar in Oskarshamn site investigation area. A total of 23 instrumented borehole sections (circulation sections) were to be measured in this campaign, c.f. Table 2-1. This was the fourth measuring campaign performed in the monitoring program and it is planned to be repeated once every year.

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

Table 2-1. Borehole sections used for groundwater flow measurements in Oskarshamn, test campaign no. 4, 2008.

Borehole/section	Borehole length (mbl)	Transmissivity (m^2/s)	Measurement period (YYMMDD–YYMMDD)
HLX14:1	96–116	5.7E–05*	081125–081201
HLX20:2	71–80	8.7E–06*	081215–081222
HLX35:2	120–130	2.3E–04*	081202–081209
HLX43:1	135–146	4.6E–05*	081203–081208
KLX01:3	171–190	3.6E–05**	090608–090613
KLX02:2	1,145–1,164	3.2E–07**	081209–081215
KLX02:5	452–494	1.0E–07**	081209–081215
KLX03:1	965–971	4.5E–07***	081203–081208
KLX03:4	729–751	4.7E–06***	081202–081208
KLX05:7	241–255	1.9E–06***	090608–090613
KLX07A:2	753–780	9.3E–06***	081209–081215
KLX08:3	626–683	5.8E–07***	081215–081222
KLX08:4	594–625	3.8E–07***	081215–081222
KLX10A:2	689–710	4.4E–08***	081125–081202
KLX10A:5	351–368	7.6E–07***	081125–081201
KLX12A:2	535–545	1.3E–07***	090608–090613
KLX13A:2	490–507	3.8E–07***	081216–081222
KLX15A:3	623–640	9.0E–07***	081124–081202
KLX15A:6	260–272	3.7E–06***	081124–081202
KLX17A:2	419–434	1.5E–05***	081208–081215
KLX17A:6	180–219	1.1E–06***	081208–081215
KLX18A:3	472–489	5.4E–08***	081215–081222
KLX21B:3	558–572	5.0E–07***	090608–090613

* From flow logging /1, 2/.

** From injection tests /3, 4/.

*** From differential flow logging /5–15/.

3 Equipment

The boreholes involved in the tests are instrumented with one to eight packers making up two to nine isolated 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 planned to be used 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 an internal circulation in the borehole section. The circulation makes it possible to obtain a homogeneous tracer concentration in the borehole section. This 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 by a down-hole pump with variable speed and measured by 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.

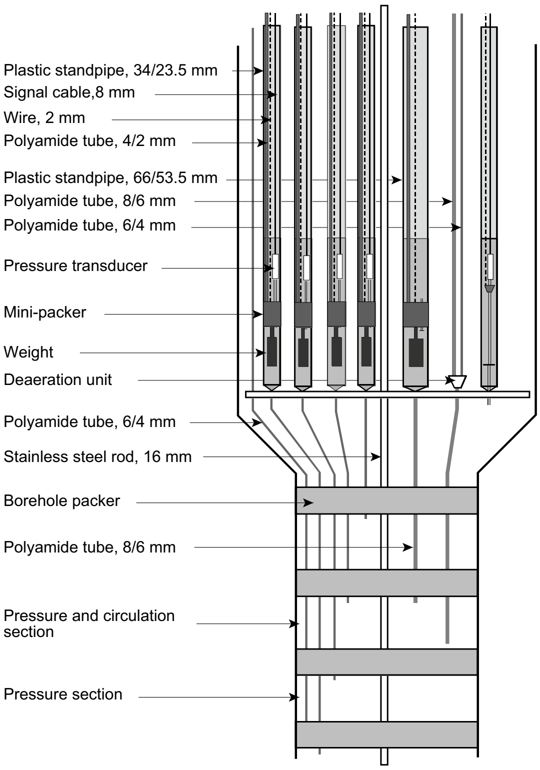


Figure 3-1. *An example of a permanently instrumented core borehole, including one circulation section.*

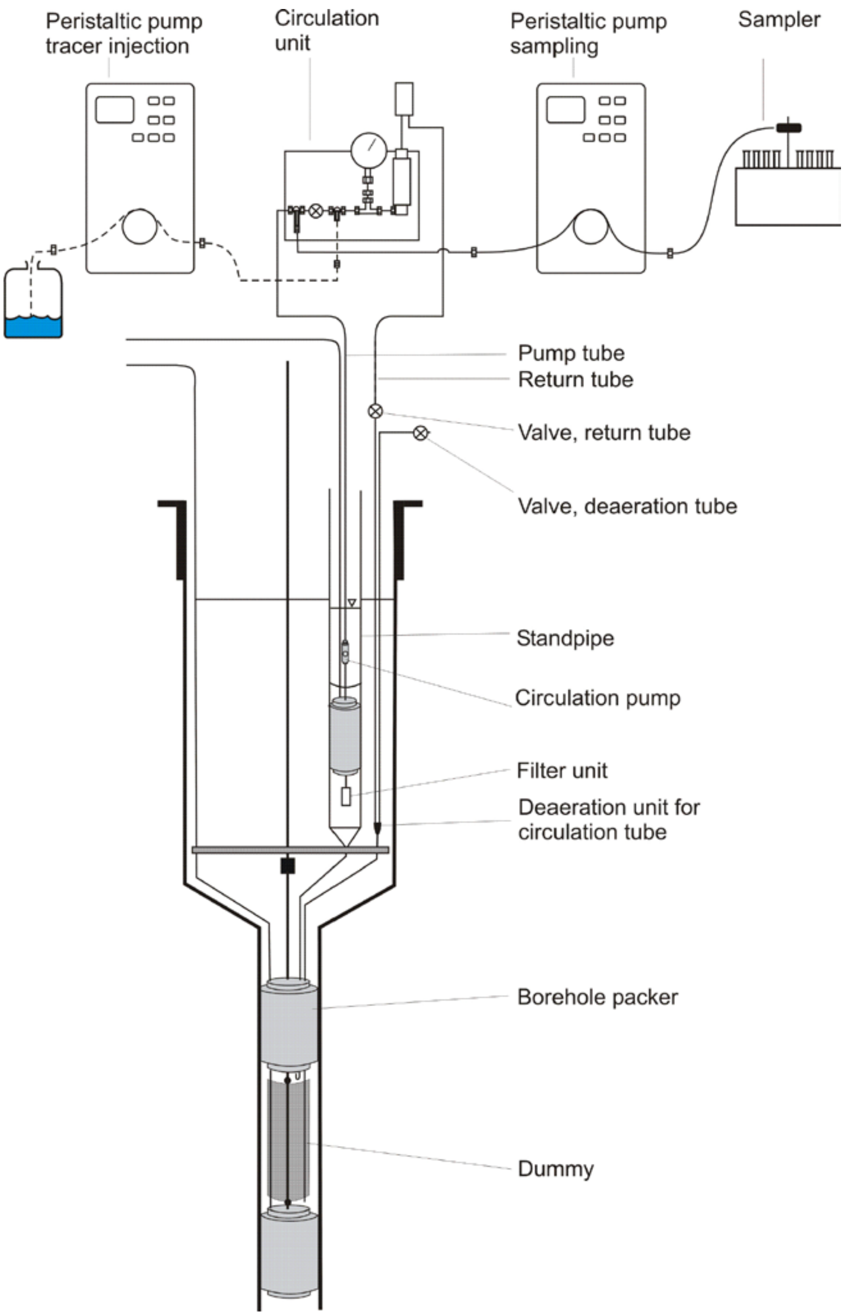


Figure 3-2. *Schematic drawing of the equipment used in tracer dilution measurements.*

4 Execution

4.1 General

In the dilution method a tracer is introduced and homogeneously distributed into a borehole test section. The tracer is subsequently diluted by the ambient groundwater flowing through the section. The dilution of the tracer is proportional to the water flow through the borehole section the groundwater flow is calculated as a function of 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 (1,000 mg/l) was mixed and the field equipment was functionality checked and calibrated.

4.3 Execution of field work

Tracer dilution tests were performed in 23 borehole sections 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 measured as a part of a long-term pumping test (LPT) and some were excluded for other reasons (low priority).

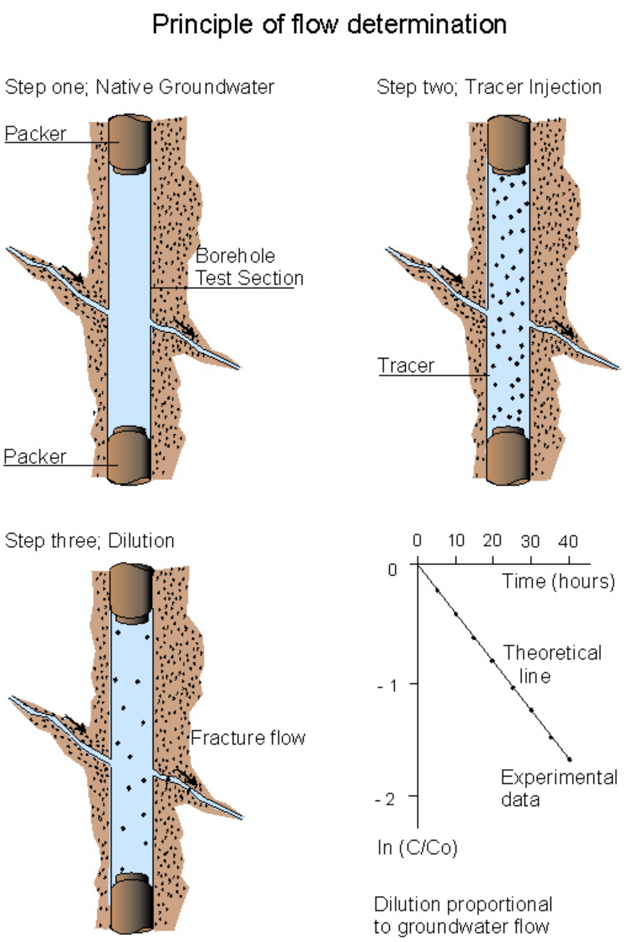


Figure 4-1. General principles of dilution and flow determination.

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

Borehole/ section	Borehole length (mbl)	No of fractures*	Geologic character (DZ= Deformation Zone)**	Comments
HLX14:1	96–116	–	Zone EW007A	
HLX20:2	71–80	–	Zone EW002A	
HLX28:2	70–90	–	Zone HLX28_DZ1	Not instrumented
HLX32:2	20–30	–	Zone NW042A	Measured during LPT
HLX35:2	120–130	–	Zone EW007A	
HLX37:1	150–200	–	Zone NS001C	Measured during LPT
HLX38:3	28–40	–	Zone NS059A	Measured during LPT
HLX39:1	187–199	–	Zone EW900B	Not prioritised
HLX43:1	135–146	–	Possible DZ	
KAV01:3	391–434	30	Zone NE012A	Not prioritised
KLX01:3	171–190	–	Possible DZ	
KLX02:2	1,145–1,164	–	Possible DZ	
KLX02:5	452–494	4	Possible DZ	
KLX03:1	965–971	2	Possible DZ	
KLX03:4	729–751	6	Zone EW946A	
KLX04:2	870–897	2	Zone NW928A	Not prioritised
KLX04:5	507–530	2	Fracture domain FSM_EW007	Not prioritised
KLX05:3	625–633	1	Single fracture FSM_NE005	Not possible to circulate
KLX05:7	241–255	4	FZM_NE005	
KLX06:3	554–570	2	No DZ	Not prioritised
KLX06:6	256–275	9	Zone NW052A	Not prioritised
KLX07A:2	753–780	15	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	Zone EW946A	
KLX10A:5	351–368	10	Fracture domain FSM_EW007	
KLX11A:3	573–586	7	Fracture domain FSM_W	Measured during LPT
KLX11A:7	256–272	4	Fracture domain FSM_W	Measured durinfg LPT
KLX12A:2	535–545	3	Fracture domain FSM_NE005	
KLX13A:2	490–507	8	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	Zone EW900B	
KLX18A:3	472–489	8	Fracture domain FSM_C	
KLX19A:3	509–517	6	Zone KLX19A_DZ5-8 dolerite	Measured during LPT
KLX20A:2	260–296	17	Fracture domain FSM_W	Measured during LPT
KLX20A:5	103–144	22	Fracture domain FSM_W	Measured during LPT
KLX21B:3	558–572	2	Zone KLX21B_DZ10–12	
KLX27A:1	640–651	3	Fracture domain FSM_W	Measured during LPT
KLX27A:6	220–259	7	Zone NW042A	Measured during LPT
KSH01A:4	532–572	9	Possible DZ	Not prioritised
KSH01A:7	238–277	12	Possible DZ	Not prioritised
KSH02:1	955–963	1	Single fracture, no DZ	Not prioritised
KSH02:4	411–439	5	No DZ	Not prioritised

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

** Geologic interpretation from /16/.

The tests were made by injecting a slug of tracer (Amino-G 1,000 mg/l) in the selected borehole section with an adjusted injection flow during the time it takes to circulate one section volume. The injection flow rate was set to get a starting concentration of approximately 1 mg/l in the borehole section. Using the equipment described in Chapter 3 the tracer solution in the borehole section was continuously circulated and sampled allowing the natural groundwater flow to dilute the tracer. Circulation was maintained during the test and the sampler was set up to change tubes every two hours.

4.4 Analyses and interpretations

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 versus time through dilution with natural unlabelled groundwater. The so-called "dilution curves" were plotted as the natural logarithm of concentration versus time c.f. /17/. Theoretically, a straight-line relationship exists between the natural logarithm of the relative tracer concentration (c/c_0) and time (t):

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

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

The sampling procedure with a constant flow of approximately 0.1 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:

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

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 are roughly estimated from Darcy's law where the gradient I is calculated as the function of the Darcy velocity v with the conductivity K:

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

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 mostly is heterogeneous and the angles in the sections not always 90º the calculation of the hydraulic gradient is a rough estimation.

4.5 Nonconformities

- The mobile electric power stations run by diesel affected the frequency of the sampler. When the sampler was set up to change tubes every 120 minutes the changing time for the tubes varied between approximately 114 and 124 minutes depending on the power station. This was compensated for in the evaluation.
- Due to other activities in the area such as the large-scale pumping test (LPT) and groundwater chemistry sampling, the measurements were paused from December 2008 till June 2009.
- Section HLX39:1, originally listed to be measured according to the activity plan, was not measured. An extensive pumping in the area, as mentioned above, was judged to affect the hydraulic conditions of the section significantly.
- Section KLX05:3, originally listed to be measured according to the activity plan, was not measured due to technical problems. This section is no longer included in the monitoring program.
- Power failure caused interrupted sampling in KLX08 after approximately 40 hours due to fuel shortage in the power station. The power was back after approximately 5 hours and this short stop 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 400-08-020). 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 23 borehole sections during natural conditions. The calculated groundwater flow rate together with transmissivity and volume gives the Darcy velocity and hydraulic gradient for the section as an additional result, see Table 5-1.

A comparison between test campaign no. 1, 2005 /18/, test campaign no. 2, 2006 /19/, test campaign no. 3, 2007 /20/ and test campaign no. 4, 2008 is shown in Table 5-2. Four of the sections in this campaign have not been measured before, hence no comparison is possible. In some sections the flow rate is decreasing over time, some is increasing and some remain unchanged. These results and trends are displayed in Figures 5-1 to 5-6.

The groundwater flow rate in the borehole section is calculated from the slope of the straight-line fit. The results show that the groundwater flow during natural undisturbed conditions varies from 0.20 to 170 ml/min in the measured sections with Darcy velocities ranging from $1.2 \cdot 10^{-9}$ to $1.3 \cdot 10^{-6}$ m/s. Hydraulic gradients are calculated according to the Darcy concept and ranging from 0.001 to 37. In Figure 5-7 an example of a typical tracer dilution curve is shown.

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 between 0.874 and 0.999 for 18 of 23 borehole sections. For five borehole sections it varies between 0.348 and 0.797. Scattered data in KLX02:2 and KLX03:1 gives low regression coefficients. This may be explained by low ground water flow in deep sections implying that mixing takes quite a long time. These values are therefore considered as uncertain.

Groundwater levels in connection with the test period are shown for the selected boreholes in Appendix 2. The groundwater levels are generally stable during the measurement period, with the exception of KLX03:1 where the groundwater level is decreasing during the dilution. This adds to the uncertainty of the result in this section.

Table 5-1. Results from groundwater flow measurements in permanent installed boreholes test campaign no. 4, 2008.

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*	8.50E+04	11	3.4E-08	0.012
HLX20:2	71–80	8.7E–06*	2.95E+04	0.29	1.9E-09	0.0020
HLX35:2	120–130	2.3E–04*	3.85E+04	71	4.2E-07	0.018
HLX43:1	135–146	4.6E–05*	4.28E+04	0.73	4.0E-09	0.00094
KLX01:3	171–190	3.6E–05**	3.49E+04	5.0	2.9E-08	0.015
KLX02:2	1,145–1,164	3.2E–07**	9.06E+04	0.20	1.2E-09	0.070
KLX02:5	452–494	1.0E–07**	7.02E+04	3.1	8.0E-09	3.4
KLX03:1	965–971	4.5E–07***	6.56E+04	0.77	1.5E-08	0.19
KLX03:4	729–751	4.7E–06***	6.66E+04	1.7	8.7E-09	0.041
KLX05:7	241–55	1.9E–06***	3.00E+04	14	1.1E-07	0.80
KLX07A:2	753–780	9.3E–06***	7.70E+04	17	7.5E-08	0.20
KLX08:3	626–683	5.8E–07***	1.03E+05	3.5	6.6E-09	0.65
KLX08:4	594–625	3.8E–07***	6.84E+04	0.54	1.9E-09	0.16
KLX10A:2	689–710	4.4E–08***	6.66E+04	0.27	1.4E-09	0.68
KLX10A:5	351–368	7.6E–07***	3.99E+04	13	8.2E-08	1.8
KLX12A:2	535–545	1.3E–07***	4.57E+04	0.60	6.5E-09	0.50
KLX13A:2	490–507	3.8E–07***	5.12E+04	0.62	4.0E-09	0.18
KLX15A:3	623–640	9.0E–07***	5.76E+04	44	2.9E-07	5.4
KLX15A:6	260–272	3.7E–06***	2.94E+04	30	2.8E-07	0.90
KLX17A:2	419–434	1.5E–05***	4.49E+04	5.6	4.1E-08	0.041
KLX17A:6	180–219	1.1E–06***	5.08E+04	0.65	1.8E-09	0.065
KLX18A:3	472–489	5.4E–08***	4.93E+04	15	1.0E-07	31
KLX21B:3	558–572	5.0E–07***	5.12E+04	170	1.3E-06	36

* From flow loggings /1–2/.

** From injection tests /3–4/.

*** From differential flow logging /5–15/.

Table 5-2. Results from groundwater flow measurements in permanent installed boreholes. Comparison between test campaign no. 1, 2005, no. 2, 2006, no. 3, 2007 and no. 4, 2008.

Borehole/ section	Measured flow (ml/min)				Darcy velocity (m/s)				Hydraulic gradient			
	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008
HLX14:1				11				3.4E-08				0.012
HLX20:2			0.57	0.29			3.8E-09	1.9E-09			0.004	0.002
HLX27:1			2.6				1.3E-08				0.004	
HLX28:2			11				3.4E-08				0.002	
HLX32:2*			15	8.3			8.7E-08	4.9E-08			0.13	0.071
HLX35:2			73	71			4.4E-07	4.2E-07			0.019	0.019
HLX37:1*				2.5				3.0E-09				0.003
HLX37:3			1.2				4.8E-09				0.008	
HLX38:3*				4.6				2.3E-08				0.005
HLX39:1			1.4				7.1E-09				0.001	
HLX43:1			83	0.7			4.5E-07	4.0E-09			0.11	0.001
KAV01:3	61	42	68		2.1E-07	1.4E-07	1.7E-07		0.59	0.39	0.48	
KLX01:3	5.9	4.1	4.8	4.9	3.4E-08	2.4E-08	2.8E-08	2.9E-08	0.018	0.013	0.015	0.015
KLX02:2	2.1	0.77	0.72	0.20	1.2E-08	4.4E-09	4.1E-09	1.2E-09	0.71	0.26	0.24	0.071
KLX02:5	3.1	2.5	1.6	3.1	8.0E-09	6.6E-09	4.2E-09	8.0E-09	3.4	2.8	1.8	3.4
KLX03:1		0.93	0.20	0.77		1.7E-08	3.7E-09	1.4E-08		0.23	0.049	0.19
KLX03:4		0.65	0.40	1.7		3.2E-09	2.0E-09	8.7E-09		0.015	0.009	0.041
KLX04:2	0.73	0.70	0.57		3.0E-09	2.8E-09	2.3E-09		0.58	0.54	0.45	
KLX04:5	0.67	0.55	0.70		3.2E-09	2.6E-09	3.4E-09		0.036	0.029	0.038	
KLX05:3		0.25				3.4E-09				5.0		
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		6.1E-09	5.4E-09	5.6E-09		0.019	0.016	0.017	
KLX06:6	2.2	2.0	1.7		1.3E-08	1.2E-08	9.7E-09		0.012	0.011	0.009	
KLX07A:2		18	19	17		7.2E-08	7.9E-08	6.9E-08		0.21	0.23	0.20
KLX08:3			26	3.4			5.0E-08	6.6E-09			4.9	0.65
KLX08:4			0.75	0.54			2.7E-09	1.9E-09			0.22	0.15
KLX10A:2		2.2	0.60	0.27		1.2E-08	3.1E-09	1.4E-09		5.7	1.5	0.66
KLX10A:5		18	19	13		1.2E-07	1.2E-07	8.2E-08		2.7	2.7	1.8
KLX11A:3*			3.1	2.6			2.7E-08	2.2E-08			0.023	0.019
KLX11A:7*			0.67	0.70			4.6E-09	4.8E-09			0.003	0.003
KLX12A:2			0.17	0.60			1.8E-09	6.5E-09			0.14	0.52
KLX13A:2				0.62				4.0E-09				0.18
KLX15A:3			18	44			1.2E-07	2.9E-07			2.3	5.5
KLX15A:6			3.0	30			2.7E-08	2.8E-07			0.087	0.90
KLX17A:2				5.6				4.1E-08				0.040
KLX17A:5				0.65				1.8E-09				0.066
KLX18A:3			0.28	15			1.9E-09	1.0E-07			0.59	31
KLX19A:3*			1.2	0.61			1.6E-08	8.3E-09			0.13	0.065
KLX20A:2*			0.70	0.69			2.1E-09	2.3E-09			0.037	0.037
KLX20A:5*			4.2	6.3			1.1E-08	1.7E-08			0.055	0.085
KLX21B:3				170				1.3E-06				36
KLX27A:1*				0.3				3.1E-09				0.010
KLX27A:6*				4.2				1.2E-08				1.16
KSH01A:4	9.0	7.3	4.6		2.5E-08	2.0E-08	1.2E-08		2.9	2.3	1.4	
KSH01A:7	1.9	2.0	1.5		5.3E-09	5.6E-09	4.4E-09		0.13	0.14	0.11	
KSH02:1	0.8	0.55	0.10		1.1E-08	7.6E-09	1.3E-09		0.16	0.11	0.019	
KSH02:4	0.7	0.33	0.18		2.6E-09	1.3E-09	6.9E-10		0.065	0.032	0.017	

*Results for 2008 from groundwater flow measurements made during large scale pumping test in HLX28, /21/.

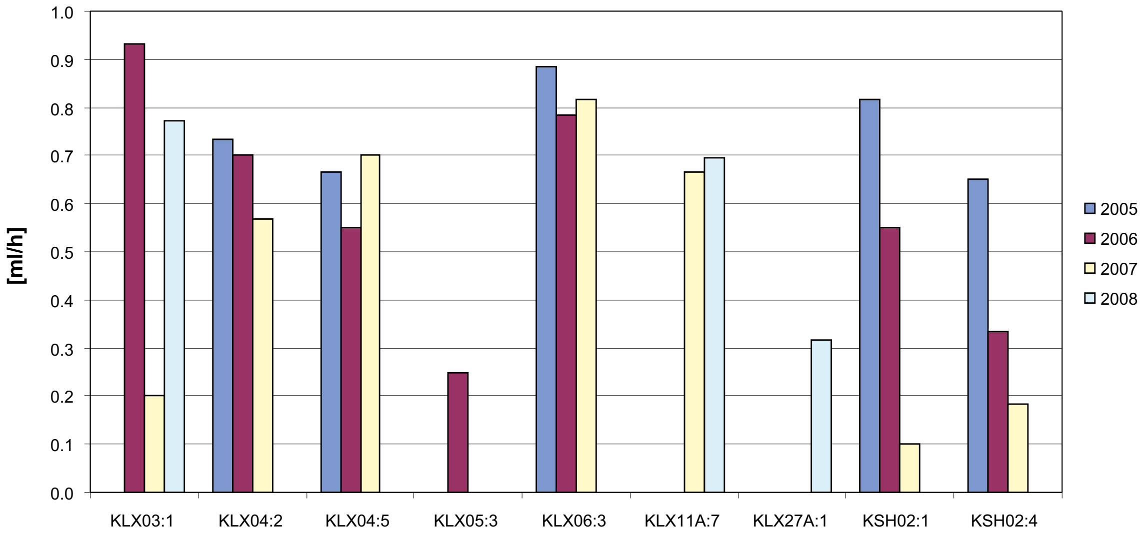


Figure 5-1. *Comparison of flow rates determined from all measurement campaigns performed for borehole sections having flow rates in the range 0.066–0.93 ml/min.*

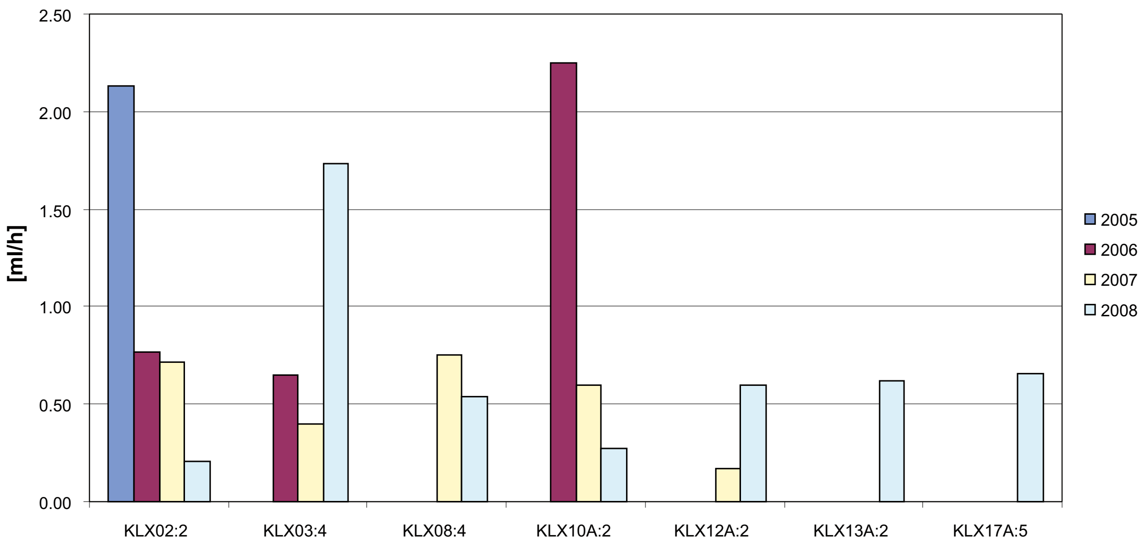


Figure 5-2. *Comparison of flow rates determined from all measurement campaigns performed for borehole sections having flow rates in the range 0.17–2.3 ml/min.*

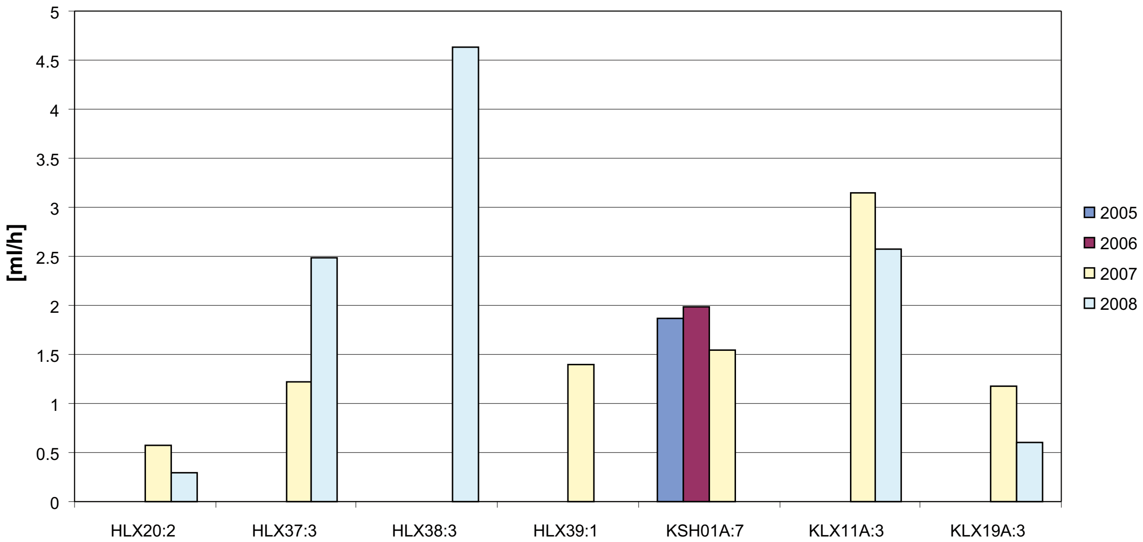


Figure 5-3. *Comparison of flow rates determined from all measurement campaigns performed for borehole sections having flow rates in the range 0.29–4.6 ml/min.*

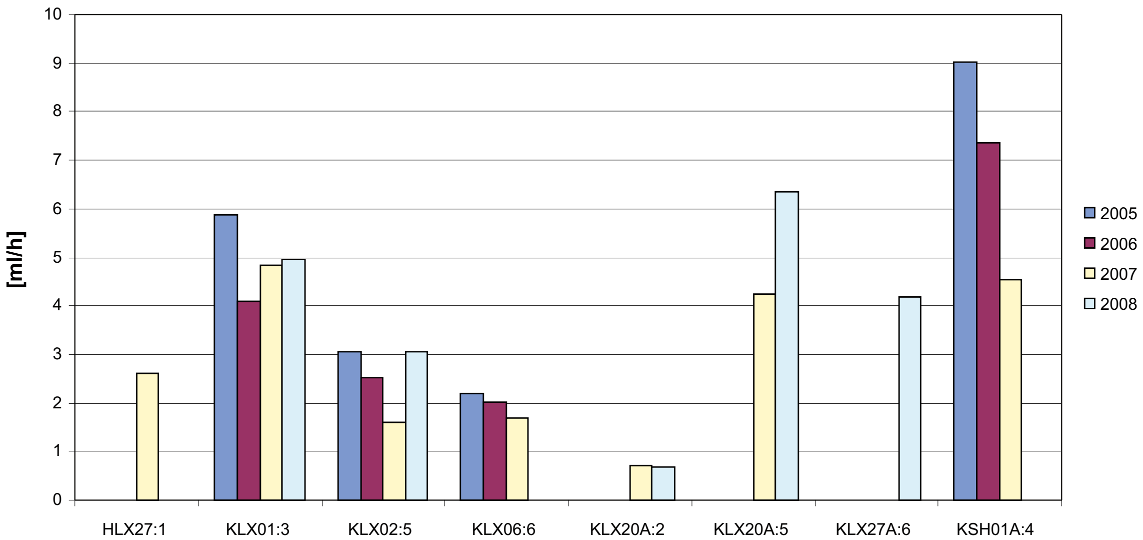


Figure 5-4. *Comparison of flow rates determined from all measurement campaigns performed for borehole sections having flow rates in the range 0.70–9.0 ml/min.*

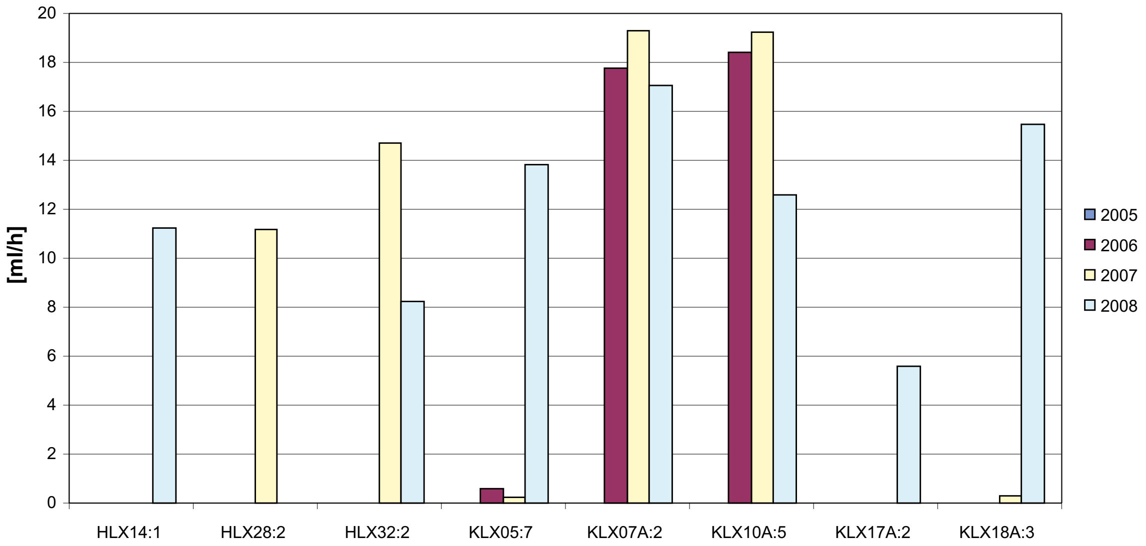


Figure 5-5. *Comparison of flow rates determined from all measurement campaigns performed for borehole sections having flow rates in the range 0.22–19 ml/min.*

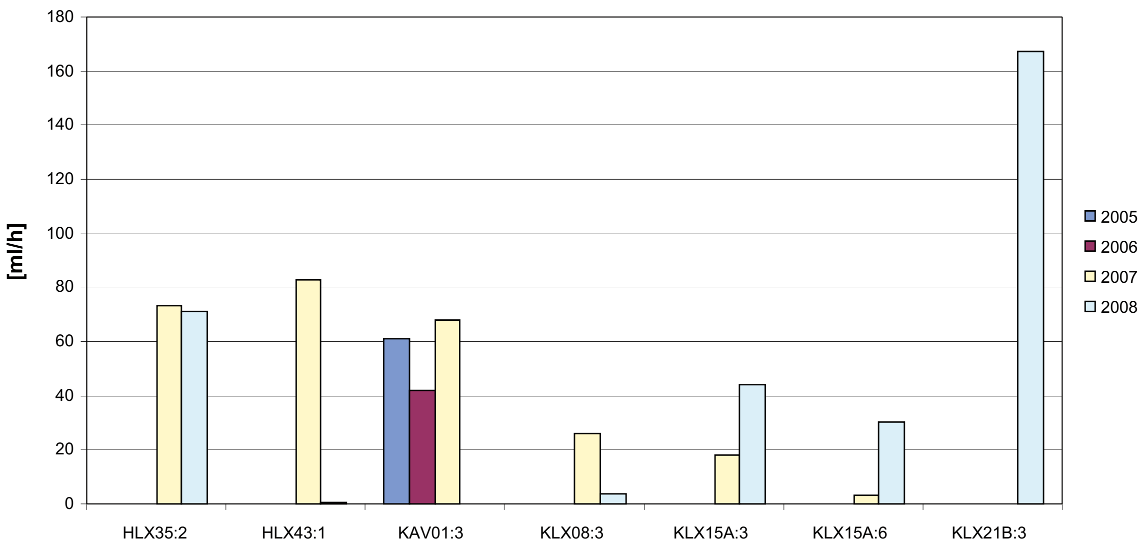


Figure 5-6. *Comparison of flow rates determined from all measurement campaigns performed for borehole sections having flow rates in the range 3.0–167 ml/min.*

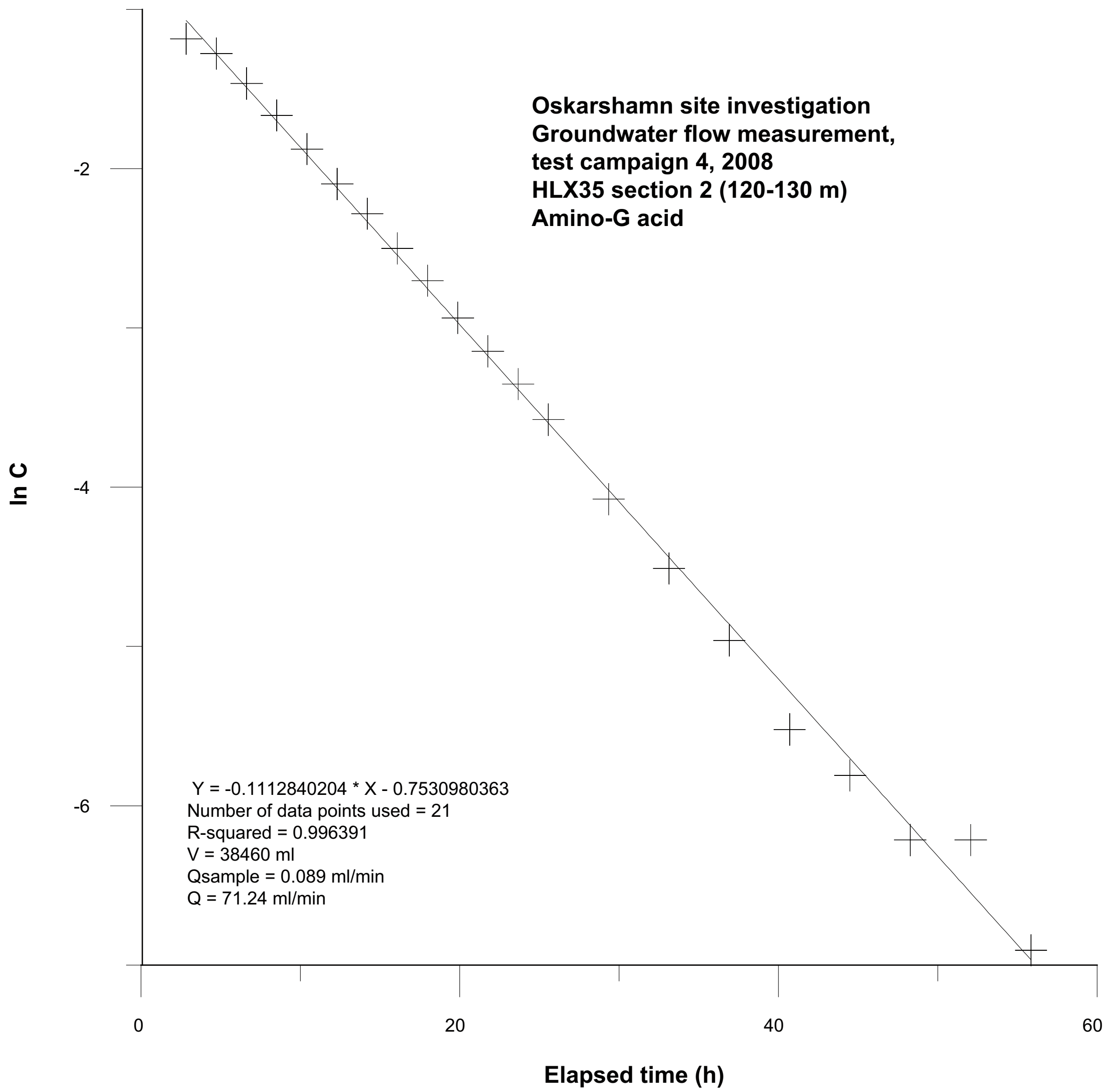


Figure 5-7. *Example of a tracer dilution graph for borehole HLX35:2, including straight-line fit.*

6 References

/1/ **Rohs S, van der Wall R, Wolf P, 2007.** Flow logging in boreholes HLX14, HLX20, HLX27, HLX28, HLX32, HLX33, HLX37, HLX39 and HLX43 Subarea Laxemar. Oskarshamn site investigation. SKB P-06-319. Svensk Kärnbränslehantering AB.

/2/ **Rohs S, 2006.** Flow logging in boreholes HLX21, HLX35 and HLX38, Subarea Laxemar. Oskarshamn site investigation. SKB P-06-147. Svensk Kärnbränslehantering AB.

/3/ **Nilsson L, 1989.** Hydraulic tests at Äspö and Laxemar, evaluation. SKB PR 25-88-14. Svensk Kärnbränslehantering AB.

/4/ **Rahm N, Enachescu C, 2004.** Hydraulic injection tests in borehole KLX02, 2003. Sub-area Laxemar. Oskarshamn site investigation. SKB P-04-288. Svensk Kärnbränslehantering AB.

/5/ **Rouhiainen P, Pöllänen J, Sokolnicki M, 2005.** Difference flow logging of borehole KLX03. Subarea Laxemar. Oskarshamn site investigation. SKB P-05-67. Svensk Kärnbränslehantering AB.

/6/ **Sokolnicki M, Rouhiainen P, 2005.** Difference flow logging of borehole KLX05. Subarea Laxemar. Oskarshamn site investigation. SKB P-05-160. Svensk Kärnbränslehantering AB.

/7/ **Sokolnicki M, Rouhiainen P, 2005.** Difference flow logging of boreholes KLX07A and KLX07B. Subarea Laxemar. Oskarshamn site investigation. SKB P-05-225. Svensk Kärnbränslehantering AB.

/8/ **Sokolnicki M, Pöölänen J, 2005.** Difference flow logging of borehole KLX08. Subarea Laxemar. Oskarshamn site investigation. SKB P-05-267. Svensk Kärnbränslehantering AB.

/9/ **Sokolnicki M, 2007.** Difference flow logging of borehole KLX10. Subarea Laxemar. Oskarshamn site investigation. SKB P-06-58. Svensk Kärnbränslehantering AB.

/10/ **Väisäsvaara J, Heikkinen P, Kristiansson S, Pöllänen J, 2006.** Difference flow logging of borehole KLX12. Subarea Laxemar. Oskarshamn site investigation. SKB P-06-185. Svensk Kärnbränslehantering AB.

/11/ **Väisäsvaara J, Pekkanen J, 2007.** Difference flow logging of borehole KLX13A. Subarea Laxemar. Oskarshamn site investigation. SKB P-06-245. Svensk Kärnbränslehantering AB.

/12/ **Pöölänen J, Sokolnicki M, Väisäsvaara J, 2007.** Difference flow logging of borehole KLX15A. Subarea Laxemar. Oskarshamn site investigation. SKB P-07-176. Svensk Kärnbränslehantering AB.

/13/ **Pöölänen J, Kristiansson S, 2007.** Difference flow logging of borehole KLX17A. Subarea Laxemar. Oskarshamn site investigation. SKB P-07-34. Svensk Kärnbränslehantering AB.

/14/ **Sokolnicki M, Kristiansson S, 2006.** Difference flow logging of borehole KLX18A. Subarea Laxemar. Oskarshamn site investigation. SKB P-06-184 Svensk Kärnbränslehantering AB.

/15/ **Sokolnicki M, Pöölänen J, 2007.** Difference flow logging of borehole KLX21B. Subarea Laxemar. Oskarshamn site investigation. SKB P-07-116 Svensk Kärnbränslehantering AB.

/16/ **Hermanson J, Fox A, Öhman J, Rhén I, 2008.** Compilation of data used for the analysis of the geological and hydrogeological DFN models. Site descriptive modelling SDM-Site Laxemar. SKB R-08-56. Svensk Kärnbränslehantering AB.

/17/ **Gustafsson E, 2002.** Bestämning av grundvattenflödet med utspädningsteknik – Modifiering av utrustning och kompletterande mätningar. SKB R-02-31 (in Swedish). Svensk Kärnbränslehantering AB.

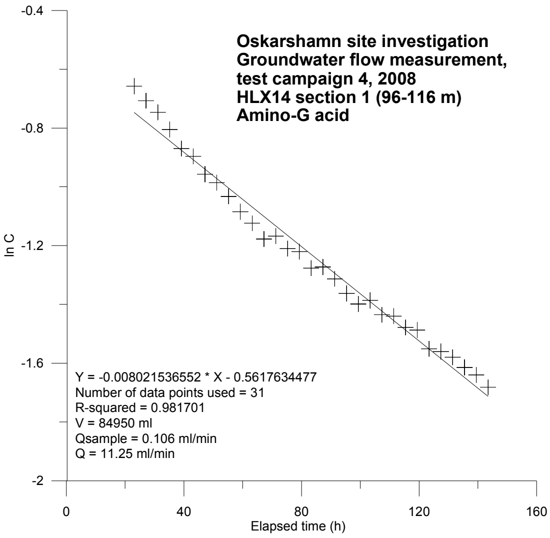
/18/ **Askling P, Andersson P, 2006.** Groundwater flow measurements in permanent installed boreholes. Test campaign no. 1. 2005. Oskarshamn site investigation. SKB P-06-61. Svensk Kärnbränslehantering AB.

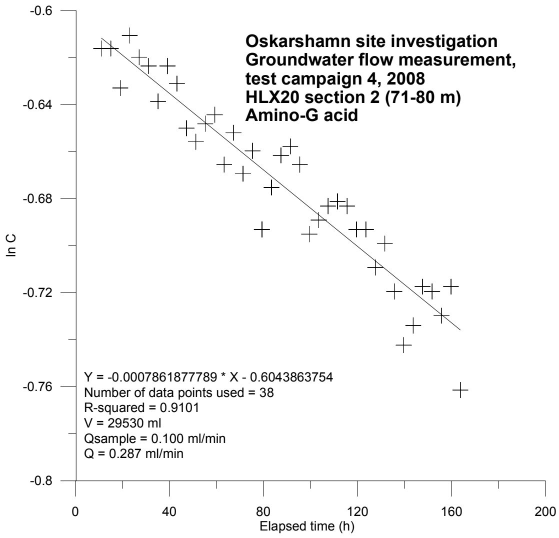
/19/ **Askling P, Andersson P, 2007.** Groundwater flow measurements in permanent installed boreholes. Test campaign no. 2. 2006. Oskarshamn site investigation. SKB P-07-181. Svensk Kärnbränslehantering AB.

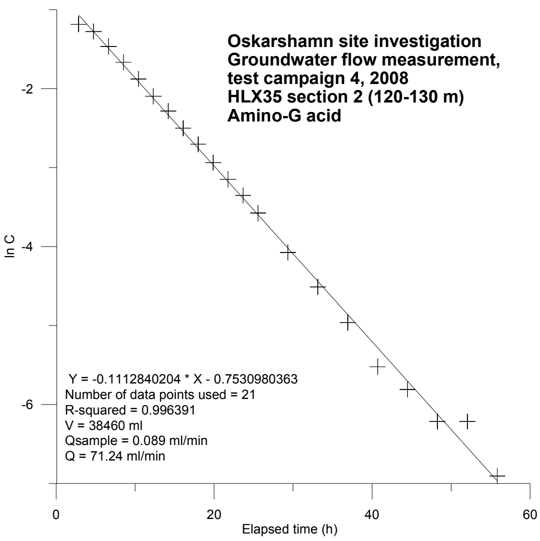
/20/ **Thur P, 2008.** Groundwater flow measurements in permanent installed boreholes. Test campaign no. 3. 2007. Oskarshamn site investigation. SKB P-08-31. Svensk Kärnbränslehantering AB.

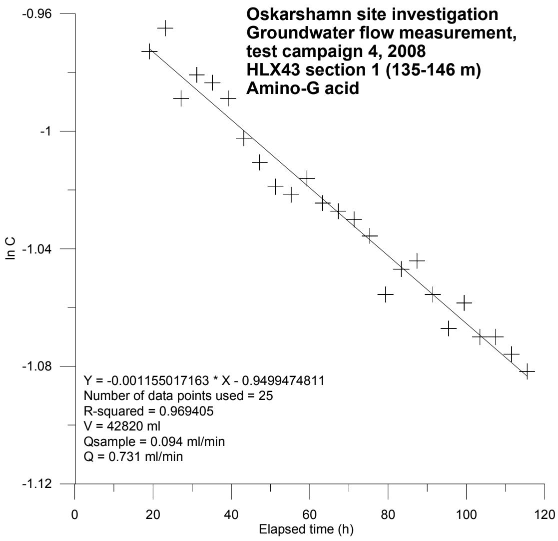
/21/ **Thur P, Hjerne C, Ludvigson J E, Svensson T, Nordqvist R, 2009.** HLX28 large-scale confirmatory multiple-hole tracer test and hydraulic interference test. Oskarshamn site investigation. SKB P-09-62, in preparation. Svensk Kärnbränslehantering AB.

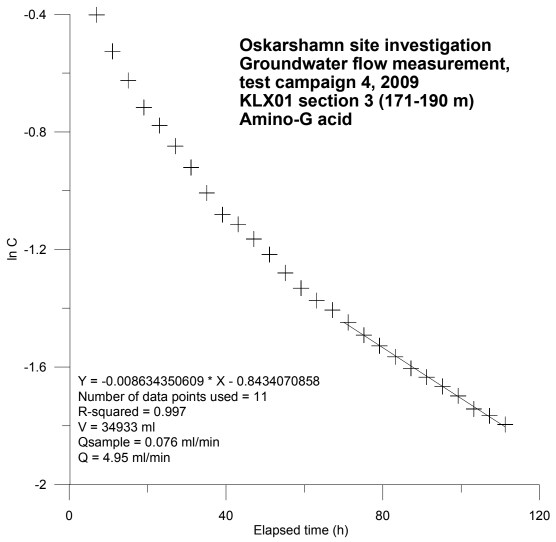
Tracer dilution graphs

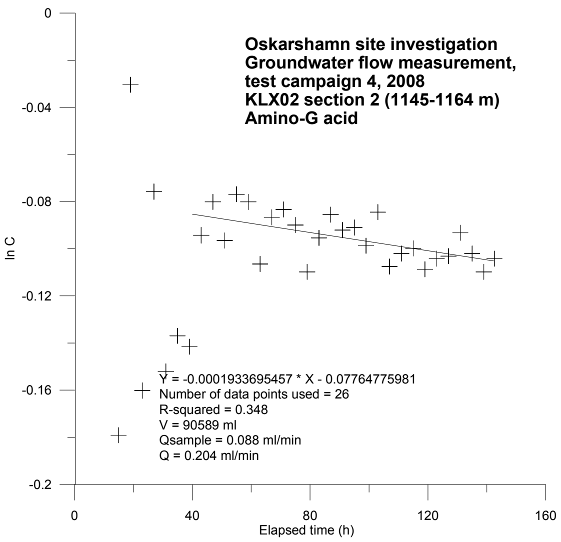


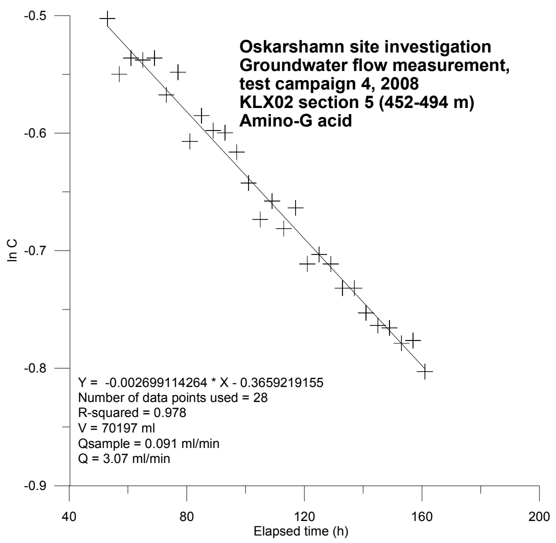


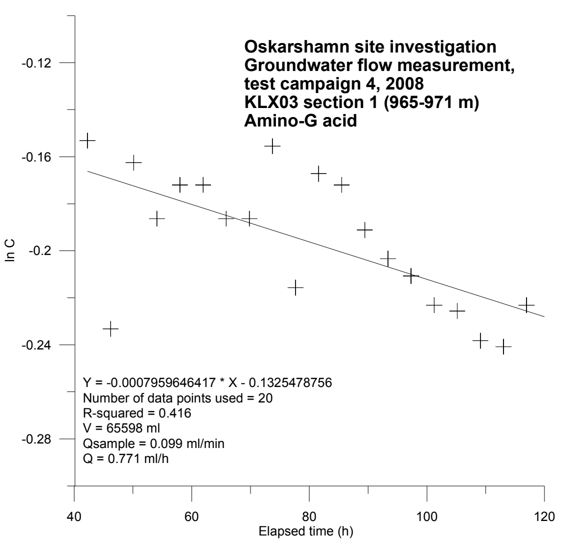





Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2009
KLX01 section 3 (171-190 m)
Amino-G acid
Y = -0.008634350609 * X - 0.8434070858
Number of data points used = 11
R-squared = 0.997
V = 34933 ml
Qsample = 0.076 ml/min
Q = 4.95 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX02 section 2 (1145-1164 m)
Amino-G acid
Y = -0.0001933695457 * X - 0.07764775981
Number of data points used = 26
R-squared = 0.348
V = 90589 ml
Qsample = 0.088 ml/min
Q = 0.204 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX02 section 5 (452-494 m)
Amino-G acid
Y = -0.002699114264 * X - 0.3659219155
Number of data points used = 28
R-squared = 0.978
V = 70197 ml
Qsample = 0.091 ml/min
Q = 3.07 ml/min
ln C
Elapsed time (h)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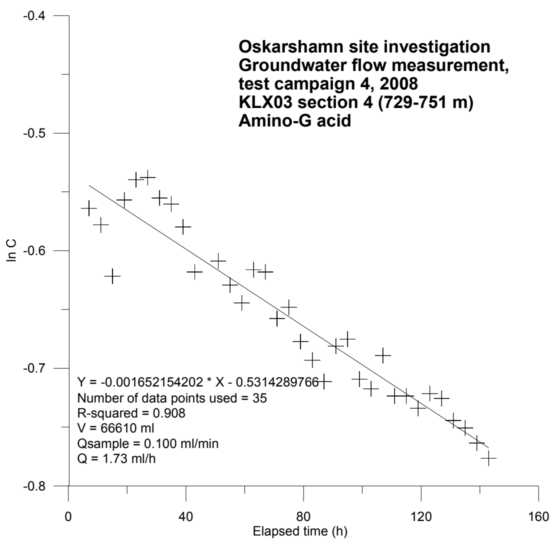
Groundwater flow measurement,
test campaign 4, 2008
KLX03 section 1 (965-971 m)
Amino-G acid
Y = -0.0007959646417 * X - 0.1325478756
Number of data points used = 20
R-squared = 0.416
V = 65598 ml
Qsample = 0.099 ml/min
Q = 0.771 ml/h
ln C
Elapsed time (h)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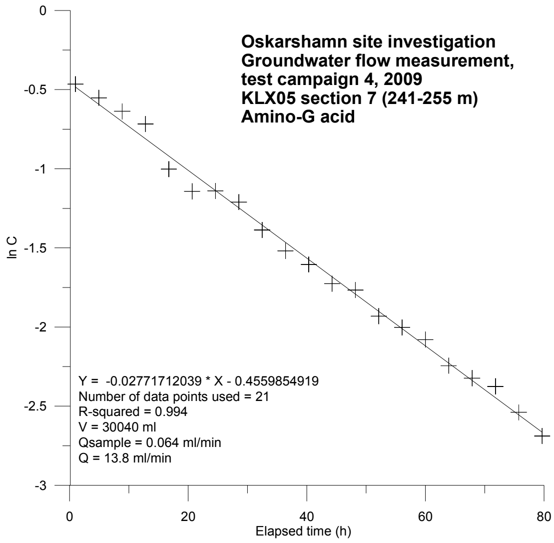
Groundwater flow measurement,
test campaign 4, 2008
KLX03 section 4 (729-751 m)
Amino-G acid
Y = -0.001652154202 * X - 0.5314289766
Number of data points used = 35
R-squared = 0.908
V = 66610 ml
Qsample = 0.100 ml/min
Q = 1.73 ml/h
ln C
Elapsed time (h)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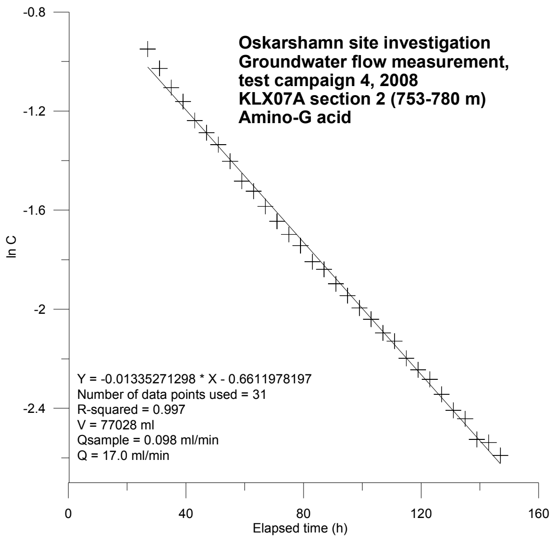
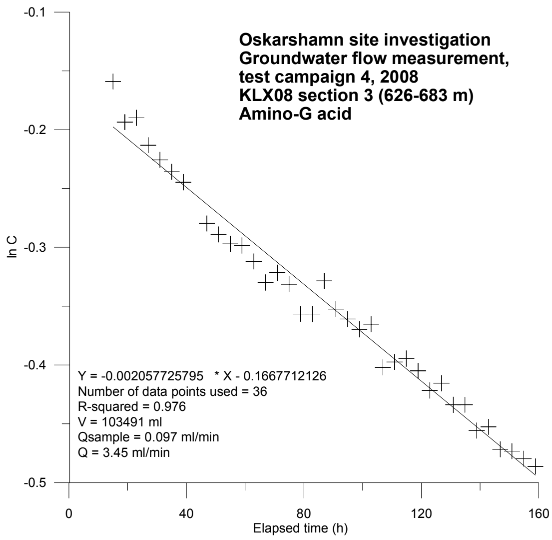
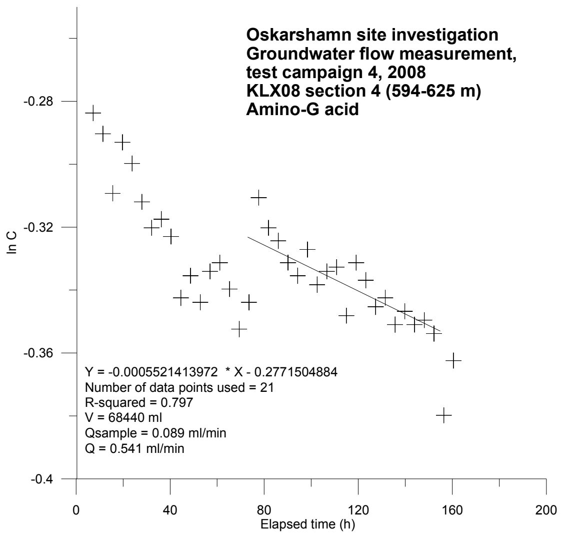
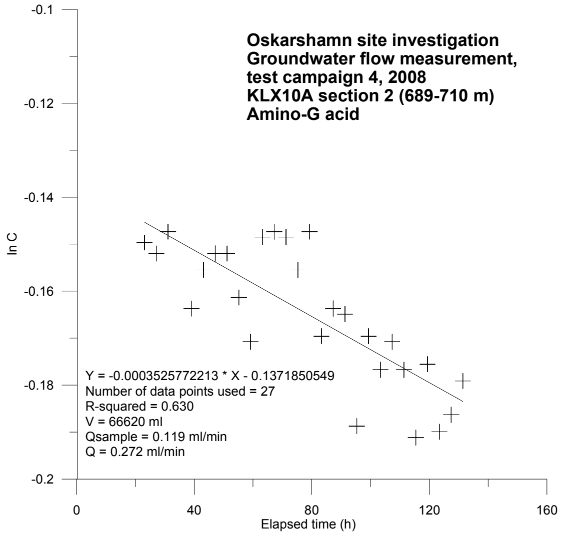
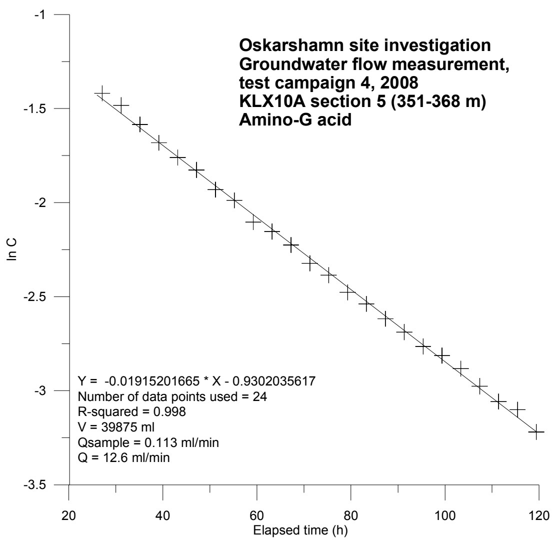
Groundwater flow measurement,
test campaign 4, 2009
KLX05 section 7 (241-255 m)
Amino-G acid
Y = -0.02771712039 * X - 0.4559854919
Number of data points used = 21
R-squared = 0.994
V = 30040 ml
Qsample = 0.064 ml/min
Q = 13.8 ml/min
ln C
Elapsed time (h)

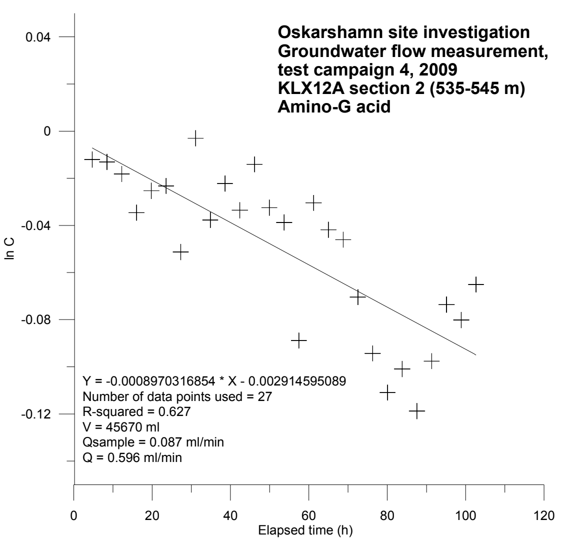

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX07A section 2 (753-780 m)
Amino-G acid
Y = -0.01335271298 * X - 0.6611978197
Number of data points used = 31
R-squared = 0.997
V = 77028 ml
Qsample = 0.098 ml/min
Q = 17.0 ml/min
ln C
Elapsed time (h)

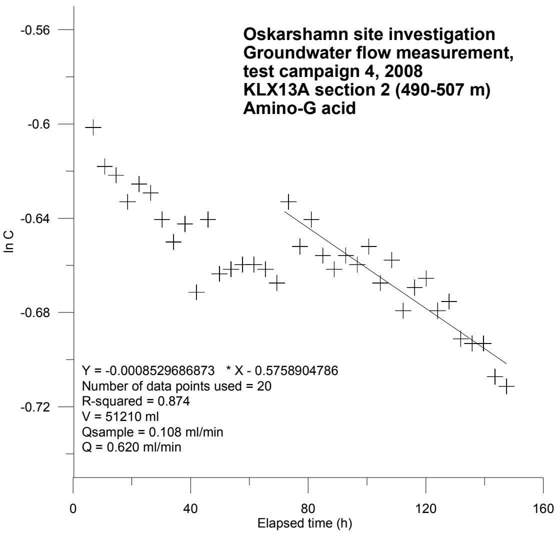

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX08 section 3 (626-683 m)
Amino-G acid
Y = -0.002057725795 * X - 0.1667712126
Number of data points used = 36
R-squared = 0.976
V = 103491 ml
Qsample = 0.097 ml/min
Q = 3.45 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX08 section 4 (594-625 m)
Amino-G acid
Y = -0.0005521413972 * X - 0.2771504884
Number of data points used = 21
R-squared = 0.797
V = 68440 ml
Qsample = 0.089 ml/min
Q = 0.541 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX10A section 2 (689-710 m)
Amino-G acid
Y = -0.0003525772213 * X - 0.1371850549
Number of data points used = 27
R-squared = 0.630
V = 66620 ml
Qsample = 0.119 ml/min
Q = 0.272 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX10A section 5 (351-368 m)
Amino-G acid
Y = -0.01915201665 * X - 0.9302035617
Number of data points used = 24
R-squared = 0.998
V = 39875 ml
Qsample = 0.113 ml/min
Q = 12.6 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2009
KLX12A section 2 (535-545 m)
Amino-G acid
Y = -0.0008970316854 * X - 0.002914595089
Number of data points used = 27
R-squared = 0.627
V = 45670 ml
Qsample = 0.087 ml/min
Q = 0.596 ml/min
ln C
Elapsed time (h)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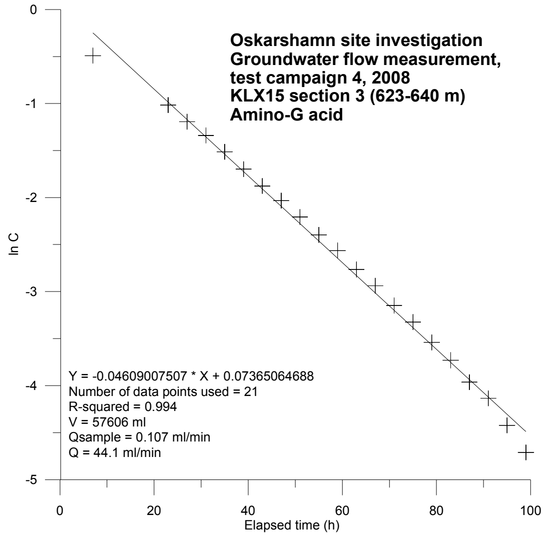
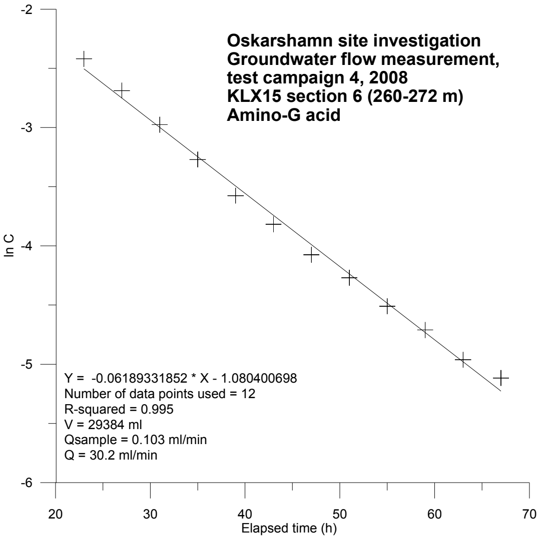
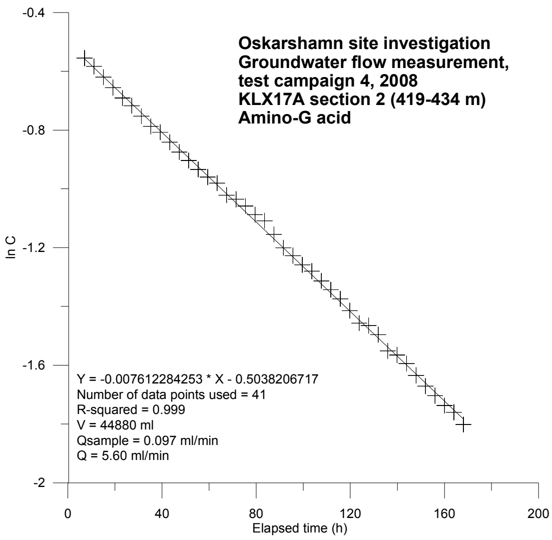
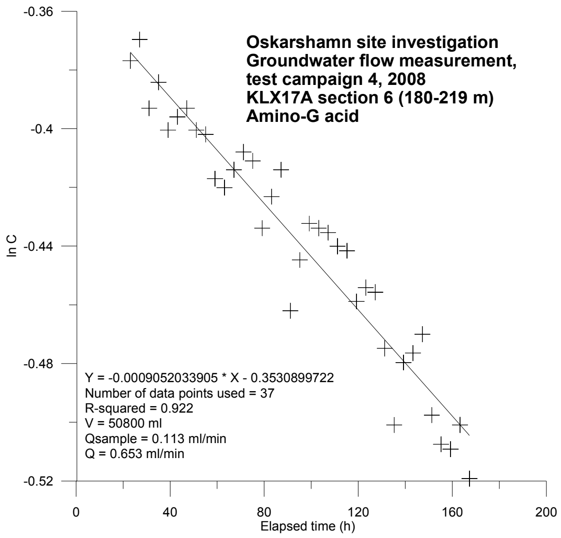
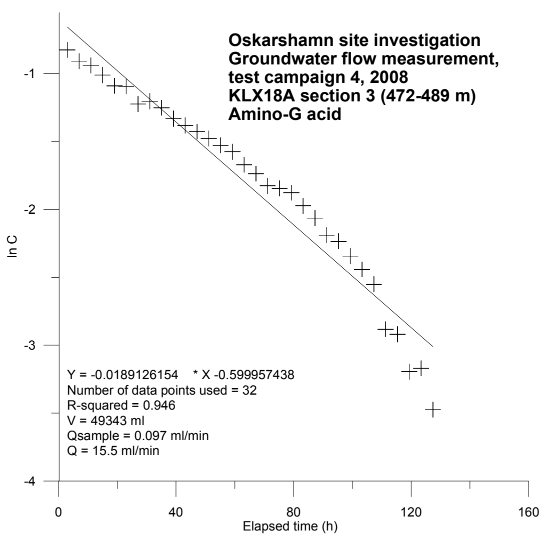
Groundwater flow measurement,
test campaign 4, 2008
KLX13A section 2 (490-507 m)
Amino-G acid
Y = -0.0008529686873 * X - 0.5758904786
Number of data points used = 20
R-squared = 0.874
V = 51210 ml
Qsample = 0.108 ml/min
Q = 0.620 ml/min
ln C
Elapsed time (h)

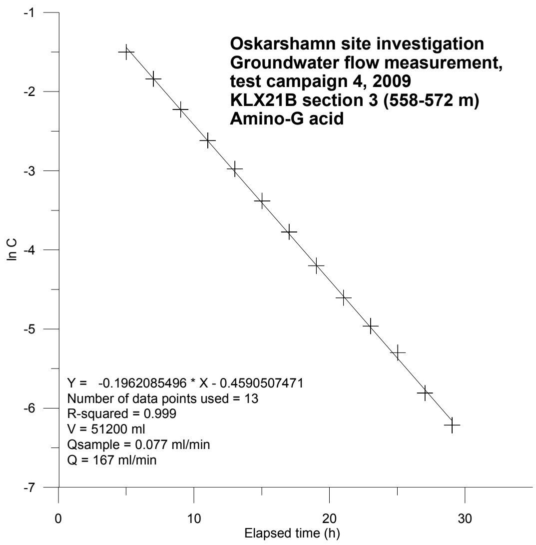

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX15 section 3 (623-640 m)
Amino-G acid
Y = -0.04609007507 * X + 0.07365064688
Number of data points used = 21
R-squared = 0.994
V = 57606 ml
Qsample = 0.107 ml/min
Q = 44.1 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX15 section 6 (260-272 m)
Amino-G acid
Y = -0.06189331852 * X - 1.080400698
Number of data points used = 12
R-squared = 0.995
V = 29384 ml
Qsample = 0.103 ml/min
Q = 30.2 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX17A section 2 (419-434 m)
Amino-G acid
Y = -0.007612284253 * X - 0.5038206717
Number of data points used = 41
R-squared = 0.999
V = 44880 ml
Qsample = 0.097 ml/min
Q = 5.60 ml/min
ln C
Elapsed time (h)

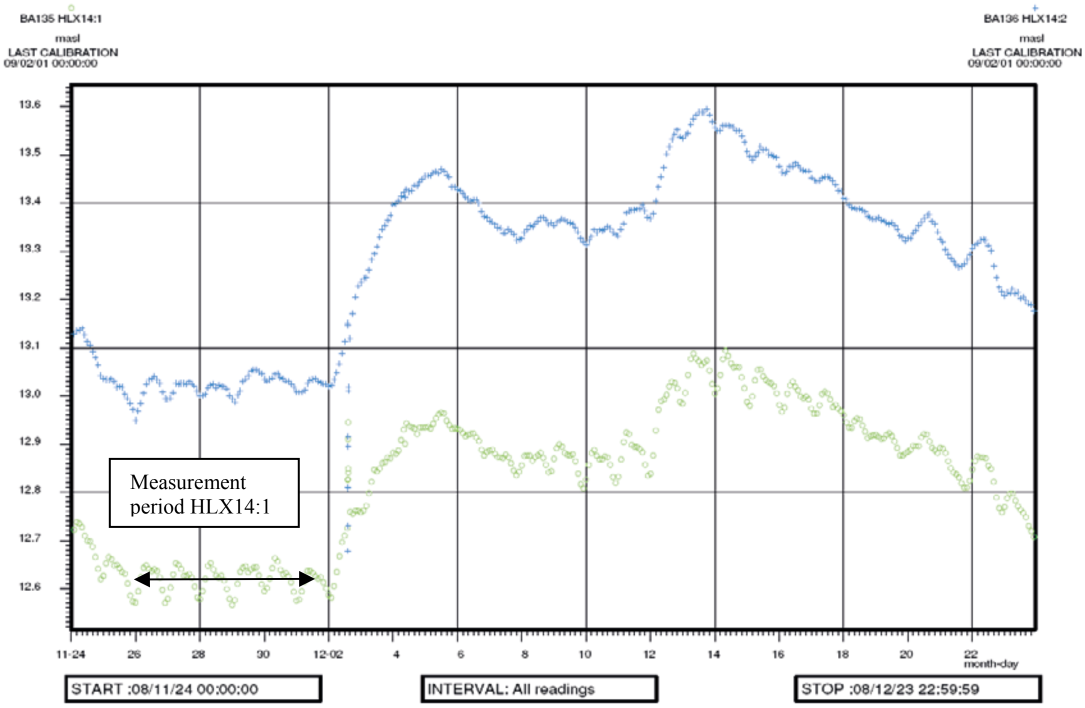

Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX17A section 6 (180-219 m)
Amino-G acid
Y = -0.0009052033905 * X - 0.3530899722
Number of data points used = 37
R-squared = 0.922
V = 50800 ml
Qsample = 0.113 ml/min
Q = 0.653 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2008
KLX18A section 3 (472-489 m)
Amino-G acid
Y = -0.0189126154 * X -0.599957438
Number of data points used = 32
R-squared = 0.946
V = 49343 ml
Qsample = 0.097 ml/min
Q = 15.5 ml/min
ln C
Elapsed time (h)


Oskarshamn site investigation
Groundwater flow measurement,
test campaign 4, 2009
KLX21B section 3 (558-572 m)
Amino-G acid
Y = -0.1962085496 * X - 0.4590507471
Number of data points used = 13
R-squared = 0.999
V = 51200 ml
Qsample = 0.077 ml/min
Q = 167 ml/min
ln C
Elapsed time (h)

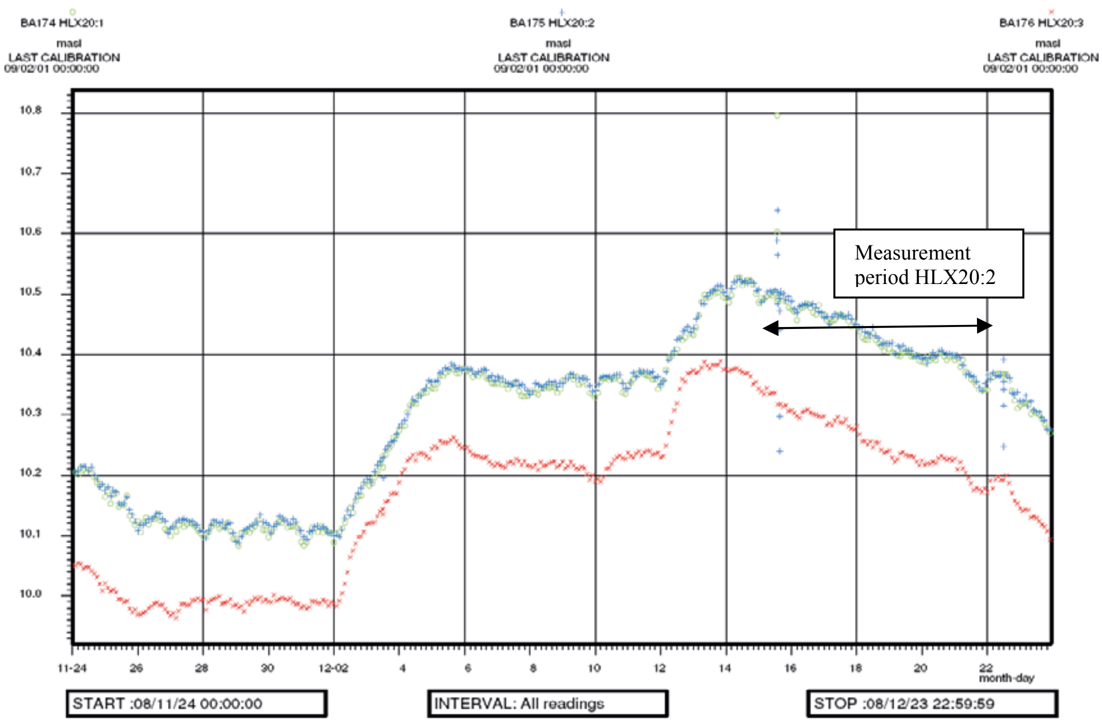
Groundwater levels (m.a.s.l.)

HLX14



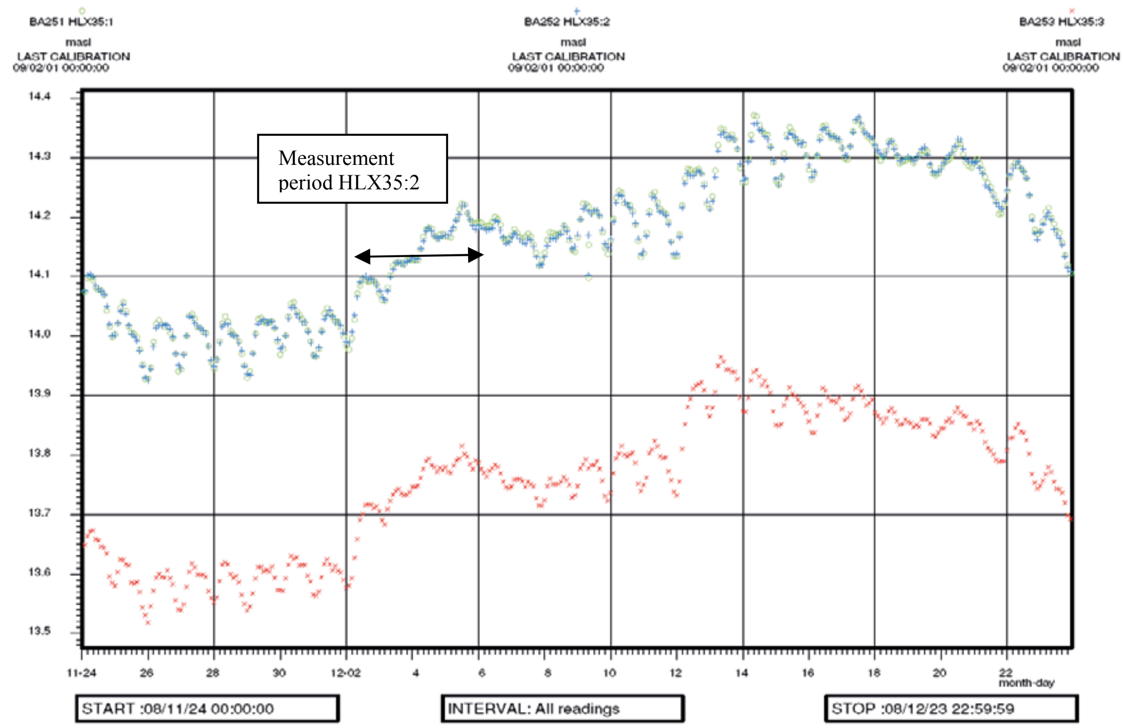
Measured section: HLX14:1 (green)

HLX20



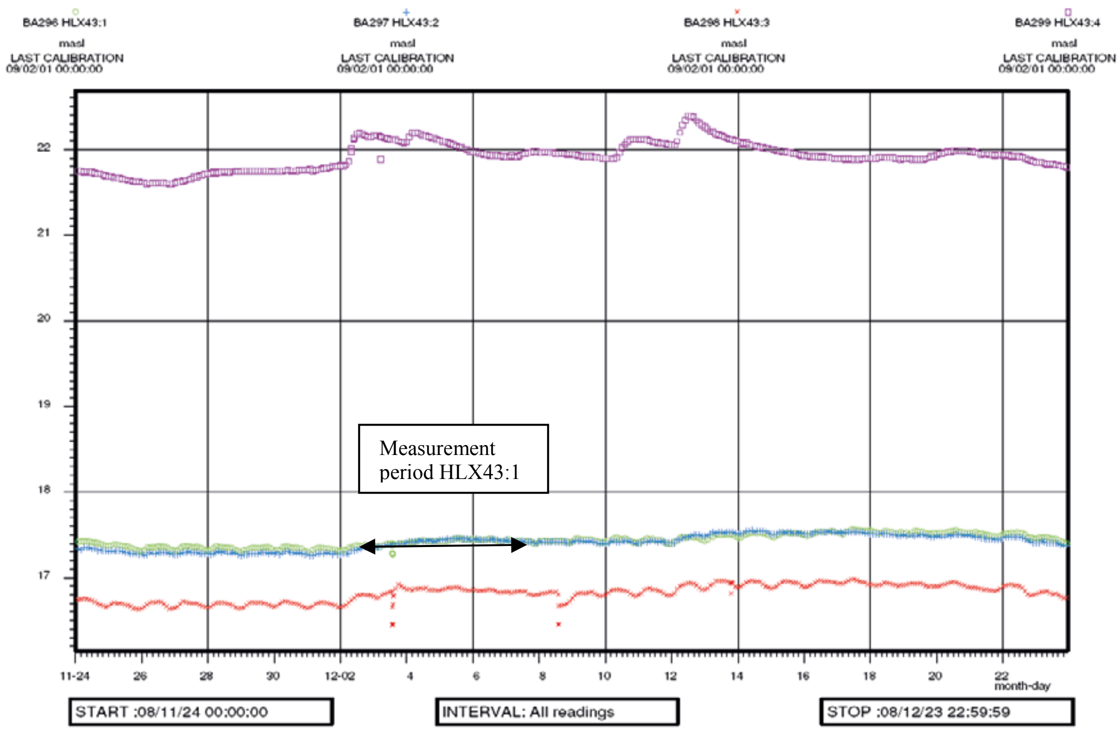
Measured section: HLX20:2 (blue)

HLX35



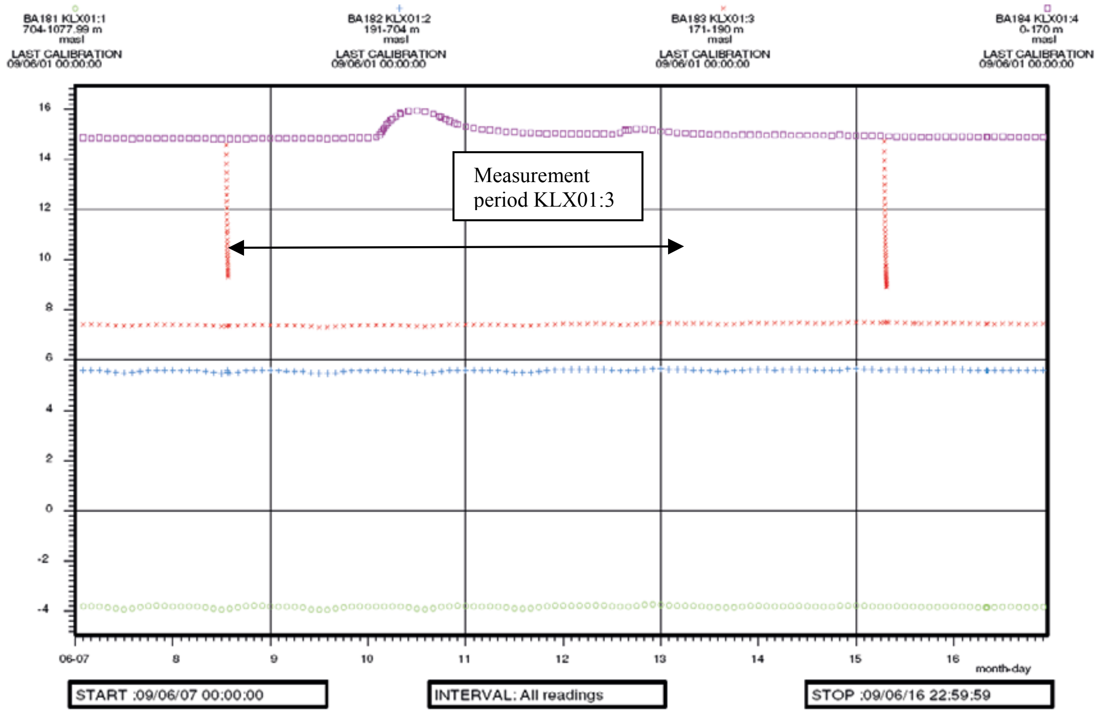
Measured sections: HLX35:2 (blue)

HLX43



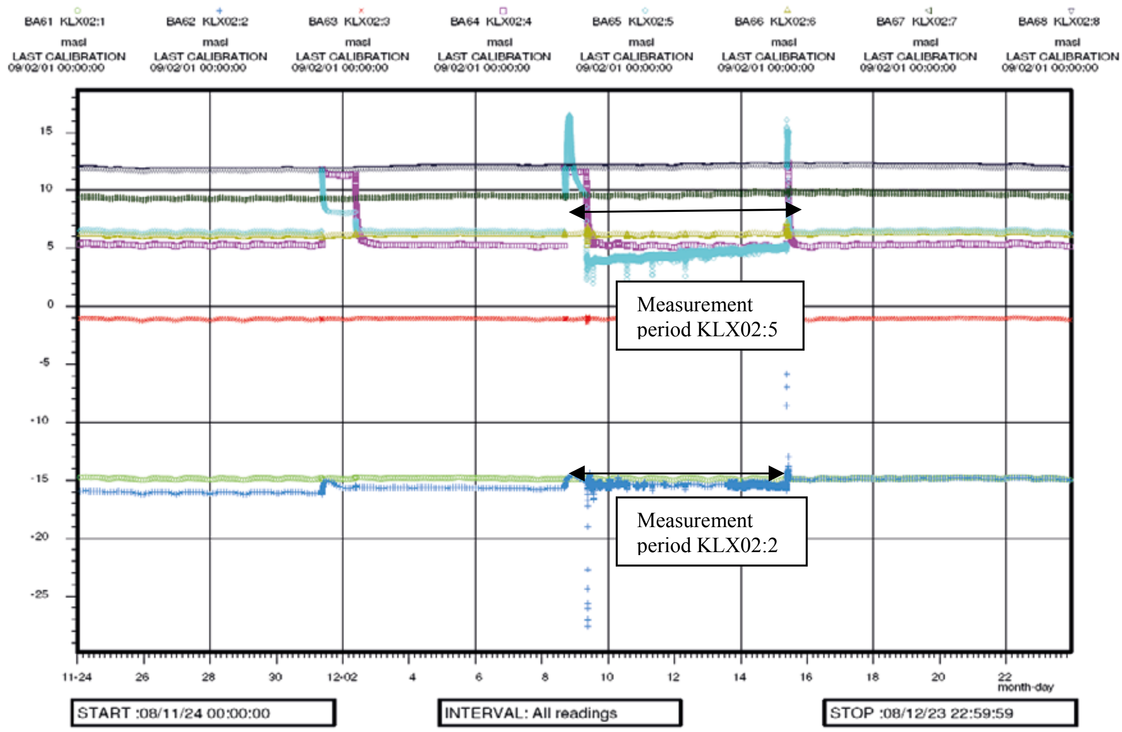
Measured section: HLX43:1 (green)

KLX01



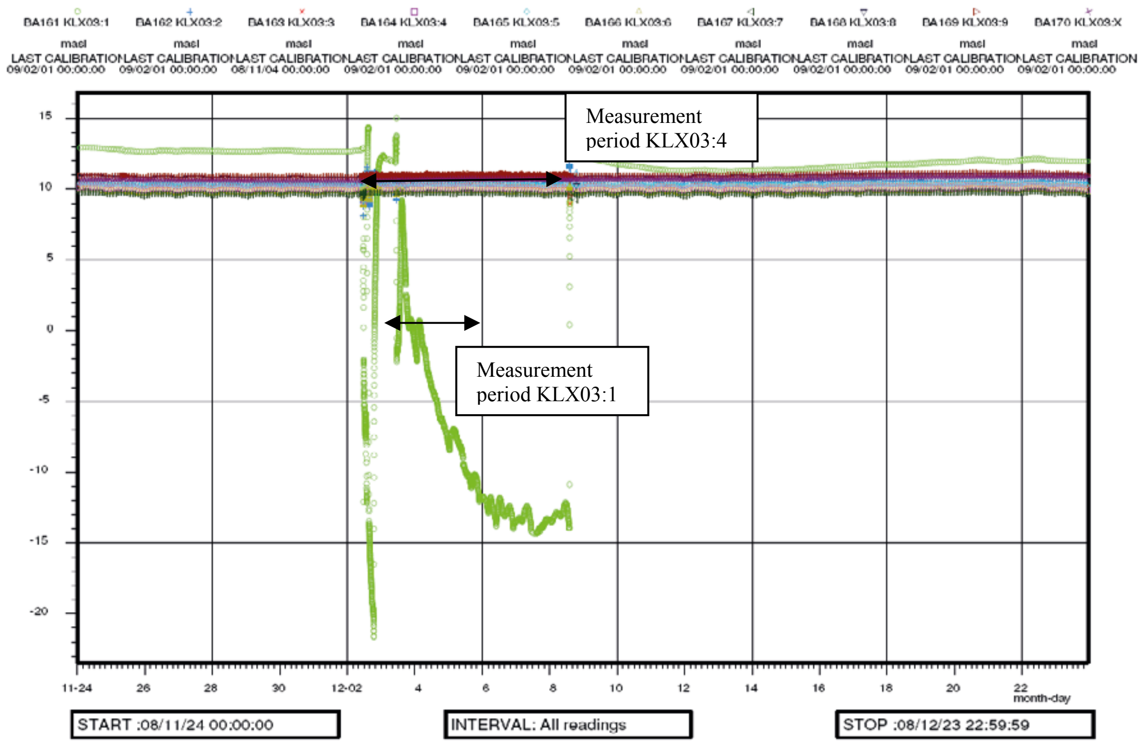
Measured section: KLX01:3 (red)

KLX02



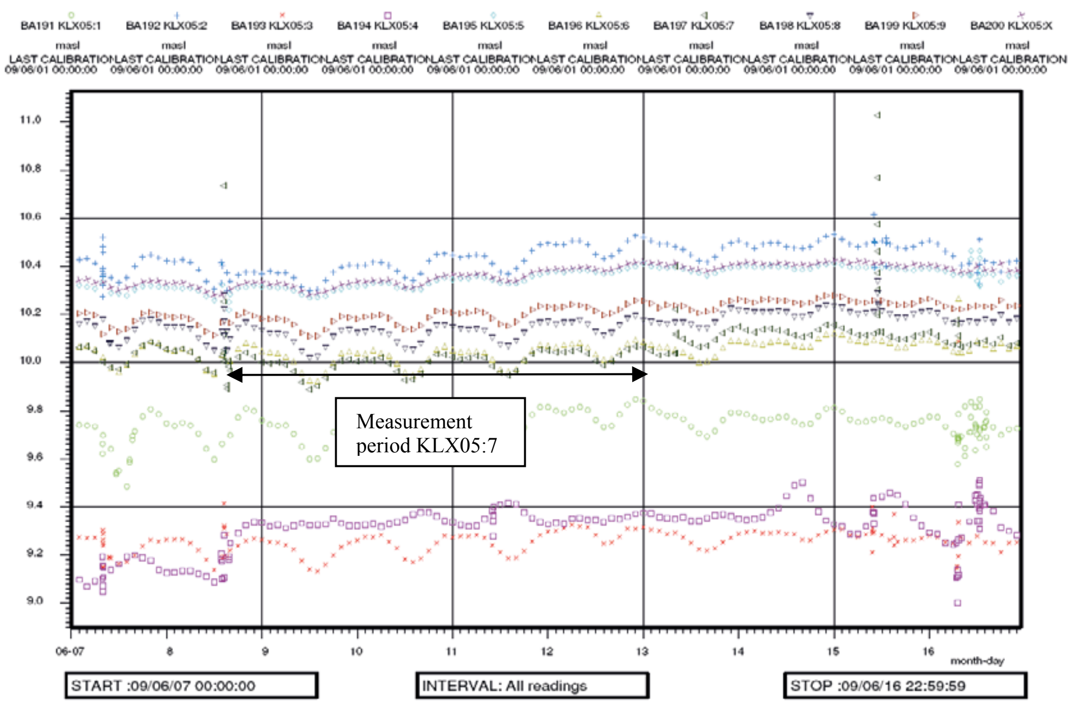
Measured sections: KLX02:2 (blue) and KLX02:5 (turquoise)

KLX03



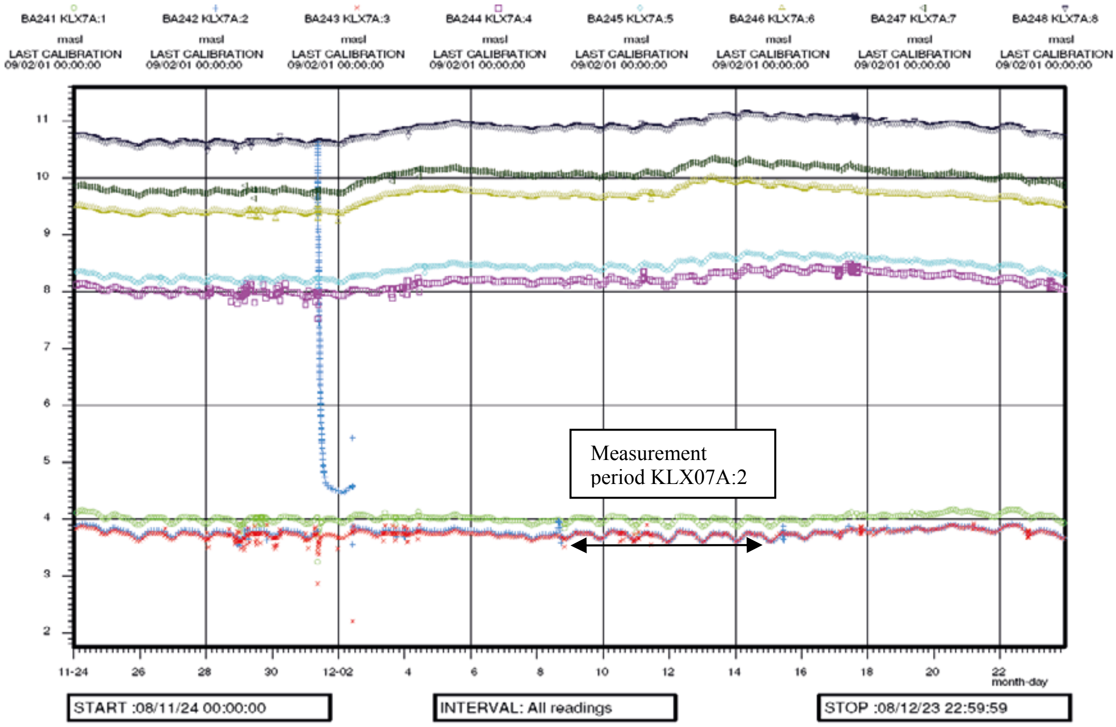
Measured sections: KLX03:1 (green) and KLX03:4 (purple)

KLX05



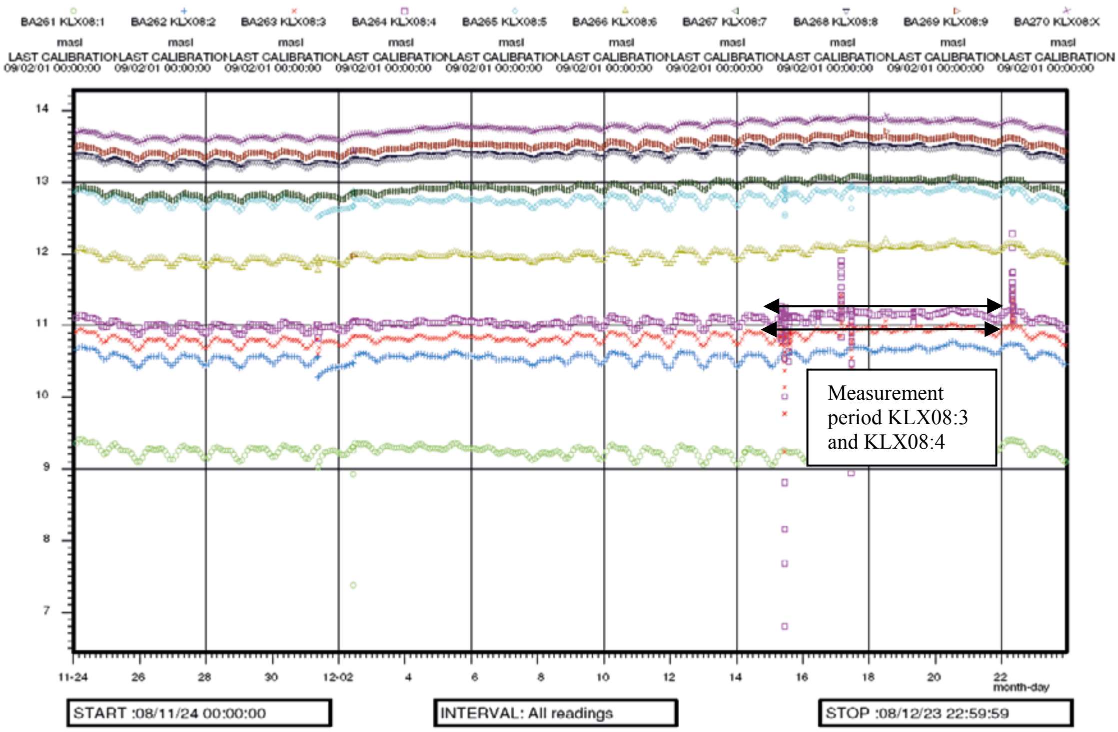
Measured section: KLX05:7 (dark green)

KLX07A



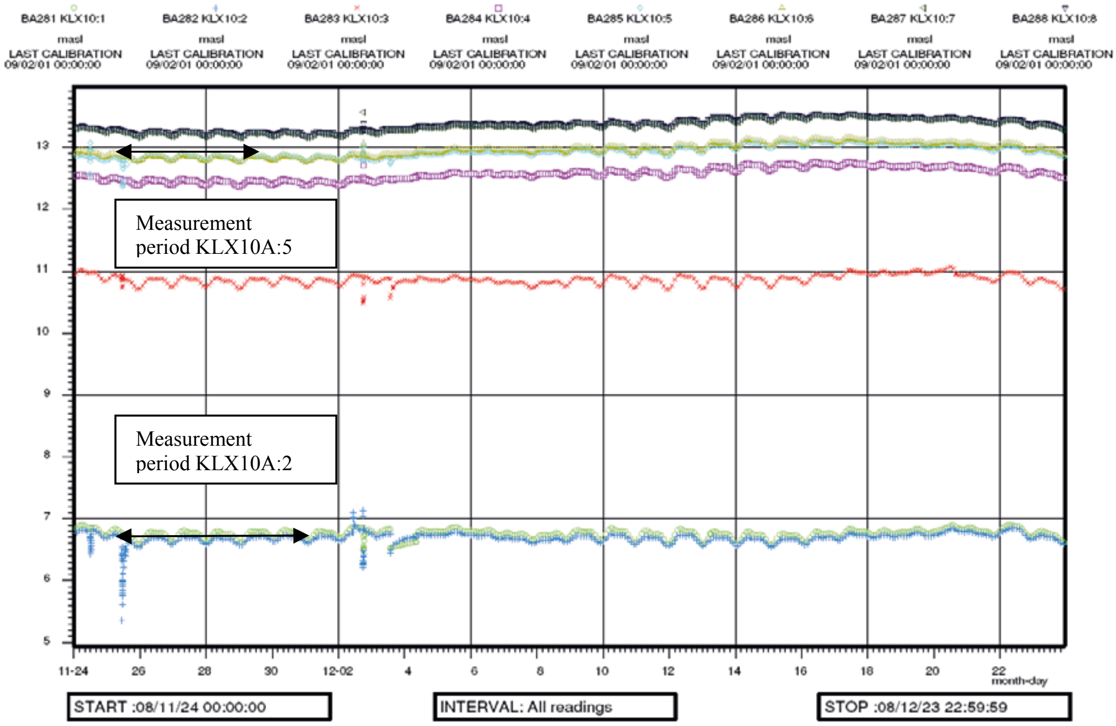
Measured section: KLX07A:2 (blue)

KLX08



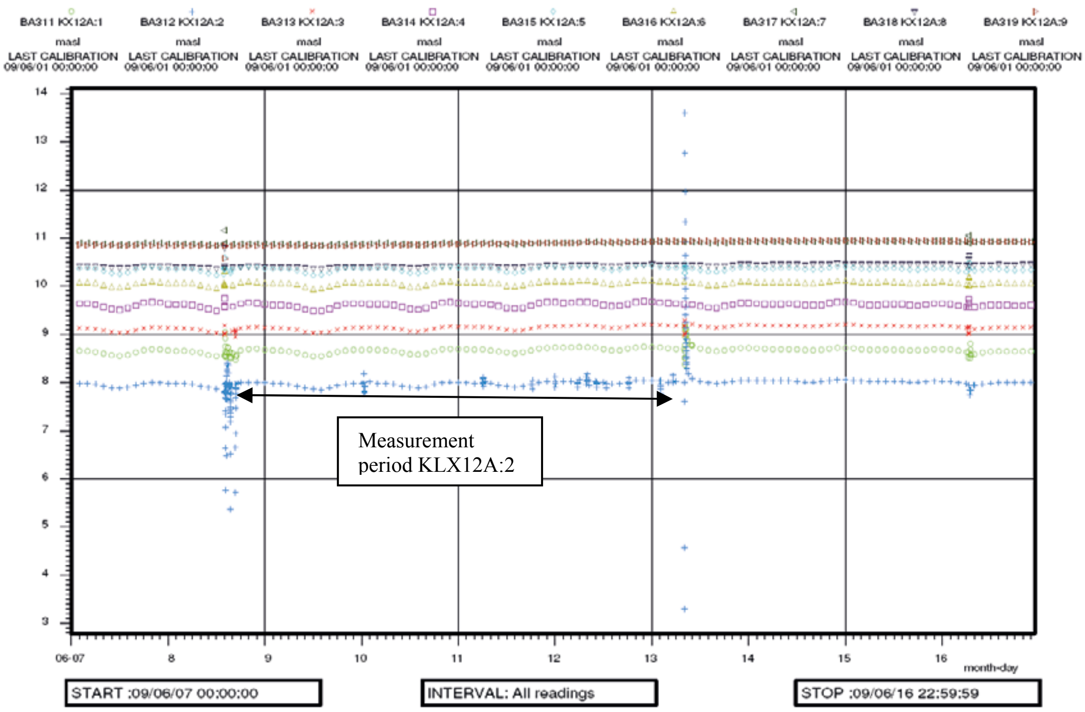
Measured sections: KLX08:3 (red) and KLX08:4 (purple)

KLX10A



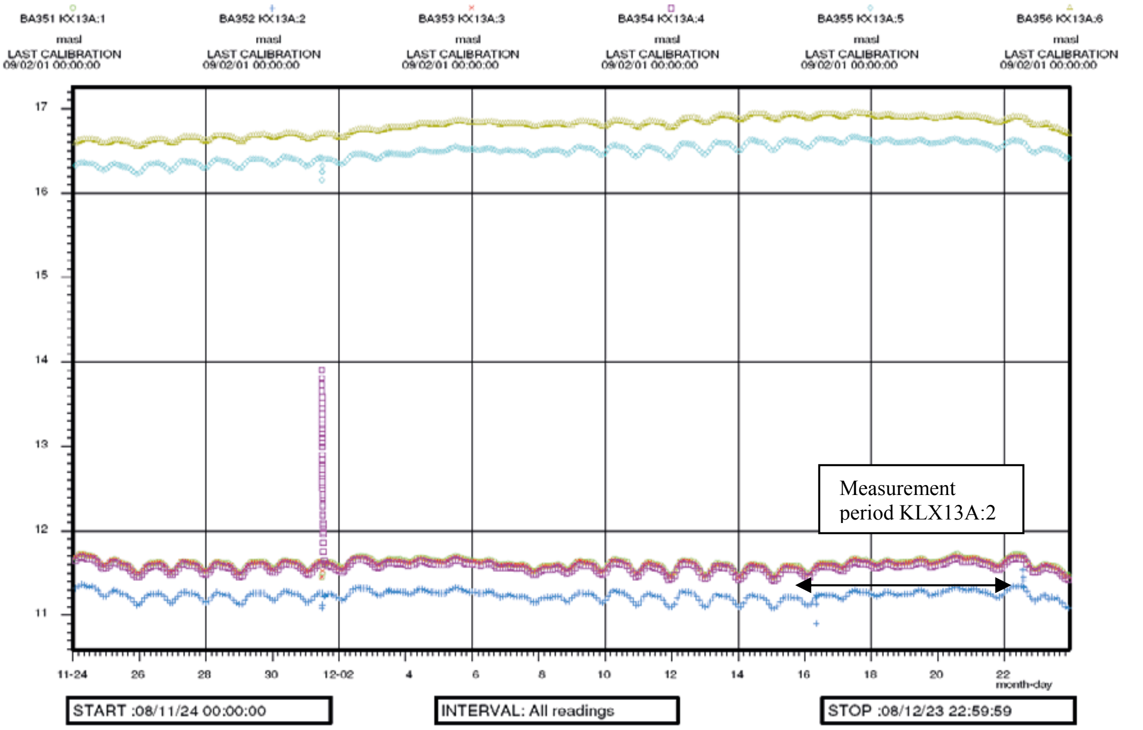
Measured sections: KLX10A:2 (blue) and KLX10A:5 (turquoise)

KLX12A



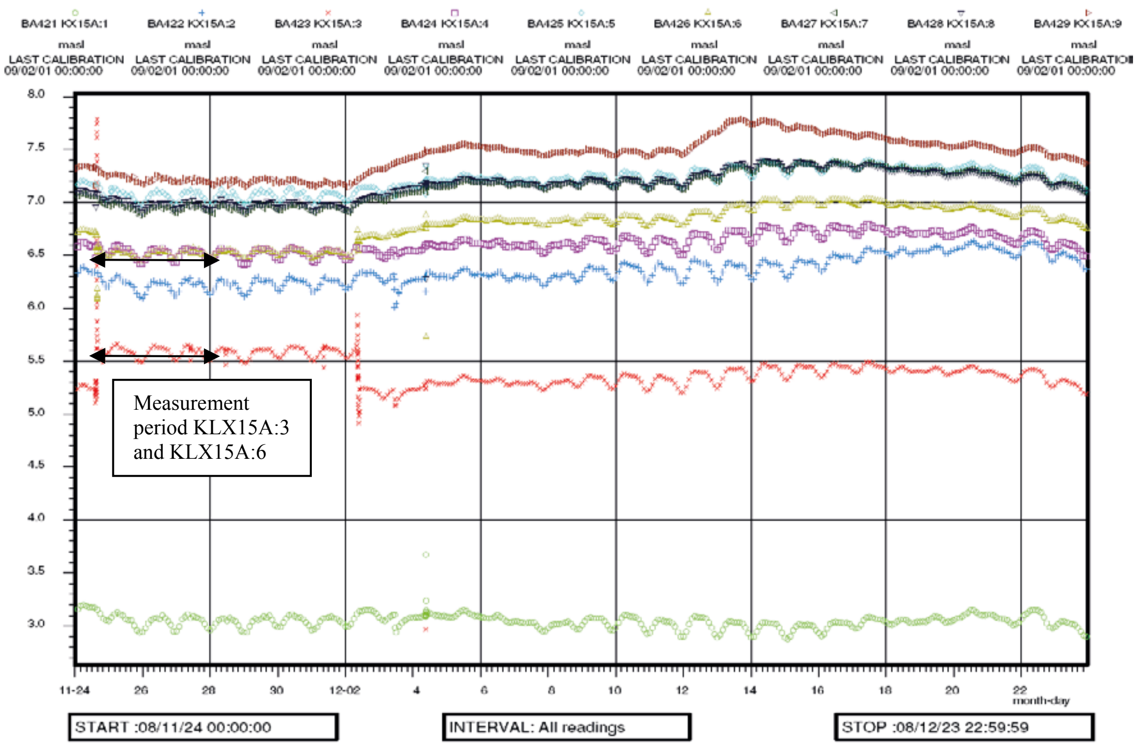
Measured section: KLX12A:2 (blue)

KLX13A



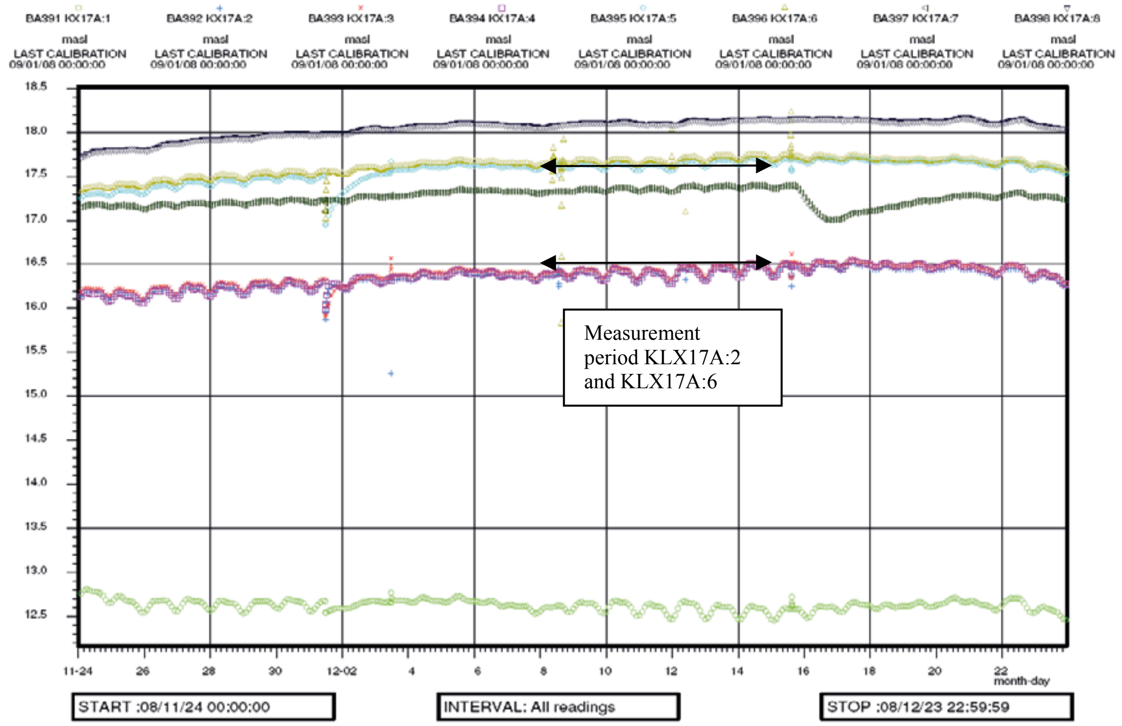
Measured section: KLX13A:2 (blue)

KLX15A



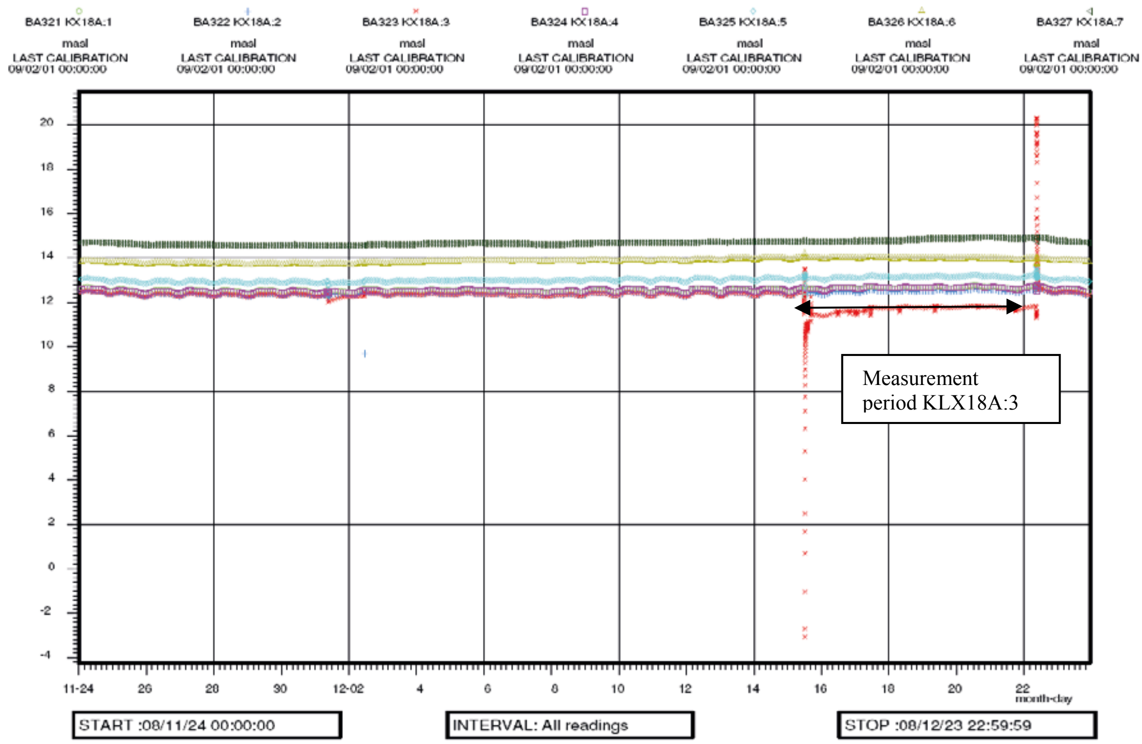
Measured sections: KLX15A:3 (red) and KLX15A:6 (beige)

KLX17A



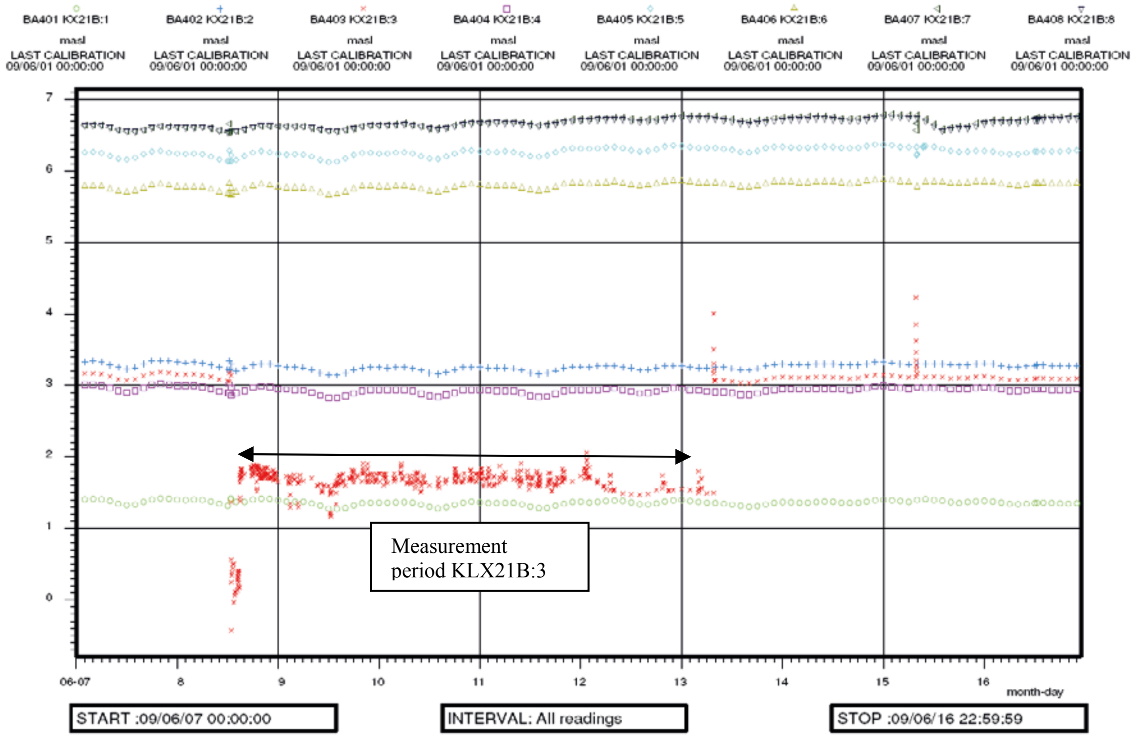
Measured section: KLX17A:2 (blue) and KLX17A:6 (beige)

KLX18A



Measured section: KLX18A:3 (red)

KLX21B



Measured section: KLX21B:3 (red)