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Forsmark site investigation

Groundwater flow measurements in permanently installed boreholes

Test campaign no. 3, 2007

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March 2008

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Keywords: Groundwater flow, Dilution test, Tracer test, AP PF 400-07-043.

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Abstract

This report describes the performance and evaluation of groundwater flow measurements in 32 borehole sections in permanently installed boreholes within the Forsmark site investigation area. The objective was to determine the groundwater flow in all, at the time available, borehole sections instrumented for this purpose. This is the third test campaign performed within 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 conditions. Measured flow rates ranged from 0.04 to 91 ml/min with calculated Darcy velocities from $2.9 \cdot 10^{-10}$ to $4.9 \cdot 10^{-7}$ m/s. Hydraulic gradients were calculated according to the Darcy concept and varied between 0.0002 and 49.

Sammanfattning

Denna rapport beskriver genomförandet och utvärderingen av grundvattenflödesmätningar i 32 borrhålssektioner i permanent installerade borrhål inom Forsmarks plats- undersöknings-område. Syftet var att bestämma grundvattenflödet i samtliga, vid denna tidpunkt och för detta ändamål, instrumenterade sektioner. Detta är den tredje mätkampanjen som genomförts i moniteringsprogrammet och mätningarna är planerade att återupprepas en gång per år.

Grundvattenflödet mättes med utspädningsmetoden under naturliga förhållanden i utvalda borrhålssektioner. Uppmätta grundvattenflöden låg i intervallet 0,04–91 ml/min med beräknade Darcy hastigheter mellan $2{,}9 \cdot 10^{-10}$ och $4{,}9 \cdot 10^{-7}$ m/s. Hydrauliska gradienter beräknades enligt Darcy-konceptet och varierade mellan 0,0002 och 49.

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1 Introduction

This document reports the results gained from the groundwater flow measurements in permanently installed boreholes, test campaign no. 3, 2007, which is one of the activities performed within the Forsmark site investigation. The work was carried out in accordance with activity plan AP PF 400-07-043 and the field work was conducted during November 2007 and January–February 2008. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

A map of the site investigation area at Forsmark including borehole locations 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 i permanent installerade borrhål, kampanj 3, 2007.	AP PF 400-07-043	1.0
Method description	**Number**	**Version**
System för hydrologisk och metrologisk datainsamling. Vattenprovtagning och utspädningsmätning i observationshål.	SKB MD 368.010	1.0

Figure 1-1. *Overview over Forsmark site investigation area, showing locations of boreholes included in this activity.*

2 Objective and scope

The objective of this activity was to determine the groundwater flow in borehole sections in permanently installed boreholes at Forsmark. Thirty-two borehole sections instrumented for this purpose (circulation sections) were measured, cf. Table 4-1. This was the second test campaign performed within the monitoring program and it is planned to be repeated once every year. The measurements will serve as a basis to study and monitor changes in the hydraulic gradients caused by activities in the area such as underground construction and drilling.

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

3 Equipment

3.1 Description of equipment and tracers used

The boreholes involved in the tests are instrumented with 1–9 inflatable packers isolating 2–10 borehole sections each. In Figure 3-1 drawings of the instrumentation in core and percussion boreholes are 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 five identical equipment set-ups, i.e. allowing five sections to be measured simultaneously. A schematic drawing of the tracer test equipment is shown in Figure 3-2. The basic idea is to cause an internal circulation in the borehole section. The circulation makes it possible to obtain a homogeneous tracer concentration in the borehole section and to sample the tracer concentration outside the borehole in order to monitor the dilution 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. The equipment and test procedure is described in detail in SKB MD 368.010, see Table 1-1.

The tracers used were two fluorescent dye tracers, Uranine (Sodium Fluorescein), from Merck (purum quality), and Amino-G Acid from Aldrich (techn. quality).

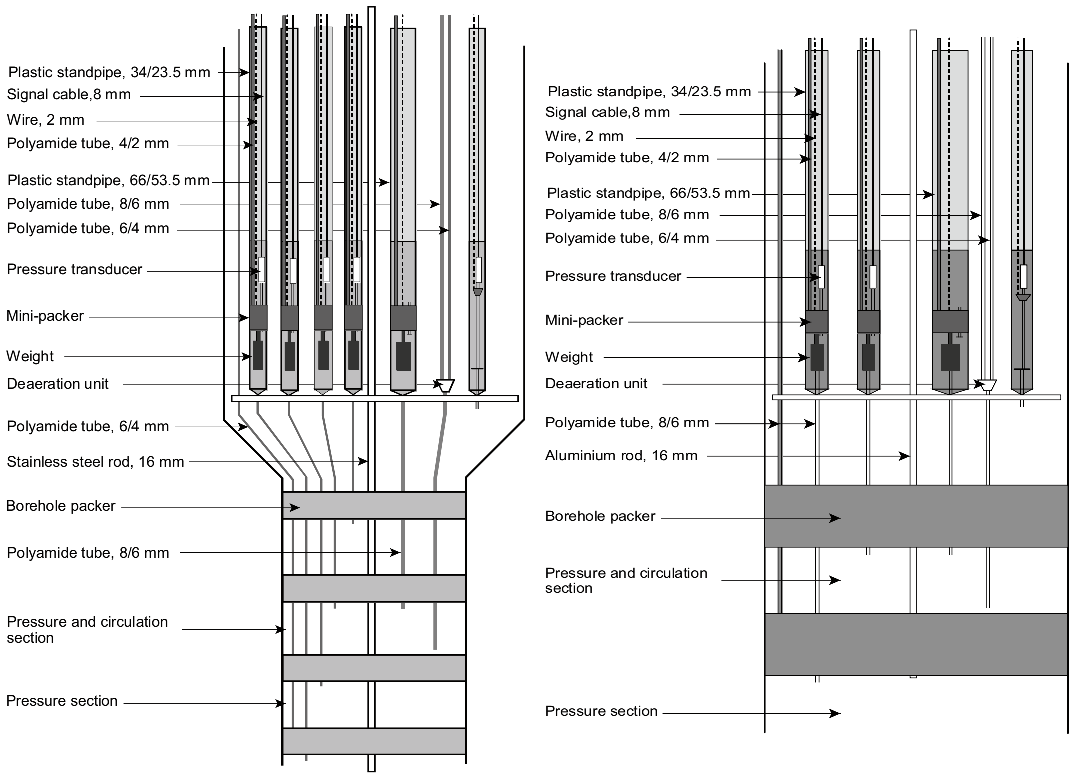

Figure 3-1. Example of permanent instrumentation in core boreholes (left) and percussion boreholes (right) with circulation sections.

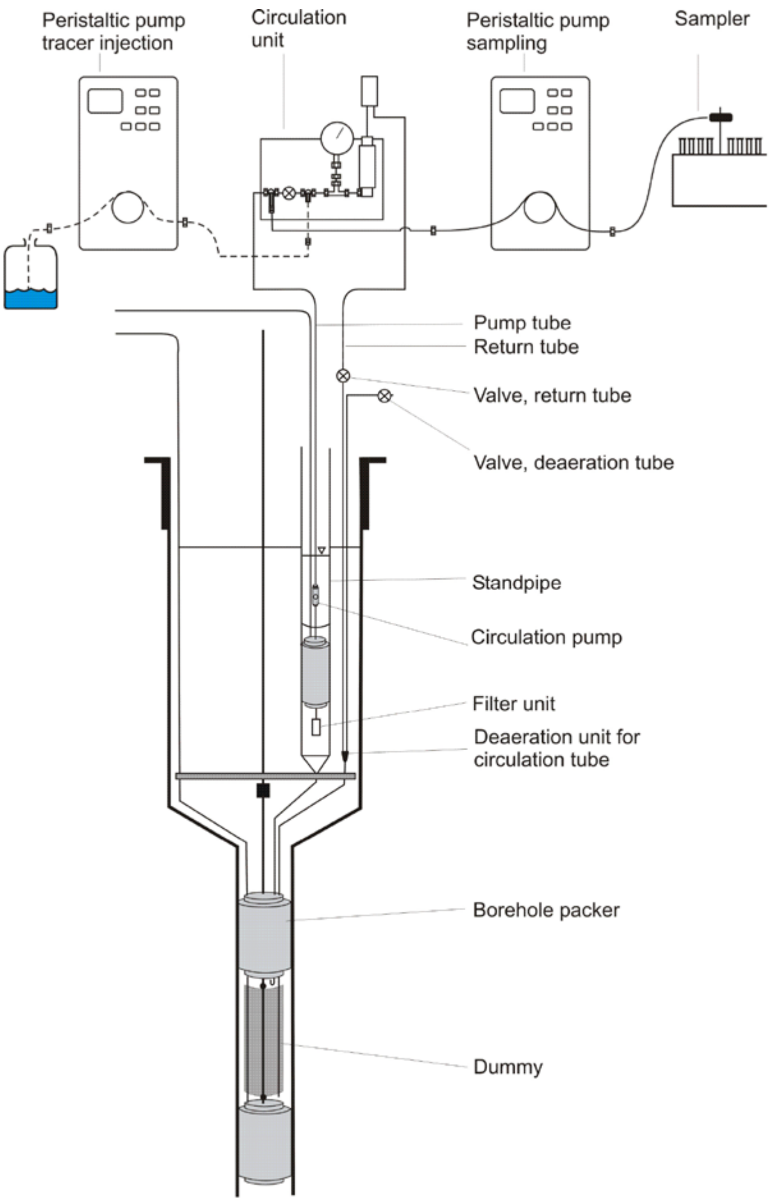

Figure 3-2. *Schematic drawing of the equipment used in tracer dilution measurements.*

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 borehole test section. The dilution of the tracer is proportional to the water flow through the borehole section and the groundwater flow is calculated as a function of the decreasing tracer concentration with time, Figure 4-1.

The method description used was "System för hydrologisk och metrologisk datainsamling. Vattenprovtagning och utspädningsmätning i observationshål." (SKB MD 368.010), cf. Table 1-1.

4.2 Preparations

The preparations included mixing of the tracer stock solution, functionality checks of the equipment and calibration of the peristaltic pumps used for sampling and tracer injections.

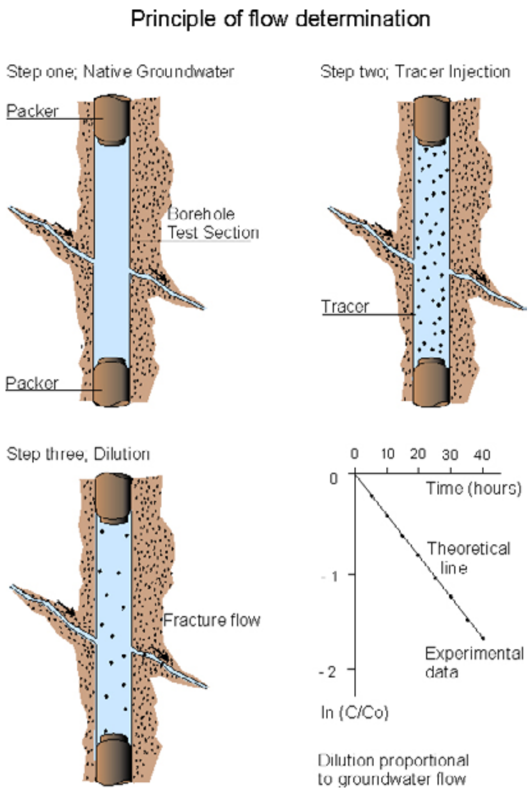

Figure 4-1. *General principles of dilution and flow determination.*

4.3 Execution of field work

The test campaign involved 32 borehole sections listed in Table 4-1. The duration of each test varied from 90 to 211 hours.

The tests were made by injecting a slug of tracer (Amino-G acid, 1,000 mg/l) into the selected borehole sections and allowing the natural groundwater flow to dilute the tracer. For the measurements performed in November 2007, a mixture of Amino-G acid (1,000 mg/l) and Uranine (500 mg/l) was injected for comparison reasons. Flow rates were evaluated from both tracers and the results show that the accordance in most cases was very good, see Table 5-1. Hence, it was decided to use Amino-G acid in the following measurements instead of the previously used

Table 4-1. Borehole sections used for groundwater flow measurements, 2007/2008.

Borehole:section	Depth (m)	Transmissivity (m^2/s)	Geologic character***	Test period (yymmdd)
KFM01A:5	109–130	1.0 E–7*	Single fracture, Fracture domain FFM02	080109–080114
KFM01D:2	429–438	8.0 E–7*	Single fracture, Fracture domain FFM01	080108–080114
KFM01D:4	311–321	2.0 E–7*	Single fracture, Fracture domain FFM01	080115–080121
KFM02A:3	490–518	2.1 E–6*	Zone ZFMF1	071112–071116
KFM02A:5	411–442	2.5 E–6*	Zone ZFMA2	071116–071120
KFM02B:2	491–506	3.0 E–5*	Not included in /26/	071113–071119
KFM02B:4	410–431	2.0 E–5*	Not included in /26/	071119–071123
KFM03A:4	633.5–650	2.4 E–6*	Zone ZFMB1	071119–071126
KFM04A:4	230–245	2.0 E–5*	Zone ZFMA2	071116–071120
KFM05A:4	254–272	1.4 E–8*	Single fracture, Fracture domain FFM01	080108–080115
KFM06A:3	738–748	1.2 E–7*	Zone ZFMNNE0725	080125–080129
KFM06A:5	341–362	3.5 E–6*	Zone ZFMB7, Zone ZFMENE0060A	080118–080125
KFM06C:3	647–666	5.3 E–8*	Possible DZ (S-NNE/WNW)	080118–080125
KFM06C:5	531–540	1.1 E–6*	Zone ZFMWNW044	080125–080129
KFM07A:2	962–972	5.0 E–7*	Zone ZFMB8, Zone ZFMNNW0100	Not measured
KFM08A:2	684–694	1.0 E–6*	Possible DZ (S-WNW)	080129–080204
KFM08A:6	265–280	1.0 E–6*	Zone ZFMENE0061A	080201–080206
KFM08D:2	825–835	2.0 E–8*	Not included in /26/	080201–080206
KFM08D:4	660–680	2.0 E–7*	Not included in /26/	080128–080206
KFM10A:2	430–440	3.0 E–5*	Zone ZFMA2	071109–071113
KFM11A:2	690–710	1.0 E–6*	Not included in /26/	080128–080201
KFM11A:4	446–456	6.0 E–7*	Not included in /26/	080122–080128
KFM12A:3	270–280	1.0 E–6*	Not included in /26/	080204–080208
HFM01:2	33.5–45.5	4.0 E–5**	Zone ZFMA2	080122–080128
HFM02:2	38–48	5.9 E–4**	Zone ZFM1203	080114–080118
HFM04:2	58–66	7.9 E–5**	Zone ZFM866	071113–071119
HFM13:1	159–173	2.9 E–4**	Zone ZFMENE0401A	071109–071113
HFM15:1	85–95	1.0 E–4**	Zone ZFMA2	080128–080201
HFM16:2	54–67	3.5 E–4**	Zone ZFMA8	080121–080125
HFM19:1	168–182	2.7 E–4**	Zone ZFMA2	080114–080118
HFM21:3	22–32	4.0 E–5**	Single fracture, Fracture domain FFM02	080109–080114
HFM27:2	46–58	4.0 E–5**	Zone ZFM1203	080204–080208

* From PSS (Pipe String System) or PFL (Posiva Flow Logging) measurements, /1/ to /17/.

** From HTHB (HydroTester HammarBorrhål) measurements, /18/ to /24/.

*** Deformation zones according to Forsmark, stage 2.2, /26/.

tracer Uranine. The reason for choosing a different tracer is the high background concentration of Uranine in many borehole sections due to remainders in the aquifer of Uranine labeled flushing water used for drilling.

The tracer was injected during a time period equivalent to the time needed to circulate one section volume. The injection/circulation flow ratio was set to 1/1,000, implying that the start concentration in the borehole section would be about 1.0 mg/l for Amino-G acid and about 0.5 mg/l for Uranine. Five sections were injected simultaneously. The tracer solution was continuously circulated and sampled using the equipment described in Section 3.1. After completion of each test, at least three section volumes were pumped from the measured section in order to remove the remaining tracer.

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

4.4 Analyses and interpretations

Flow rates were calculated from the decay of tracer concentration versus time through dilution with natural, unlabelled groundwater, cf. /27/. The so-called "dilution curves" were plotted as the natural logarithm of concentration versus time. Theoretically, a straight-line relationship exists between the natural logarithm of the relative tracer concentration (c/c_0) and time, t (s):

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

where Q_{bh} (m^3/s) is the groundwater flow rate through the borehole section and V (m^3) is the 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 4–10 ml/h also creates a dilution of tracer. The sampling flow rate is therefore subtracted from the value obtained from Equation 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 practice, a 90° 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 are roughly estimated from Darcy´s law where the gradient, I, is calculated as the function of the Darcy velocity, v, with the hydraulic conductivity, K (m/s):

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

where T_{bh} (m^2/s) is the transmissivity of the section, obtained from PSS or HTHB measurements, A the cross section area between the packers and d_{bh}, (m) the borehole diameter.

The factor α is commonly given the value 2 in the calculations, which is the theoretical value for a homogeneous porous medium. Since the rock mostly is heterogeneous and the angles in the sections not always 90°, the calculation of the hydraulic gradient is a rough estimation.

4.5 Nonconformities

Borehole sections KFM03A:1 (969.5–9994.5 m), KFM07A:2 (962–972 m) and HFM32:3 (26–31 m), included in the monitoring program and listed in the Activity Plan (AP PF 400-07-043), were for different reasons not measured.

Previous test campaigns have shown that borehole section KFM03A:1 is very difficult or even impossible to circulate and borehole HFM32 is situated on a small island with no electric power which makes measurement more difficult to perform. Groundwater flow has also been measured quite frequently in HFM32:3 during the last years. It was therefore decided to exclude these two sections from the test campaign this time.

Borehole section KFM07A:2 (962–972 m) was not possible to circulate and could therefore not be measured. Even if a very slow circulation rate (3–4 l/h) was used, it was not possible to maintain circulation of the section water more than a few hours. The reason for this may be the large depth and gasification combined with quite low transmissivity. Also, the section has a large volume (about 70 litres) and long tubing which decreases the circulation capacity of the pump.

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 PF 400-07-043). 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.

A summary of the results obtained is presented in Table 5-1 including measured groundwater flow rates, Darcy velocities and hydraulic gradients together with transmissivities and volumes used. Also, a comparison with flow rates obtained from previously performed measurements during natural gradient is compiled in Table 5-2.

In Figure 5-1 an example of a typical tracer dilution curve is shown. The flow rate is calculated from the slope of the straight-line fit. Tracer dilution graphs for each borehole section are presented in Appendix 1. In Appendix 2 the groundwater level during the entire test period is shown for the selected boreholes, see also Table 4-1 for actual measurement period for each section.

The results show that the groundwater flow during natural conditions varies from 0.04 to 91 ml/min in the measured sections with Darcy velocities ranging from $2.9 \cdot 10^{-10}$ to $4.9 \cdot 10^{-7}$ m/s.

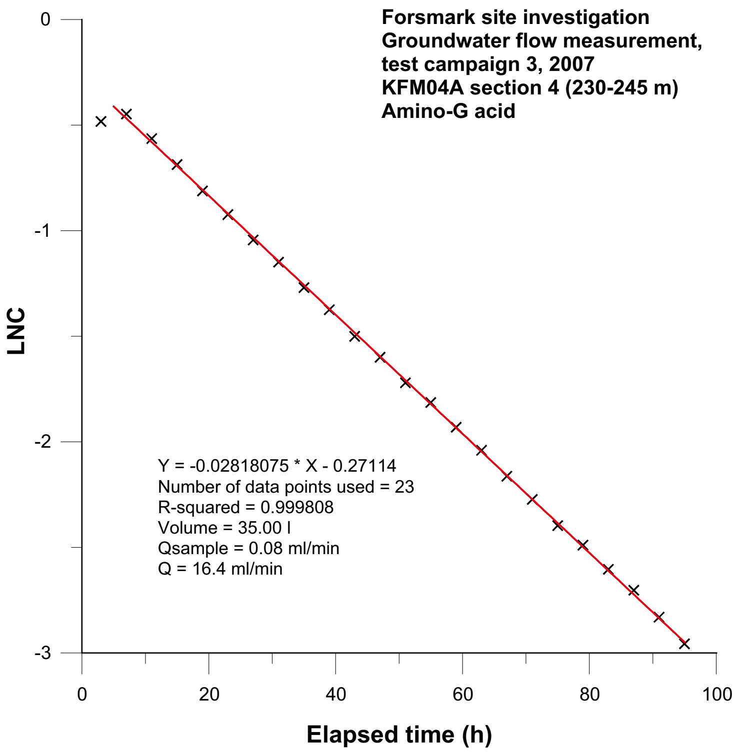

***Figure 5-1.** Example of a tracer dilution graph (logarithm of concentration versus time) for borehole KFM04, section 4, including straight-line fit.*

Table 5-1. Results from groundwater flow measurements, test campaign 3, 2007. Darcy velocity and hydraulic gradient are calculated from Amino-G data.

Borehole:section	Depth (m)	Transmissivity (m^2/s)	Vol. (l)	Measured flow (ml/min) Amino-G	Uranine	Darcy velocity (m/s)	Hydraulic gradient (m/m)
KFM01A:5	109–130	1.0 E–7*	33.21	0.2	–	1.0 E–9	0.21
KFM01D:2	429–438	8.0 E–7*	38.33	0.3	–	3.2 E–9	0.037
KFM01D:4	311–321	2.0 E–7*	31.21	0.2	–	1.7 E–9	0.087
KFM02A:3	490–518	2.1 E–6*	66.33	0.8	1.7	3.2 E–9	0.043
KFM02A:5	411–442	2.5 E–6*	60.78	0.7	0.7	2.5 E–9	0.031
KFM02B:2	491–506	3.0 E–5*	48.63	4.6	4.5	3.4 E–8	0.017
				16.4	16.4	1.2 E–7	0.060
KFM02B:4	410–431	2.0 E–5*	47.58	23	19	1.2 E–7	0.13
KFM03A:4	633.5–650	2.4 E–6*	58.04	0.6	1.0	4.0 E–9	0.028
KFM04A:4	230–245	2.0 E–5*	35.00	16.4	16.3	1.2 E–7	0.089
KFM05A:4	254–272	1.4 E–8*	40.62	0.1	–	7.7 E–10	0.99
KFM06A:3	738–748	1.2 E–7*	58.25	0.2	–	2.1 E–9	0.17
KFM06A:5	341–362	3.5 E–6*	46.64	5.7	–	2.9 E–8	0.18
KFM06C:3	647–666	5.3 E–8*	64.00	0.05	–	2.9 E–10	0.10
KFM06C:5	531–540	1.1 E–6*	43.61	0.2	–	2.4 E–9	0.020
KFM08A:2	684–694	1.0 E–6*	55.15	0.8	–	9.0 E–9	0.045
KFM08A:6	265–280	1.0 E–6*	34.67	0.2	–	1.3 E–9	0.019
KFM08D:2	825–835	2.0 E–8*	63.44	2.6	–	2.8 E–8	14
KFM08D:4	660–680	2.0 E–7*	64.13	91	–	4.9 E–7	49
KFM10A:2	430–440	3.0 E–5*	39.52	2.7	2.6	2.9 E–8	0.010
KFM11A:2	690–710	1.0 E–6*	68.91	0.2	–	1.3 E–9	0.027
KFM11A:4	446–456	6.0 E–7*	40.47	0.04	–	4.5 E–10	0.0074
KFM12A:3	270–280	1.0 E–6*	31.76	0.3	–	3.4 E–9	0.034
HFM01:2	33.5–45.5	4.0 E–5**	39.83	7.8	–	3.9 E–8	0.012
HFM02:2	38–48	5.9 E–4**	28.53	33	–	2.0 E–7	0.0034
HFM04:2	58–66	7.9 E–5**	27.52	0.8	0.8	5.7 E–9	0.0006
HFM13:1	159–173	2.9 E–4**	39.28	12.6	16.4	5.6 E–8	0.0027
HFM15:1	85–95	1.0 E–4**	35.74	8.5	–	5.1 E–8	0.0051
HFM16:2	54–67	3.5 E–4**	43.61	1.0	–	4.7 E–9	0.0002
HFM19:1	168–182	2.7 E–4**	44.65	24	–	1.1 E–7	0.0055
HFM21:3	22–32	4.0 E–5**	31.39	1.9	–	1.1 E–8	0.0029
HFM27:2	46–58	4.0 E–5**	40.29	0.5	–	2.5 E–9	0.0008

* From PSS (Pipe String System) or PFL (Posiva Flow Logging) measurements, /1/ to /10/, /12/ to /17/.

** From HTHB (HydroTester HammarBorrhål) measurements, /18/ to /24/.

Hydraulic gradients are calculated according to the Darcy concept and are within the expected range in the majority of the measured sections. It should be noted that the Darcy concept is built on assumptions of a homogeneous porous medium and values for fractures should therefore be treated with great care. In KFM01A:5, KFM05A:4 and in both sections measured in KFM06A and in KFM08D, the hydraulic gradient is considered to be very large. In KFM05A:4 the groundwater level is decreased about 1 m during the test, as seen in Appendix 2, which may have affected the flow rate and calculated hydraulic gradient. In KFM08D:4 the measured flow rate is much higher than expected from the transmissivity and may not really be accurate due to pump problems, as discussed further below. The large gradients may also be due to wrong estimates of the correction factor, α, and/or the hydraulic conductivity of the fracture. KFM05A:4 and KFM01A:5 also represent single fractures (cf. Table 4-1) where the Darcy concept may be questioned.

The comparison in Table 5-2 shows relatively small changes in most of the 18 sections where previous measurements have been performed. Only one section, KFM06A:5, demonstrates a significantly increased flow, whereas four sections, KFM05A:4, KFM06C:3, KFM10A:2 and HFM04:2 display significantly decreased flow (more than a factor 2).

Table 5-2. Results from groundwater flow measurements in November 2007/January–February 2008 compared with results from earlier performed measurements (natural gradient).

Borehole:section	Depth (m)	T (m^2/s)	Nov–Dec 2005 /28/ (ml/min)	Jun–Jul 2006 /29/ (ml/min)	Nov 2006 /30/ (ml/min)	Jun 2007 /31/ (ml/min)	Nov/Jan 2007-08 (ml/min)
KFM01A:5	109–130	1.0 E–7*	–	–	0.1	–	0.2
KFM01D:2	429–438	8.0 E–7*	–	–	–	–	0.3
KFM01D:4	311–321	2.0 E–7*	–	–	–	–	0.2
KFM02A:3	490–518	2.1 E–6*	2.1	2.0	0.8	–	0.8
KFM02A:5	411–442	2.5 E–6*	1.0	0.5	0.4	–	0.7
KFM02B:2	491–506	3.0 E–5*	–	–	–	–	4.6
KFM02B:4	410–431	2.0 E–5*	–	–	–	–	23
KFM03A:4	633.5–650	2.4 E–6*	0.5	–	0.5	–	0.6
KFM04A:4	230–245	2.0 E–5*	–	–	–	–	16.4
KFM05A:4	254–272	1.4 E–8*	0.5	1.5	1.4	–	0.1
KFM06A:3	738–748	1.2 E–7*	0.3	0.8	0.6	–	0.2
KFM06A:5	341–362	3.5 E–6*	0.5	0.4	0.6	–	5.7
KFM06C:3	647–666	5.3 E–8*	–	–	0.4	–	0.05
KFM06C:5	531–540	1.1 E–6*	–	–	0.3	–	0.2
KFM08A:2	684–694	1.0 E–6*	–	–	–	–	0.8
KFM08A:6	265–280	1.0 E–6*	–	–	–	–	0.2
KFM08D:2	825–835	2.0 E–8*	–	–	–	–	2.6
KFM08D:4	660–680	2.0 E–7*	–	–	–	–	91
KFM10A:2	430–440	3.0 E–5*	–	–	–	10.0	2.7
KFM11A:2	690–710	1.0 E–6*	–	–	–	–	0.2
KFM11A:4	446–456	6.0 E–7*	–	–	–	–	0.04
KFM12A:3	270–280	1.0 E–6*	–	–	–	–	0.3
HFM01:2	33.5–45.5	4.0 E–5**	–	–	–	7.8	7.8
HFM02:2	38–48	5.9 E–4**	38	21	8.9–38	–	33
HFM04:2	58–66	7.9 E–5**	2.2	–	10.4	–	0.8
HFM13:1	159–173	2.9 E–4**	24	8.3	4.3	7.1	12.6
HFM15:1	85–95	1.0 E–4**	0.8	1.4	5.2	2.6	8.5
HFM16:2	54–67	3.5 E–4**	–	–	1.6–6.6	–	1.0
HFM19:1	168–182	2.7 E–4**	9.7	6.2	3.4	12.6	24
HFM21:3	22–32	4.0 E–5**	–	–	–	–	1.9
HFM27:2	46–58	4.0 E–5**	–	–	0.4	–	0.5

* From PSS (Pipe String System) or PFL (Posiva Flow Logging) measurements, /1/ to /10/, /12/ to /17/.

** From HTHB (HydroTester HammarBorrhål) measurements, /18/–/25/.

In general, the equipment has worked well and no major hydraulic disturbance has occurred during the tests, cf. Appendix 2. However, in KFM08D:4 a malfunctioning circulation pump had to be exchanged during the measurement period. This may have caused pressure disturbances so that the flow rate obtained is not really representative of undisturbed conditions, even if only samples taken after the exchange were used for flow rate calculation. Also, the circulation of section water and mixing of tracer into the section volume was not functioning properly until after the pump exchange. Therefore, the dilution of tracer could be more of a mixing effect instead of groundwater flow through the borehole section, why the flow rate is overestimated.

The tracer dilution graph for KFM02B:2 gives two different flow rates (Appendix 1). The early time data are believed to be influenced by the mixing procedure. Consequently, the late time slope of the dilution curve is believed to represent the most reliable data. Similar phenomena can be observed in several of the other borehole sections as well, see Appendix 1.

In HFM27 the borehole equipment was lifted for repair of a packer leakage prior to the measurement. The re-installation work was finished just an hour before measurement start, why the last part of the dilution curve probably is the most representative of natural conditions.

6 References

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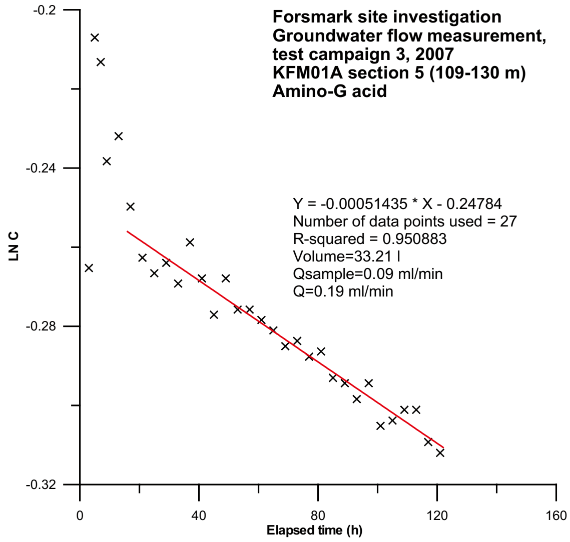
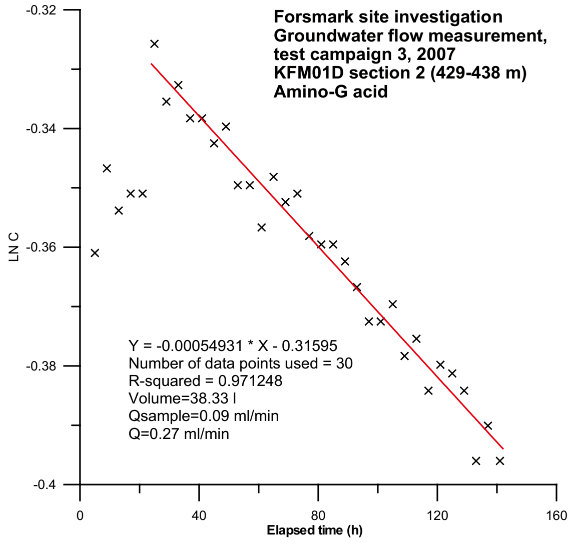
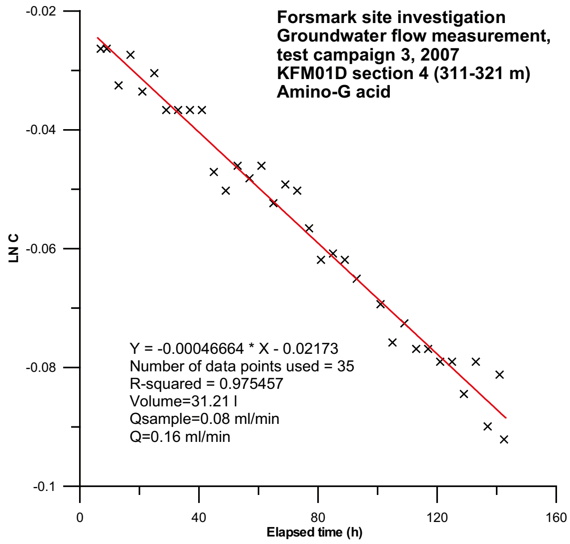
Appendix 1

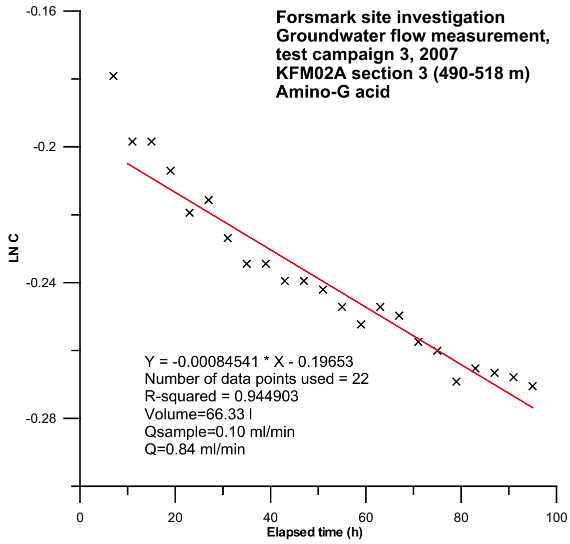
Tracer dilution graphs

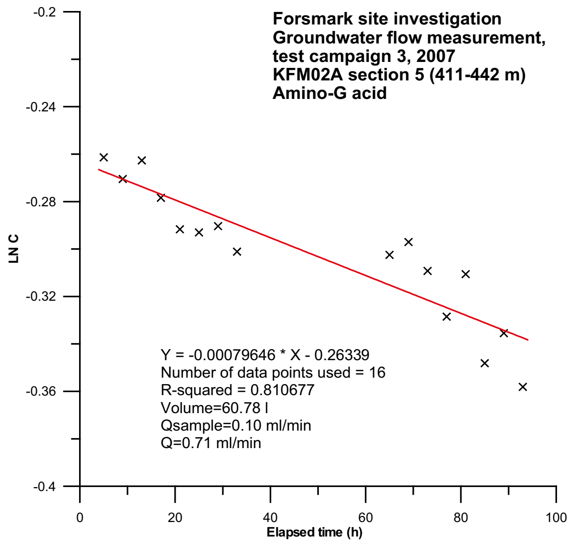
Core boreholes

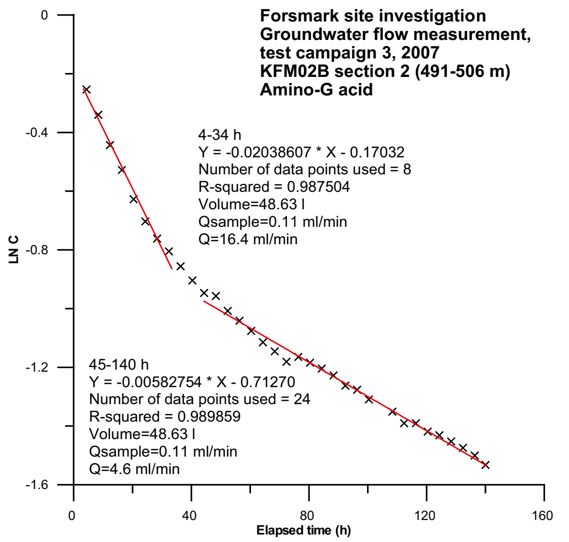


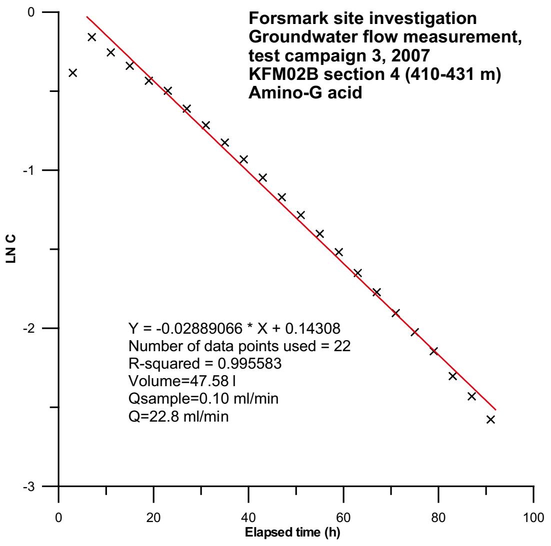








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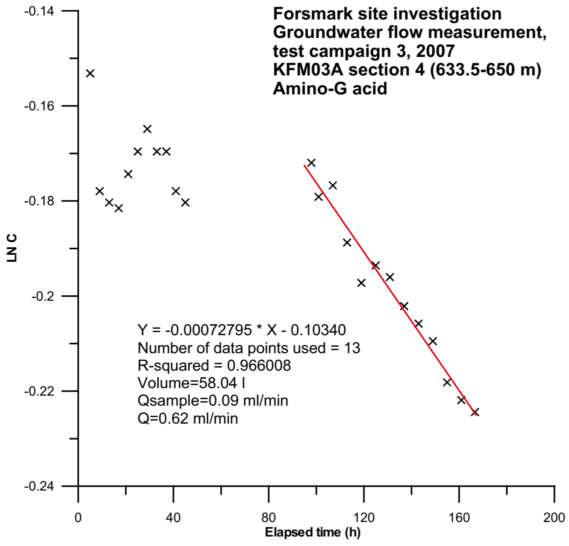
Groundwater flow measurement,
test campaign 3, 2007
KFM02B section 4 (410-431 m)
Amino-G acid
Y = -0.02889066 * X + 0.14308
Number of data points used = 22
R-squared = 0.995583
Volume=47.58 l
Qsample=0.10 ml/min
Q=22.8 ml/min
LN C
Elapsed time (h)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Groundwater flow measurement,
test campaign 3, 2007
KFM03A section 4 (633.5-650 m)
Amino-G acid
Y = -0.00072795 * X - 0.10340
Number of data points used = 13
R-squared = 0.966008
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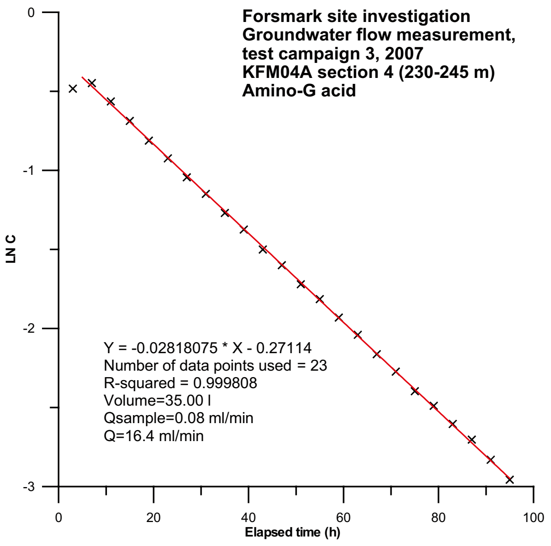
Qsample=0.09 ml/min
Q=0.62 ml/min
LN C
Elapsed time (h)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KFM04A section 4 (230-245 m)
Amino-G acid
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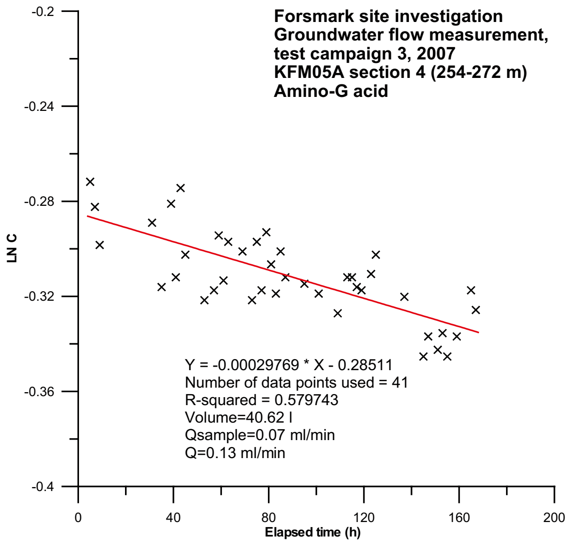
Number of data points used = 23
R-squared = 0.999808
Volume=35.00 l
Qsample=0.08 ml/min
Q=16.4 ml/min
LN C
Elapsed time (h)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KFM05A section 4 (254-272 m)
Amino-G acid
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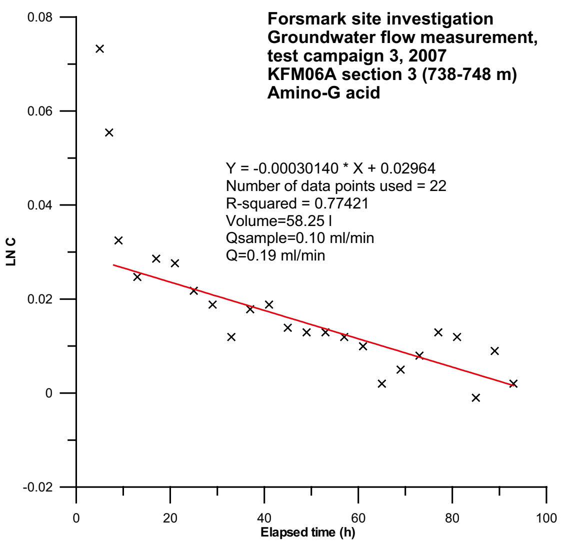
Qsample=0.07 ml/min
Q=0.13 ml/min
LN C
Elapsed time (h)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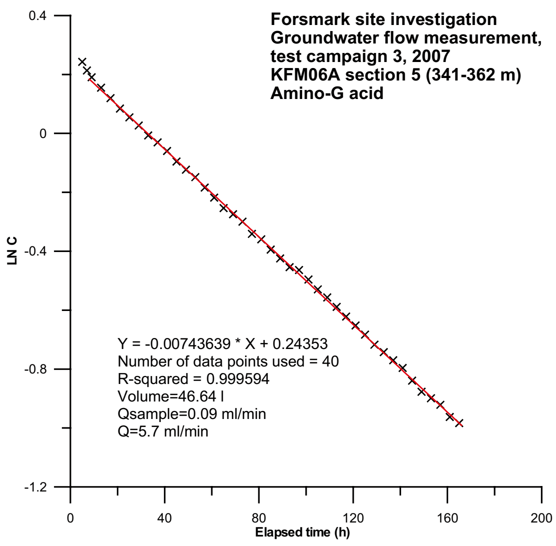
Q=0.19 ml/min
LN C
Elapsed time (h)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KFM06A section 5 (341-362 m)
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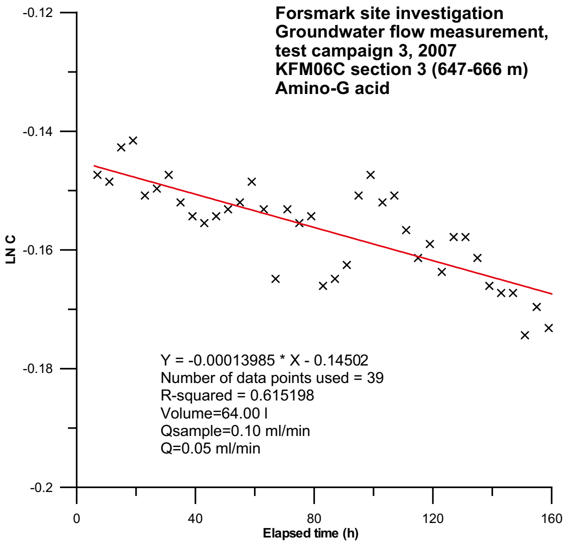
Elapsed time (h)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KFM06C section 3 (647-666 m)
Amino-G acid
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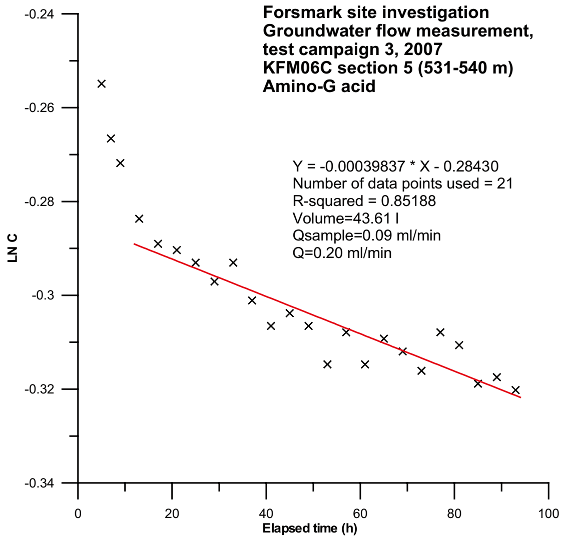
Q=0.05 ml/min
LN C
Elapsed time (h)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R-squared = 0.85188
Volume=43.61 l
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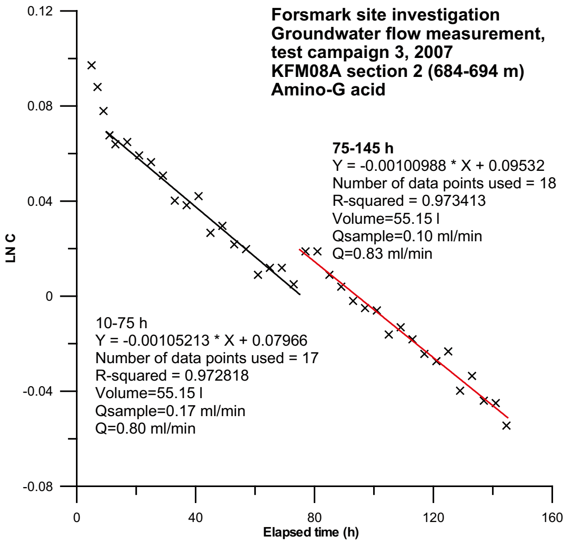
Q=0.20 ml/min
LN C
Elapsed time (h)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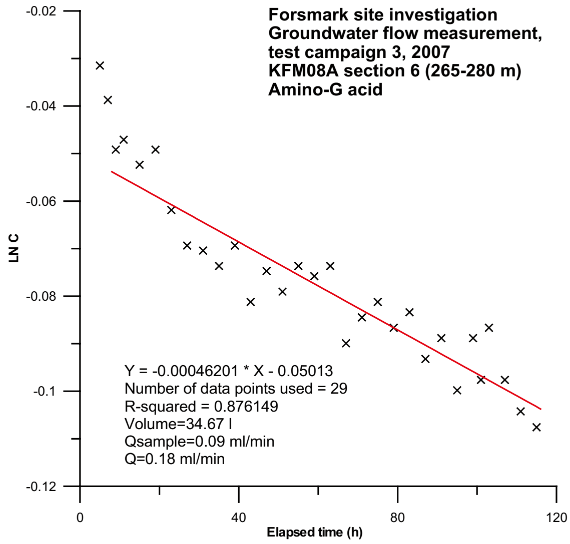
Groundwater flow measurement,
test campaign 3, 2007
KFM08A section 2 (684-694 m)
Amino-G acid
75-145 h
Y = -0.00100988 * X + 0.09532
Number of data points used = 18
R-squared = 0.973413
Volume=55.15 l
Qsample=0.10 ml/min
Q=0.83 ml/min
10-75 h
Y = -0.00105213 * X + 0.07966
Number of data points used = 17
R-squared = 0.972818
Volume=55.15 l
Qsample=0.17 ml/min
Q=0.80 ml/min
LN C
Elapsed time (h)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Groundwater flow measurement,
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KFM08A section 6 (265-280 m)
Amino-G acid
Y = -0.00046201 * X - 0.05013
Number of data points used = 29
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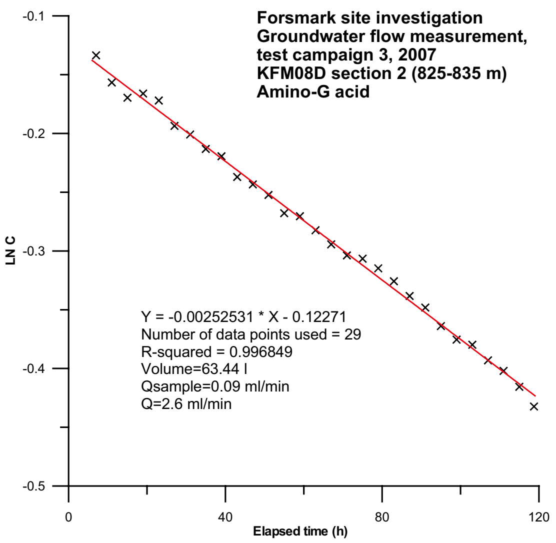
Volume=34.67 l
Qsample=0.09 ml/min
Q=0.18 ml/min
LN C
Elapsed time (h)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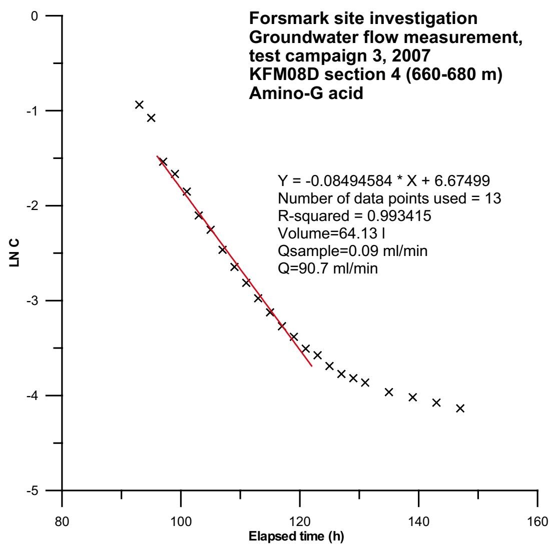
LN C
Elapsed time (h)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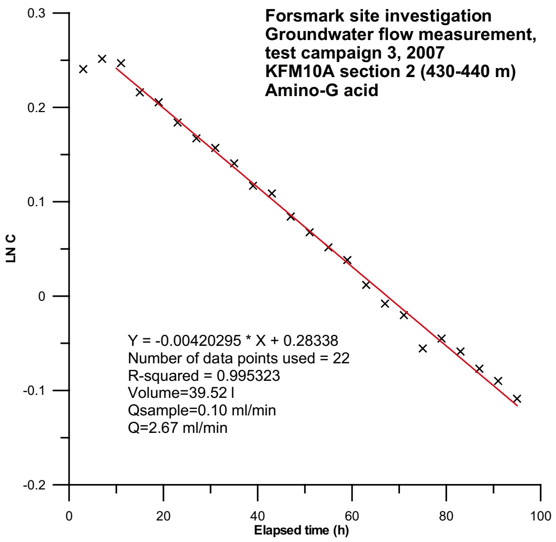
LN C
Elapsed time (h)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Amino-G acid
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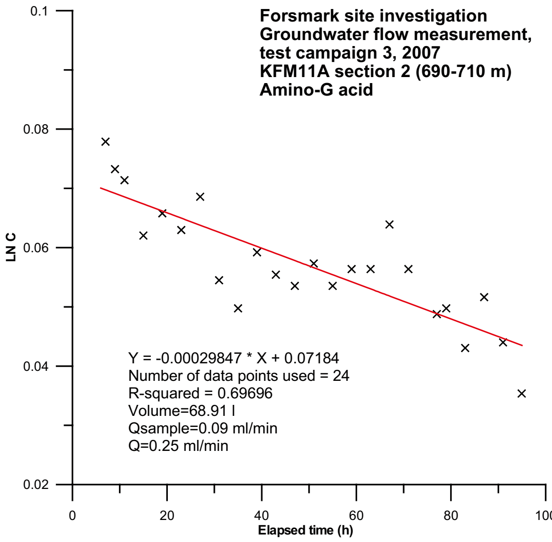
LN C
Elapsed time (h)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KFM11A section 2 (690-710 m)
Amino-G acid
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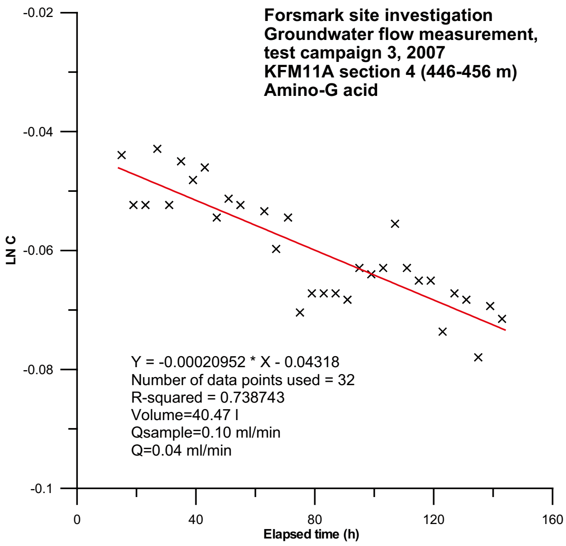
LN C
Elapsed time (h)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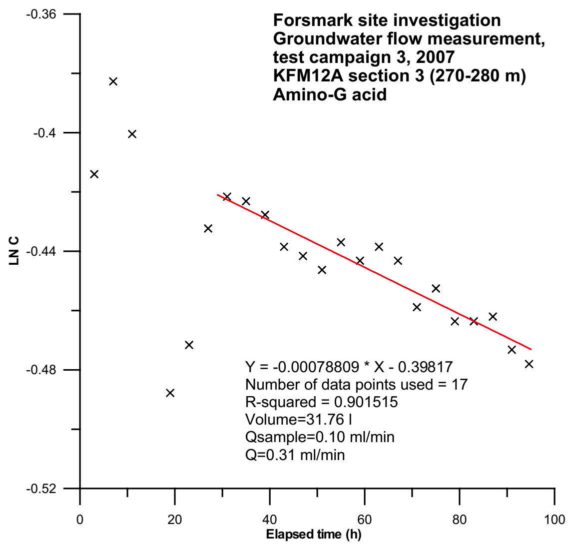
LN C
Elapsed time (h)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Groundwater flow measurement,
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Amino-G acid
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Number of data points used = 17
R-squared = 0.901515
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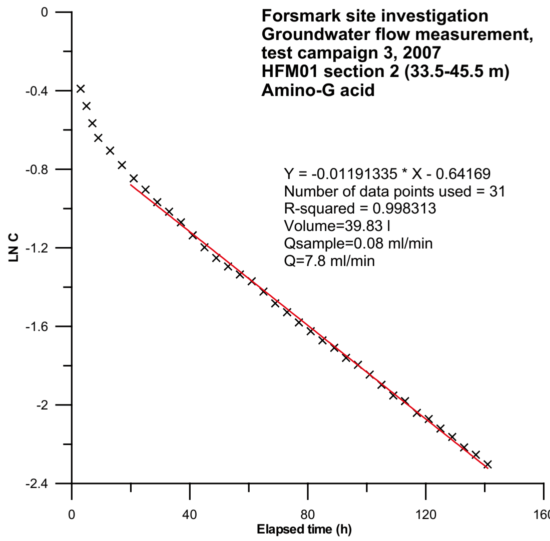
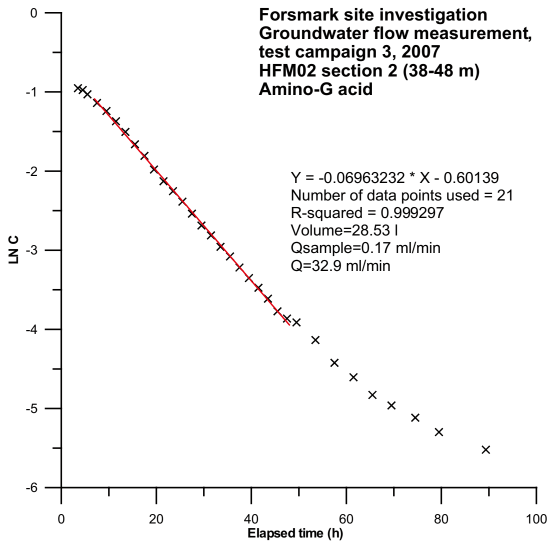
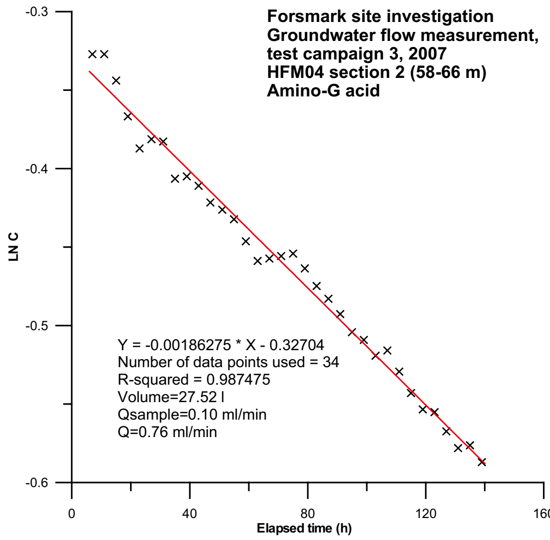
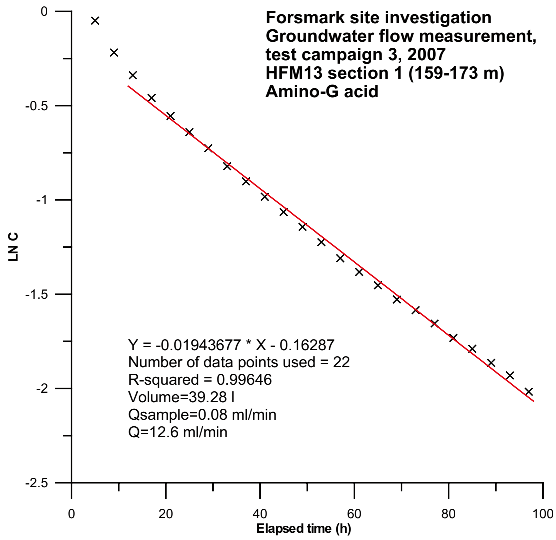
LN C
Elapsed time (h)

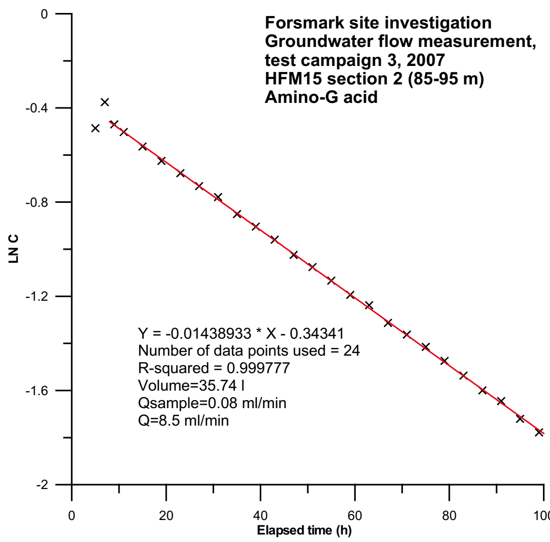
Percussion boreholes

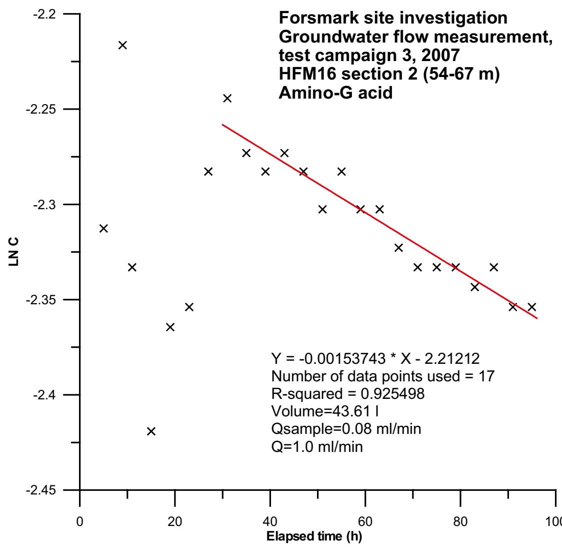










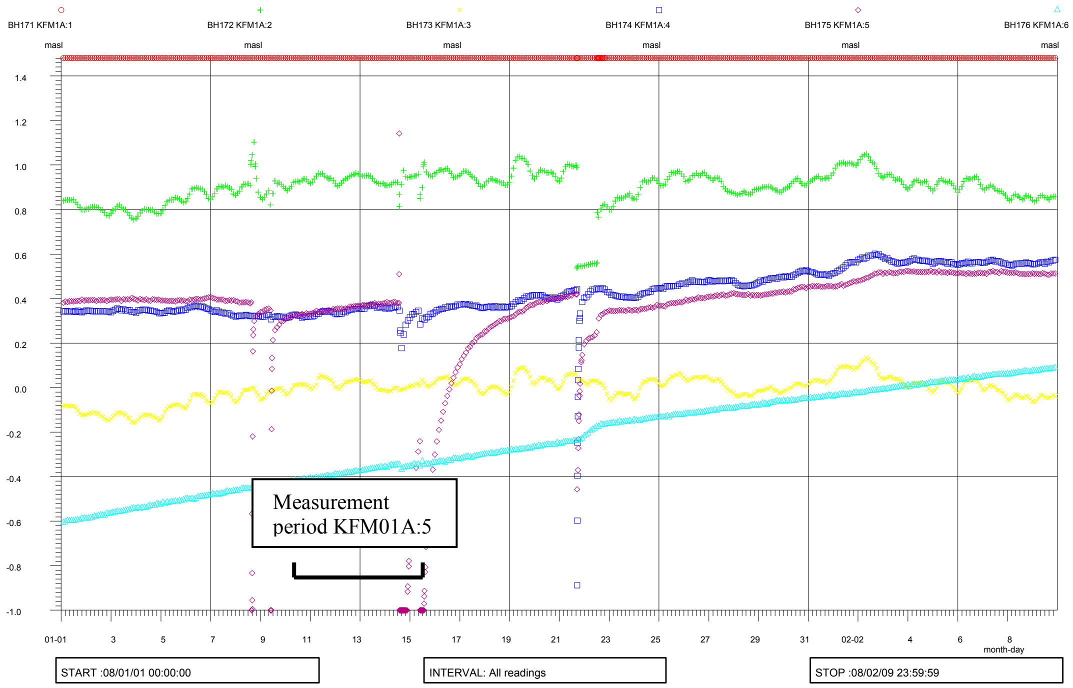


Groundwater levels (m.a.s.l.)

2007-11-01–2007-12-01. (Boreholes KFM02A, KFM02B, KFM03A, KFM04A, KFM10A, HFM04 and HFM13)

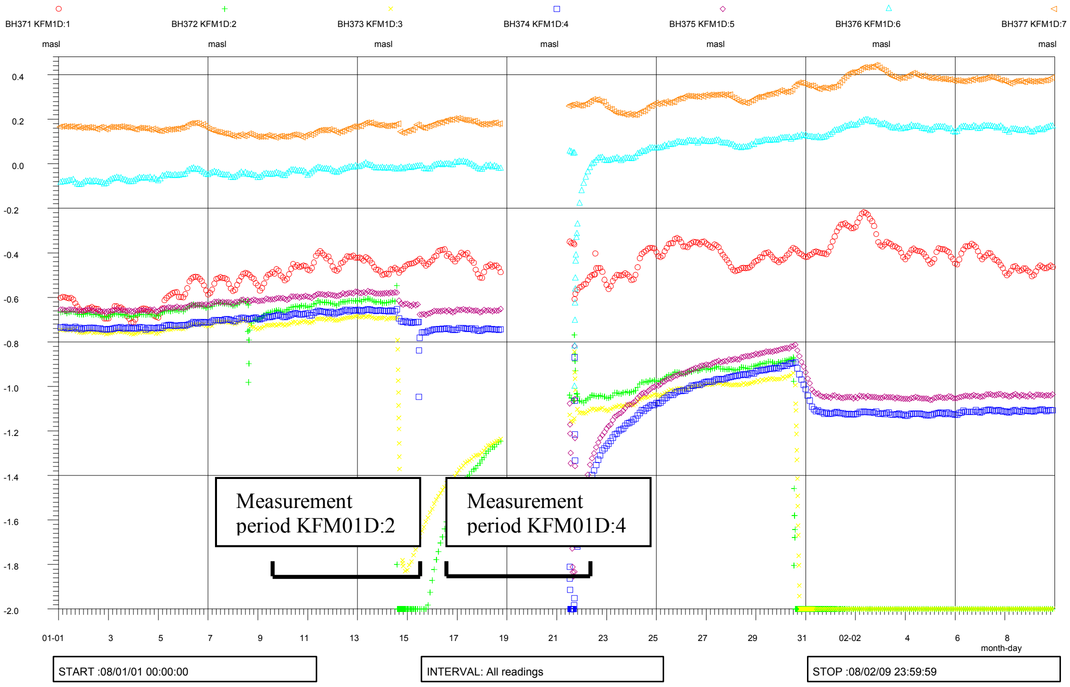
2008-01-01–2008-02-10. (Boreholes KFM01A, KFM01D, KFM05A, KFM06A, KFM06C, KFM08A, KFM08D, KFM11A, KFM12A, HFM01, HFM02, HFM15, HFM16, HFM19, HFM21 and HFM27)

KFM01A



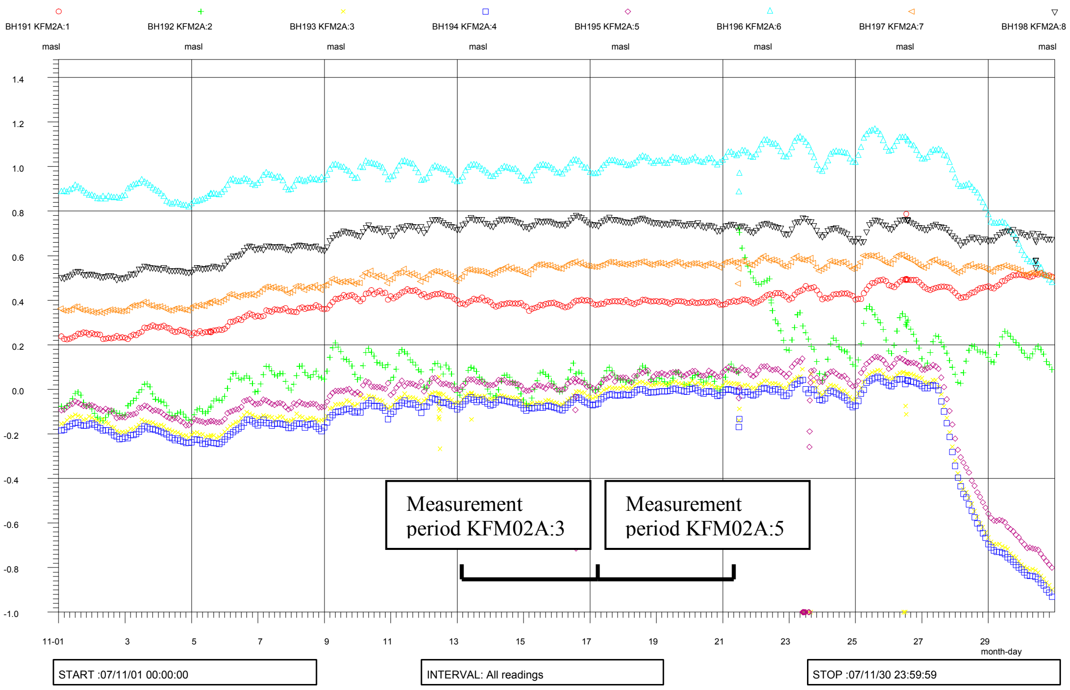
Measured section: KFM01A:5 (mauve)

KFM01D



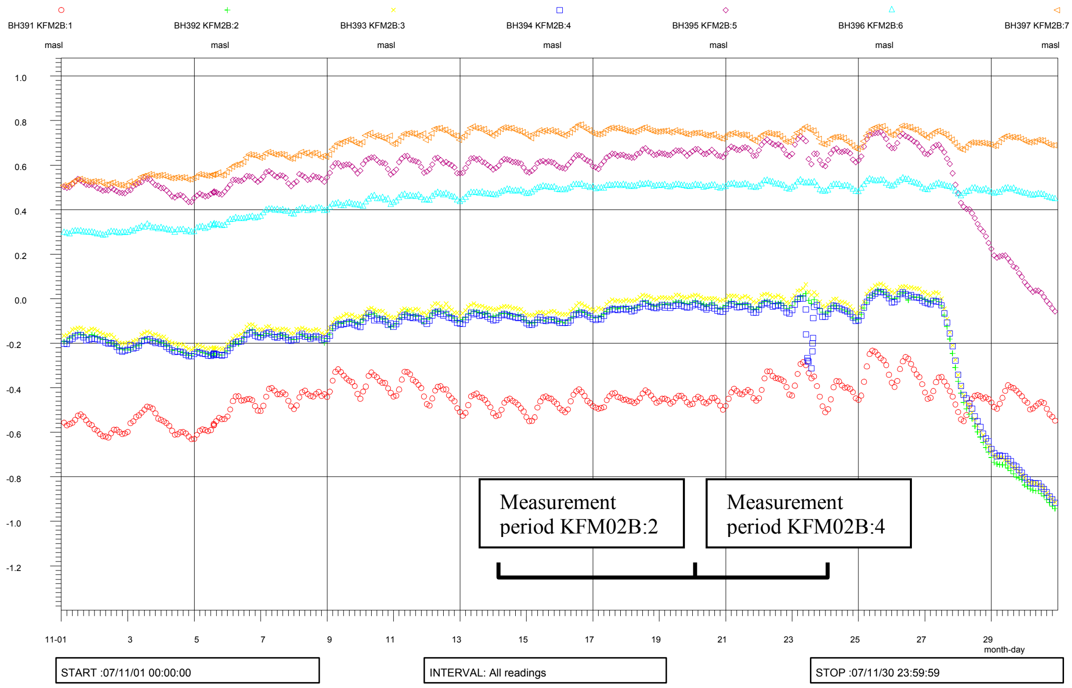
Measured sections: KFM01D:2 (green) and KFM01D:4 (dark blue)

KFM02A



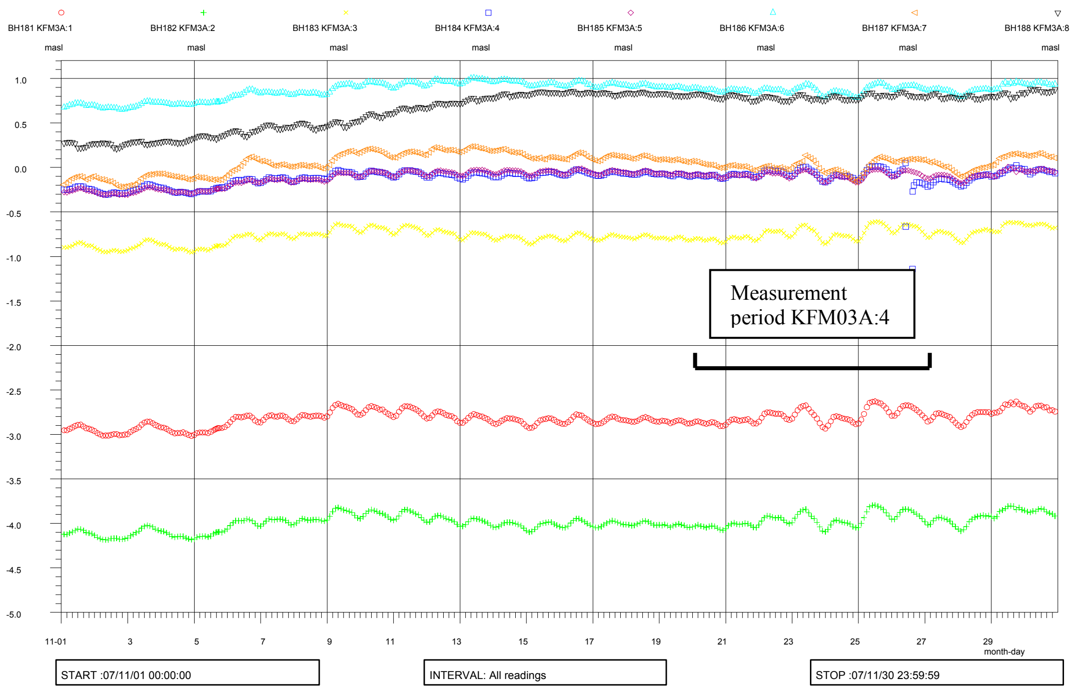
Measured sections: KFM02A:3 (yellow) and KFM02A:5 (mauve)

KFM02B



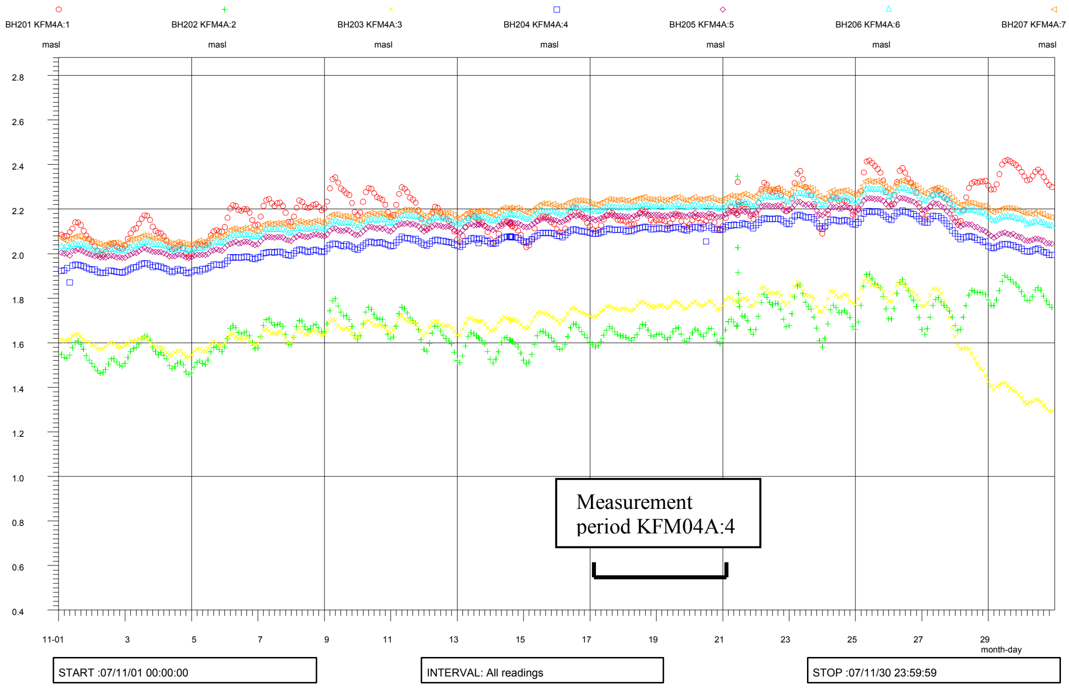
Measured sections: KFM02B:2 (green) and KFM02B:4 (dark blue)

KFM03A



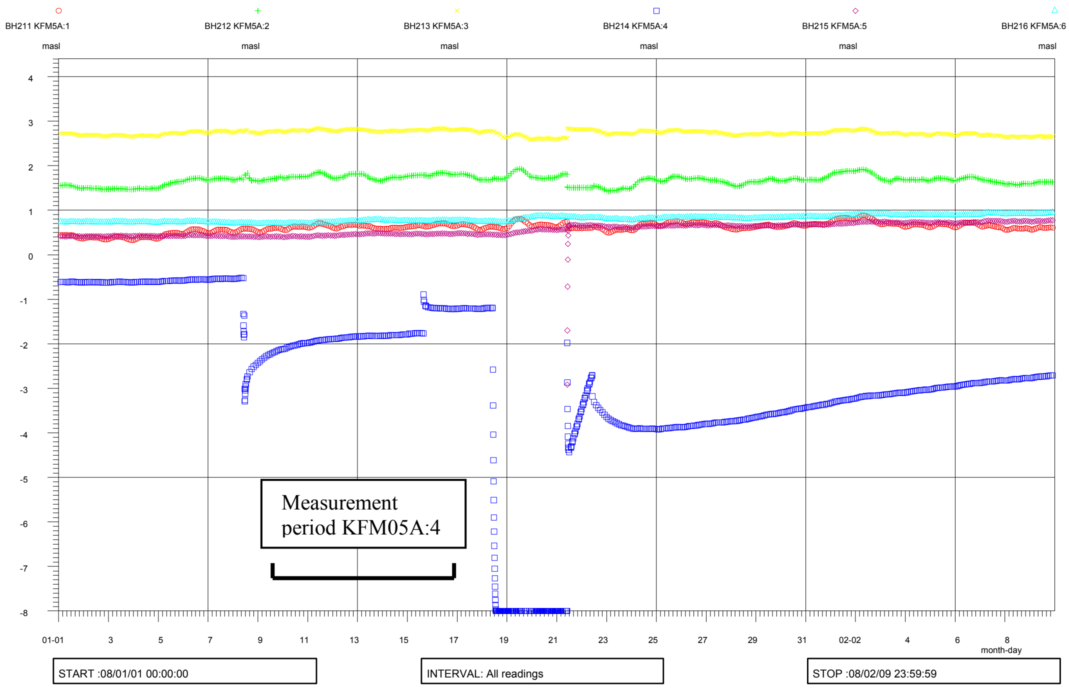
Measured section: KFM03A:4 (dark blue)

KFM04A



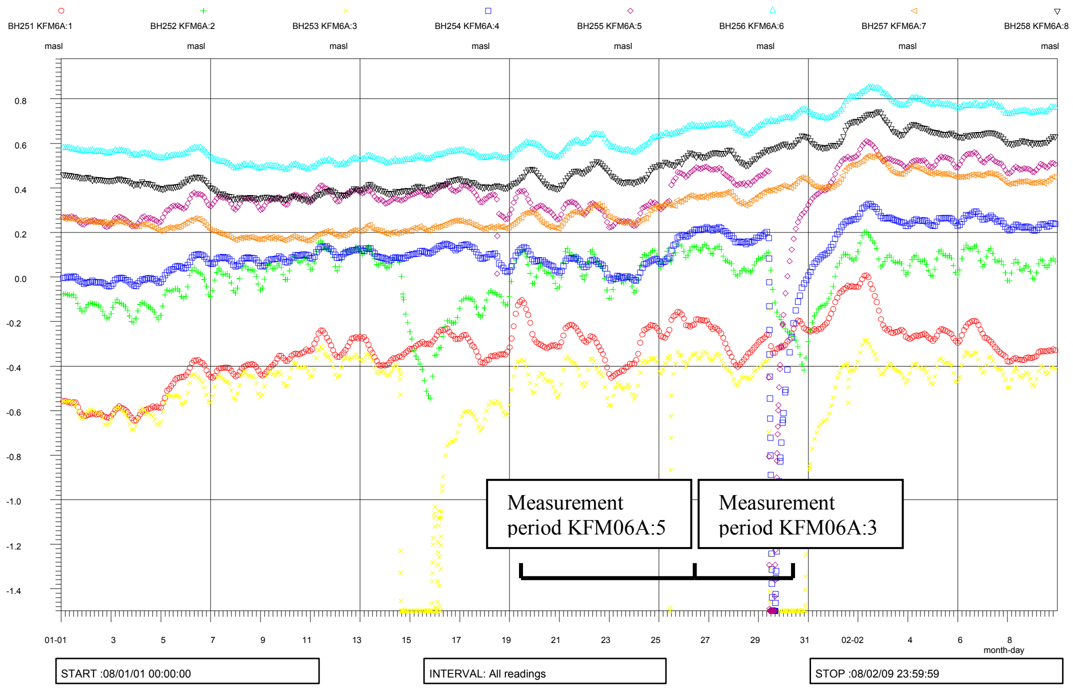
Measured section: KFM04A:4 (dark blue)

KFM05A



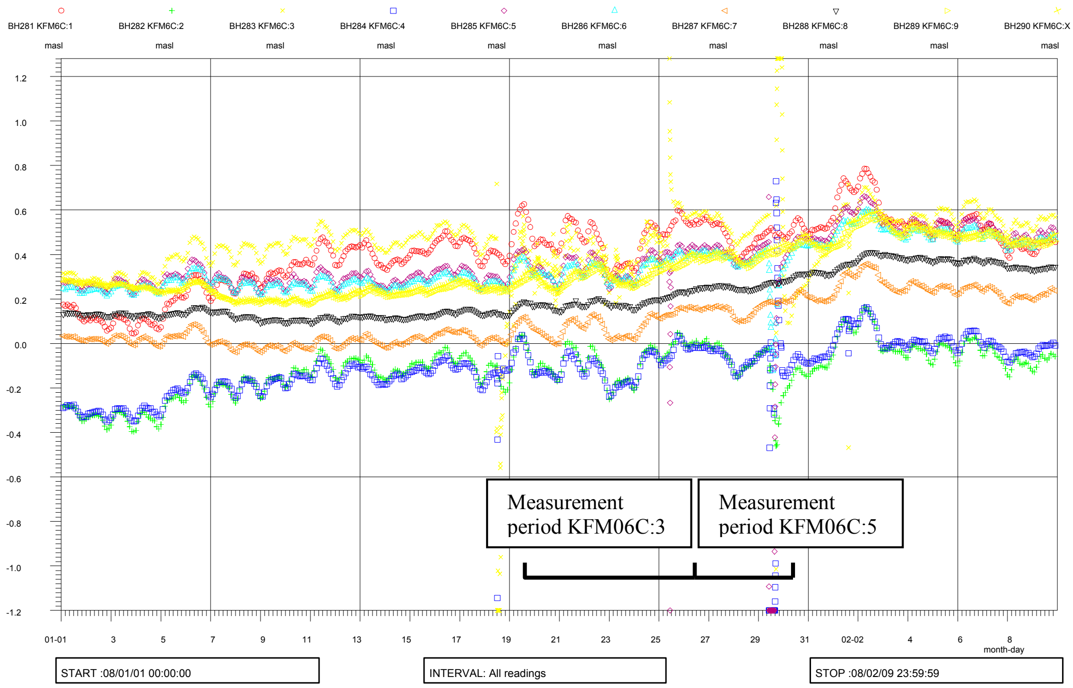
Measured section: KFM05A:4 (dark blue)

KFM06A



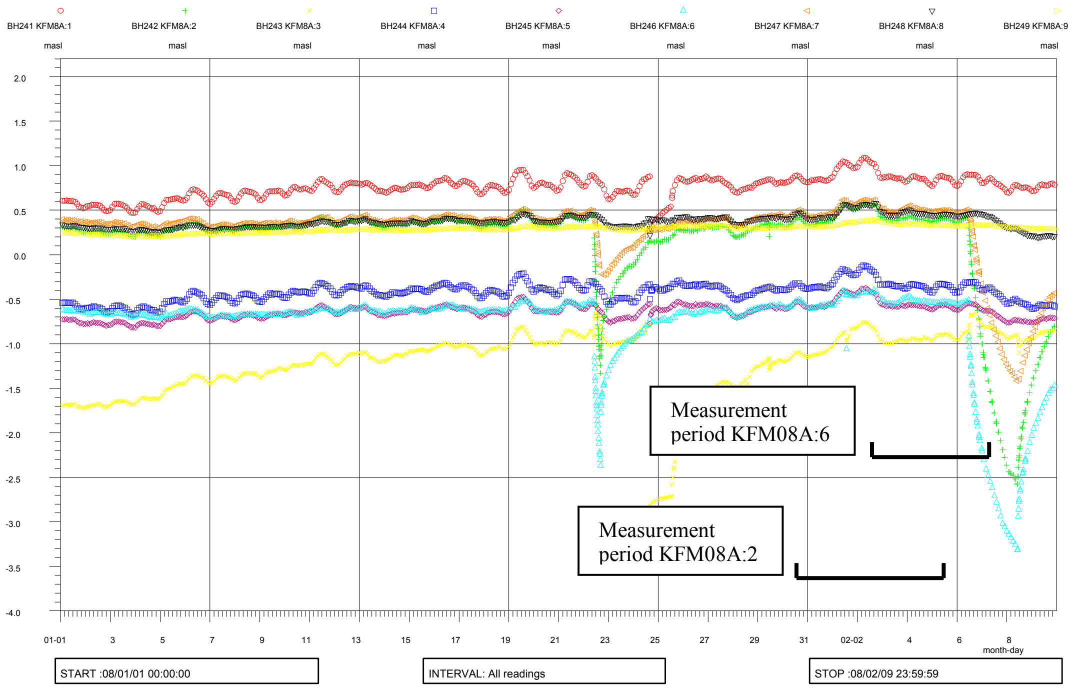
Measured sections: KFM06A:3 (yellow) and KFM06A:5 (mauve)

KFM06C



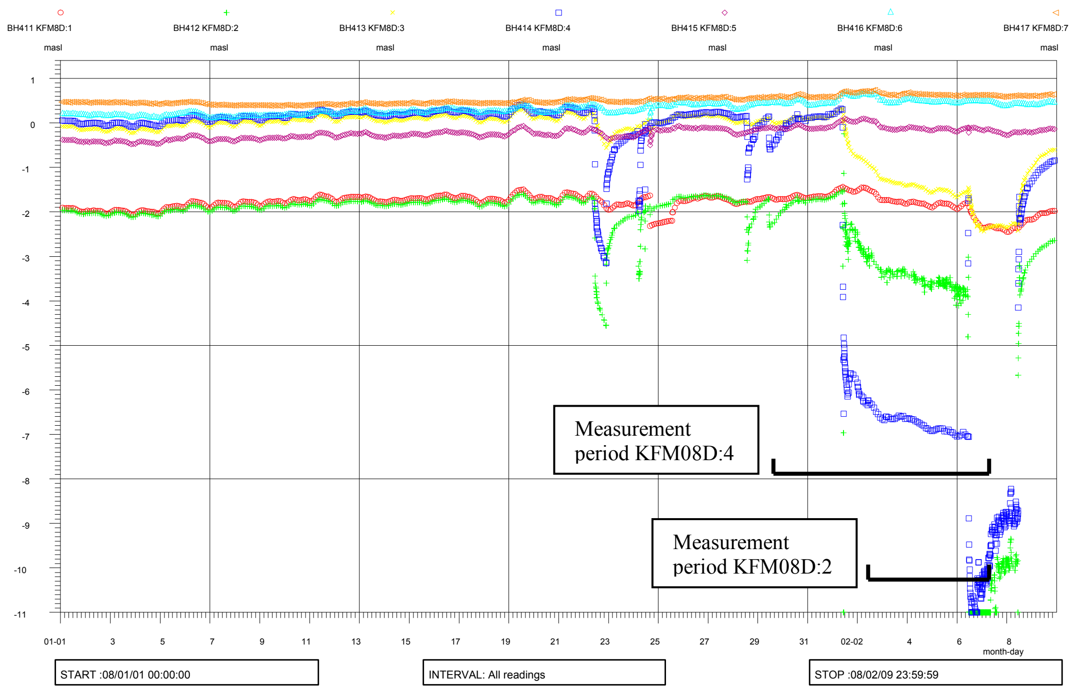
Measured sections: KFM06C:3 (yellow) and KFM06C:5 (mauve)

KFM08A



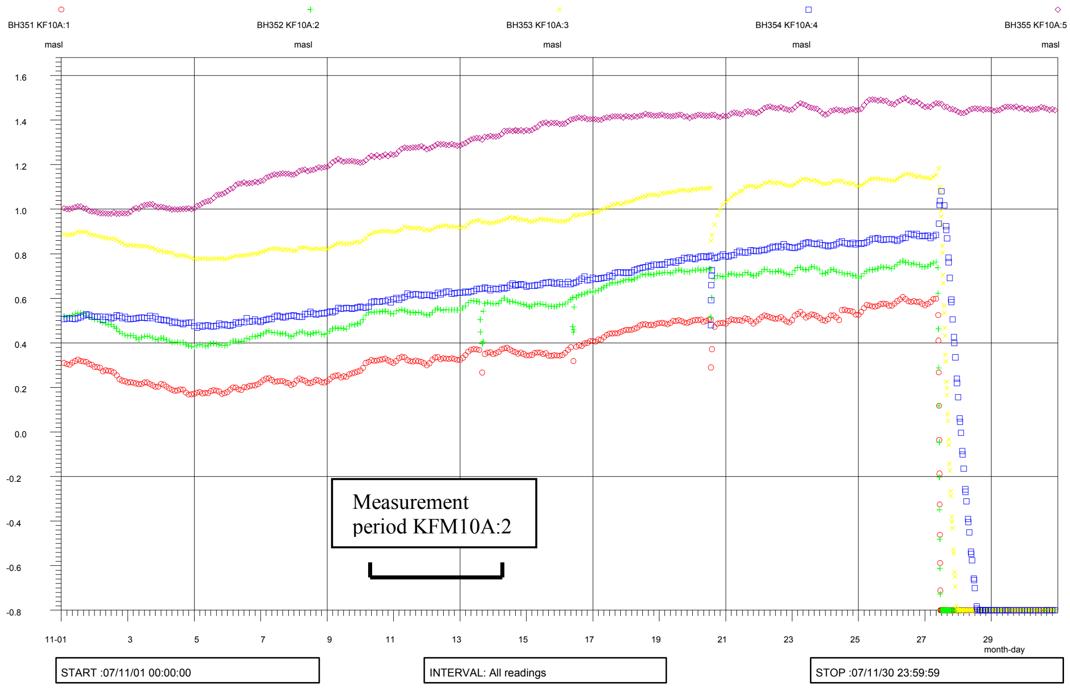
Measured sections: KFM08A:2 (green) and KFM08A:6 (pale blue)

KFM08D



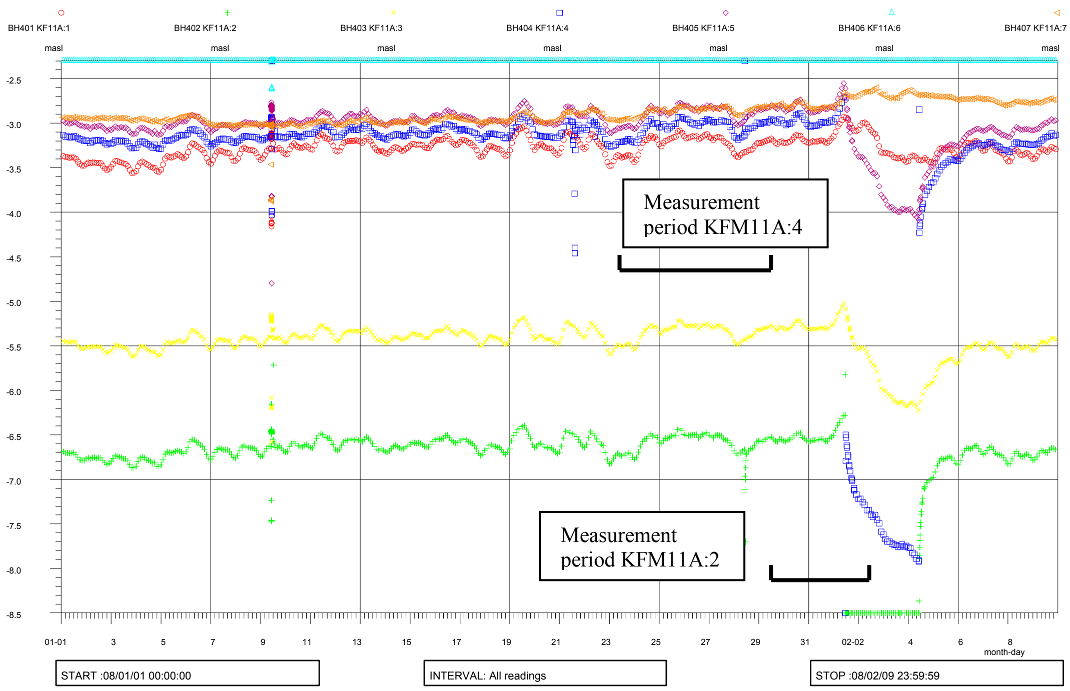
Measured sections: KFM08D:2 (green) and KFM08D:4 (dark blue)

KFM10A



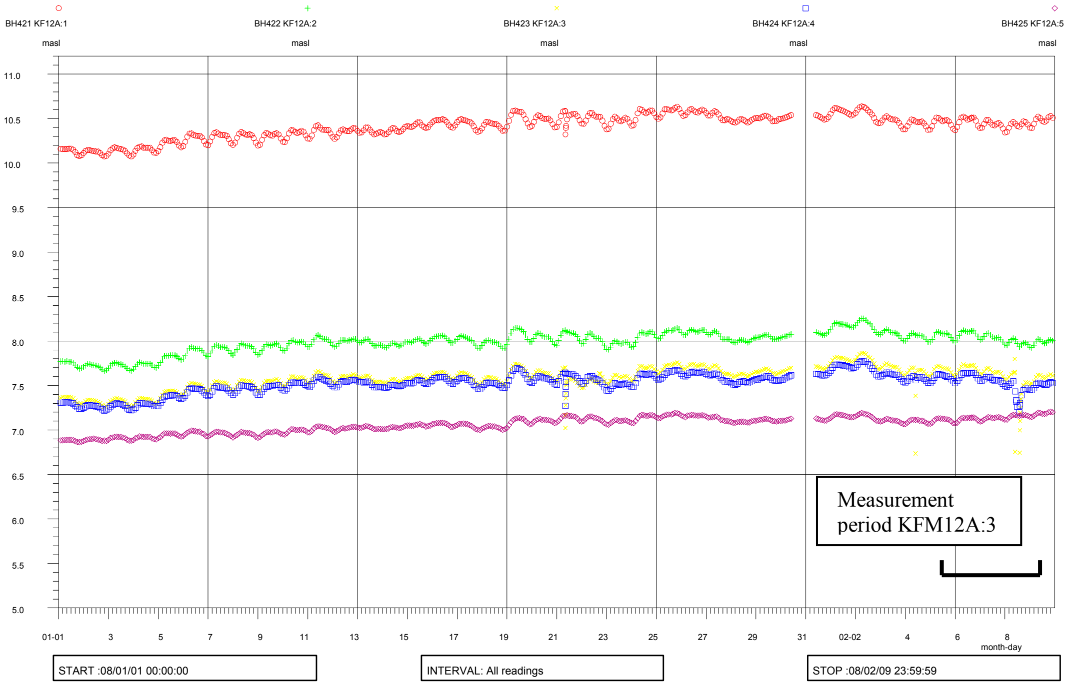
Measured section: KFM10A:2 (green)

KFM11A



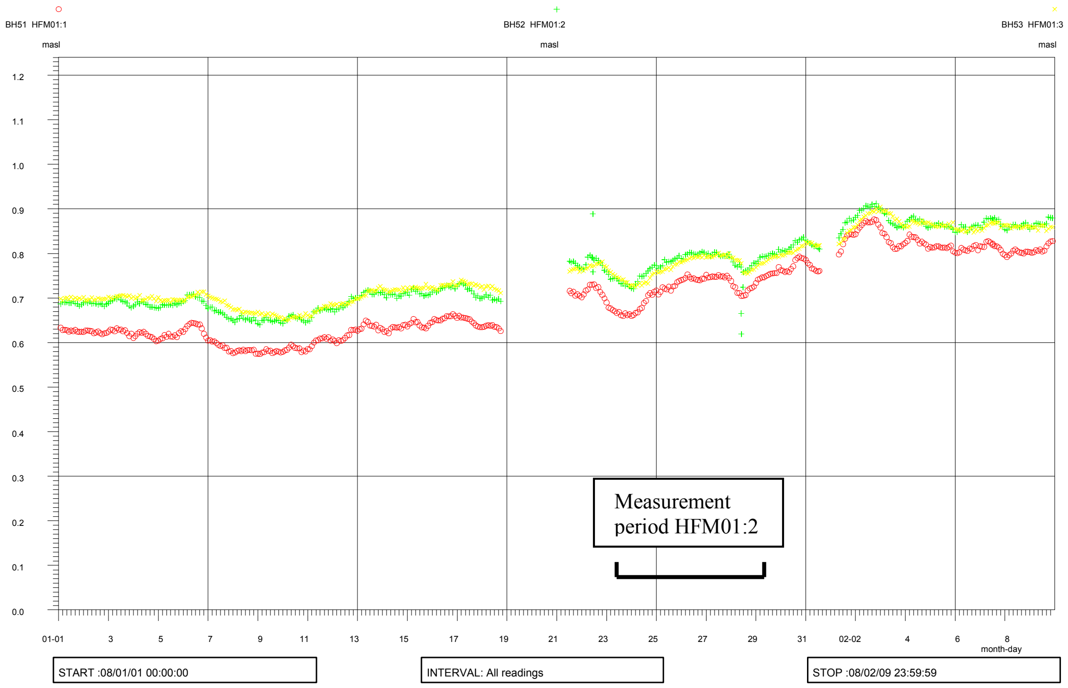
Measured sections: KFM11A:2 (green) and KFM11A:4 (dark blue)

KFM12A



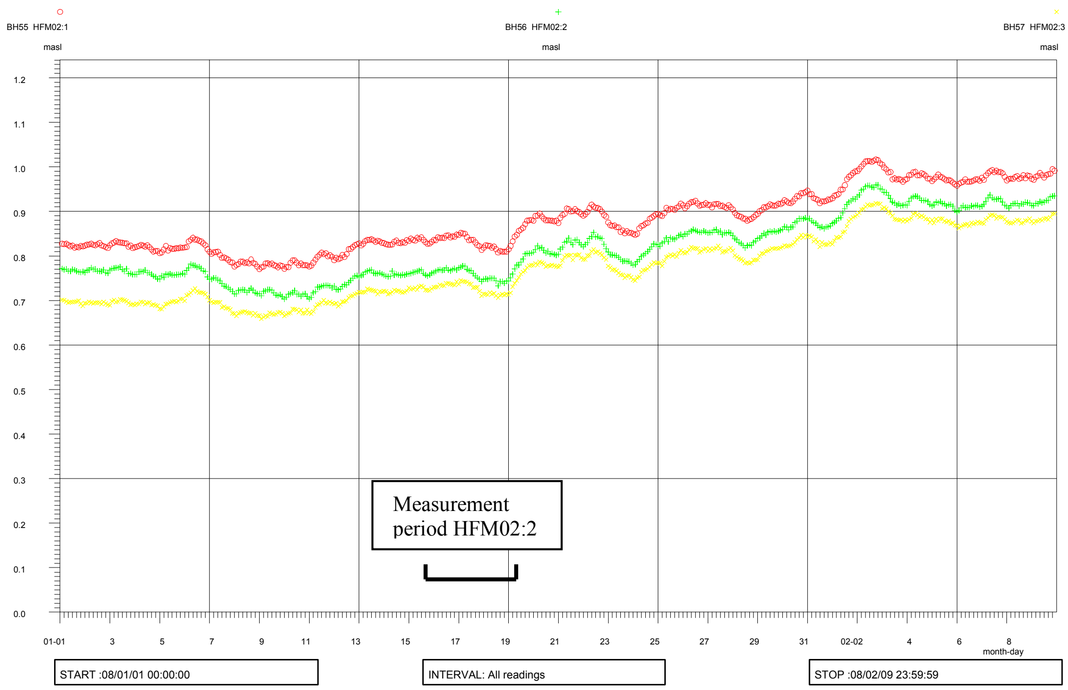
Measured section: KFM12A:3 (yellow)

HFM01



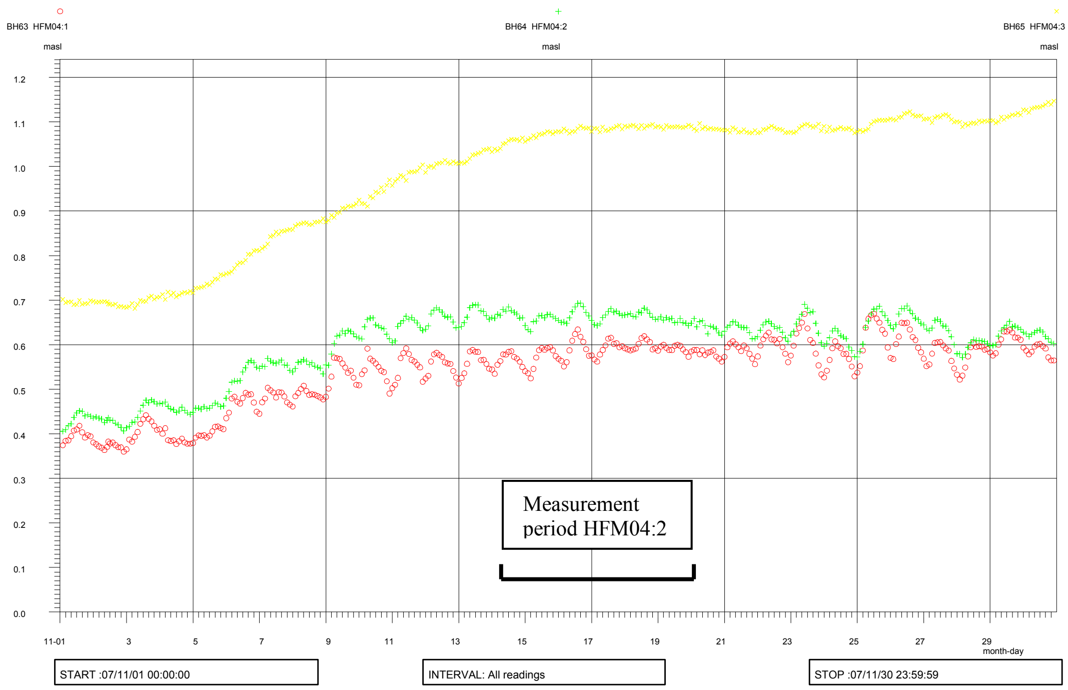
Measured section: HFM01:2 (green)

HFM02



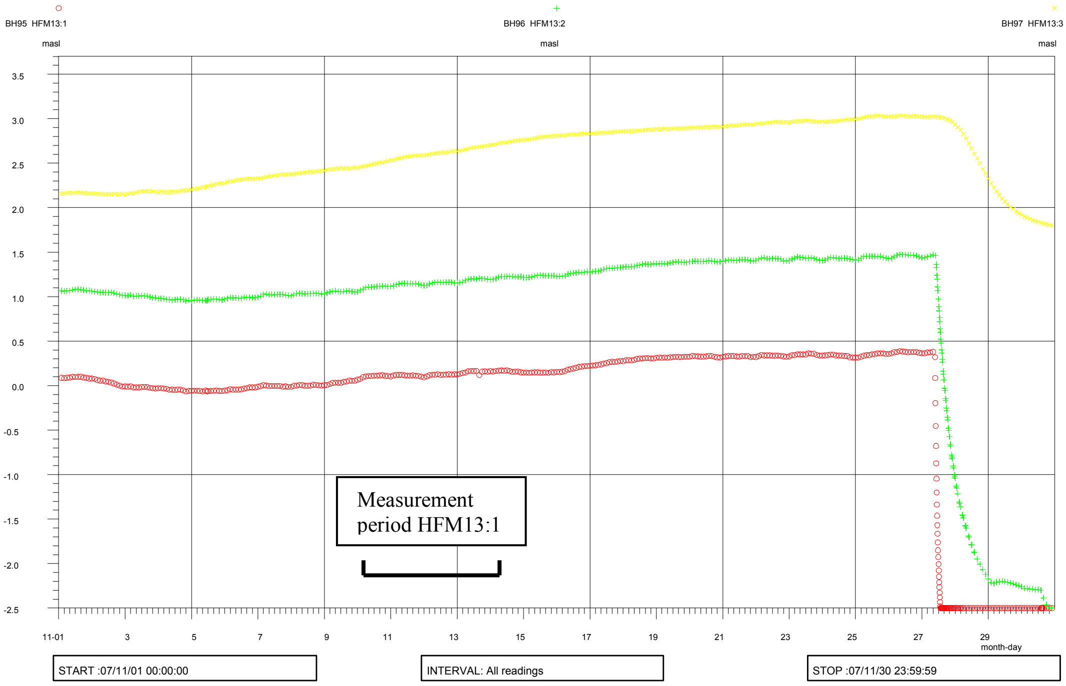
Measured section: HFM02:2 (green)

HFM04



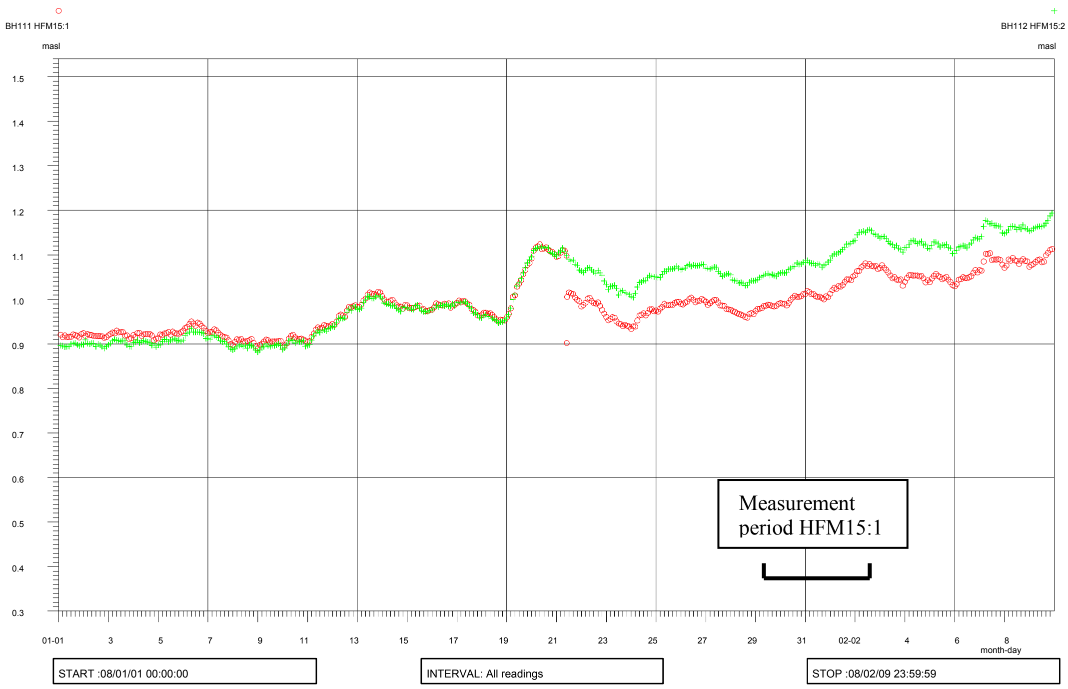
Measured section: HFM04:2 (green)

HFM13



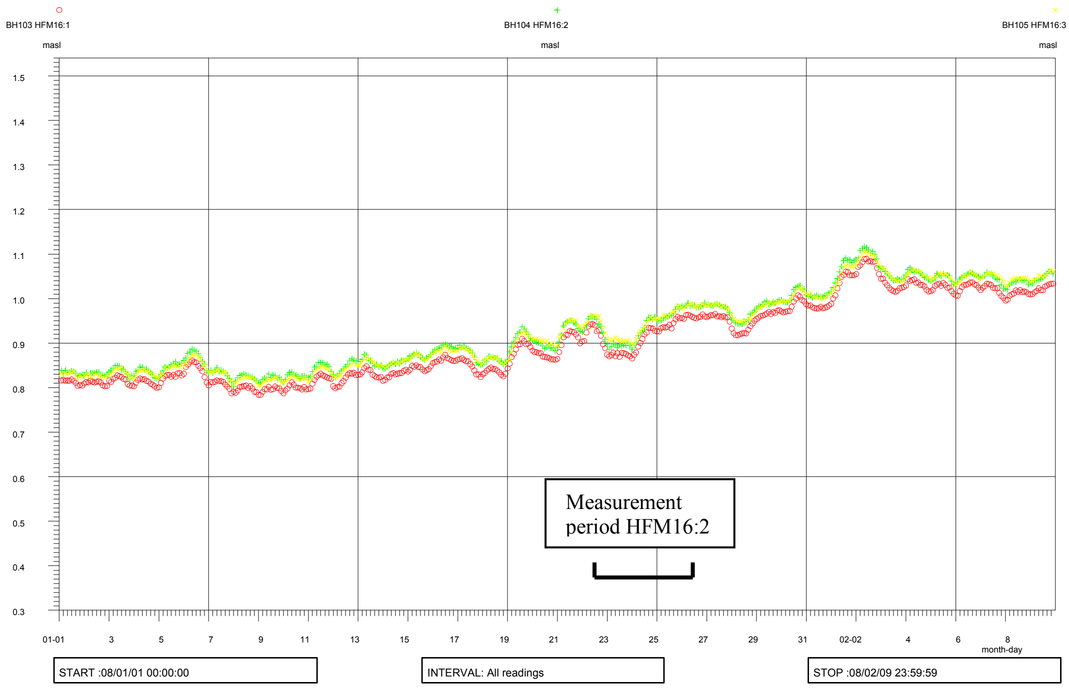
Measured section: HFM13:1 (red)

HFM15



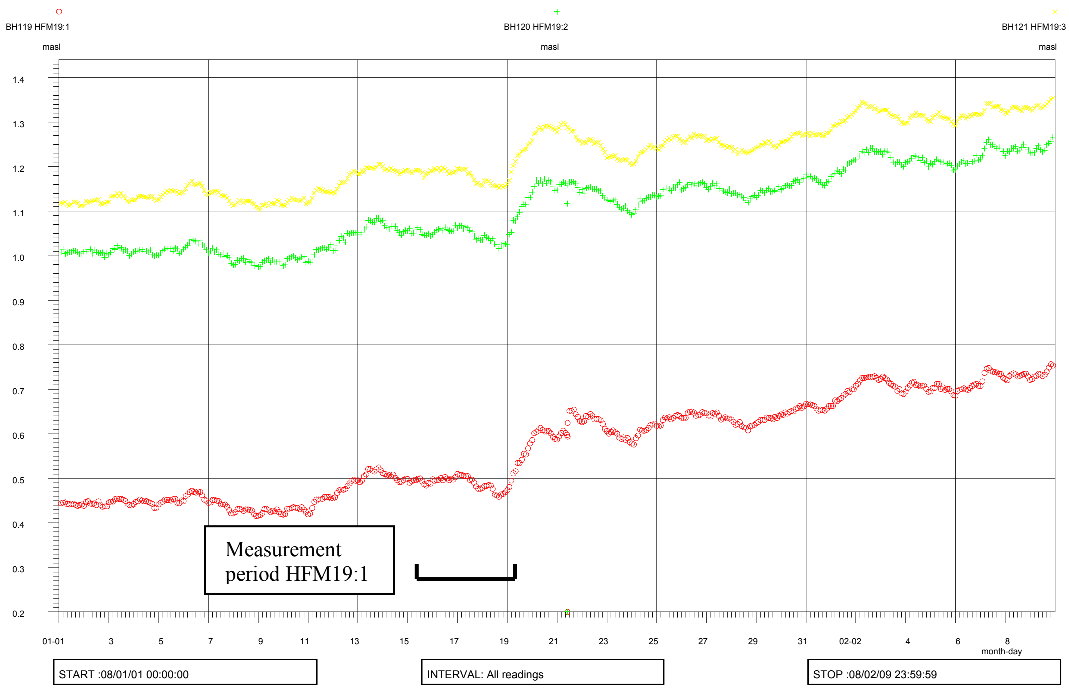
Measured section: HFM15:1 (red)

HFM16



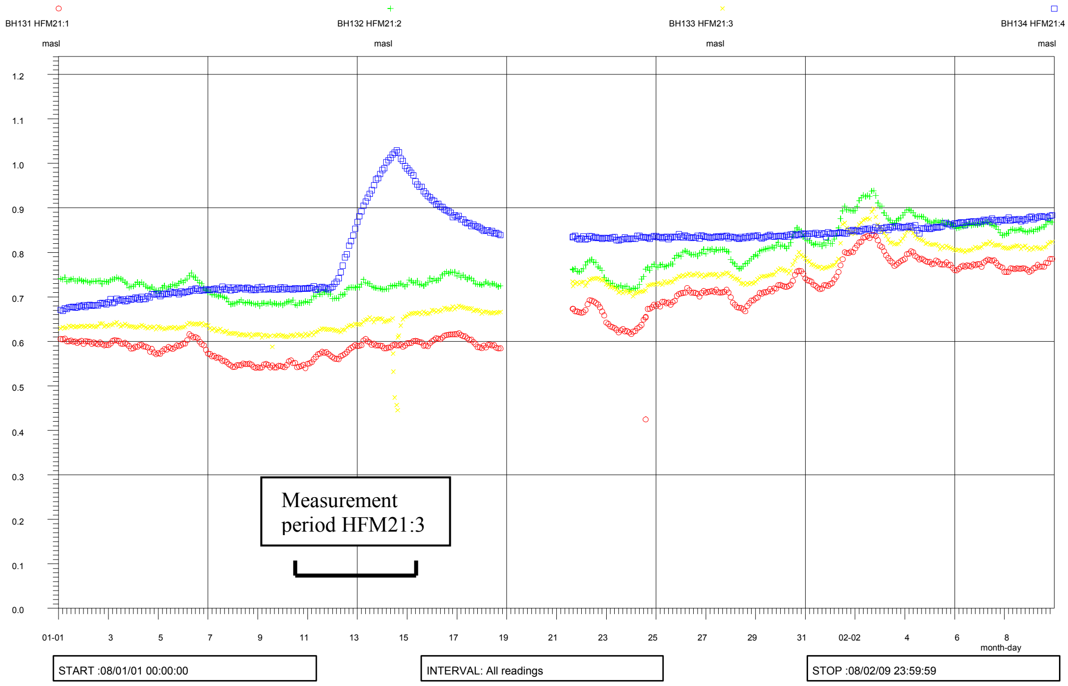
Measured section: HFM16:2 (green)

HFM19



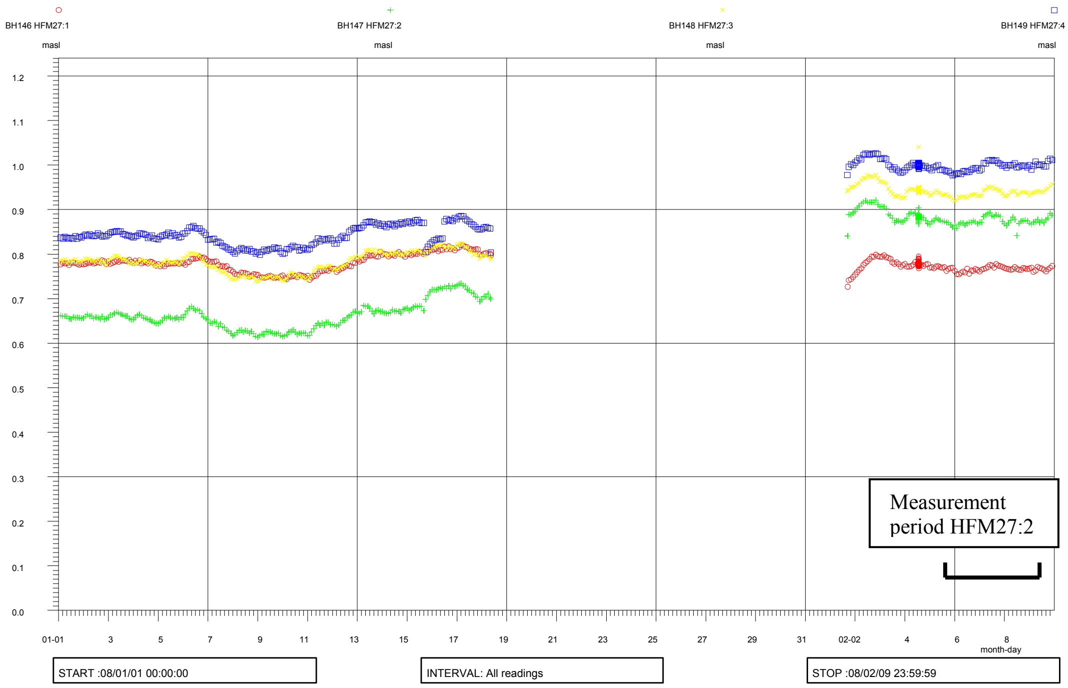
Measured section: HFM19:1 (red)

HFM21



Measured section: HFM21:3 (yellow)

HFM27



Measured section: HFM27:2 (green)