P-06-61

Oskarshamn site investigation

Groundwater flow measurements in permanent installed boreholes

Test campaign no. 1, 2005

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Geosigma AB

October 2006

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Keywords: Groundwater flow, Dilution test, Tracer test, AP PS 400-05-077.

Abstract

This report describes the performance and evaluation of measurements of ground water flow in twelve borehole sections in permanent installed boreholes within the site investigation at Oskarshamn (Simpevarp, Ävrö and Laxemar). The objective was to determine the groundwater flow in all borehole sections instrumented for this purpose. This is the first test campaign performed in 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 varies from 24 to 2,900 ml/h in the measured sections with Darcy velocities ranging from 1.4E–08 to 3.9E–06 m/s. Hydraulic gradients are calculated according to the Darcy concept and ranging from 0.013 to 27.

Sammanfattning

Denna rapport beskriver genomförandet och utvärderingen av grundvattenflödesmätningar i tolv borrhålssektioner i permanent installerade borrhål i Oskarshamnområdet (Simpevarp, Ävrö och Laxemar). Syftet var att bestämma grundvattenflödet i samtliga för ändamålet instrumenterade borrhålssektioner. Denna mätning är den första som genomförts i moniteringsprogrammet och mätningarna är planerade att återupprepas en gång per år.

Grundvattenflödet i de utvalda borrhålssektionerna mättes med utspädningsmetoden under naturliga ostörda förhållanden. Uppmätta grundvattenflöden ligger i intervallet 24–2 900 ml/timme med beräknade Darcy hastigheter mellan 1,4E–08 och 3,9E–06 m/s. Hydrauliska gradienten beräknades till mellan 0,013 och 27.

Contents

1 Introduction

This document reports the results gained by the groundwater flow measurements in permanent installed boreholes, test campaign no. 1, 2005, 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 400-05-077. 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 field work was performed in November and December 2005. 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 I permanent installerade borrhål, mätkampanj 1, 2005	AP PS 400-05-077	1.1
Method descriptions	**Number**	**Version**
Mätsystembeskrivning (MSB) – Handhavande del: System för hydrologisk och metrologisk datainsamling. Vattenprovtagning och utspädningsmätning i observationshål.	SKB MD 368.010	1.0

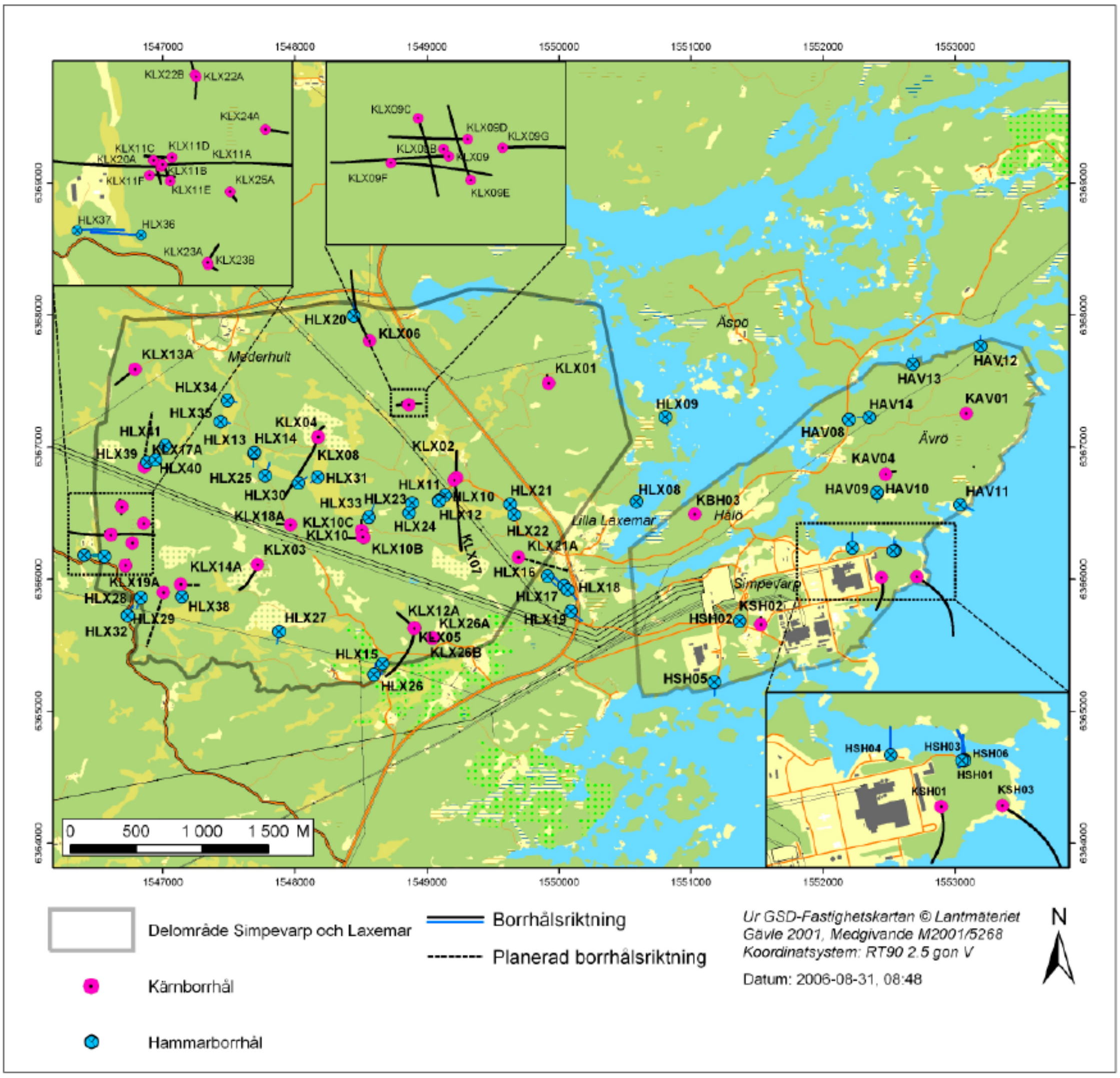


Figure 1-1. *General overview over Oskarshamn site investigation area.*

2 Objective and scope

The objective of this activity was to determine the groundwater flow in borehole sections in permanent installed boreholes at Oskarshamn. Twelve borehole sections instrumented for this purpose (circulation sections) were to be measured. This was the first 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, autumn 2005.

Borehole/ section	Borehole length (m)	Transmissivity (m^2/s)	Measurement period (YYMMDD–YYMMDD)
KAV01:3	391–434	4.2 E–5*	051123–051128
KLX01:3	171–190	3.6 E–5*	051129–051207
KLX02:5	452–494	3.1 E–7*	051208–051215
KLX02:2	1,145–1,164	3.2 E–7*	051209–051215
KLX04:5	507–530	2.7 E–6*	051209–051215
KLX04:2	870–897	4.9 E–8**	051208–051215
KLX06:6	256–275	1.0 E–4*	051128–051207
KLX06:3	554–570	1.1 E–5*	051123–051128
KSH01A:7	238–277	7.4 E–6*	051129–051207
KSH01A:4	532–572	8.4 E–7*	051129–051207
KSH02:4	411–439	3.1 E–7*	051123–051128
KSH02:1	955–963	6.8 E–8*	051122–051128

* From PSS measurements.

** From PFL measurements.

3 Equipment

3.1 Description of equipment

The boreholes involved in the tests are instrumented with one to seven inflatable packers isolating two to eight borehole sections each. 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 identical equipment set-ups, i.e. allowing four sections to be measured simultaneously. 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 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 procedure follows the detailed descriptions given in SKB internal controlling documents, cf Table 1-1.

The tracer used was a fluorescent dye tracer, Uranine (Sodium Fluorescein) from Merck (purum quality).

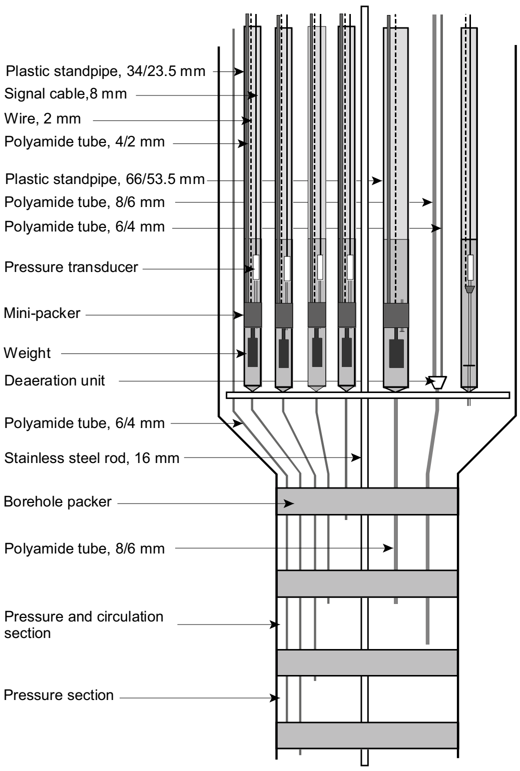


Figure 3-1. An example of permanent instrumentation in core boreholes with circulation sections.

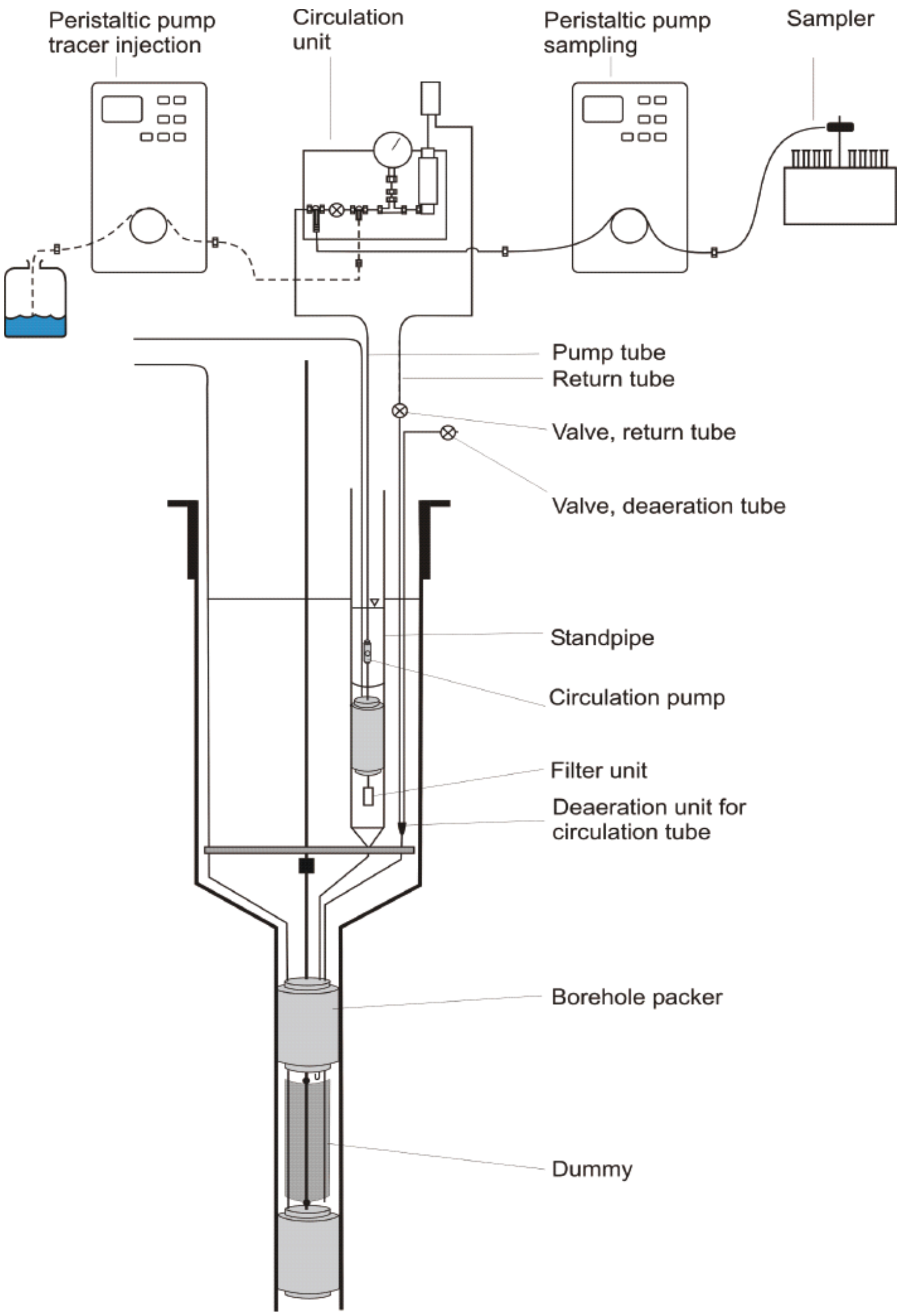


Figure 3-2. *Schematic drawing of the equipment used in tracer dilution measurements.*

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.

4.2 Preparations

Before the field work started, a tracer stock solution (Uranine, 500 mg/l) was mixed and the field equipment was functionality tested and calibrated.

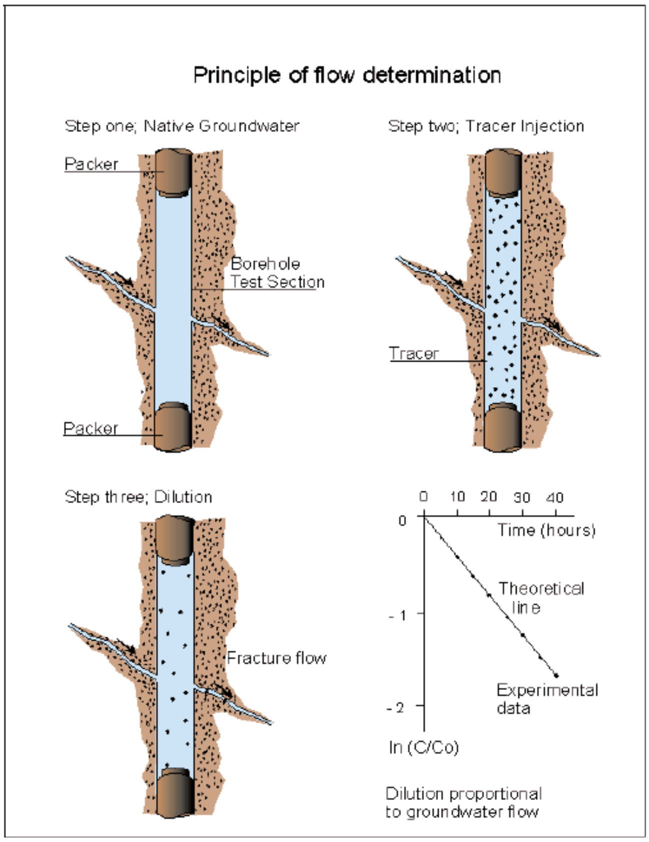


Figure 4-1. *General principles of dilution and flow determination.*

4.3 Execution of field work

Tracer dilution tests were performed in twelve borehole sections listed in Table 2-1.

The tests were made by injecting a slug of tracer (Uranine, 500 mg/l) in the selected borehole section with an adjusted injection flow during the time it takes to circulate one section volume and in this way dilute the tracer to approximately 0.5 mg/l as a start concentration in the borehole section. Using the equipment described in Chapter 3.1 the tracer solution in the borehole section was continuously circulated and sampled allowing the natural groundwater flow to dilute the tracer. Circulation was maintained between 5 and 9 days and the sampler was set up to change tubes every 120 minutes.

4.4 Analyses and interpretations

The samples were analysed for dye tracer content 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, cf /1/. Theoretically, a straight-line relationship exists between the natural logarithm of the relative tracer concentration (c/c_0) and time (t):

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

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 5–9 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 practise, 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 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 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

- Gasification occurred in most of the borehole sections disturbing the circulation of groundwater in the borehole section and the sampling.
- In boreholes KLX02:2, KLX02:5, and KSH01A:4 the sampler changed more than one tube at the time which resulted in empty or almost empty tubes. However, this is not considered to have any impact on the quality of the measurements.
- In borehole KLX04:2 the sampler didn't change tubes which resulted in flooding of the equipment and loss of samples for about 3 days, see Appendix 1. This incident is considered to increase the uncertainty of the measurement in the section.
- 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 it changed tubes after 115.3 or 107.8 minutes depending on the power station. This was compensated for in the evaluation.

5 Results

The results obtained within this activity are groundwater flow rates in borehole sections KAV01:3, KLX01:3, KLX02:5, KLX02:2, KLX04:5, KLX04:2, KLX06:6, KLX06:3, KSH01A:7, KSH01A:4, KSH02:4 and KSH02:1 during natural conditions. The groundwater flow rates calculated together with transmissivities and volumes used will obtain Darcy velocities and hydraulic gradients as additional results, see Table 5-1.

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. The results show that the groundwater flow during natural undisturbed conditions varies from 24 to 2,900 ml/h in the measured sections with Darcy velocities ranging from 1.4E–08 to 3.9E–06 m/s. Hydraulic gradients are calculated according to the Darcy concept and ranging from 0.013 to 27.

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 0.88 and 0.998. However, in a few cases (KLX01:3, KLX02:5 and KLX06:6) one may distinguish more than one slope on the experimental curves. This may be a result of a changing hydraulic gradient during the measurement. This is certainly the case for the first 24 hours of the measurement in KLX02:5 where a transient pressure pulse was created by the installation of the circulation pump. In this case only the latter part of the dilution curve was used for evaluation. Another effect that may be seen in the dilution data is that mixing takes quite a long time in sections having large volume and long tubing. This decreases the circulation capacity of the pump. This effect is clearly visible in the data from KLX02:2 (1,145 m borehole length) and KSH02:1 (955 m borehole length) where mixing takes between 2–3 days.

Groundwater level during the entire test period is shown for the selected boreholes in Appendix 2. The groundwater levels are generally stable during the measurement period.

The original results are stored in the primary data base SICADA. The data in this data base is available for further interpretation and is traceable by the Activity Plan number (AP PS 400-05-077).

Table 5-1. Results from groundwater flow measurements, test campaign no. 1, 2005.

Borehole/ section	Depth (m)	Transmissivity (m^2/s)	Volume (ml)	Measured flow (ml/h)	Darcy velocity (m/s)	Hydraulic gradient
KAV01:3	391–434	4.2 E–5*	38,267	2,900	3.9E–06	4.0
KLX01:3	171–190	3.6 E–5*	20,222	200	1.6E–07	0.085
KLX02:5	452–494	3.1 E–7*	44,187	110	2.0E–07	27
KLX02:2	1,145–1,164	3.2 E–7*	75,300	100	8.4E–08	5.0
KLX04:5	507–530	2.7 E–6*	39,851	28	2.7E–08	0.23
KLX04:2	870–897	4.9 E–8**	61,640	31	3.5E–08	19
KLX06:6	256–275	1.0 E–4*	24,607	88	7.0E–08	0.013
KLX06:3	554–570	1.1 E–5*	40,477	39	2.6E–08	0.038
KSH01A:7	238–277	7.4 E–6*	30,134	62	1.0E–07	0.54
KSH01A:4	532–572	8.4 E–7*	47,369	330	5.6E–07	27
KSH02:4	411–439	3.1 E–7*	36,282	24	2.8E–08	2.6
KSH02:1	955–963	6.8 E–8*	60,738	43	1.4E–08	1.7

* From PSS measurements.

** From PFL measurements.

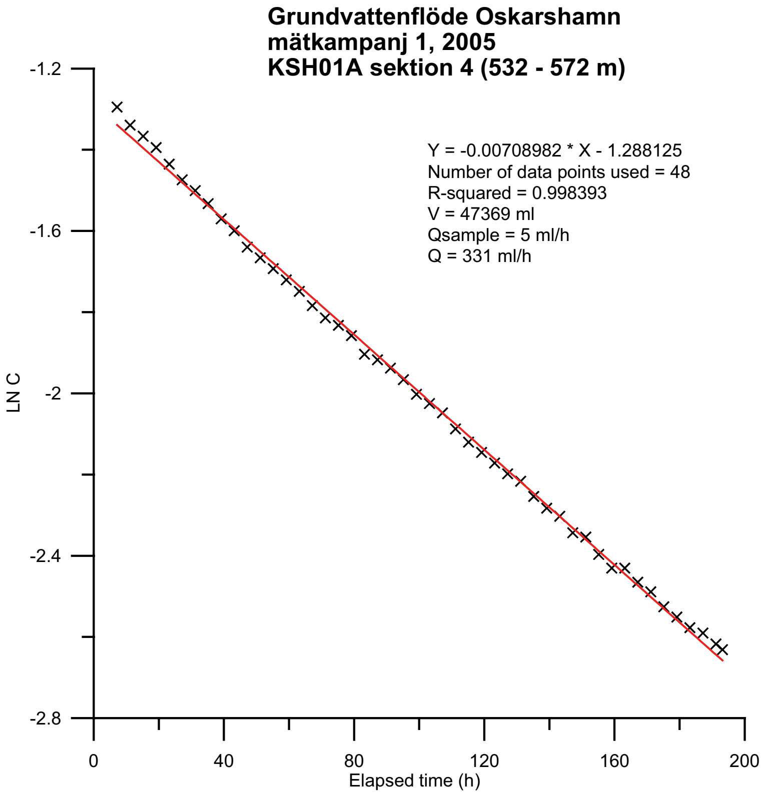


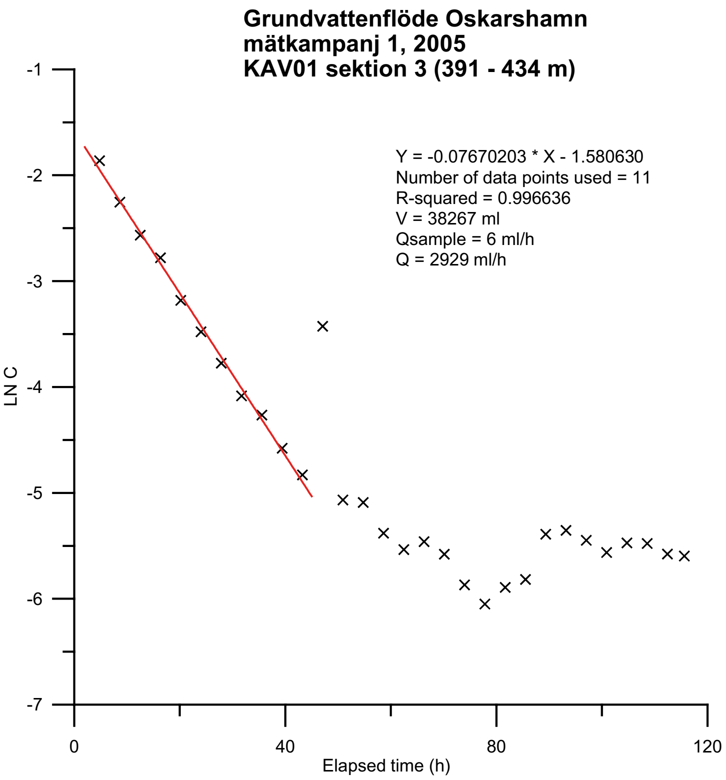
Figure 5-1. *Example of a tracer dilution graph for borehole KSH01A:4, including straight-line fit.*

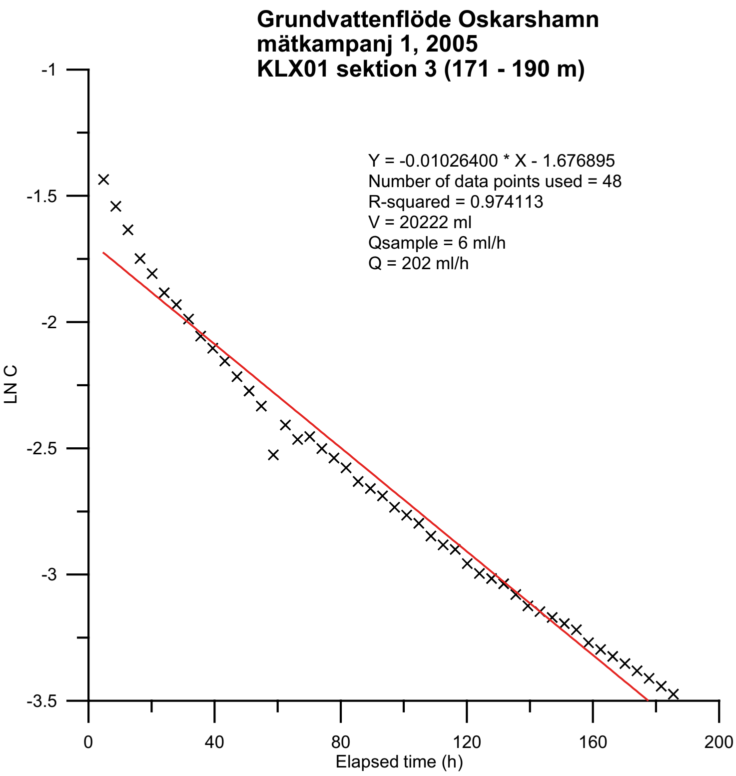
6 References

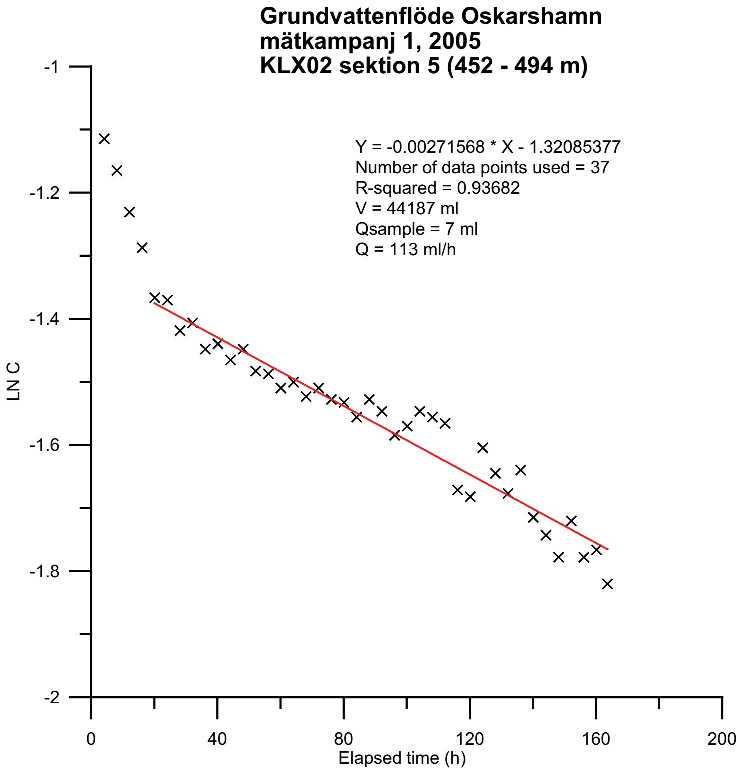
/1/ **Gustafsson E, 2002**. Bestämning av grundvattenflödet med utspädningsteknik – Modifiering av utrustning och kompletterande mätningar. SKB R-02-31 (in Swedish). Svensk Kärnbränslehantering AB.

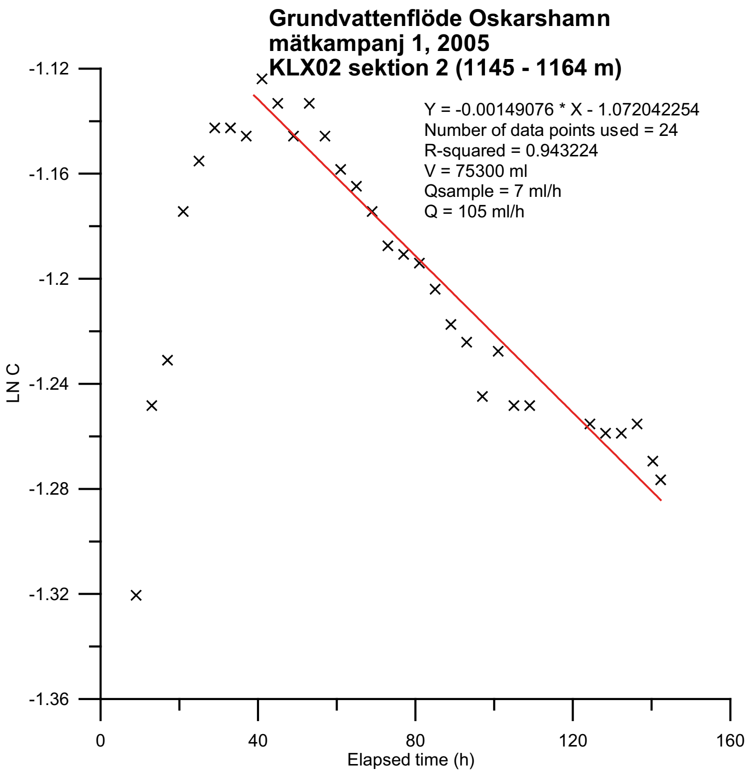
Appendix 1

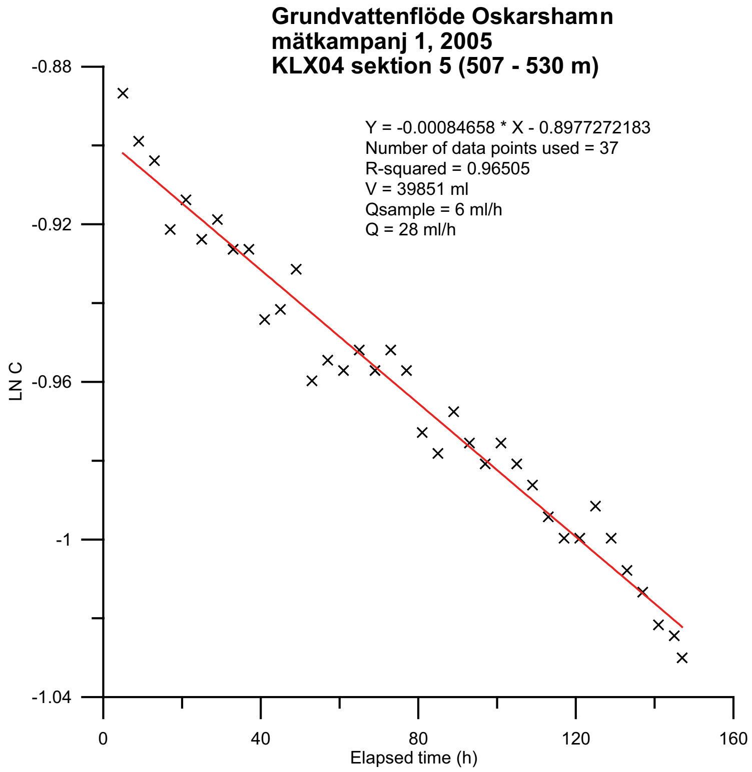
Tracer dilution graphs

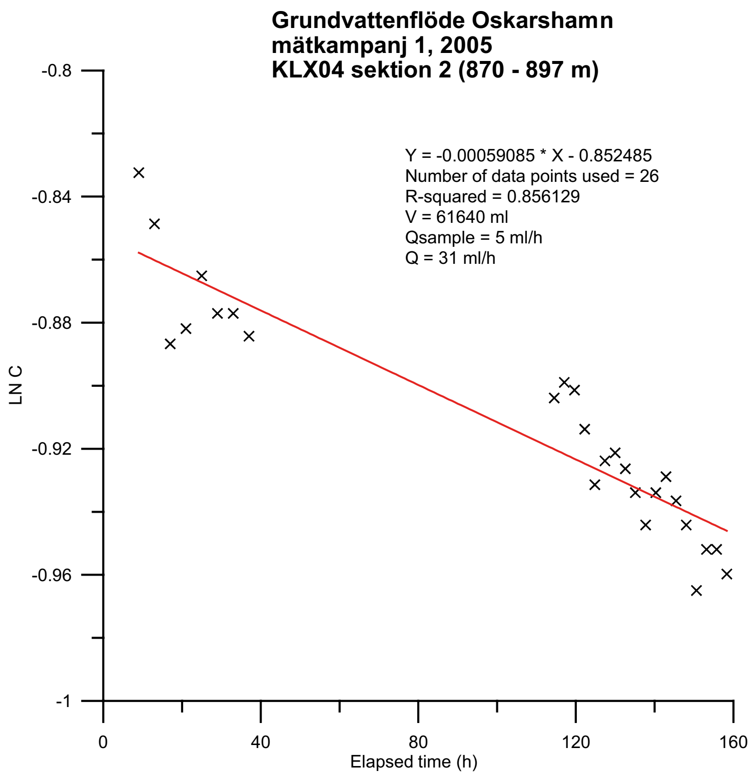


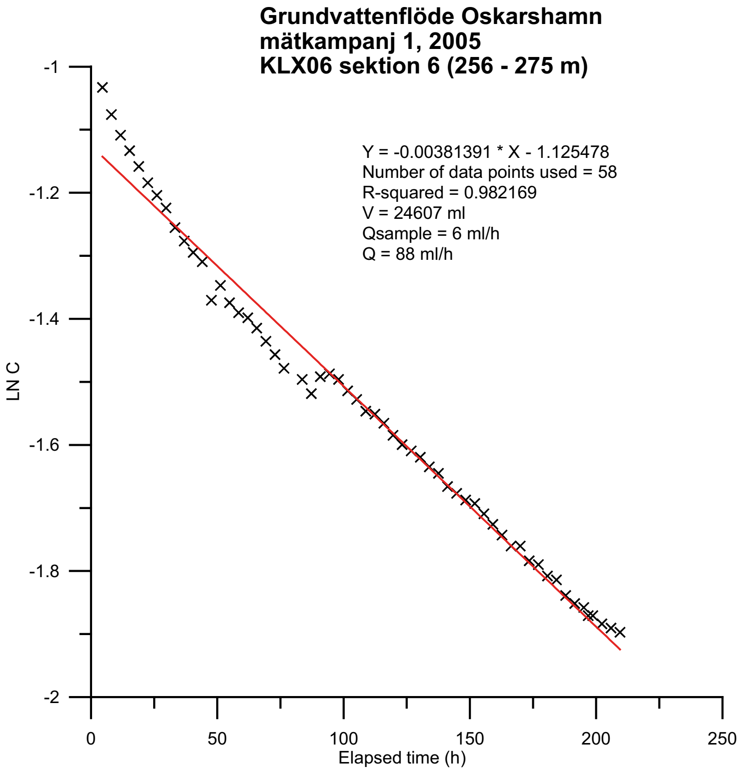


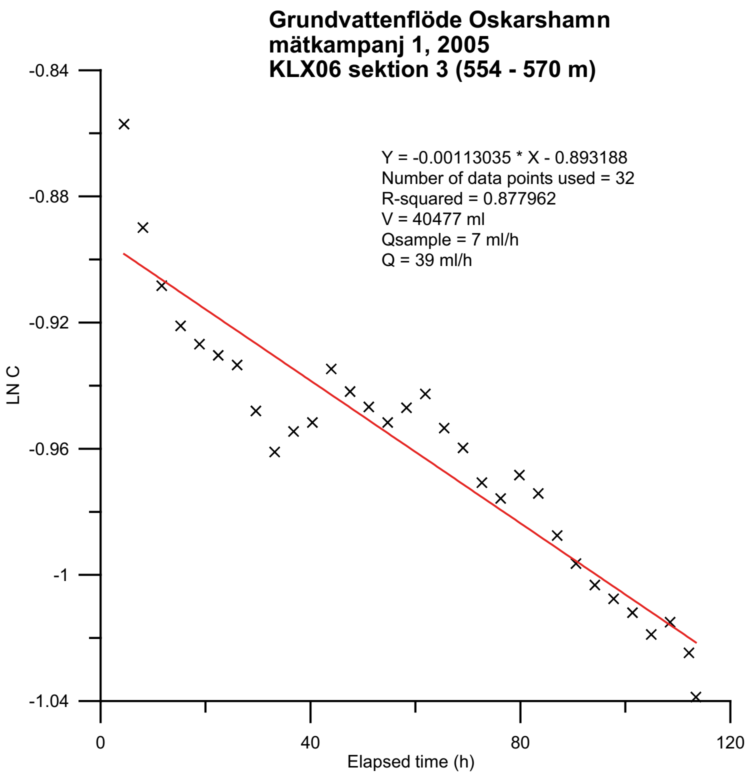

Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KLX02 sektion 5 (452 - 494 m)
Y = -0.00271568 * X - 1.32085377
Number of data points used = 37
R-squared = 0.93682
V = 44187 ml
Qsample = 7 ml
Q = 113 ml/h
LN C
-1
-1.2
-1.4
-1.6
-1.8
-2
0
40
80
120
160
200
Elapsed time (h)

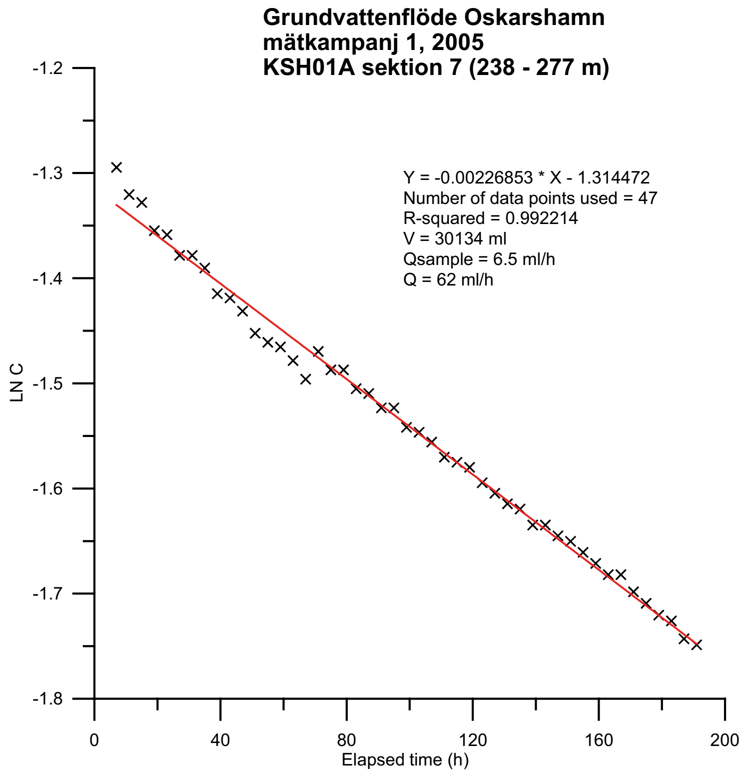

Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KLX02 sektion 2 (1145 - 1164 m)
Y = -0.00149076 * X - 1.072042254
Number of data points used = 24
R-squared = 0.943224
V = 75300 ml
Qsample = 7 ml/h
Q = 105 ml/h
LN C
-1.12
-1.16
-1.2
-1.24
-1.28
-1.32
-1.36
0
40
80
120
160
Elapsed time (h)

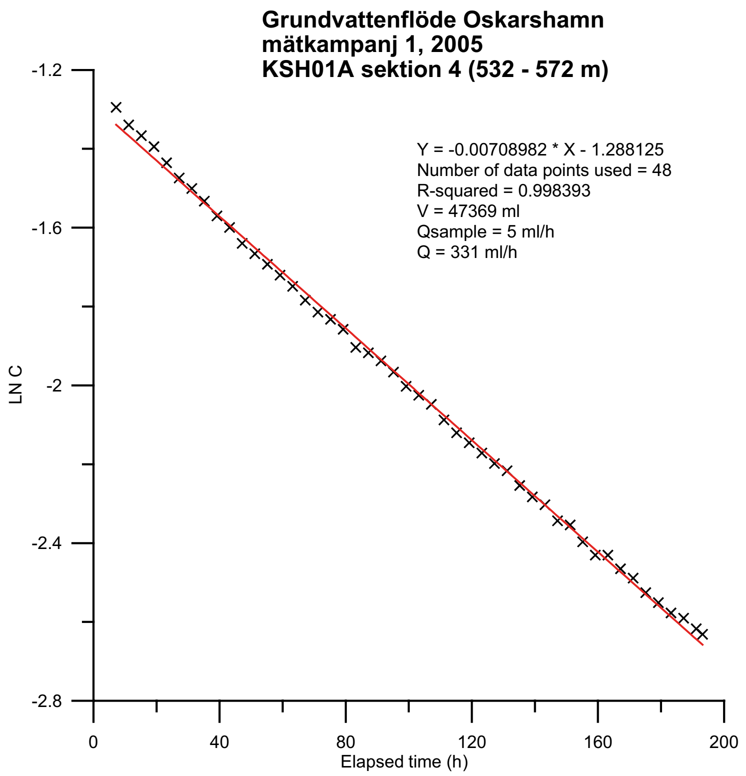

Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KLX04 sektion 5 (507 - 530 m)
Y = -0.00084658 * X - 0.8977272183
Number of data points used = 37
R-squared = 0.96505
V = 39851 ml
Qsample = 6 ml/h
Q = 28 ml/h
-0.88
-0.92
-0.96
-1
-1.04
LN C
0
40
80
120
160
Elapsed time (h)

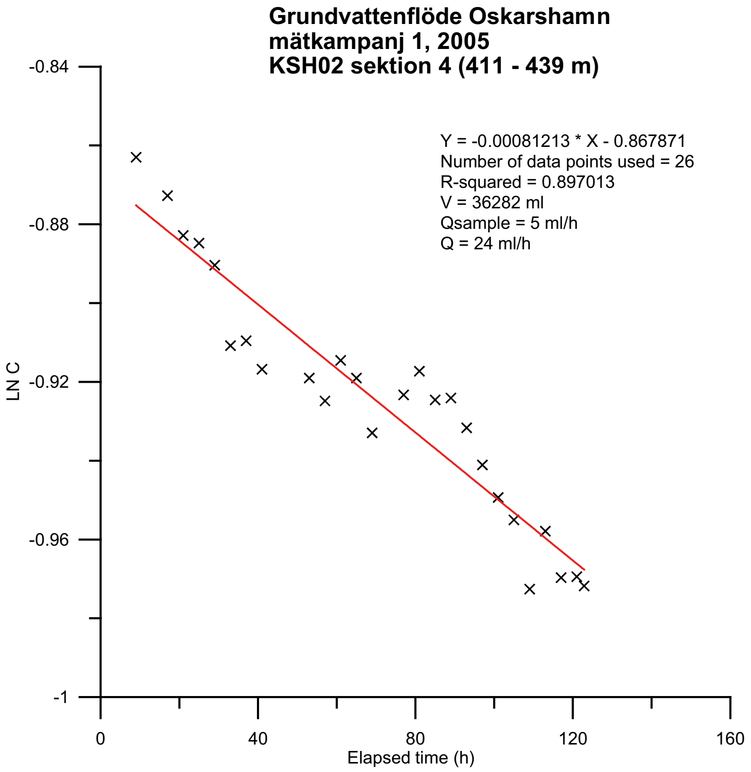

Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KLX04 sektion 2 (870 - 897 m)
Y = -0.00059085 * X - 0.852485
Number of data points used = 26
R-squared = 0.856129
V = 61640 ml
Qsample = 5 ml/h
Q = 31 ml/h
-0.8
-0.84
-0.88
-0.92
-0.96
-1
LN C
0
40
80
120
160
Elapsed time (h)


Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KLX06 sektion 6 (256 - 275 m)
Y = -0.00381391 * X - 1.125478
Number of data points used = 58
R-squared = 0.982169
V = 24607 ml
Qsample = 6 ml/h
Q = 88 ml/h
LN C
-1
-1.2
-1.4
-1.6
-1.8
-2
0
50
100
150
200
250
Elapsed time (h)

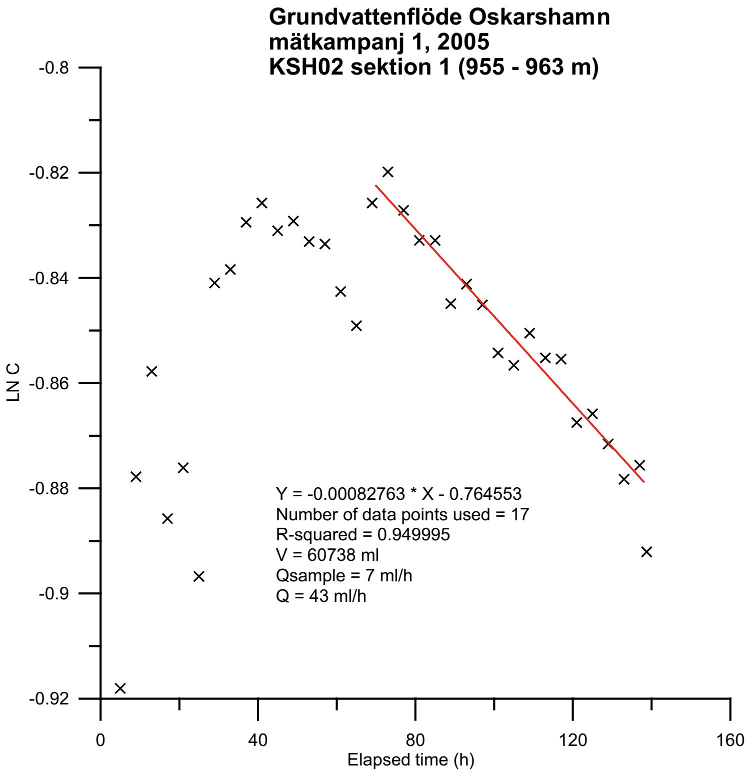

Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KLX06 sektion 3 (554 - 570 m)
Y = -0.00113035 * X - 0.893188
Number of data points used = 32
R-squared = 0.877962
V = 40477 ml
Qsample = 7 ml/h
Q = 39 ml/h
LN C
-0.84
-0.88
-0.92
-0.96
-1
-1.04
0
40
80
120
Elapsed time (h)


Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KSH01A sektion 7 (238 - 277 m)
Y = -0.00226853 * X - 1.314472
Number of data points used = 47
R-squared = 0.992214
V = 30134 ml
Qsample = 6.5 ml/h
Q = 62 ml/h
LN C
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
0
40
80
120
160
200
Elapsed time (h)


Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KSH01A sektion 4 (532 - 572 m)
Y = -0.00708982 * X - 1.288125
Number of data points used = 48
R-squared = 0.998393
V = 47369 ml
Qsample = 5 ml/h
Q = 331 ml/h
LN C
-1.2
-1.6
-2
-2.4
-2.8
0
40
80
120
160
200
Elapsed time (h)



Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KSH02 sektion 4 (411 - 439 m)
Y = -0.00081213 * X - 0.867871
Number of data points used = 26
R-squared = 0.897013
V = 36282 ml
Qsample = 5 ml/h
Q = 24 ml/h
-0.84
-0.88
-0.92
-0.96
-1
LN C
0
40
80
120
160
Elapsed time (h)

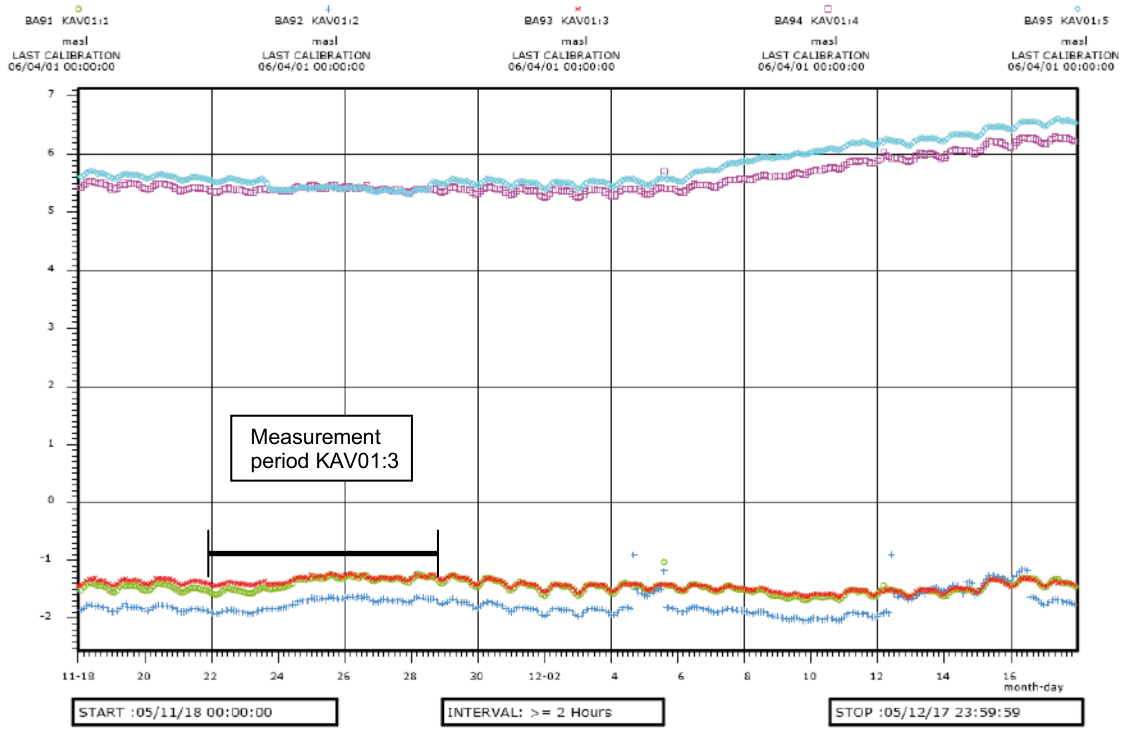


Grundvattenflöde Oskarshamn
mätkampanj 1, 2005
KSH02 sektion 1 (955 - 963 m)
Y = -0.00082763 * X - 0.764553
Number of data points used = 17
R-squared = 0.949995
V = 60738 ml
Qsample = 7 ml/h
Q = 43 ml/h
-0.8
-0.82
-0.84
-0.86
-0.88
-0.9
-0.92
LN C
0
40
80
120
160
Elapsed time (h)

Appendix 2

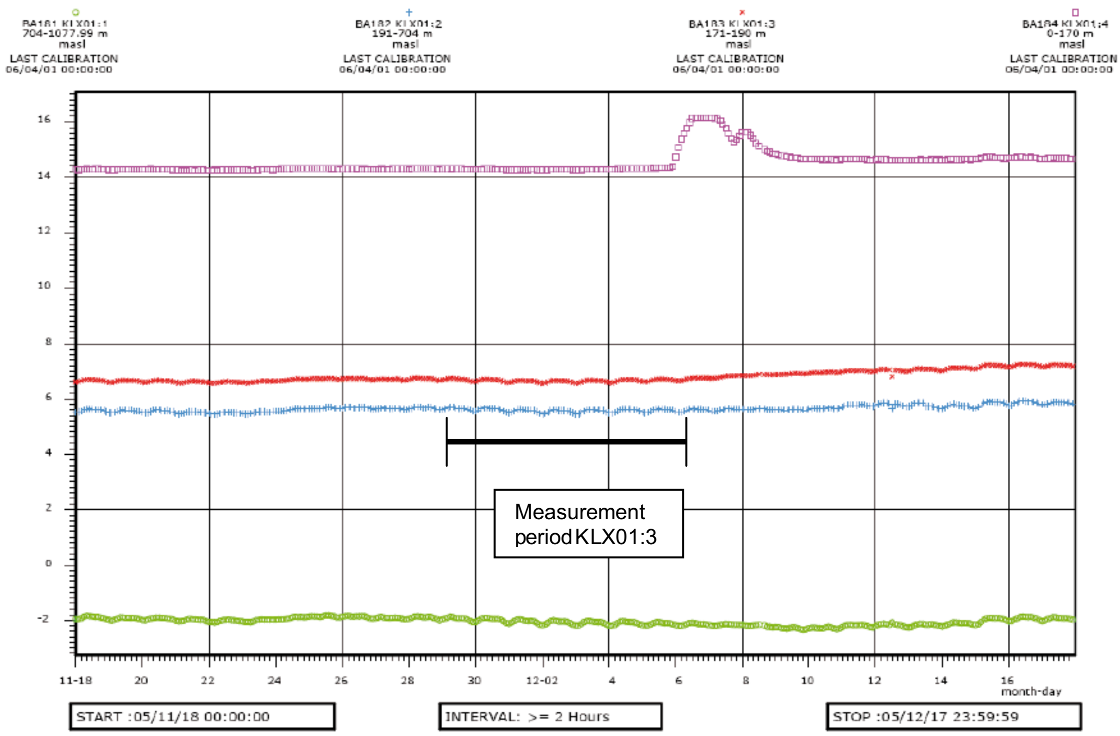
Groundwater level (m.a.s.l.)

KAV01



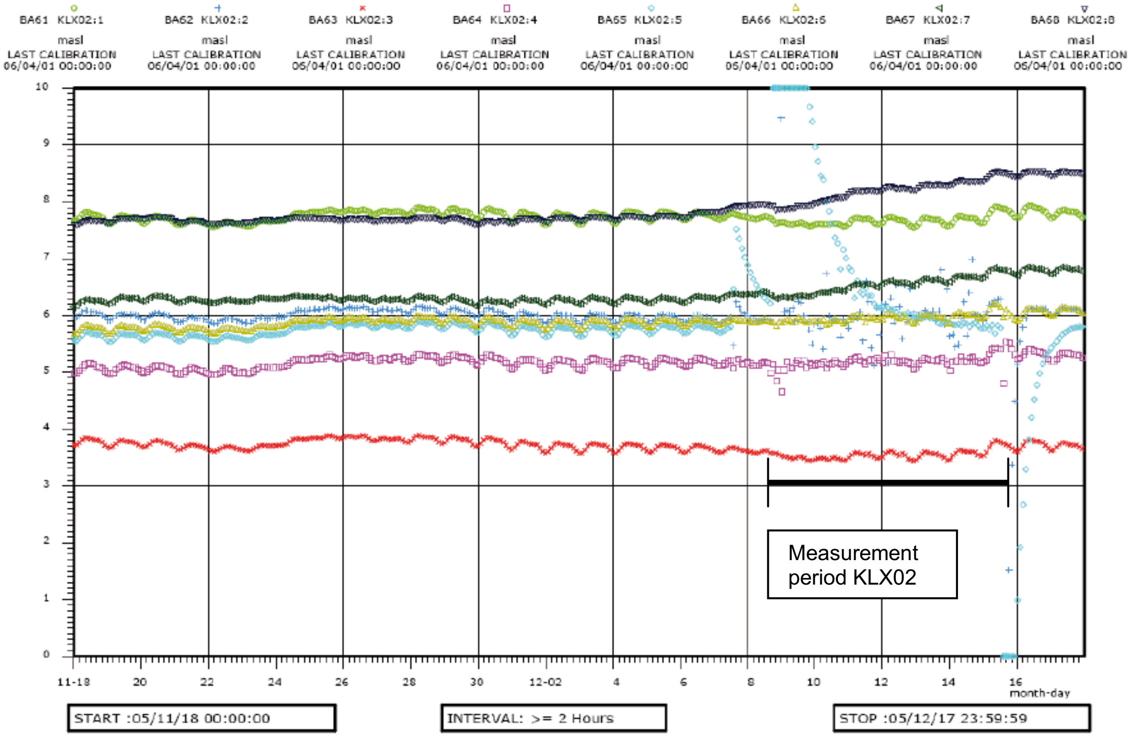
Measured section: KAV01:3 (red)

KLX01



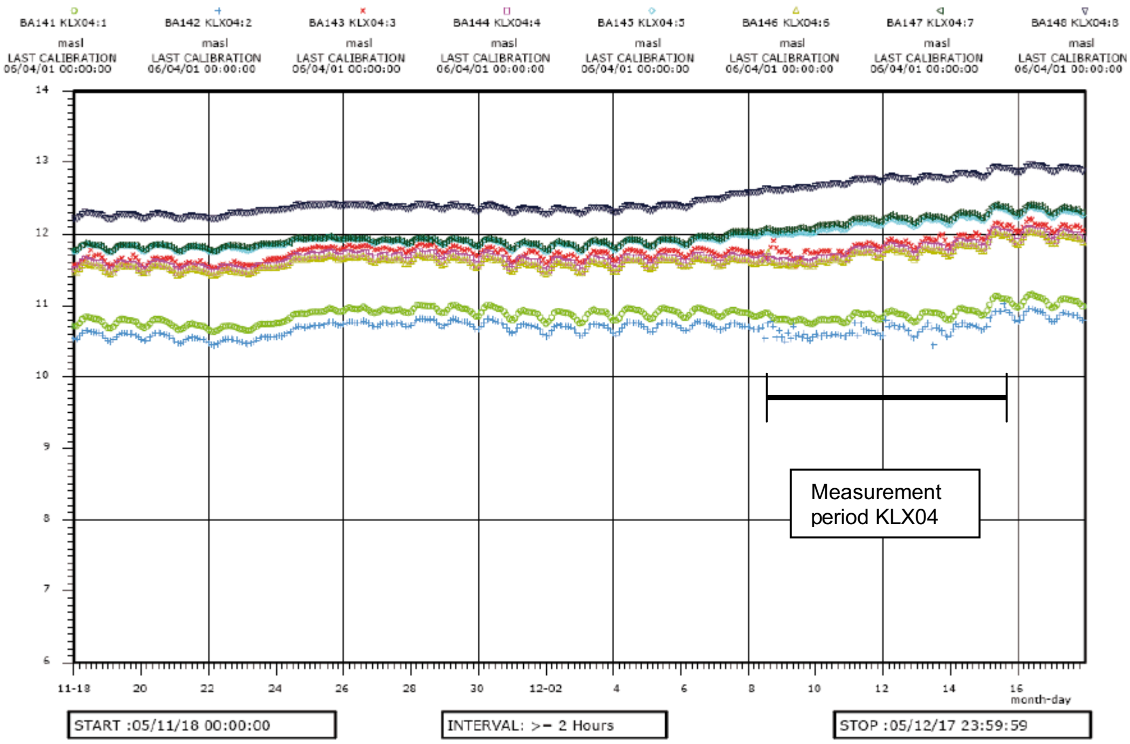
Measured section: KLX01:3 (red)

KLX02



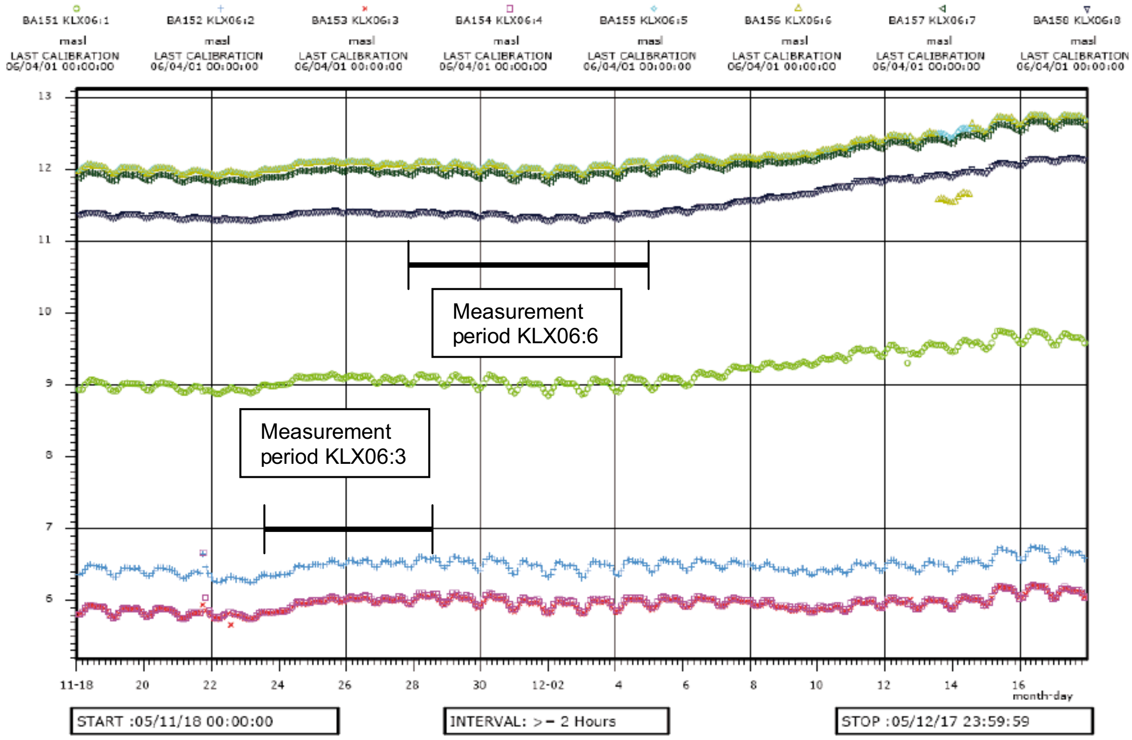
Measured sections: KLX02:2 (dark blue) and KLX02:5 (light blue)

KLX04



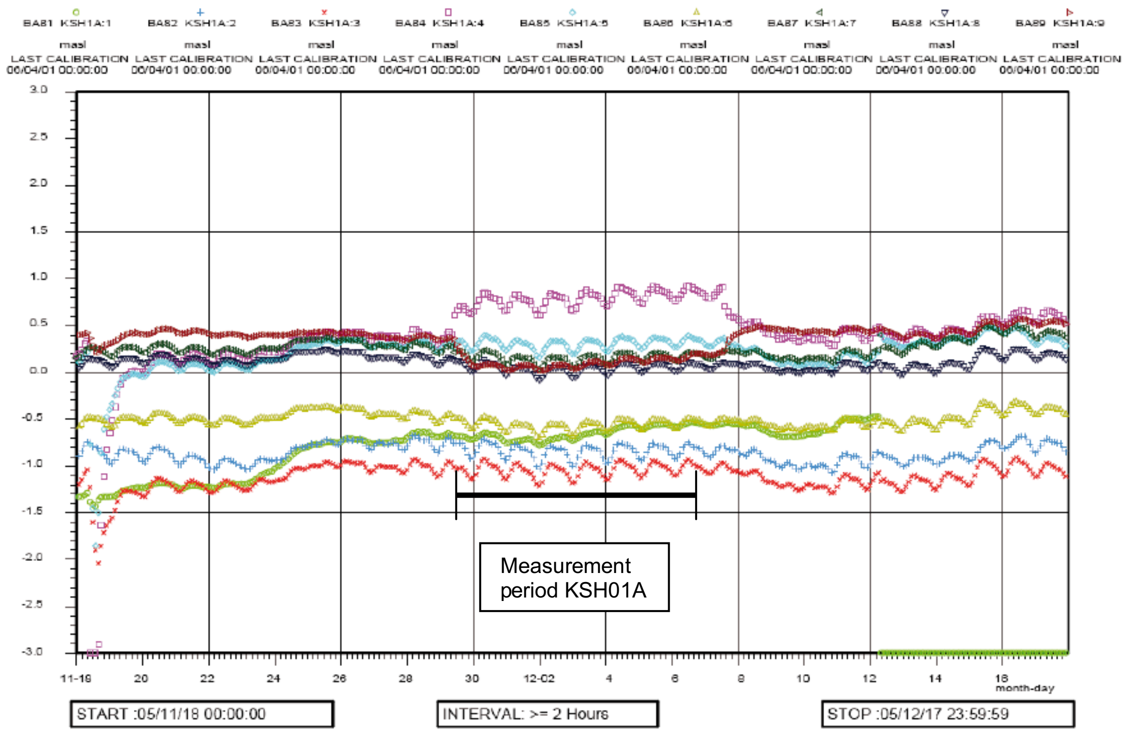
Measured sections: KLX04:2 (dark blue) and KLX04:5 (light blue)

KLX06



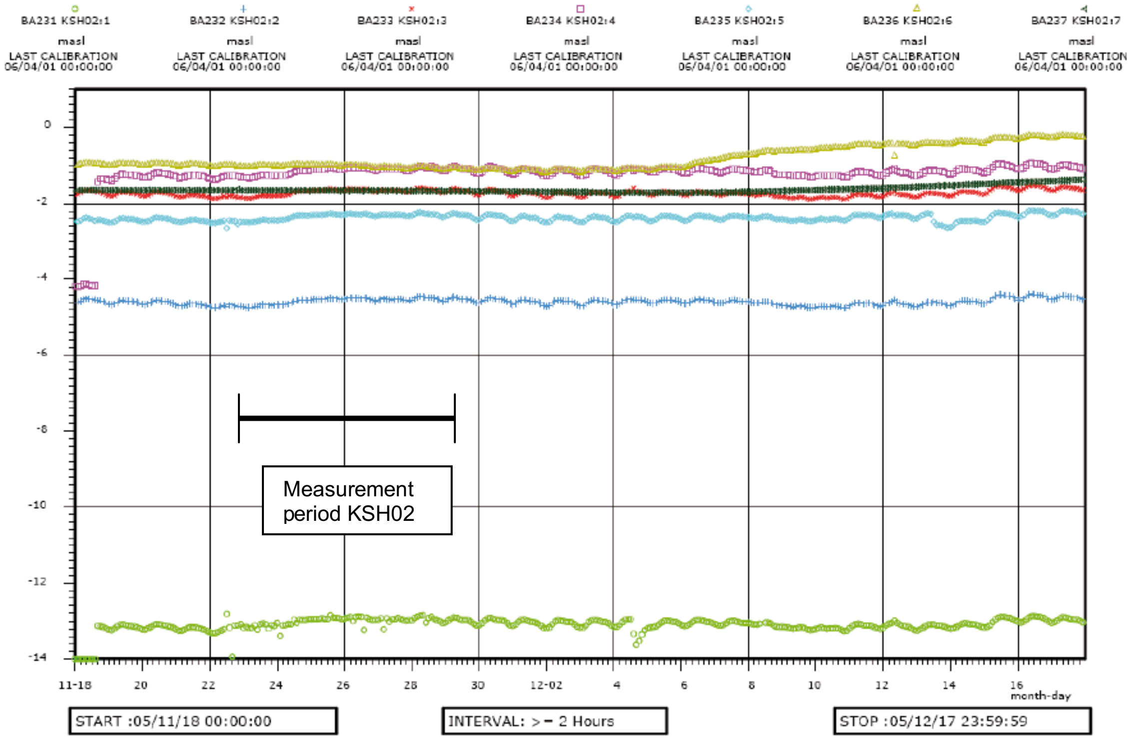
Measured sections: KLX06:3 (red) and KLX06:6 (dark green)

KSH01A



Measured sections: KSH01A:4 (mauve) and KSH01A:7 (gray)

KSH02



Measured sections: KSH02:1 (green) and KSH01A:4 (mauve)