P-07-197

Oskarshamn site investigation

Groundwater flow measurements in soil wells SSM000243, SSM000244, SSM000261, SSM000262 and SSM000263, spring 2007

Subarea Laxemar

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September 2007

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Keywords: Groundwater flow, Dilution test, Tracer test, Darcy velocity, Hydraulic gradient, aquifer.

Abstract

This report describes the performance and evaluation of measurements of ground water flow in five soil wells within the site investigation at Oskarshamn (Laxemar). The objective was to determine the unperturbed groundwater flow in the soil wells.

The groundwater flow in the soil wells was determined through dilution measurements during natural undisturbed conditions. Measured flow rates vary from 1,200 to 9,200 mL/h with Darcy velocities ranging from 3.3 E–6 to 1.9 E–5 m/s. Hydraulic gradients are calculated according to the Darcy concept and ranging from 0.0094 to 3.1.

Sammanfattning

Denna rapport beskriver genomförandet och utvärderingen av grundvattenflödesmätningar i fem jordrör i Oskarshamnområdet (Laxemar). Syftet var att bestämma det ostörda grundvattenflödet i jordrören.

Grundvattenflödet i jordrören mättes med utspädningsmetoden under naturliga ostörda förhållanden. Uppmätta grundvattenflöden ligger i intervallet 1 200 till 9 200 ml/timme med beräknade Darcy hastigheter mellan 3,3 E–6 och 1,9 E–5 m/s. Hydrauliska gradienten beräknades till mellan 0,0094 och 3,1.

Contents

1 Introduction

This document reports the results gained by the groundwater flow measurements in 5 soil wells in Laxemar, 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 400-06-142. 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 May and August 2007. Two maps showing the locations of the soil wells are 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 the performance of the activity.

Activity Plan	Number	Version
Grundvattenflödesmätningar i 5 grundvattenrör i Laxemar.	AP PS 400-06-142	1.0
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

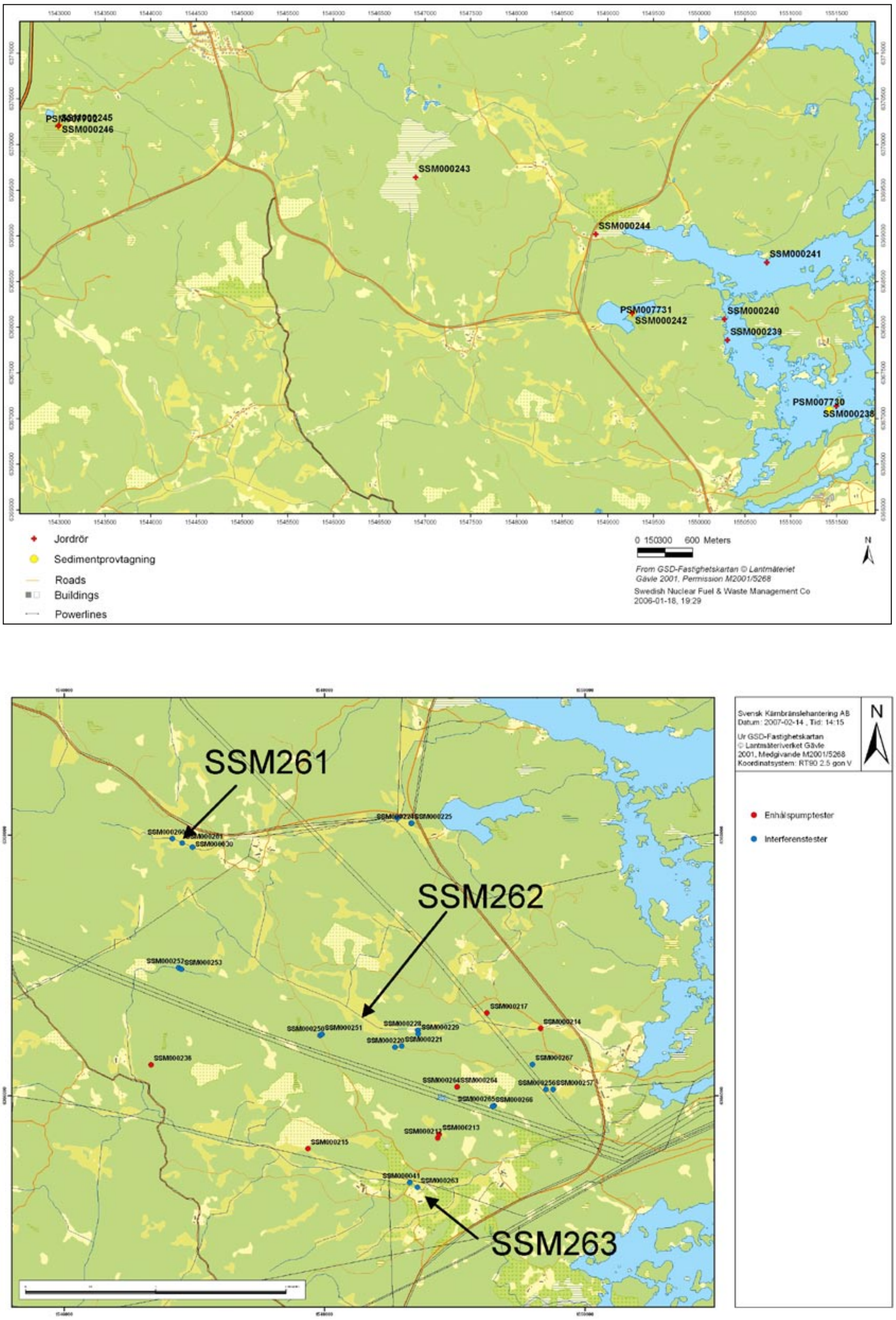


Figure 1-1. *Maps showing the locations of soil wells SSM000243, SSM000244, SSM000261, SSM000262 and SSM000263.*

2 Objective and scope

The objective of this activity was to determine the groundwater flow in soil wells at Oskarshamn. Five soil wells were to be measured.

The groundwater flow in the soil wells was determined through dilution measurements during natural undisturbed conditions.

Table 2 1. Soil wells used for groundwater flow measurements in Oskarshamn, spring 2007.

Soil well	Soil well length (m)	Screen (m)	Soil type	Transmissivity (m^2/s)	Measurement period (YYMMDD–YYMMDD)
SSM000243	12.1 m	11.00–12.00	Sandy till	1.5 E–4*	070821–070822
SSM000244	12.1 m	11.00–12.00	Sandy till	–	070524–070525
SSM000261	10.5 m	9.20–10.20	Sand	5.8 E–5*	070524–070525
SSM000262	15.0 m	11.70–14.70	Till	9.0 E–3*	070522–070524
SSM000263	8.6 m	6.30–8.30	Till	4.1 E–4*	070522–070524

*From previously performed slug tests, mean values from injection and recovery period.

3 Equipment

3.1 Description of equipment

The soil wells involved in the tests are open wells with a natural ground water level. In Figure 3-1 a drawing of soil well SSM000243 is shown, whose construction is common to all the tested wells.

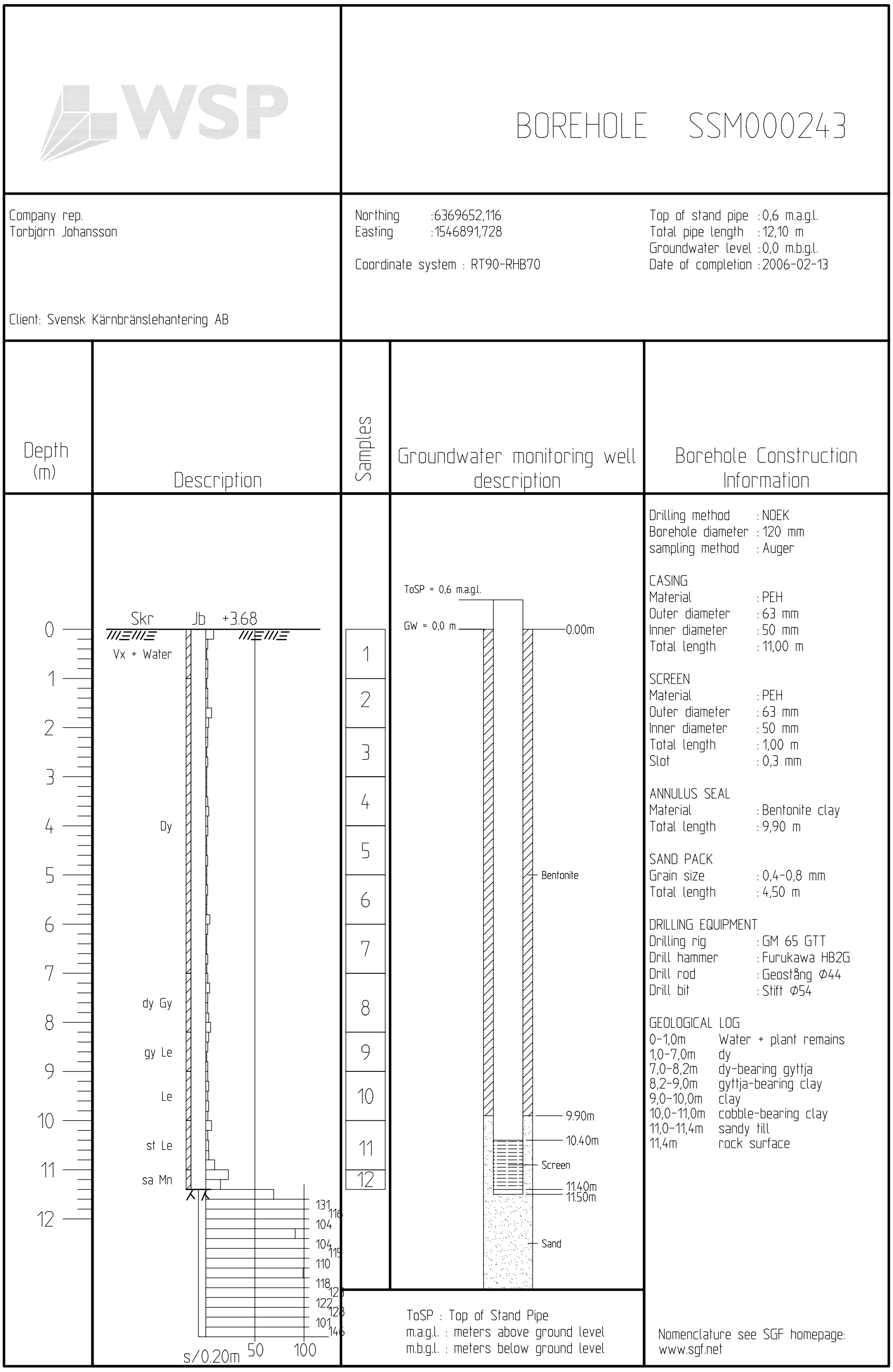


***Figure 3-1.** An example of a drawing of a soil well, SSM000243l.*

The tracer dilution tests were performed using three identical equipment set-ups, i.e. allowing three soil wells 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 soil well. The circulation makes it possible to obtain a homogeneous tracer concentration in the soil well and to sample the tracer concentration outside the well 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, SKB internal document.

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

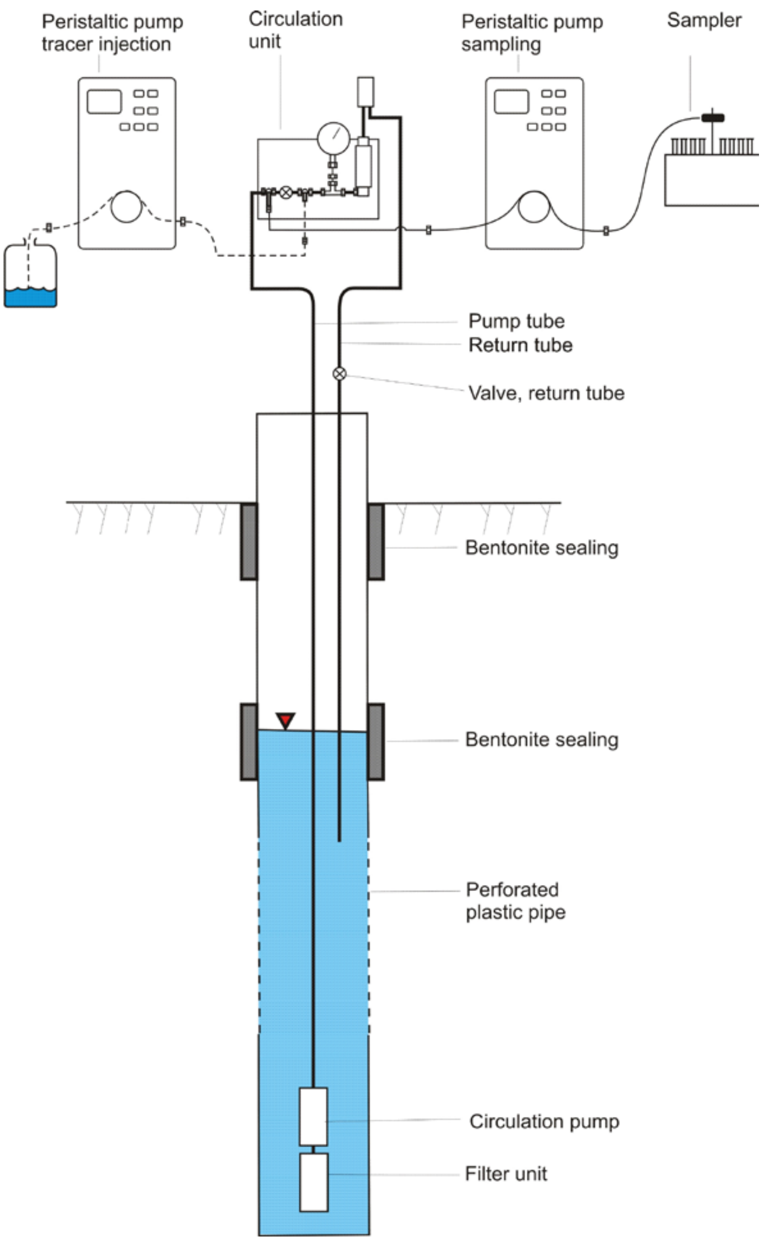


Figure 3-2. *Schematic drawing of the equipment used in tracer dilution measurements.*

4 Execution

4.1 General

In the dilution method a tracer is introduced and homogeneously distributed into a well test section. The tracer is subsequently diluted by the ambient groundwater, flowing through the well test section. The dilution of the tracer is proportional to the water flow through the well section and the groundwater flow is calculated as a function of the decreasing tracer concentration with time, Figure 4-1.

The groundwater flow measurements were performed in accordance the method description SKB MD 368.010, SKB internal document.

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.

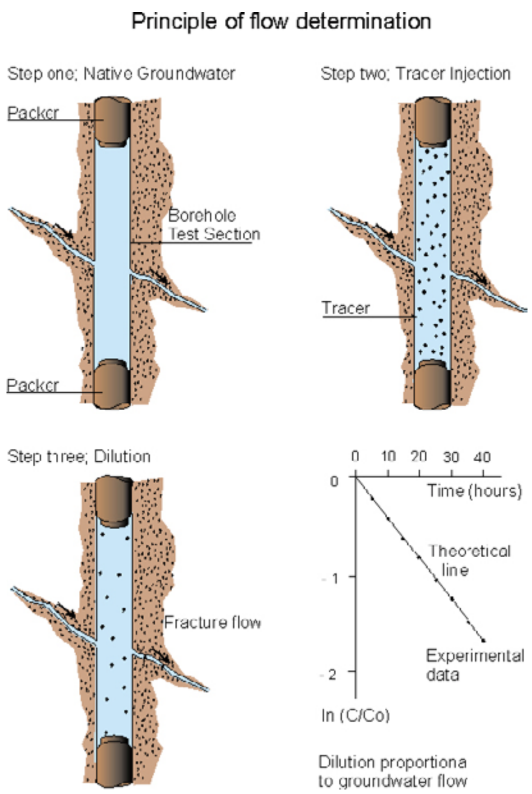


Figure 4-1. *General principles of dilution and flow determination.*

4.3 Execution of field work

Tracer dilution tests were performed in five soil wells listed in Table 2-1.

The tests were made by injecting a slug of tracer (Uranine, 500 mg/L) in the selected well 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 well. Using the equipment described in Section 3.1 the tracer solution in the well was continuously circulated and sampled allowing the natural groundwater flow to dilute the tracer. Circulation was maintained between 19 and 35 hours and the sampler was set up to change tubes every 60 minutes.

For detailed descriptions see activity plan and method description (Table 1-1).

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 well and V (m^3) is the volume of the soil well i.e. bottom to groundwater level. By plotting ln (c/c_0) versus t, and by knowing the well 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 9–11.5 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 well and the angle between the well and flow direction. In practise, a 90° angle between the well 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 well screen, 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 well screen (m), r_{bh} is the well radius (m) and α is the factor accounting for the distortion of flow caused by the well.

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 ground water level and the bottom of the soil well and d_{bh}, the soil well 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

- The sampler was affected by the bright sunlight through the white "canvas" of the tent. It started to move the test tubes at random. It has been difficult to evaluate the results because the time for changing test tube is uncertain. *This is considered to have impact on the quality of the measurements.*
- There were orange-brown coloured sediments in the samples from some soil wells. *This may have impact on the quality of the measurements*.
- Mobile electric power stations run by diesel affected the frequency of the sampler. When the sampler was set up to change tubes every 60 minutes it changed tubes after approximately 53 to 60 minutes depending on the power station. This was compensated for in the evaluation.
- Rain during the night can have disturbed the dilution in SSM000243 between 9 and 18 hours elapsed time (see Appendix 1). The soil well is situated in a discharge area (a former lake) so the extra dilution after 9 hours is probably caused by the rain.
- In two cases (SSM000243 and SSM000262) one may distinguish more than one slope on the experimental curves. This may be a result of a changing hydraulic gradient during the measurement.

5 Results

The results obtained within this activity are groundwater flow rates in soil well SSM000243, SSM000244, SSM000261, SSM000262 and SSM000263 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 1,200 to 9,200 mL/h in the measured sections with Darcy velocities ranging from 3.3 E–6 to 1.9 E–5 m/s. Hydraulic gradients are calculated according to the Darcy concept and ranging from 0.0094 to 3.1.

Tracer dilution graphs together with straight line fits for each soil well are presented in Appendix 1 where concentration are given in mg/L. The straight line fits to the experimental data are very good with regression coefficients between 0.81 and 0.999. However, in two cases (SSM000243 and SSM000262) one may distinguish more than one slope on the experimental curves. This may be a result of a changing hydraulic gradient during the measurement.

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 400-06-142).

Table 5-1. Results from groundwater flow measurements in soil wells, 2007.

Soil Well	Soil well length (m)	Groundwater level (mbtoc)	Transmissivity (m^2/s)	Volume (mL)	Measured flow (mL/h)	Darcy velocity (m/s)	Hydraulic gradient
SSM000243	12.1 m	1.75	1.5 E–4*	20,954	1,200	3.3 E–6	0.23
SSM000244	12.1 m	1.37	–	21,634	1,800	5.0 E–6	–
SSM000261	10.5 m	1.01	5.8 E–5*	19,414	6,900	1.9 E–5	3.1
SSM000262	15.0 m	0.95	9.0 E–3*	27,579	6,500	6.0 E–6	0.0094
SSM000263	8.6 m	2.40	4.1 E–4*	13,523	9,200	1.3 E–5	0.19

*From slug tests, mean values from injection and recovery period.

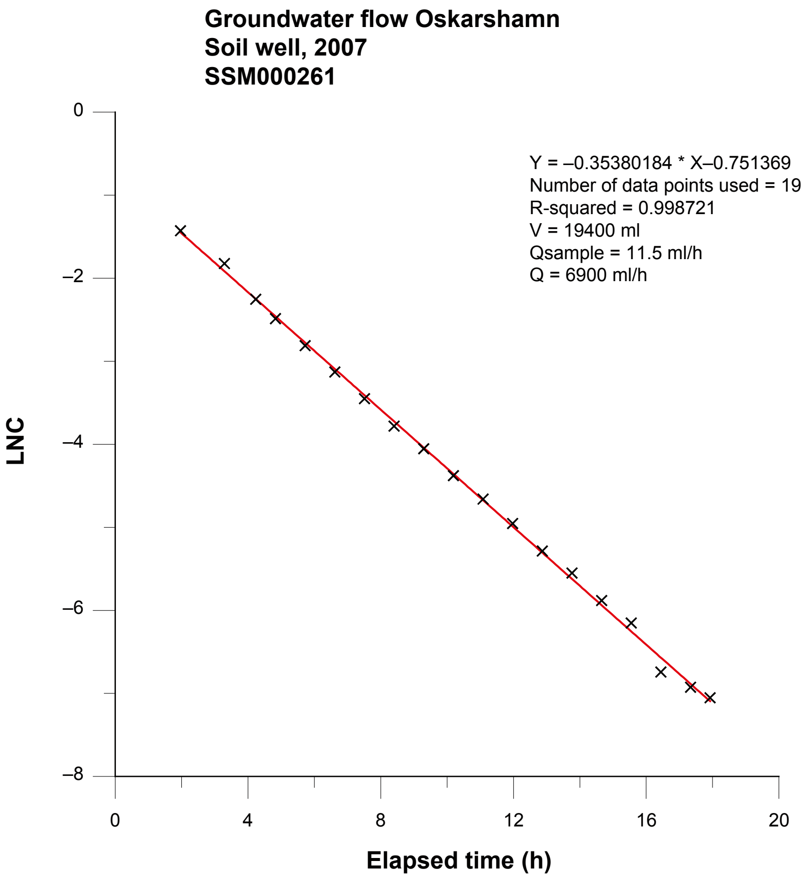


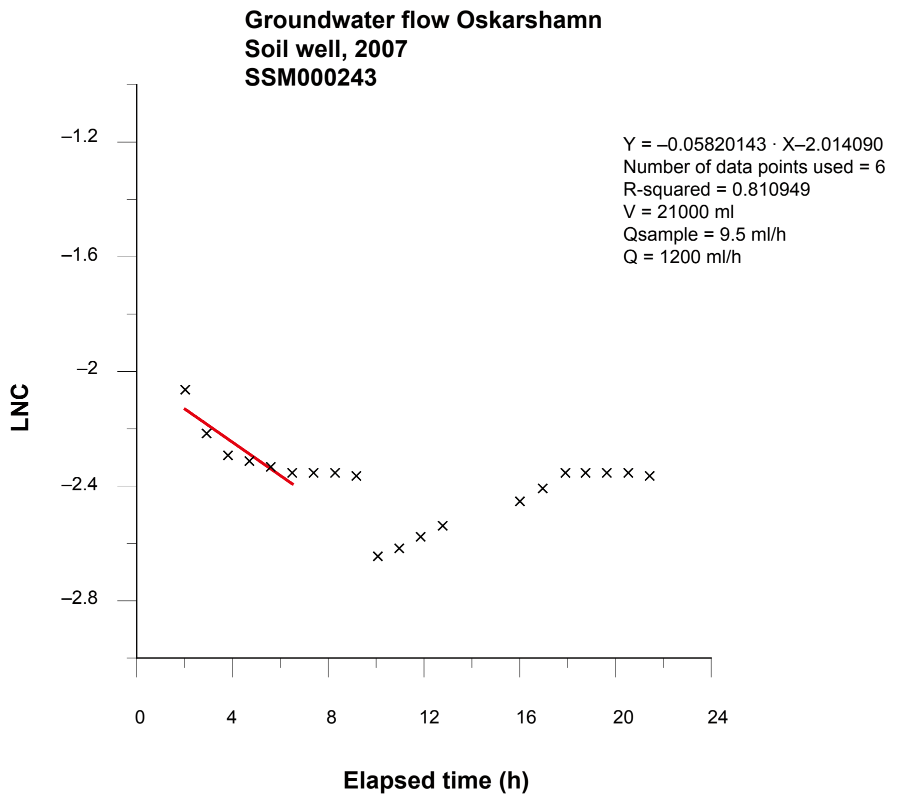
Figure 5-1. *Example of a tracer dilution graph for soil well SSM000261, including straight-line fit.*

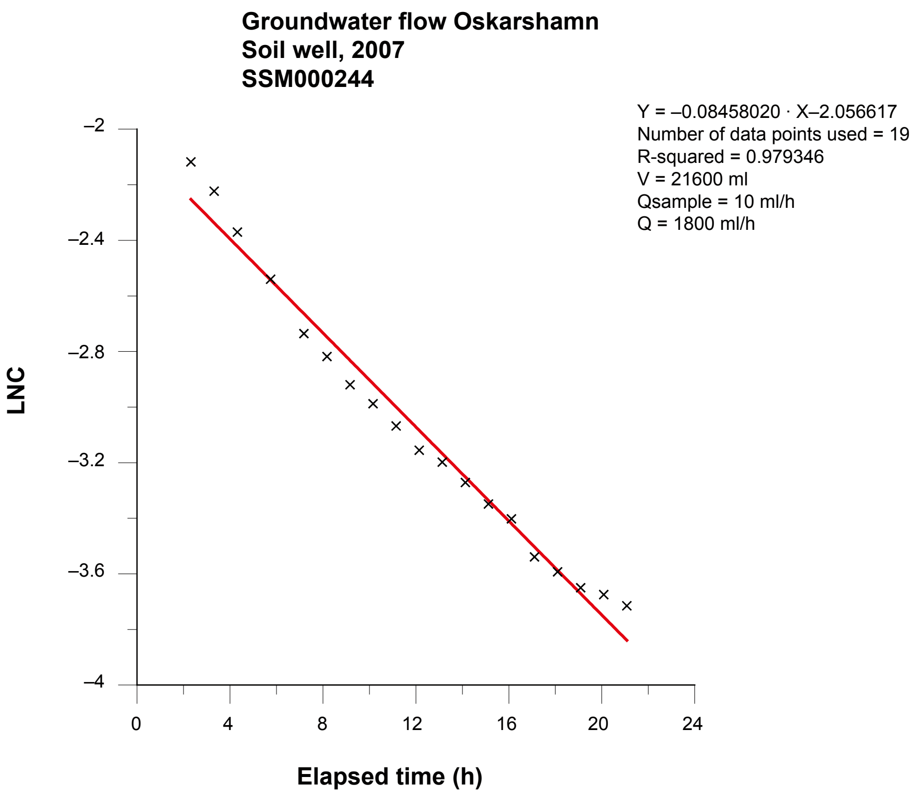
6 References

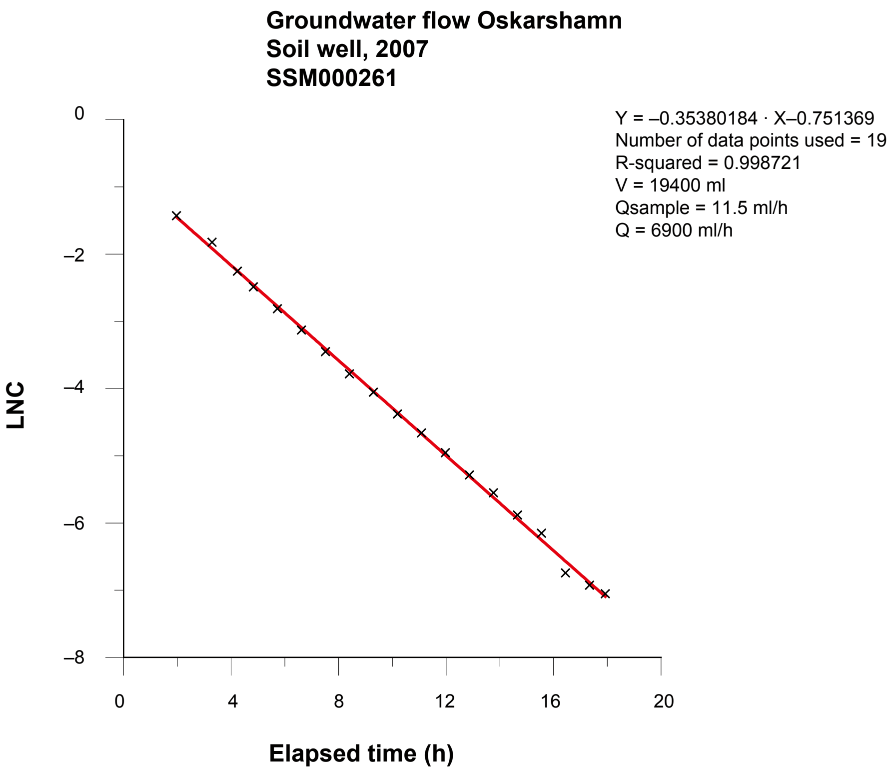
/1/ **Gustafsson E, 2002**. Bestämning av grundvattenflödet med utspädningsteknik Modifiering av utrustning och kompletterande mätningar. SKB R-02-31 (in Swedish). Svensk Kärnbränslehantering AB.

Appendix 1

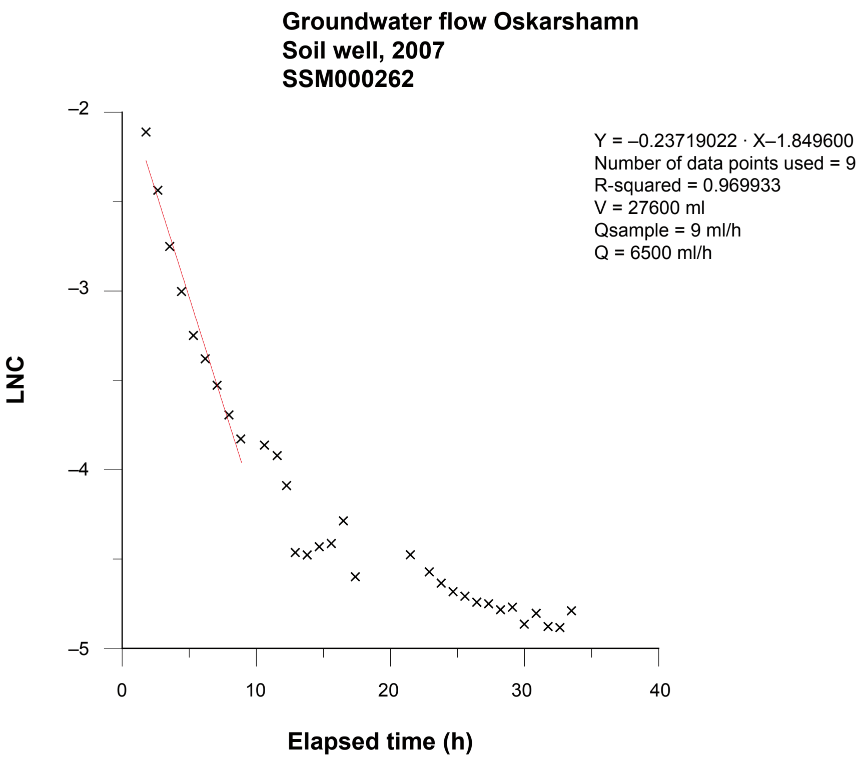
Tracer dilution graphs



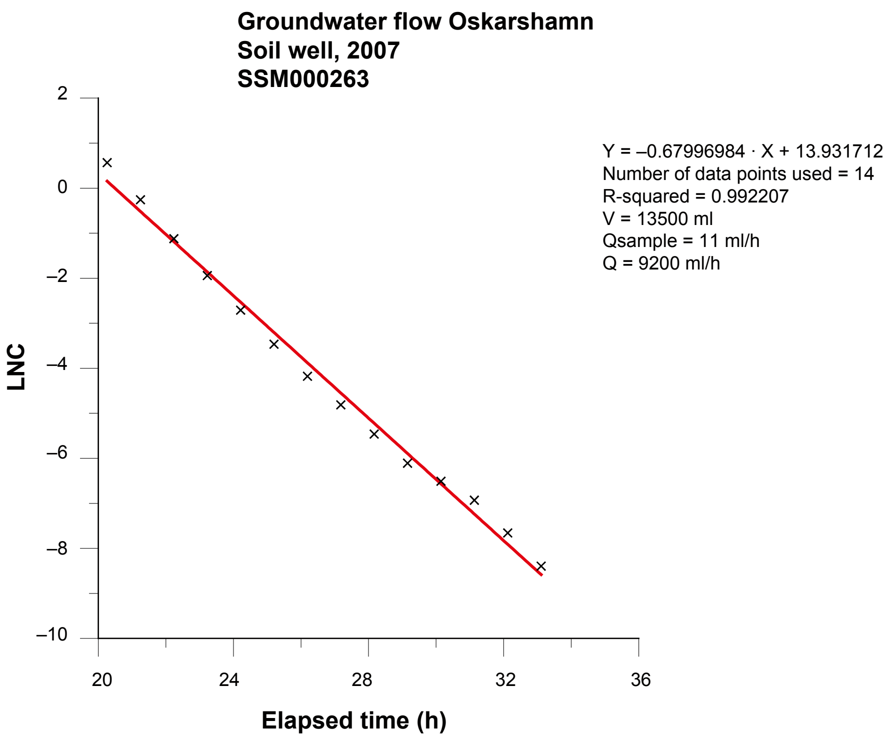




Groundwater flow Oskarshamn
Soil well, 2007
SSM000261
Y = –0.35380184 · X–0.751369
Number of data points used = 19
R-squared = 0.998721
V = 19400 ml
Qsample = 11.5 ml/h
Q = 6900 ml/h
LNC
0
–2
–4
–6
–8
0
4
8
12
16
20
Elapsed time (h)



Groundwater flow Oskarshamn
Soil well, 2007
SSM000262
Y = –0.23719022 · X–1.849600
Number of data points used = 9
R-squared = 0.969933
V = 27600 ml
Qsample = 9 ml/h
Q = 6500 ml/h
LNC
–2
–3
–4
–5
0
10
20
30
40
Elapsed time (h)


Groundwater flow Oskarshamn
Soil well, 2007
SSM000263
Y = –0.67996984 · X + 13.931712
Number of data points used = 14
R-squared = 0.992207
V = 13500 ml
Qsample = 11 ml/h
Q = 9200 ml/h
LNC
2
0
–2
–4
–6
–8
–10
20
24
28
32
36
Elapsed time (h)