P-07-182

Oskarshamn site investigation

Pump- and interference testing of percussion drilled section of cored boreholes KLX09, KLX11A, KLX12A, KLX13A, KLX18A, KLX19A and HLX39

Subarea Laxemar

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Keywords: Pumping tests, Interference test, Hydraulic tests, Transmissivity, Storativity, Storage coefficient, Connectivity, Fractured rock, Ävrö granite, Granite, Quartzmonzo diorite, Fractured rock, Bedrock.

Abstract

The report documents a selected number of pumping and interference tests performed during the site investigations. How they were executed and the basic results obtained, in term of hydraulic connectivity and the aquifers parameters transmissivity and storativity.

Sammanfattning

Rapporten dokumenterar ett antal pump- och interferenstester som utförts inom ramen för platsundersökningarna. Hur de har utförts samt de parametervärden som erhölls, i termer av hydraulisk konnektivitet, transmissivitet och magasinskoefficient.

Contents

1 Introduction

The Swedish Nuclear Fuel and Waste Management Company, hereinafter refered to as SKB, has a general program for site investigations /SKB 2001/ (SKB TR-01-29) and a site specific program for the Oskarshamn area /SKB 2006/ (SKB R-06-29).

The field work for the present activites was carried out as separate activities spanning a period August 2005 to September 2006 by SKB.

This document reports the results gained by the hydraulic testing of percussion drilled section of cored boreholes KLX09, KLX11A, KLX12A, KLX13A, KLX18A, KLX19A and HLX39, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with Activity Plans and Method Descriptions as specified in Table 1-1. Both Activity Plans and Method Descriptions are SKB's internal controlling documents.

Typically the upper 100 m of a core drilled hole is percussion drilled with larger diameter. The pumping tests reported in this document are in such boreholes except for HLX39. The field performance of the tests activity form part of the drilling activity, whereas the analysis is contained in a different activity. The tests were performed by SKB between August 2005 and September 2006.

Borehole locations are shown in Figure 1-1 and construction details in Appendix 7. Note that at the time if testing, except for KLX12A, the core drilled part of the hole with diameter 76 mm was not drilled.

Original results are stored in the primary data bases (SICADA) and are traceable by the Activity Plan number.

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

Activity Plan	Number	Version
Utvärdering av pumptester och borrningsresponser, September 2006	AP PS 400-06-115	1.0
Kärnborrning KLX09	AP PS 400-05-020	1.0
Kärnborrning KLX11A	AP PS 400-05-065	1.0
Kärnborrning KLX12A	AP PS 400-05-070	1.0
Kärnborrning KLX13A	AP PS 400-06-010	1.0
Kärnborrning KLX18A	AP PS 400-06-011	1.0
Kärnborrning KLX19A	AP PS 400-06-054	1.0
Hammarborrning HLX38–HLX41 för lieamentsundersäkningar i Laxemar	AP PS 400-06-037	1.0
Method Descriptions	**Number**	**Version**
Hantering av primärdata vid platsundersökningar	SKB SDP-508	1.0
Hydraulisk Enhålspumptester	SKB MD 321.003	1.0
Analysis of injection and single-hole pumping tests	SKB MD 320.004e	1.0

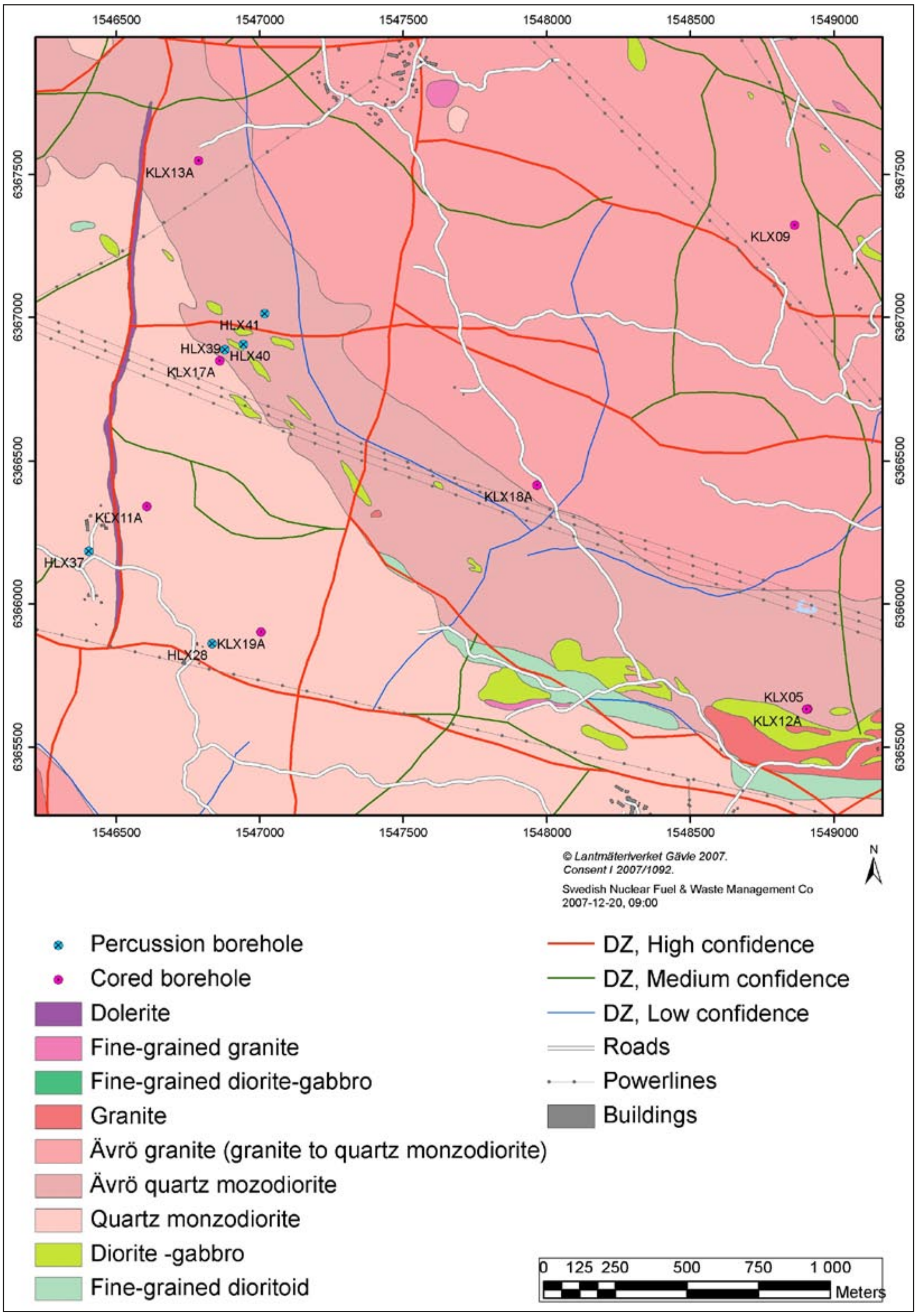

Figure 1-1. *Location of tested boreholes in the Laxemar subarea.*

2 Objective and scope

The objective with the present activity is to characterise the rock in terms of its transmissivity and storativity but also to establish hydraulic connectivity. This was done by performing pumping- and interference tests as follows.

- KLX09 pumping test
- KLX11A pumping test
- KLX12A interference tests 17.92–200.15 m
- KLX12A interference test 102.47–200.15 m
- KLX13A pumping test
- KLX18A pumping test
- KLX19A interference test
- HLX39 interference test

The purpose with this report is to document on how the activity was executed and its basic results.

3 Equipment

3.1 Description of equipment/interpretation tools

Different equipments were utilised for different tests, these are described below.

Equipment when testing boreholes KLX19A and HLX39

The pumping and interference test was performed with an integrated field unit consisting of a container at at the pumped borehole housing a:

- submersible pump: Grundfoss SPE5-70, range is about 5–100 L/min,
- absolute pressure transducer: Druck PTX1830, 10 bar range and ± 0.1% accuracy,
- water level dipper,
- flow gauge: Krohne IFM1010 electromagnetic, 0–150 L/min.

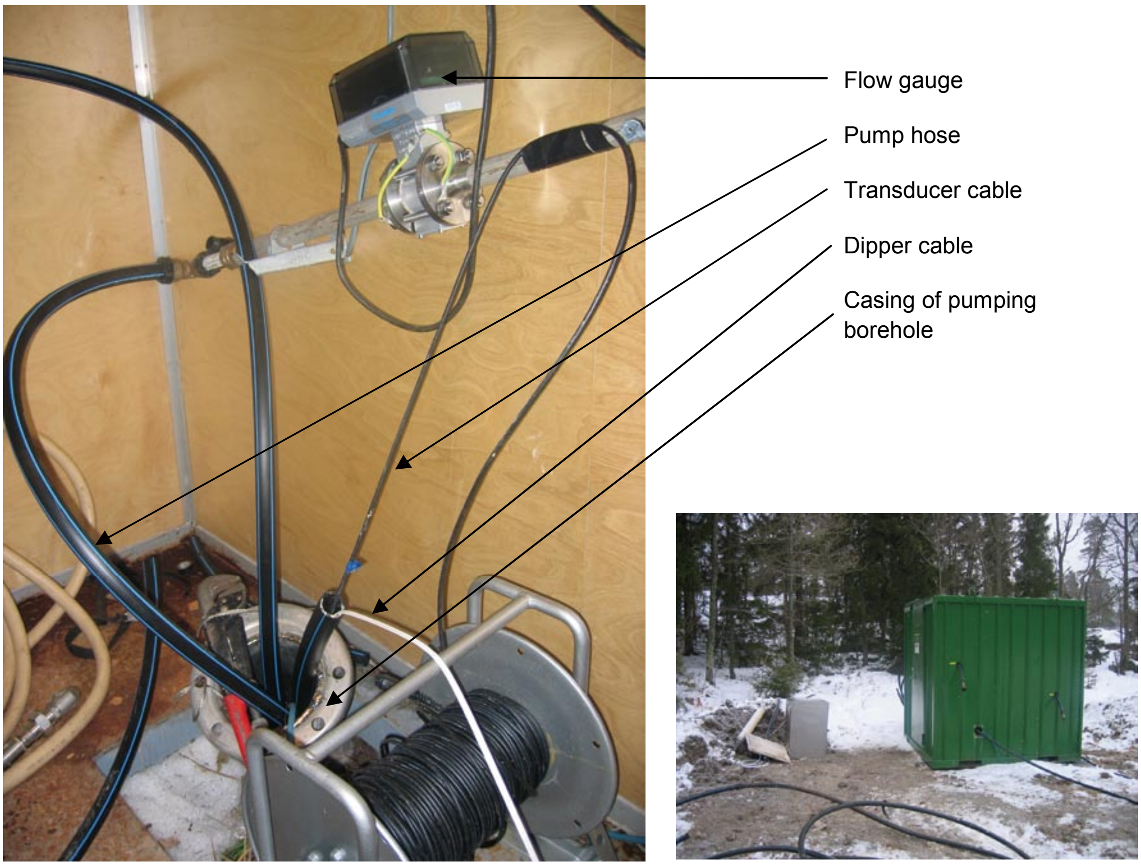

Figure 3-1. *Container housing the testing equipment (right) and instrumentation inside (left) in borehole.*

The observation wells were equipped with absolute pressure gauges datalogger as follows:

- KLX05: Druck PTX1830–3642 6 barA accuracy: ± 0.1% FS and Datataker logger.
- HLX28: Druck 10 barA and Mitec logger.
- HLX37, HLX40 and HLX41: 30 PSIA MiniTroll integrated gauge and logger 10.0 m b toc along the borehole with accuracy of ± 0.2% of full scale and resolution of ± 0.01% of full scale.

Equipment when testing KLX09, 11A,12A, 13A and 18A

The equipment described in this section was utilised when testing the following boreholes:

a) KLX09, 12–100 m

b) KLX11A, 12–100 m

c) KLX12A, 18–200 m

d) KLX12A, 102–215 m

e) KLX13A, 12–100 m

f) KLX18A, 12–101 m

The test were performed with the Wire line Probe and DMS (Drilling Monitoring System) which is an integrated field system custom made for to perform pumping tests during drilling as well as monitoring a number of variables relevant for the supervision of drilling (SKB MD 321.002 v1.0 internal controlling document). The equipment is shown in Figure 3-2 comprise the following basic components:

- submersible pump: Grundfoss MP1, range 0.1–35 L/min,
- logger Campbell CR23X and absolute pressure transducers:
  - Druck PTX1830 with 0–500 kPa range and accuracy + 0.1% FS for KLX11A and KLX13A,
  - Druck PTX1830 with 0–1,100 kPa range and accuracy + 0.1% FS forKLX09, KLX12A, KLX18A and KLX19A,
- logger and absolute pressure transducer RBR DR-1050 with 0–20 MPa range and ± 0.05% accuracy of full scale, resolution < 0.001% full scale. Only used for KLX12A, 102–215 m,
- water level dipper,
- inflatable packer. Only used for KLX12A,102–215 m,
- flow gauge: range is 0–83 L/min and an accuracy of ± 0.5% of actual flow value and also ± 0.062% of full scale current (4–20 mA).

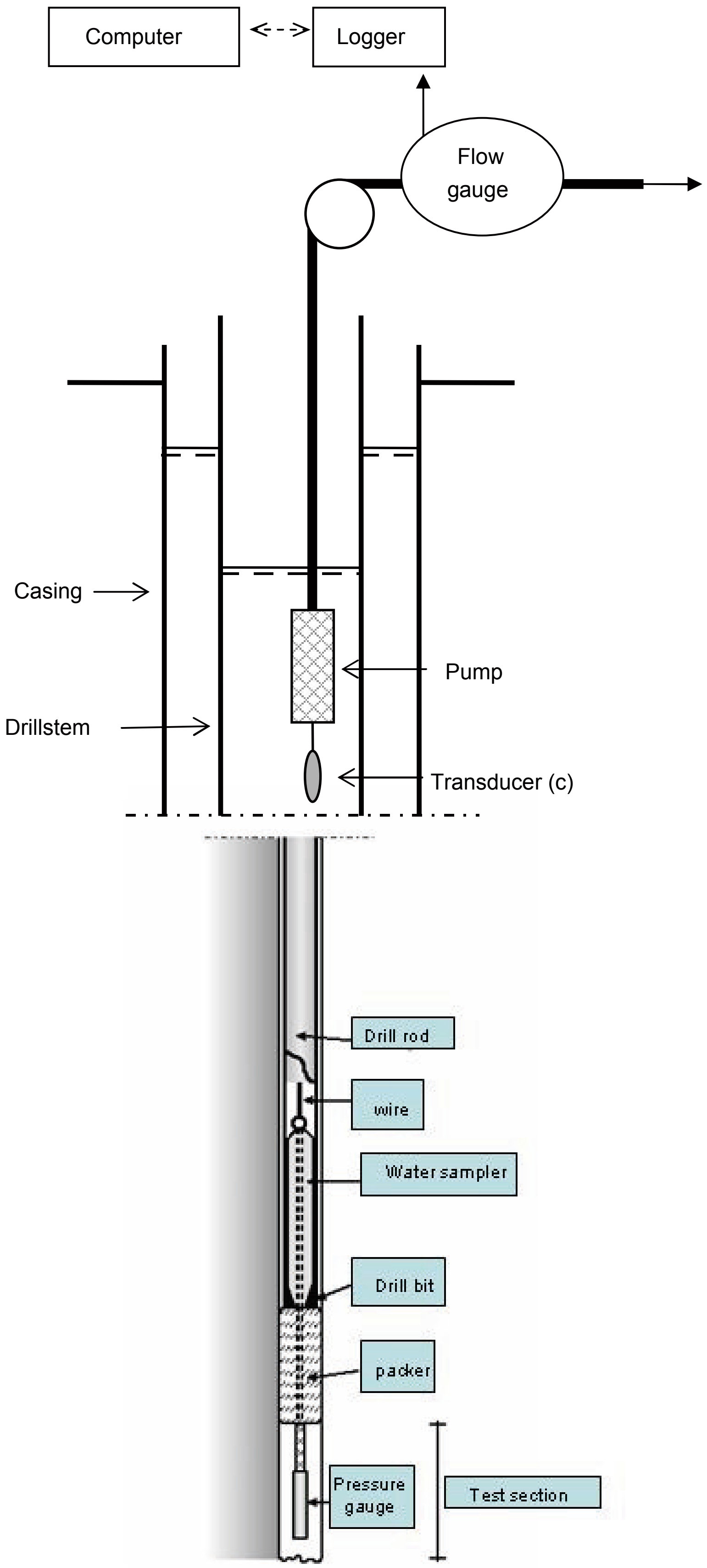

Figure 3-2. *Overview sketch of basic components of the wireline probe testing equipment. The upper sketch show the borehole head and the lower sketch borehole bottom. All tests except d) were configured according to the upper sketch while test d) also involved the lower.*

4 Execution

4.1 General

Most tests derscribed here are performed in the uppermost part of the hole which was drilled with a percussion down-the-hole hammer rig. Its is drilled to about 100 m length with a diameter of about 197 mm. The upper part of the tested section is defined as the lowere edge of the casing. Exception is the KLX12A 102–200 m tests which was performed in the cored 76 mm part of the hole utlising a packer at the top of the test section.

Tests were performed as constant rate pumping tests with a drawdown phase followed by a recovery phase. For some tests observation boreholes were in place and interference testing was performed, see Table 4-1.

4.2 Preparations

Generally the equipment was installed down the hole at least one day ahead of pump start and logging of water groundwater head was initiated.

4.3 Execution of field work

Test perfomed are compiled in Table 4-1. Manual measurements of waterlevel and flow in the pumped borehole were done as quality control of the gauge given values.

Table 4-1. Tests performed.

Test	Tested section (m)	Diameter (mm)	Source hole	Pumped flowrate (L/min)	Observation hole	Test type	Start of pumping	Stop of pumping
KLX09	11.95–100.50	196.9	KLX09	17		1B	050824 14.55	050824 20.00
KLX11A	12.05–99.96	195.0	KLX11A	13		1B	051126 16.25	051127 01.16
KLX12A	17.92–200.15	196.6 for 17.92–100.40 75.8 for 100.40–200.15	KLX12A	5.5	KLX05	2	051115 13.46	051115 21.15
KLX12A	102.47–200.15	75.8	KLX12A		KLX05	2	051114 12.30	051115 03.39
KLX13A	11.75–99.60	197.3	KLX13A	20		1B	060511 10.33	060512 10.45
KLX18A	9.30–99.93	197.7	KLX18A	1		1B	060329 17.10	060330 04.47
KLX19A	6.3–98.8	200	KLX19A	117	HLX28,37	1B	060512 12.01	060513 12.29
HLX39	6.1–199.30	139.0–137.9	HLX39	23	HLX40, 41	2	060901 10.20	060902 11.00

*1B: pumping test-submersible pump
2: interference test

4.4 Data handling/post processing

Data from all pressure gauges was corrected with respect to atmospheric pressure and converted to groundwater head expressed in metre above sea level. All data and filed protocols of flow and water level are sored in the site characterisation database (SICADA).

4.5 Analyses and interpretations

Hydraulic pumping- and interference test

Level data from boreholes and the precipitation were plotted as linear time series to assess cofluctuations, if any, and deduce cause/effects processes.

Analysis of pumping and interference test was then done according to Method Descriptions SKB MD 321.003 v.1 (Metodbeskrivning för hydrauliska enhålstester), SKB MD 330.003 v.1 (Metodbeskrivning för interferenstester) and instruction SKB MD 320.004e v.1 (Instruction for analysis of injection and single hole pumping tests). These are SKB internal controlling documents.

Briefly, the analysis is based on diagnostic log-log plot of the drawdown and the derivative of the drawdown in order to understand the different evolving flow regimes during the test. This is utilized to chose an appropriate analytical model from which the aquifers parameters, transmissivity and storage coefficient, are calculated. Observation wells were modeled with the line source solution while for the pumping well the borehole volume was included.

Interference tests were interpreted for response indexes, flow regime and aquifer parameter. For calculation of distances between the pumped hole and the observations hole the point of application was the middle of the borehole or section length, see Table 5-7 and 5-9.

Response index follows SKB MD 330.003 (Metodbeskrivning för interferenstester) SKB internal controlling document.

Index 1:

r_s^2/dt_L = normalised distance r_s with respect to the response time [m²/s],

Index 2:

s_p/Q_p = normalised drawdown with respect to the pumping rate [s/m^2].

Additionally, a third index was calculated including drawdown and distance. This index is calculated as follows:

Index 2 new:

$(s_p/Q_p)\cdot\ln(r_s/r_0)$ $r_0 = 1$ and for the pumped borehole $r_s = e^1$ (fictive borehole radius of 2.718).

The classification based on the indices is given as follows:

Index 1 (r_s^2/dt_L)		Index 2 (s_p/Q_p)		Colour code
$r_s^2/dt_L > 100$ m²/s	Excellent	$s_p/Q_p > 1\cdot10^5$ s/m²	Excellent	
$10 < r_s^2/dt_L \leq 100$ m²/s	High	$3\cdot10^4 < s_p/Q_p \leq 1\cdot10^5$ s/m²	High	
$1 < r_s^2/dt_L \leq 10$ m²/s	Medium	$1\cdot10^4 < s_p/Q_p \leq 3\cdot10^4$ s/m²	Medium	
$0.1 < r_s^2/dt_L \leq 1$ m²/s	Low	$s_p/Q_p \leq 1\cdot10^4$ s/m²	Low	
		$s_p < 0.1$ m	No response	

Index 2 new $(s_p/Q_p)\cdot\ln(r_s/r_0)$		Colour code
$(s_p/Q_p)\cdot\ln(r_s/r_0) > 5\cdot10^5$ s/m²	Excellent	
$5\cdot10^4 < (s_p/Q_p)\cdot\ln(r_s/r_0) \leq 5\cdot10^5$ s/m²	High	
$5\cdot10^3 < (s_p/Q_p)\cdot\ln(r_s/r_0) \leq 5\cdot10^4$ s/m²	Medium	
$5\cdot10^2 < (s_p/Q_p)\cdot\ln(r_s/r_0) \leq 5\cdot10^3$ s/m²	Low	
sp < 0.1 m	No response	

The response indexes which were calculated are compiled in Table 5-7 and 5-9.

The test interpretation for flow regimes and aquifer parameters was done with Aqtesolv 4.0 from HydroSOLVE Inc., USA.

4.6 Nonconformities

There were no nonconformities.

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, see Table 1-1. 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. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major revisions entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

All results are in Appendices 1–6, one per test. Here are linear plots, semi-log and log-log plots showing data and simulated curves along with the evaluated parameters.

Construction drawings for all holes are in Appendix 7. In the following the main considerations and conclusions of each test are presented along with salient derived parameters.

5.1 KLX09 single hole pumping test

The borehole is dominated by Ävrö granite. After c. 60 min during the flow period the flow rapidly increased (see linear plot of Q and P) which affected the transient evaluation of the flow period. A good type curve fit for the entire flow period was not possible; hence the transient evaluation was divided in an early and a late part. The transmissivity was estimated from the early part of the flow period and was assumed to be the same during the late part of the flow period. The estimated skin factor was significantly higher during the late part of the flow period indicating a flow rate dependent skin factor.

The change in flow rate during the flow period in combination with a short flow period complicated the transient evaluation for this borehole. Nevertheless, during both the flow and recovery period, initial wellbore storage effects are transitioning to an assumed pseudo-spherical flow regime. The transient evaluation of the pumping test in borehole KLX09 was made according to a leaky aquifer model including skin and wellbore storage by /Moench 1985/. Only one semi-confining layer was assumed.

No unambiguous transient evaluation was possible of the recovery period. Hence the same transmissivity as was determined from the early flow period was assumed for the recovery period. The parameter values from the late flow period are selected as the most representative. The analysis of the early part of the flow period is presented in the test summary sheet below.

Table 5-1. Calculated aquifers parameters for test in KLX09.

ID code	Activity	Start date	Secup (m b toc)	Seclow (m b toc)	Value type	Best choice	Transmissivity (m^2/s)	Eval method
KLX09	Pumping test-submersible pump	2005-08-24 14:55:30	11.95	100.06	0	1	1.9E–5	Tt
KLX09	Pumping test-submersible pump	2005-08-24 14:55:30	11.95	100.06	0	0	2.3E–5	Moye

Valuetype: –1,0,1 for below , within and above measurement limit.
Best choice: 1 if the value is considered the most representative, else 0.
Evaluation method: Tt = transient evalution of pumped hole, Moye = steady state evaluation of pumped hole, T0 = transient evalution of observation hole.

5.2 KLX11A single hole pumping test

The borehole is dominated by quartzmonzodiorite.During both the flow and recovery period, wellbore storage effects are followed by dominating pseudo-radial flow after c. 80 minutes.

The agreement in evaluated parameter values between the flow and recovery period is good. The parameter values from the flow period is selected as the most representative.

5.3 KLX12A interference test 18–200 m

The borehole is dominated by Ävrö granite.The level variations in observation hole KLX05 are interpreted as being tidaly induced fluctuations and not a result of the pumping in KLX12A. Therefore no further evaluations were made for the borehole KLX05. Borehole locations are shown in Figure 5-1.

The flow period indicates a wellbore storage effect followed by dominating pseudo-radial flow after c. 290 minutes.

During the recovery period no obvious pseudo-radial flow regime is developed after the initial period dominated by wellbore storage. No unambiguous transient evaluation was possible for the recovery period. Therefore the transmissivity from the flow period was assumed for the recovery period while estimating skin and r(c).

The parameter values from the flow period are selected as the most representative, Table 5-3.

Table 5-2. Calculated aquifers parameters for test in KLX11A.

ID code	Activity	Start date	Secup (m b toc)	Seclow (m b toc)	Value type	Best choice	Transmissivity (m^2/s)	Eval method
KLX11A	Pumping test-submersible pump	2005-11-26 16:25:30	12.05	100.06	0	0	1.5E–5	Moye
KLX11A	Pumping test-submersible pump	2005-11-26 16:25:30	12.05	100.06	0	1	1.3E–5	Tt

Valuetype: –1,0,1 for below , within and above measurement limit.
Best choice: 1 if the value is considered the most representative, else 0.
Evaluation method: Tt = transient evalution of pumped hole, Moye = steady state evaluation of pumped hole, T0 = transient evalution of observation hole.

Table 5-3. Calculated aquifers parameters for test in KLX12A.

ID code	Activity	Start date	Secup (m b toc)	Seclow (m b toc)	Value type	Best choice	Transmissivity (m^2/s)	Eval method
KLX12A	Pumping test-submersible pump	2005-11-15 13:46:40	17.92	200.15	0	1	5.9E–6	Tt
KLX12A	Pumping test-submersible pump	2005-11-15 13:46:40	17.92	200.15	0	0	6.0E–6	Moye

Valuetype: –1,0,1 for below , within and above measurement limit.
Best choice: 1 if the value is considered the most representative, else 0.
Evaluation method: Tt = transient evalution of pumped hole, Moye = steady state evaluation of pumped hole, T0 = transient evalution of observation hole.

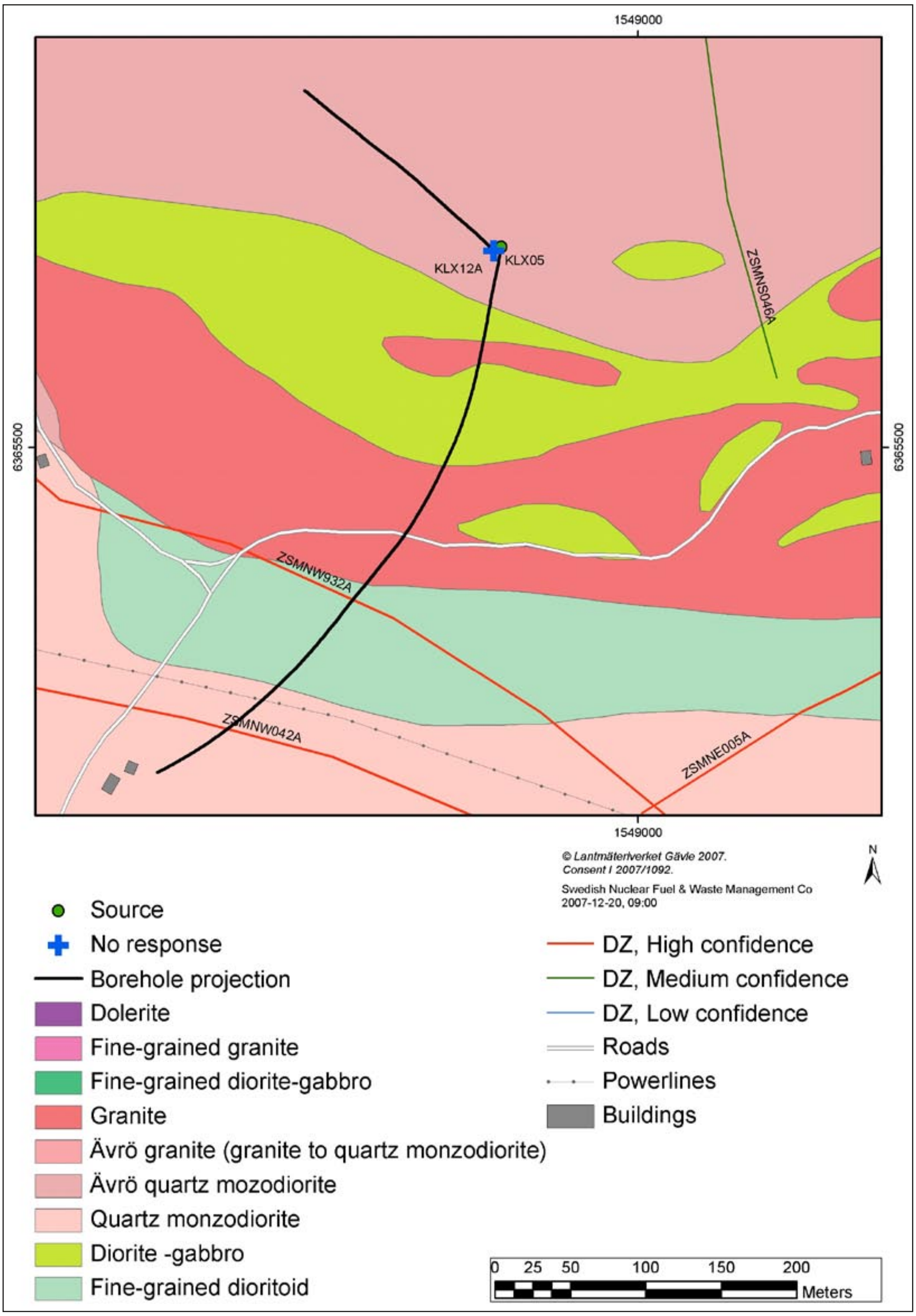

Figure 5-1. *Location of pumped borehole KLX12A and observation hole KLX05.*

5.4 KLX12A interference test 102–200 m

The borehole is dominated by Ävrö granite. The level variations in observation hole KLX05 are interpreted as being tidaly induced fluctuations and not a result of the pumping in KLX12A. Therefore no further evaluations were made for the borehole KLX05.

The test was performed in the cored 76 mm part of the hole utlising a packer at the top of the test section.

Both the flow and the recovery periods are affected by wellbore storage. The recovery period is judged to be too short for a transient evaluation.

The many flow rate changes brings a certain amount of uncertainty to the parameter estimation. Interpretation of flow regime following the WBS period is not possible.

5.5 KLX13A single hole pumping test

The borehole is dominated by Ävrö granite. During both the flow and recovery period, wellbore storage effects are followed by dominating pseudo-radial flow after c. 100 and c. 200 minutes respectively.

The variations in derivative during the flow period were a result of flow rate changes. Derived parameters from the flow period are selected as the most representative. The agreement in transmissivity between the flow and the recovery period is good while the skin factor becomes higher for the recovery.

Table 5-4. Calculated aquifers parameters for test in KLX12A.

ID code	Activity	Start date	Secup (m b toc)	Seclow (m b toc)	Value type	Best choice	Transmissivity (m^2/s)	Eval method
KLX12A	Pumping test-submersible pump	2005-11-14 12:31:10	102.50	200.15	0	1	1.9E–6	Tt
KLX12A	Pumping test-submersible pump	2005-11-14 12:31:10	102.50	200.15	0	0	2.9E–6	Moye

Valuetype: –1,0,1 for below , within and above measurement limit.
Best choice: 1 if the value is considered the most representative, else 0.
Evaluation method: Tt = transient evalution of pumped hole, Moye = steady state evaluation of pumped hole, T0 = transient evalution of observation hole.

Table 5-5. Calculated aquifers parameters for test in KLX13A.

ID code	Activity	Start date	Secup (m b toc)	Seclow (m b toc)	Value type	Best choice	Transmissivity (m^2/s)	Eval method
KLX13A	Pumping test-submersible pump	2006-05-11 10:33:00	11.75	99.86	0	1	2.2E–5	Tt
KLX13A	Pumping test-submersible pump	2006-05-11 10:33:00	11.75	99.86	0	0	1.8E–5	Moye

Valuetype: –1,0,1 for below , within and above measurement limit.
Best choice: 1 if the value is considered the most representative, else 0.
Evaluation method: Tt = transient evalution of pumped hole, Moye = steady state evaluation of pumped hole, T0 = transient evalution of observation hole.

5.6 KLX18A single hole pumping test

The borehole is dominated by Ävrö granite. Both the flow and the recovery period is dominated by wellbore storage effects. No unambiguous transient evaluation is possible neither for the flow or the recovery period.

5.7 KLX19A interference test

Observation hole responses

When pumping KLX19A responses were observed in both observation holes, HLX28 and HLX37, see Figure 5-2. Response data is compiled in Table 5-7.

KLX19A pumped hole

The borehole is dominated by quartzmonzodiorite. During both the flow and recovery periods of the pumped borehole KLX19A, pseudo linear flow regime is followed by a no flow boundary influence. The response may be interpreted as being dominated by a single fracture with limited extent.

The agreement in evaluated parameter values between the flow and recovery period is good. The parameter values from the flow period are selected as the most representative.

A model by Gringarten-Ramey for a single horizontal fracture is used in this case instead of the generally used model for radial flow by Dougherty-Babu.

Table 5-6. Calculated aquifers parameters for test in KLX18A.

ID code	Activity	Start date	Secup (m b toc)	Seclow (m b toc)	Value type	Best choice	Transmissivity (m²/s)	Eval method
KLX18A	Pumping test-submersible pump	2006-03-29 17:09:50	11.80	99.90	0	1	9.9E–7	Tt
KLX18A	Pumping test-submersible pump	2006-03-29 17:09:50	11.80	99.90	0	0	8.2E–7	Moye

Valuetype: –1,0,1 for below , within and above measurement limit.
Best choice: 1 if the value is considered the most representative, else 0.
Evaluation method: Tt = transient evalution of pumped hole, Moye = steady state evaluation of pumped hole, T0 = transient evalution of observation hole.

Table 5-7. Response data for KLX19A interference test.

Test date : 2006-05-12–2006-05-13									Index1	Index 2	Index 2 new
Bh	Secup (m)	Seclow (m)	Point of appl. (m)	Qp (L/min)	tp (h)	r (m)	dp (m)	dt_L* (s)	r^2/t_L (m²/s)	(dp/Qp) (m/(m³/s)	(dp/Qp)*ln(r/r_0) (m/(m³/s)
KLX19A	6.3	99.3	52.8	108	24.46		8.72	–	–	4,846	4,846
HLX28	6	154.2	80.1		24.46	188	6.62	600	58.91	3,677.78	19,258.47
HLX37	12	199.8	105.9		24.46	620	1.01	9,900	38.83	561.11	3,607.79

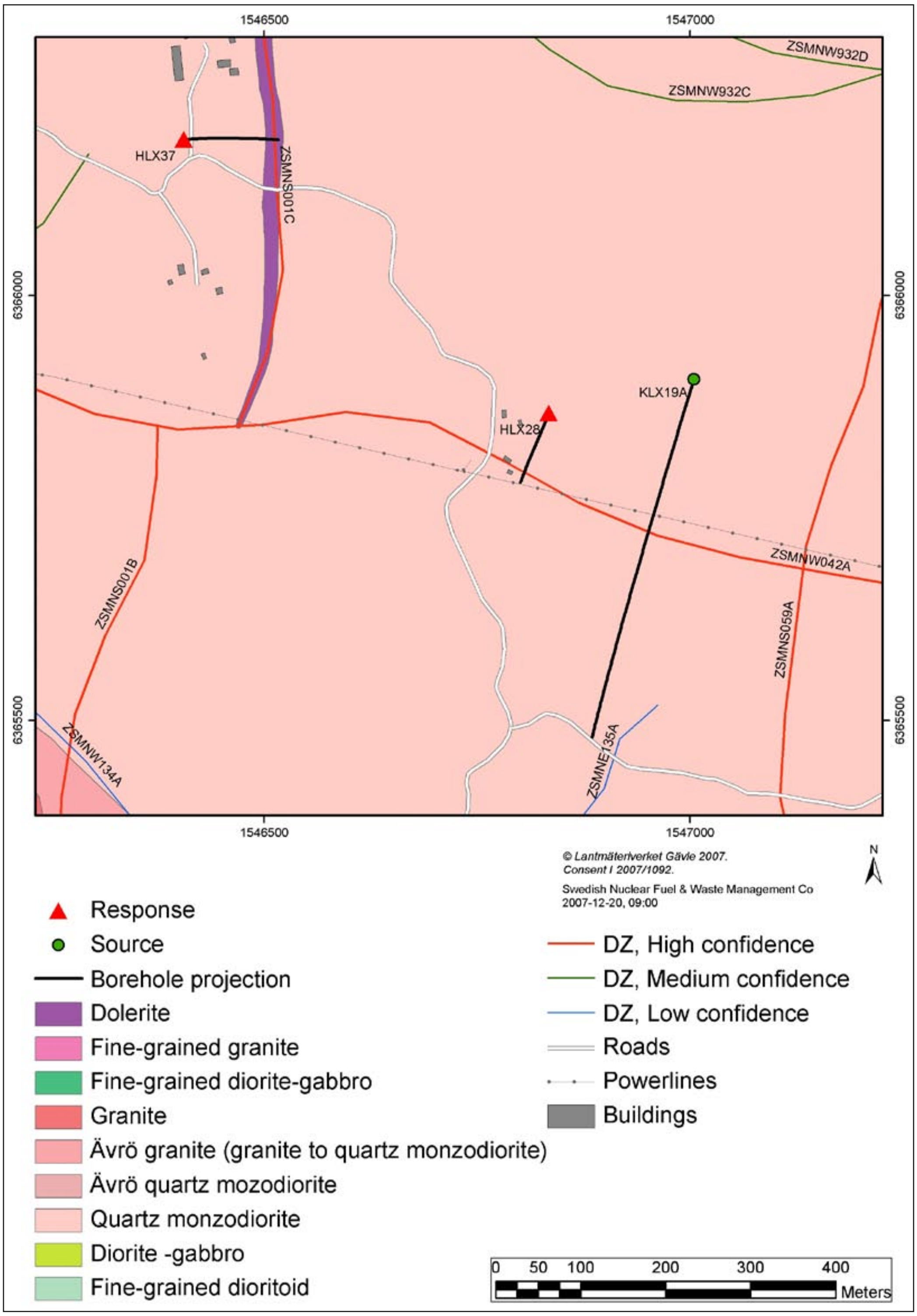

Figure 5-2. *Location of pumped borehole KLX19A and observations holes HLX28 and HLX37.*

HLX28 observation hole

The borehole is dominated by quartzmonzodiorite. For the observation borehole HLX28, the agreement between the flow and the recovery period is good. The results from the recovery period are chosen as most representative, mainly due to the disturbance occurring after c. 150 minutes during the flow period.

HLX37 observation hole

The borehole is dominated by quartzmonzodiorite. The agreement between the flow and the recovery period is good. The results from the recovery period are chosen as most representative.

5.8 HLX39 interference test

Observation hole responses when pumping HLX39

The borehole is dominated by Ävrö granite. When pumping HLX39 responses were observed in observation holes HLX40 and HLX41 but not in KLX17A, see Figure 5-3. Response data is compiled in Table 5-9.

Table 5-8. Calculated aquifers parameters for interference test in KLX19A.

ID code	Activity	Start date	Secup (m b toc)	Seclow (m b toc)	Value type	Best choice	Transmissivity (m^2/s)	Eval method
KLX19A	Pumping test-submersible pump	2006-05-12 12:01:20	6.30	99.30	0	1	2.8E–4	Tt
KLX19A	Pumping test-submersible pump	2006-05-12 12:01:20	6.30	99.30	0	0	2.36E–4	Moye
HLX28	Interference test-obs.holes	2006-05-12 12:01:20	6.00	154.20	0	1	4.3E–5	To
HLX37	Interference test-obs.holes	2006-05-12 12:01:20	12.00	199.80	0	1	1.9E–4	To

Valuetype: –1,0,1 for below , within and above measurement limit.
Best choice: 1 if the value is considered the most representative, else 0.
Evaluation method: Tt = transient evalution of pumped hole, Moye = steady state evaluation of pumped hole, T0 = transient evalution of observation hole.

Table 5-9. Response data for HLX39 interference test.

Test date : 2006-09-01–2006-09-02									Index1	Index 2	Index 2 new
Bh	Secup (m)	Seclow (m)	Point of appl. (m)	Qp (L/min)	tp (h)	r (m)	dp (m)	dt_L* (s)	r^2/t_L (m^2/s)	(dp/Qp) (m/(m^3/s)	(dp/Qp)*ln(r/r_0) (m/(m^3/s)
HLX39	6.1	199.3	102.7	23.6	24.63		6.73	–	–	17,113	17,113
HLX40	6.1	199.5	102.8		24.63	63	2.7	360	11.03	6,864	28,440
HLX41	6.1	199.5	102.8		24.63	98	1.12	26,880	0.36	2,847	13,055

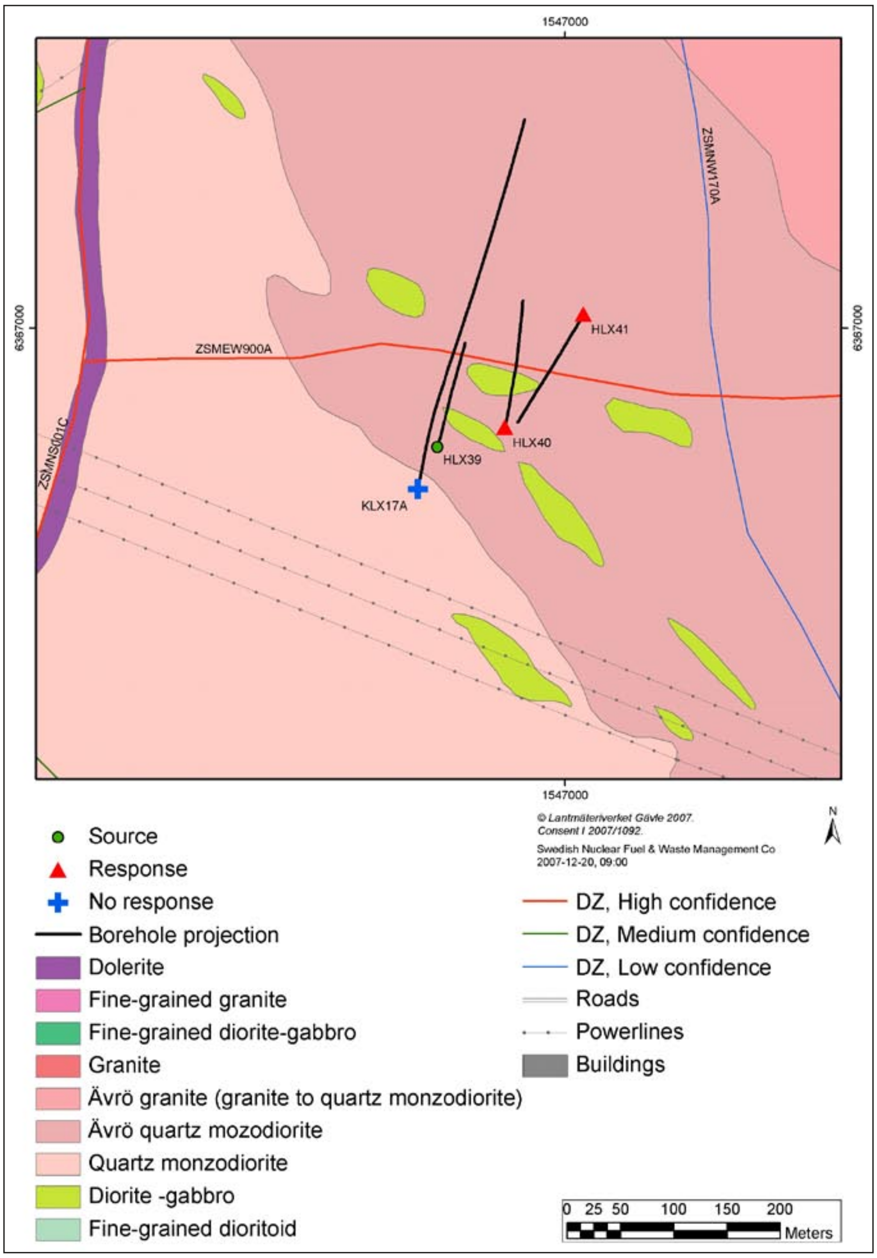

Figure 5-3. *Location of boreholes pumped borehole HLX39 and observation holes HLX40, HLX41 and KLX17A.*

HLX40 observation hole

The borehole is dominated by Ävrö granite. During both the flow and recovery period, wellbore storage effects are followed by an apparent no flow boundary.

The resulting parameters from the flow and the recovery period are somewhat contradictory, but the parameter values from the flow period is selected as the most representative.

A change in pumping flow rate is affecting the early part of the flow period.

HLX41 observation hole

The borehole is dominated by Ävrö granite. During both the flow and recovery period an apparent no flow boundary effect may be seen.

The parameter values from the flow period is selected as the most representative.

Table 5-10. Calculated aquifers parameters for interference test in HLX39.

ID code	Activity	Start date	Secup (m b toc)	Seclow (m b toc)	Value type	Best choice	Transmissivity (m^2/s)	Eval method
HLX39	Pumping test-submersible pump	2006-09-01 08:00:00	6.10	199.30	0	0	7.8E–5	Moye
HLX39	Pumping test-submersible pump	2006-09-01 08:00:00	6.10	199.30	0	1	1.0E–4	Tt
HLX40	Interference test-obs.holes	2006-09-01 08:00:00	6.10	199.50	0	1	1.5E–4	To
HLX41	Interference test-obs.holes	2006-09-01 08:00:00	6.10	199.50		1	1.1E–5	To

Valuetype: –1,0,1 for below , within and above measurement limit.
Best choice: 1 if the value is considered the most representative, else 0.
Evaluation method: Tt = transient evalution of pumped hole, Moye = steady state evaluation of pumped hole, T0 = transient evalution of observation hole.

6 Summary of results

Results of this activity are summarised in the three tables below. Table 6-1 showing measured response variables, Table 6-2 with calculated parameters from observation holes and Table 6-3 with calculated parameters from pumped holes.

Table 6-1. Measured test variables from observation holes.

Pumped borehole ID code	secup (m)	seclow (m)	Observation hole idcode	secup (m)	seclow (m)	start_flow (yyyymmdd hh:mm:ss)	stop_flow (yyyymmdd hh:mm:ss)	lp (m)	rs (m)	dtl (s)	pi (kPa)	pp (kPa)
HLX39	6.00	199.30	HLX40	6.10	199.50	2006-09-01 10:20:40	2005-09-02 10:58:20	102.75	63	360	148.10	121.30
HLX39	6.00	199.30	HLX41	6.10	199.50	2006-09-01 10:20:40	2005-09-02 10:58:20	102.80	98	26 880	159.50	148.60
KLX12A	17.92	200.15	KLX05			2005-11-15 13:46:40	2005-11-15 21:14:40					
KLX12A	102.50	200.15	KLX05			2005-11-14 12:31:10	2005-11-15 03:39:35					
KLX19A	6.30	99.30	HLX28	6.00	154.20	2006-05-12 12:01:20	2006-05-13 12:28:45	80.10	188	600	116.60	51.50
KLX19A	6.30	99.30	HLX37	12.00	199.80	2006-05-12 12:01:20	2006-05-13 12:28:45	105.90	620	9 900	139.20	129.30

Table 6-2. Calculated parameters from observation holes.

Pumped borehols Id code	secup (m)	seclow (m)	Observation holes idcode	start_date	stop_date	secup (m)	seclow (m)	lp (m)	T (m**2/s)	S
HLX39	6.00	199.30	HLX40	2006-09-01 08:00	2006-09-04 00:00	6.00	199.50	102.75	1.5E–4	3.4E–5
HLX39	6.00	199.30	HLX41	2006-09-01 08:00	2006-09-04 00:00	6.10	199.50	102.80	1.1E–5	2.9E–4
KLX12A	17.92	200.15	KLX05	2005-11-15 13:46	2005-11-16 00:00				No response	
KLX12A	102.50	200.15	KLX05	2005-11-14 12:31	2005-11-15 00:00				No response	
KLX19A	6.30	99.30	HLX28	2006-05-12 12:01	2006-05-14 00:00	6.00	154.20	80.10	4.3E–5	2.1E–5
KLX19A	6.30	99.30	HLX37	2006-05-12 12:01	2006-05-14 00:00	12.00	199.80	105.90	1.9E–4	3.3E–5

Table 6-3. Calculated parameters from pumped holes.

idcode	start_date	stop_date	secup (m)	seclow (m)	lp (m)	Q/s (m**2/s)	Tmoye (m**2/s)	Tt (m**2/s)	Utilised S	ri (m)	c (m**3/P)	skin
KLX09	2005-08-24 14:55	2005-08-25	11.95	100.60	56	2.0E–5	2.3E–5	1.9E–5	3.1E–6	453	6.0E–6	3.5
KLX11A	2005-11-26 16:25	2005-11-27	12.05	100.60	56	1.2E–5	1.5E–5	1.3E–5	2.6E–6	773	3.9E–6	–1.7
KLX13A	2006-05-11 10:33	2006-05-13	11.75	99.86	56	1.2E–5	1.8E–5	2.2E–5	3.3E–6	145	3.9E–6	2.0
KLX18A	2006-03-29 17:09	2006-03-31	11.80	99.90	56	7.2E–7	8.2E–7	9.9E–7	7.0E–7	365	3.0E–6	
HLX33	2006-06-28 14:37	2006-08-29	9.00	202.10	106	1.2E–4	1.6E–4	2.2E–4	1.1E–5	1,610	2.3E–6	–0.2
HLX37	2005-10-18 11:34	2005-11-03	12.00	199.80	106	2.5E–5	3.4E–5	2.2E–5	3.3E–6	67	2.2E–6	–5.2
HLX39	2006-09-01 08:00	2006-09-04	6.00	199.30	103	5.8E–5	7.8E–5	1.0E–4	5.0E–6	1,997	2.3E–6	–4.5
KLX12A	2005-11-15 13:46	2005-11-16	17.92	200.15	109	4.7E–6	6.0E–6	5.9E–6	1.7E–6	59	3.0E–6	–0.5
KLX12A	2005-11-14 12:31	2005-11-15	102.50	200.20	151	2.4E–6	2.9E–6	1.9E–6	1.0E–6	483	1.5E–7	–5.6
KLX19A	2006-05-12 12:01	2006-05-14	6.30	99.30	53	2.1E-4	2.4E–4	2.8E–4	1.2E–5	2,150	5.9E–6	

Explanations to table header:

lp: point of application, point where distance rs is calculated for
rs: spherical distance between pump and observation hole
dtL: time elapsed for a 0.1 m response
pi: initial pressure, prior to pumpstart
pp: final pressure, befor pumpstop
T: transsmissivity
S: storage coefficient
Q/s: specific capacity
Tmoye: steady state transmisivity
Tt: tramsmissivity derived from transient phase
ri: radius of influence
C: wellbore storage coefficient

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SKB, 2006. Oskarshamn site investigations: Programme for further investigations of bedrock, soil, water and environment in Laxemar subarea, SKB R-06-29, Svensk Kärnbränslehantering AB, March 2006.

Appendix 1

Test diagrams for the pumping test in KLX09

Nomenclature in AQTESOLV:

T = transmissivity (m^2/s)

S = storativity (–)

K_Z/K_r = ratio of hydraulic conductivities in the vertical and radial direction (set to 1)

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

b = aquifer thickness

Pumping test in KLX09: 12.0–100.6 m

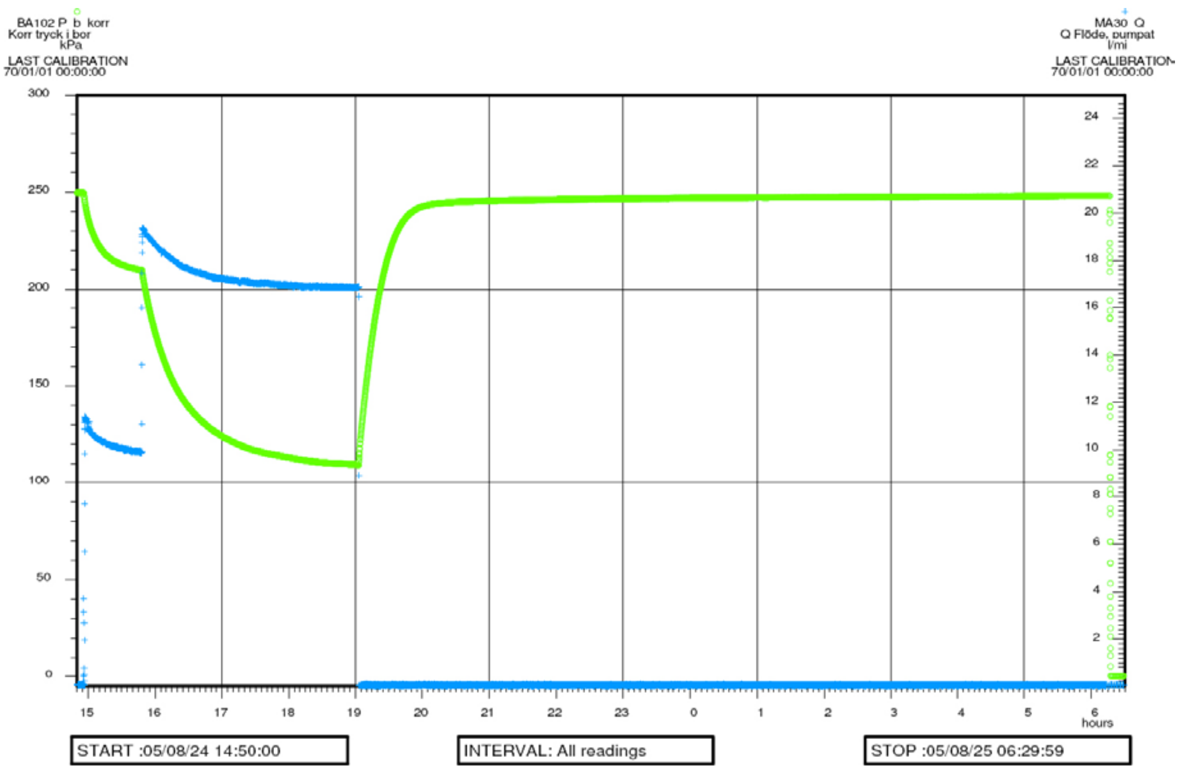


Figure A1-1. Linear plot of flow rate and pressure versus time in the pumping borehole KLX09.

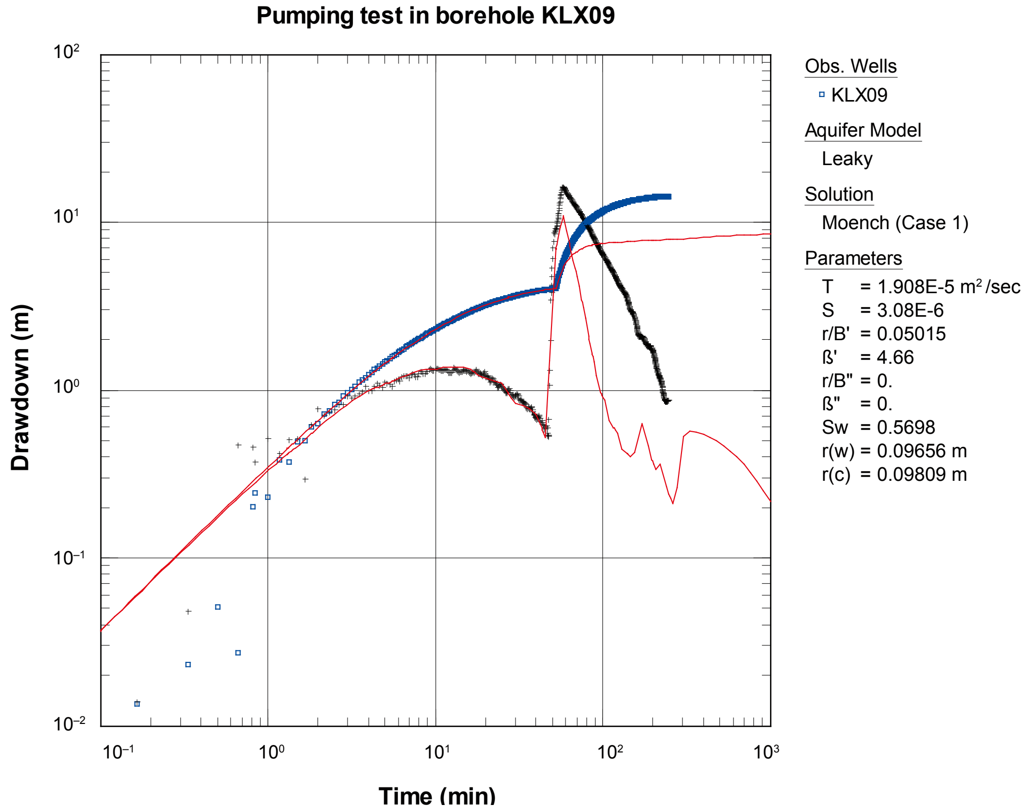


Figure A1-2. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red), showing fit to the early part of the drawdown in borehole KLX09.*

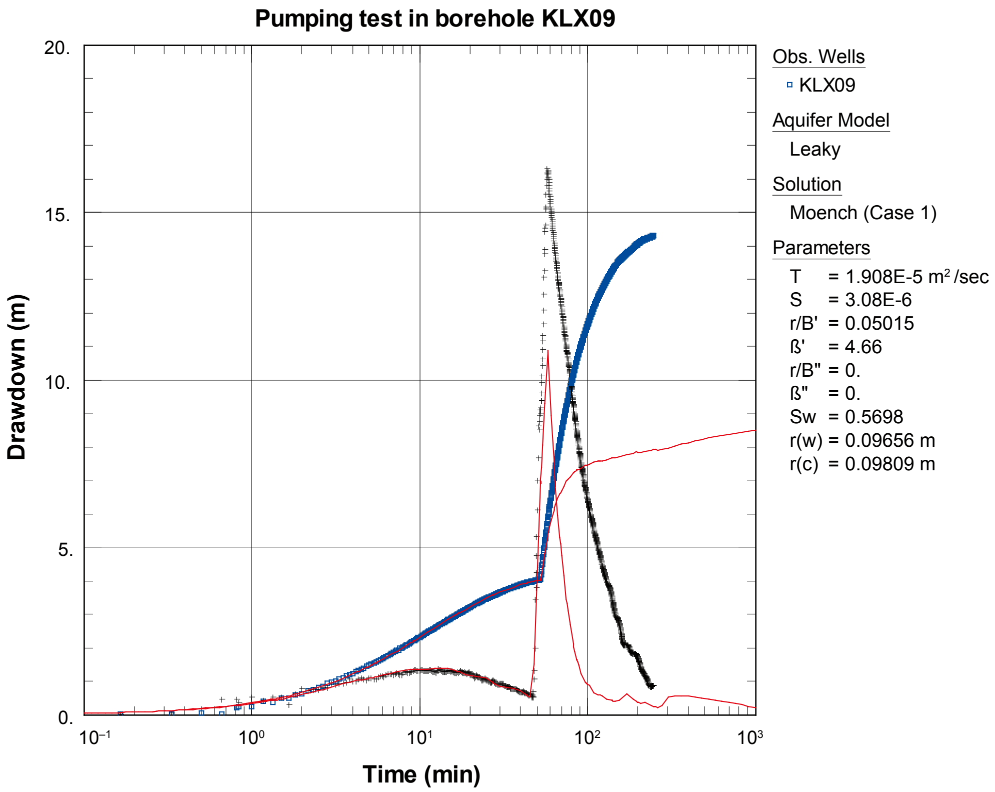


Figure A1-3. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red), showing fit to the early part of the drawdown in borehole KLX09.*

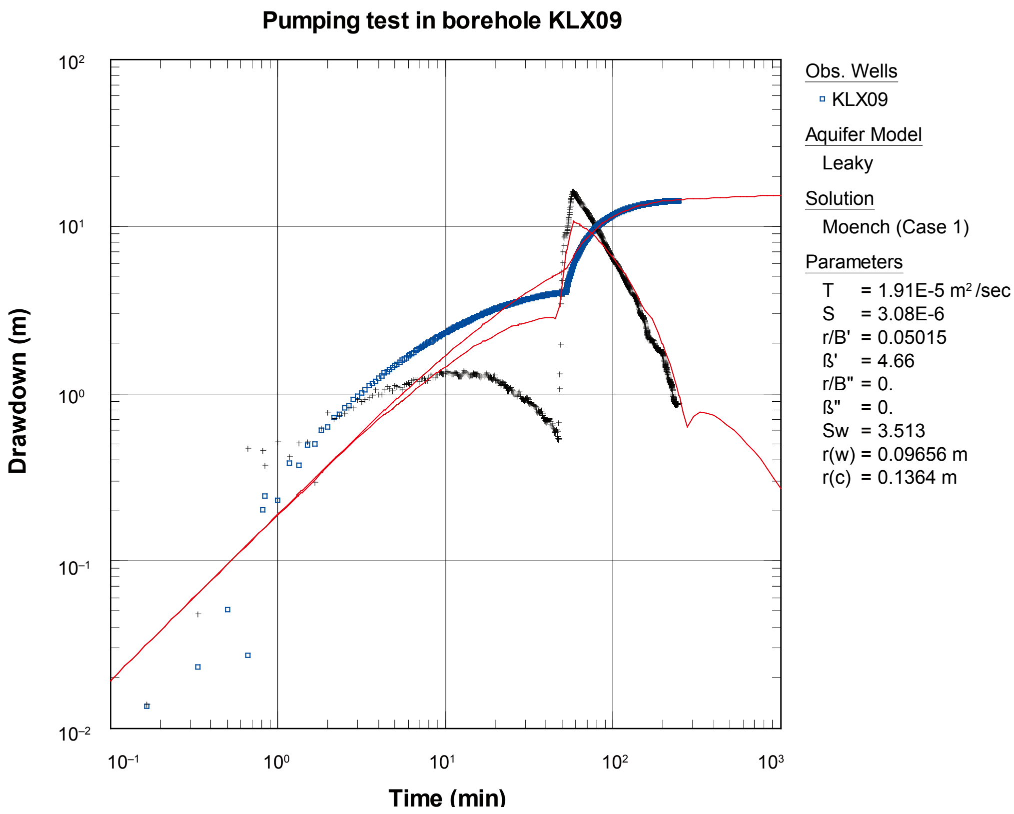


Figure A1-4. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red), showing fit to the later part of the drawdown in borehole KLX09.*

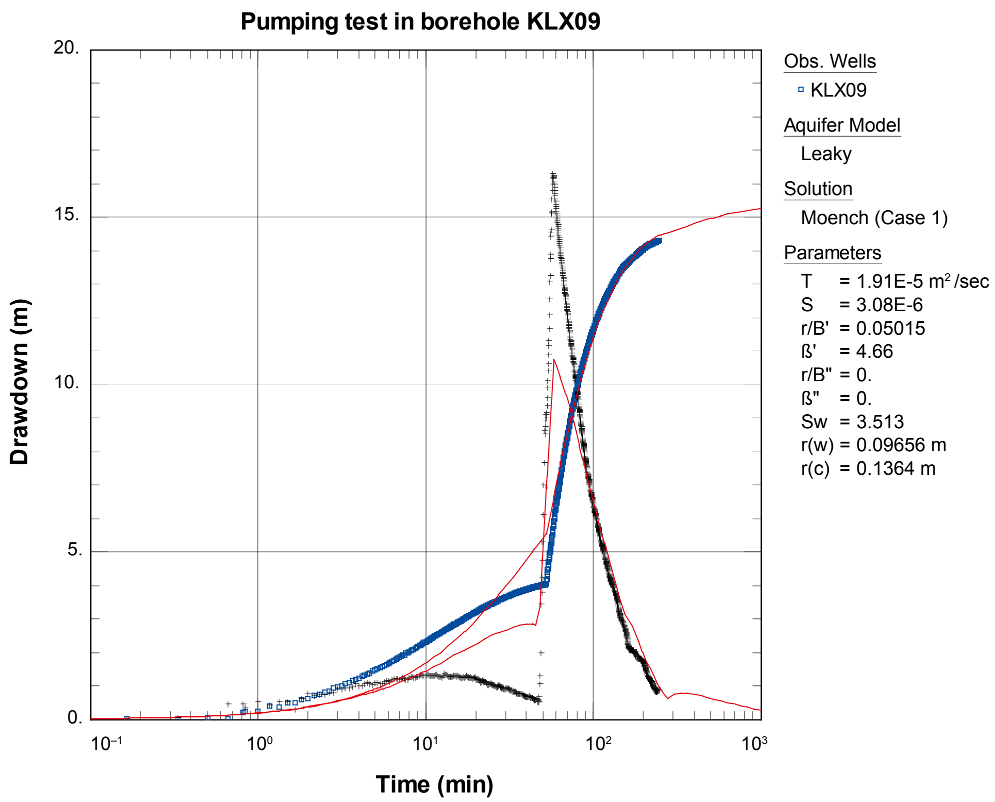


Figure A1-5. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red), showing fit to the later part of the drawdown in borehole KLX09.*

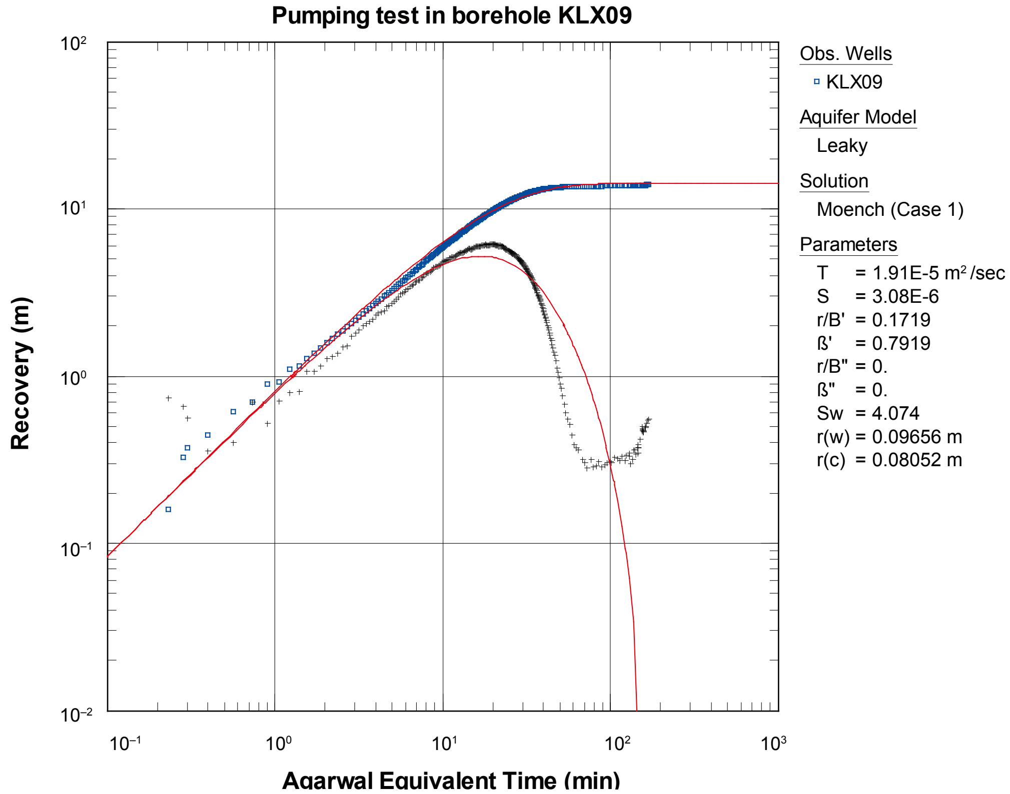


Figure A1-6. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in borehole KLX09.*

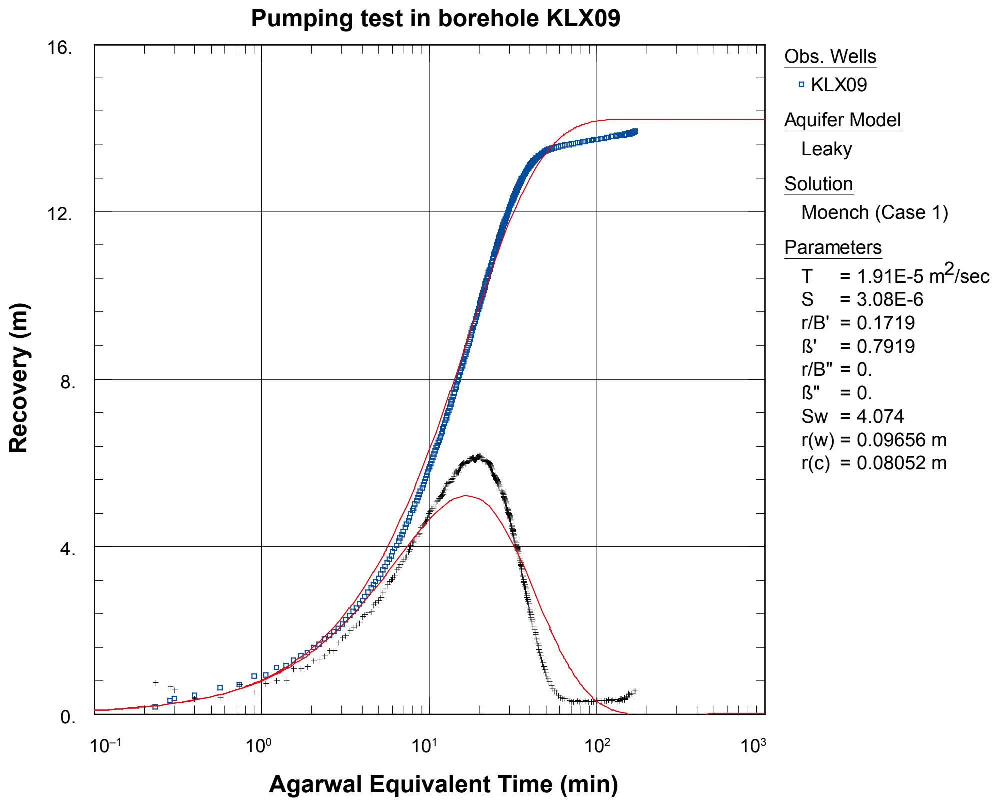


Figure A1-7. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in borehole KLX09.*

Test diagrams for the pumping test in KLX11A

Nomenclature in AQTESOLV:

T = transmissivity (m^2/s)

S = storativity (–)

K_Z/K_r = ratio of hydraulic conductivities in the vertical and radial direction (set to 1)

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

b = aquifer thickness

Pumping test in KLX11A: 12.1–100.1 m

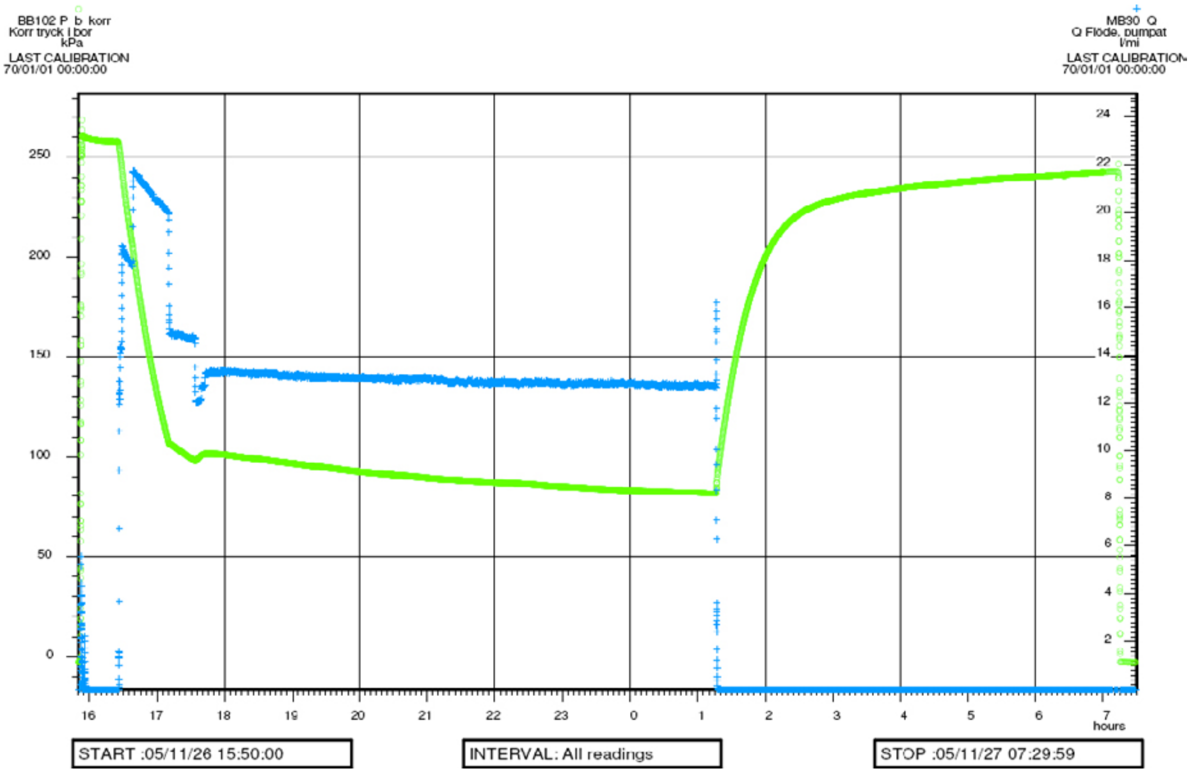


Figure A2-1. *Linear plot of flow rate and pressure versus time in the pumping borehole KLX11A.*

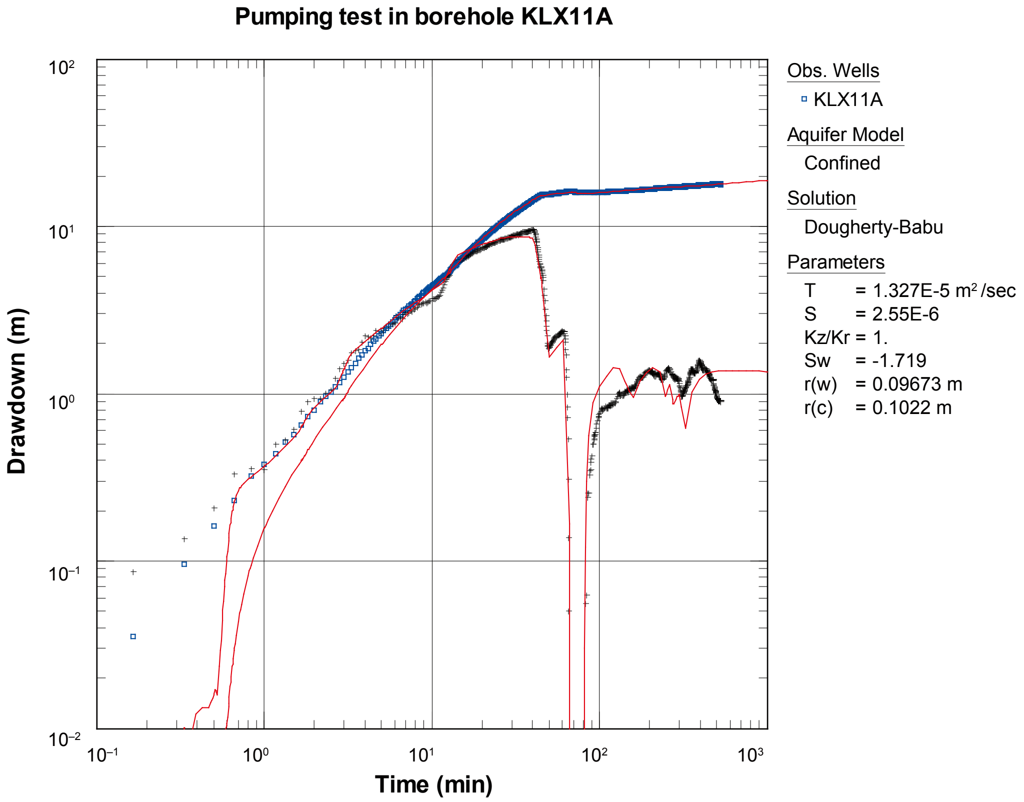


Figure A2-2. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in borehole KLX11A.*

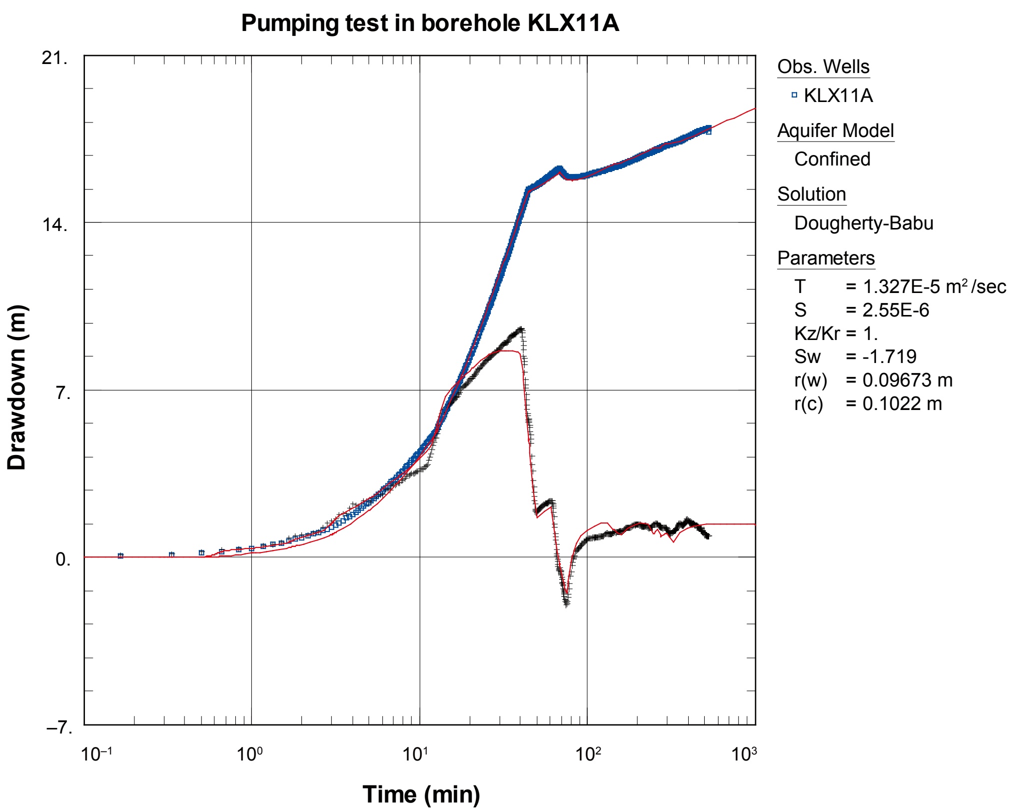


Figure A2-3. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in borehole KLX11A.*

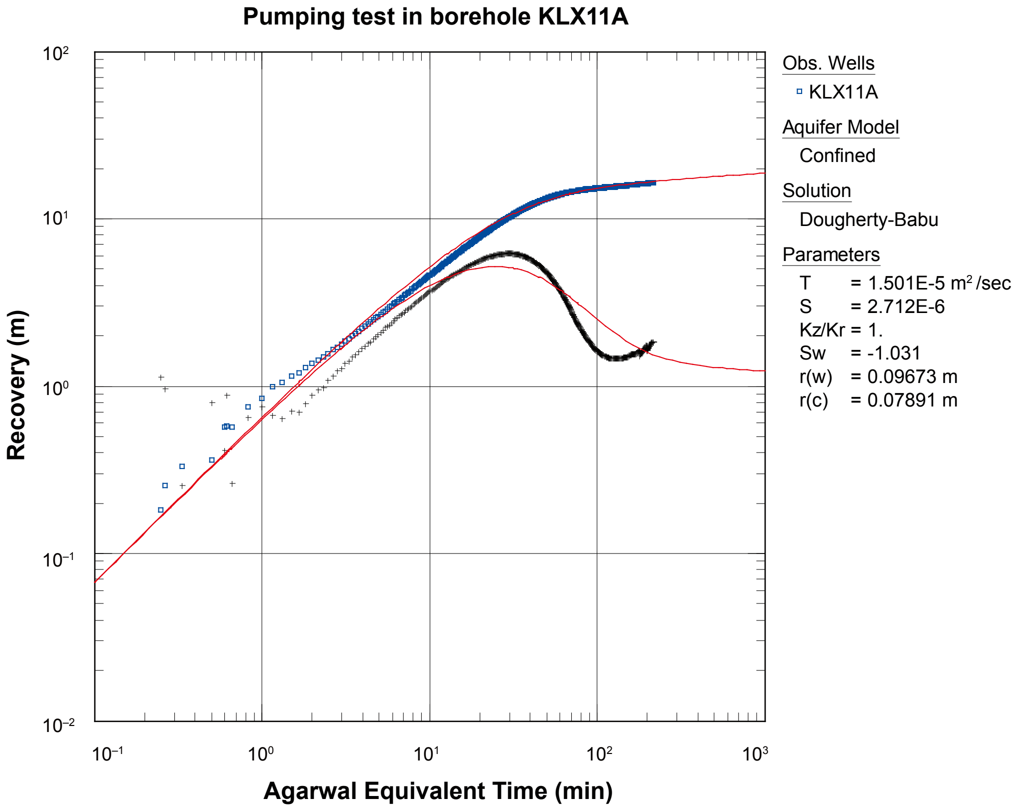


Figure A2-4. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in borehole KLX11A.*

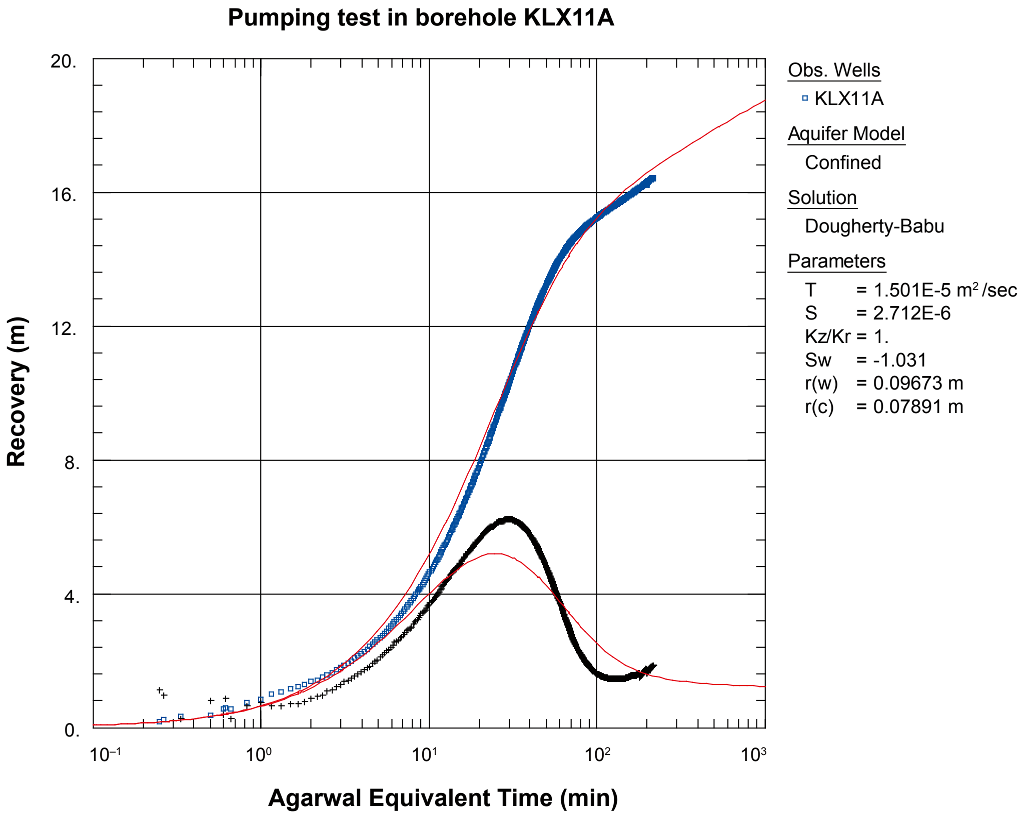


Figure A2-5. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in borehole KLX11A.*

Test diagrams for the pumping test in KLX13A

Nomenclature in AQTESOLV:

T = transmissivity (m^2/s)

S = storativity (–)

K_Z/K_r = ratio of hydraulic conductivities in the vertical and radial direction (set to 1)

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

b = aquifer thickness

Pumping test in KLX13A: 11.8–99.9 m

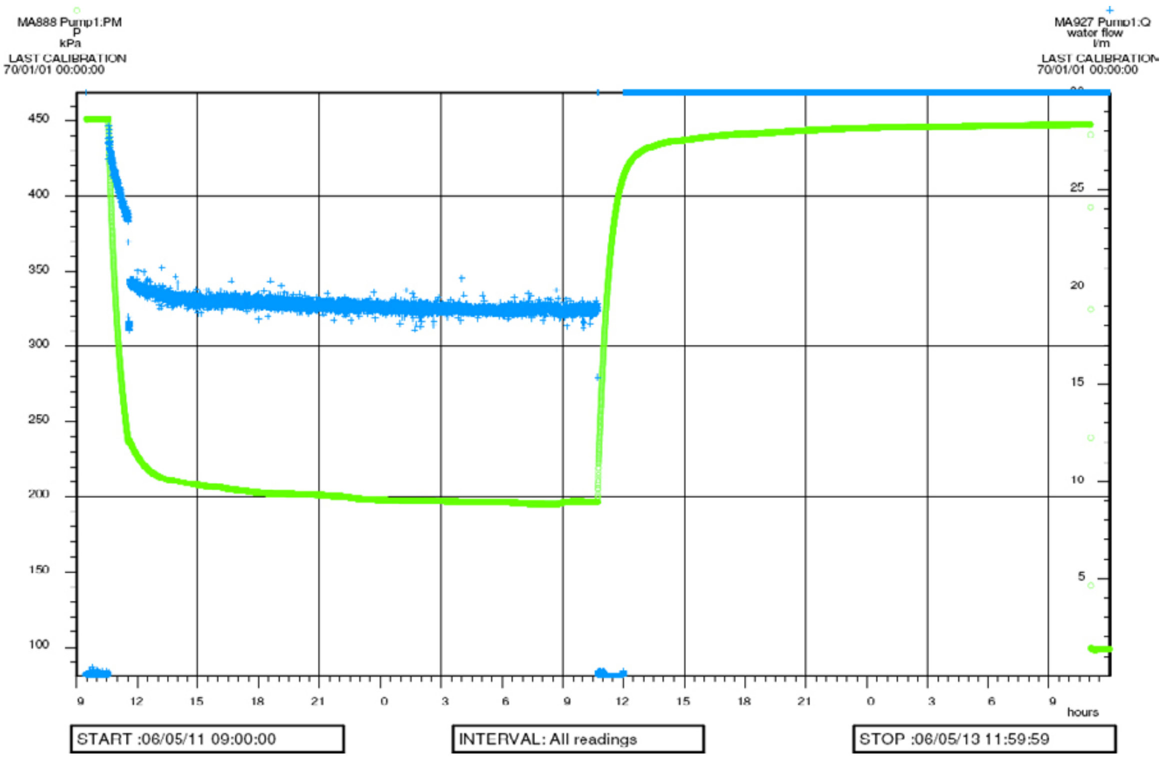


Figure A3-1. Linear plot of flow rate and pressure versus time in the pumping borehole KLX13A.

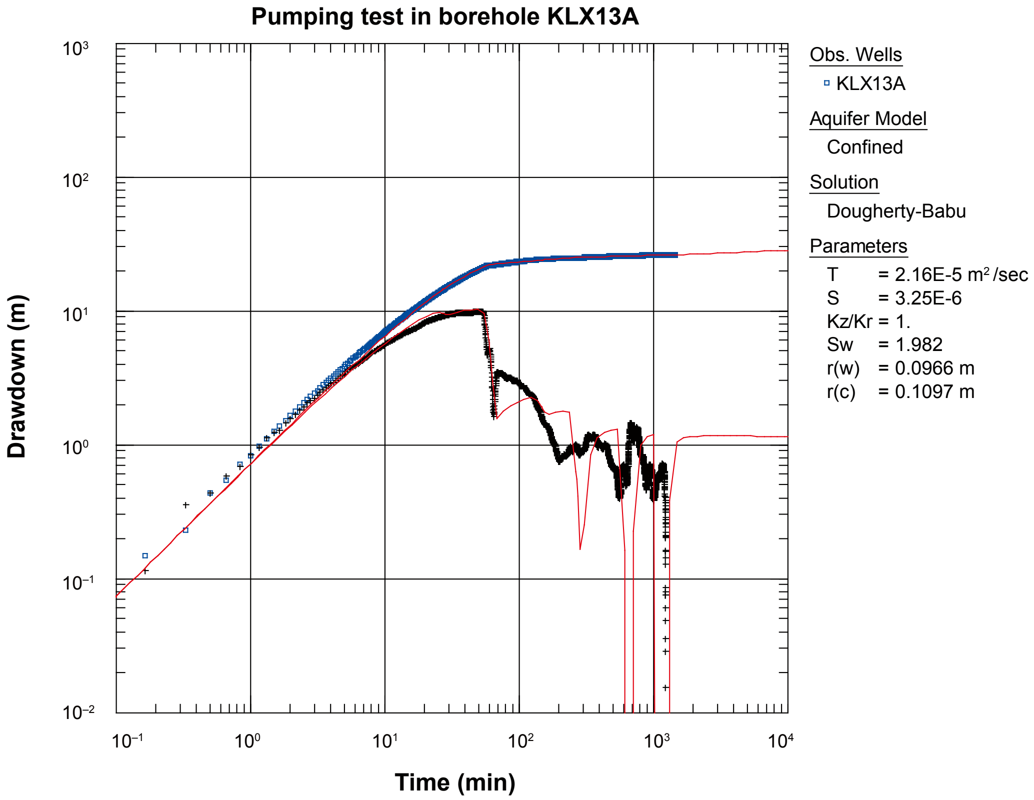


Figure A3-2. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the pumping borehole KLX13A.*

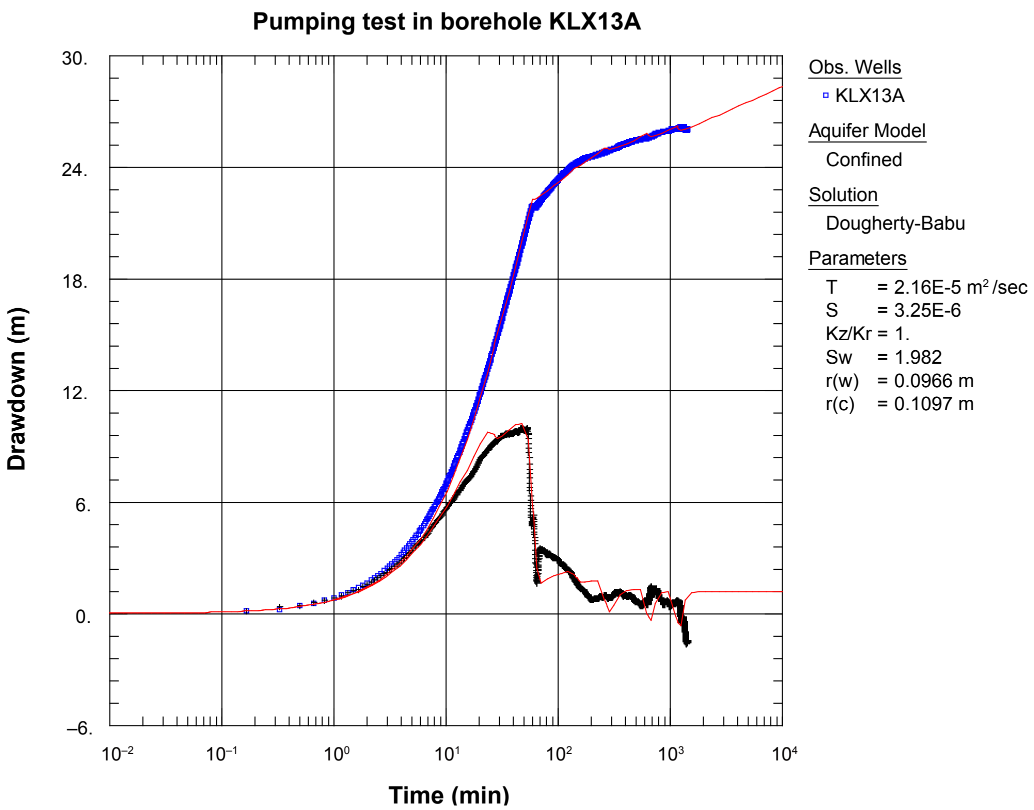


Figure A3-3. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the pumping borehole KLX13A.*

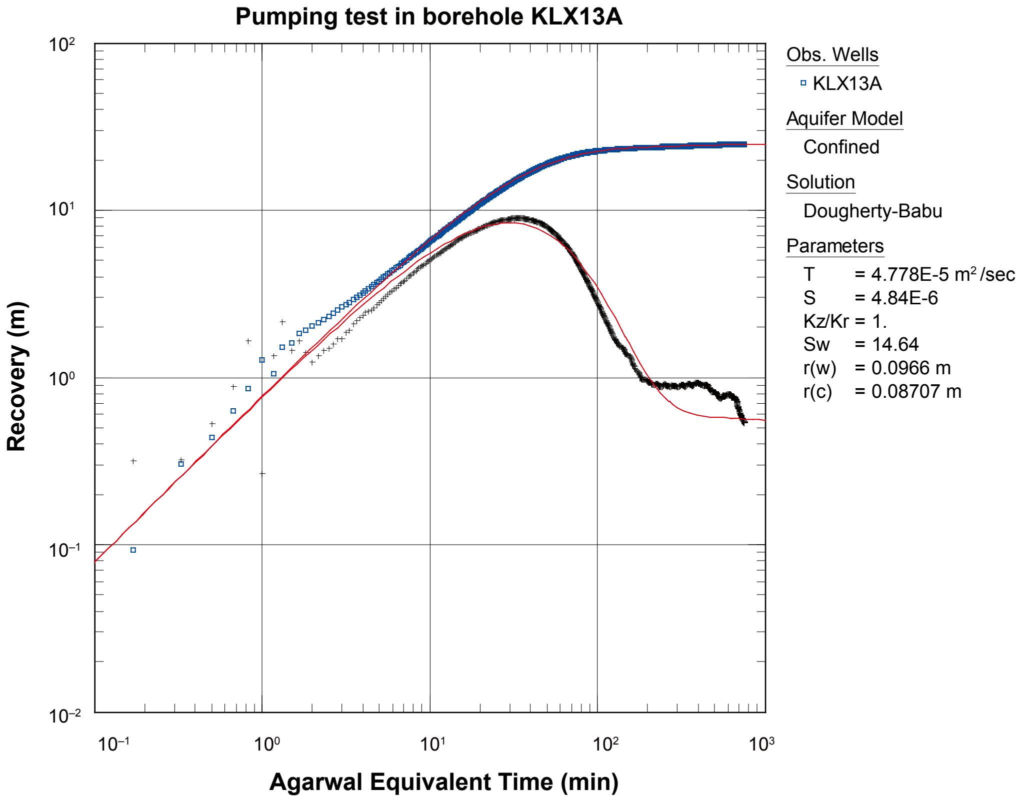


Figure A3-4. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the pumping borehole KLX13A.*

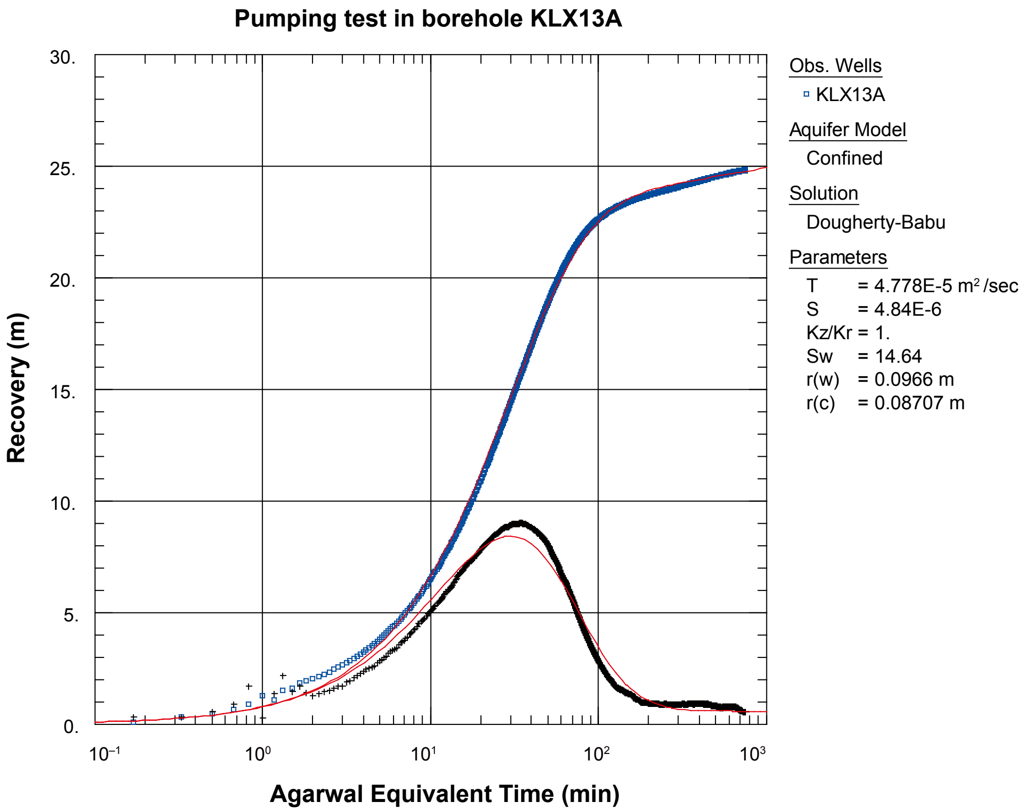


Figure A3-5. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the pumping borehole KLX13A.*

Test diagrams for the pumping test in KLX18A

Nomenclature in AQTESOLV:

T = transmissivity (m^2/s)

S = storativity (–)

K_Z/K_r = ratio of hydraulic conductivities in the vertical and radial direction (set to 1)

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

b = aquifer thickness

Pumping test in KLX18A: 11.8–99.9 m

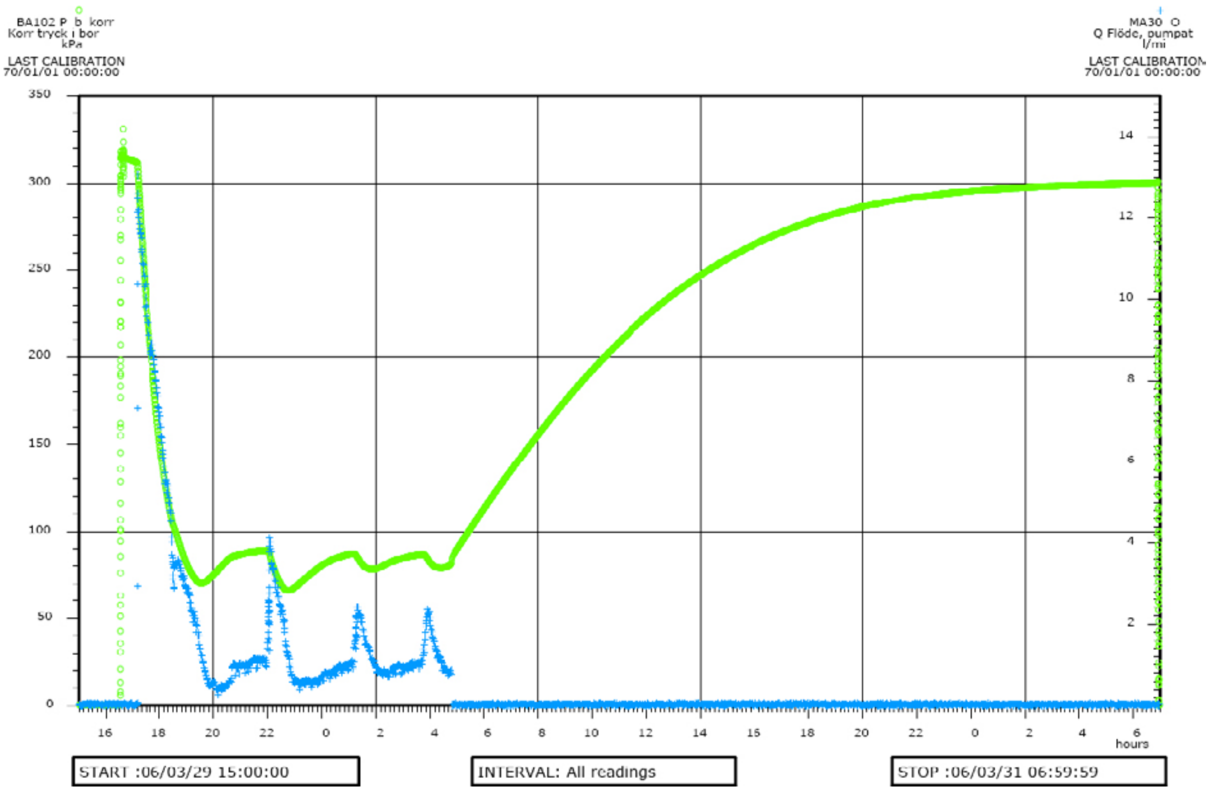


Figure A4-1. *Linear plot of flow rate and pressure versus time in the pumping borehole KLX18A.*

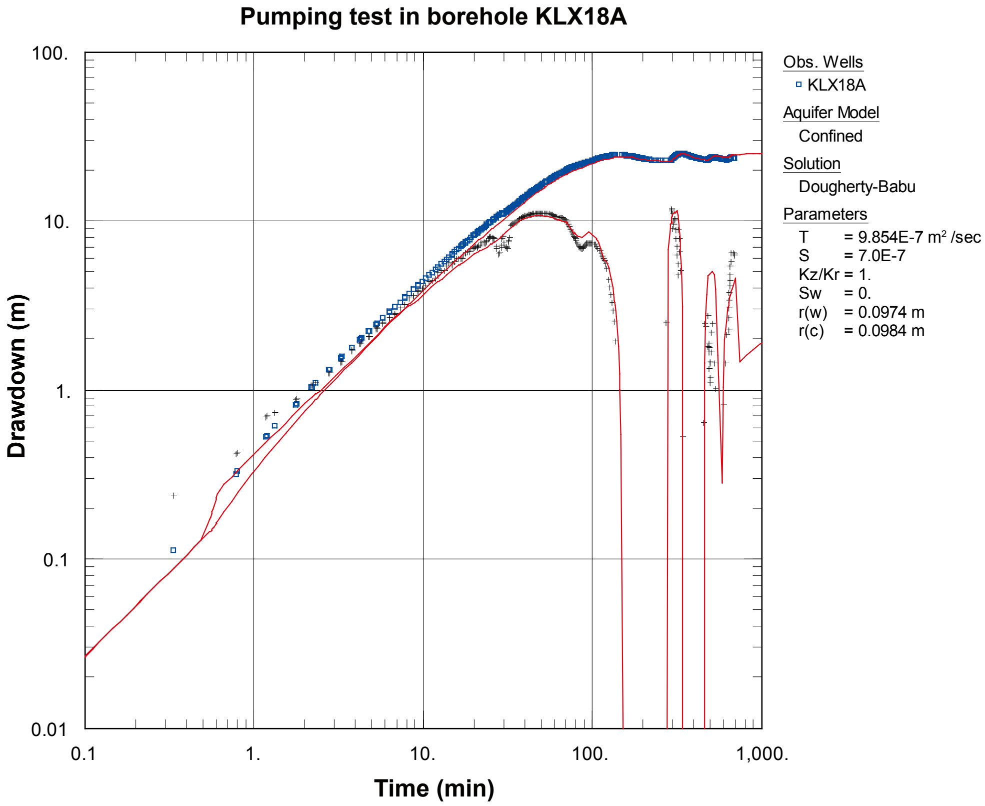


Figure A4-2. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in borehole KLX18A.*

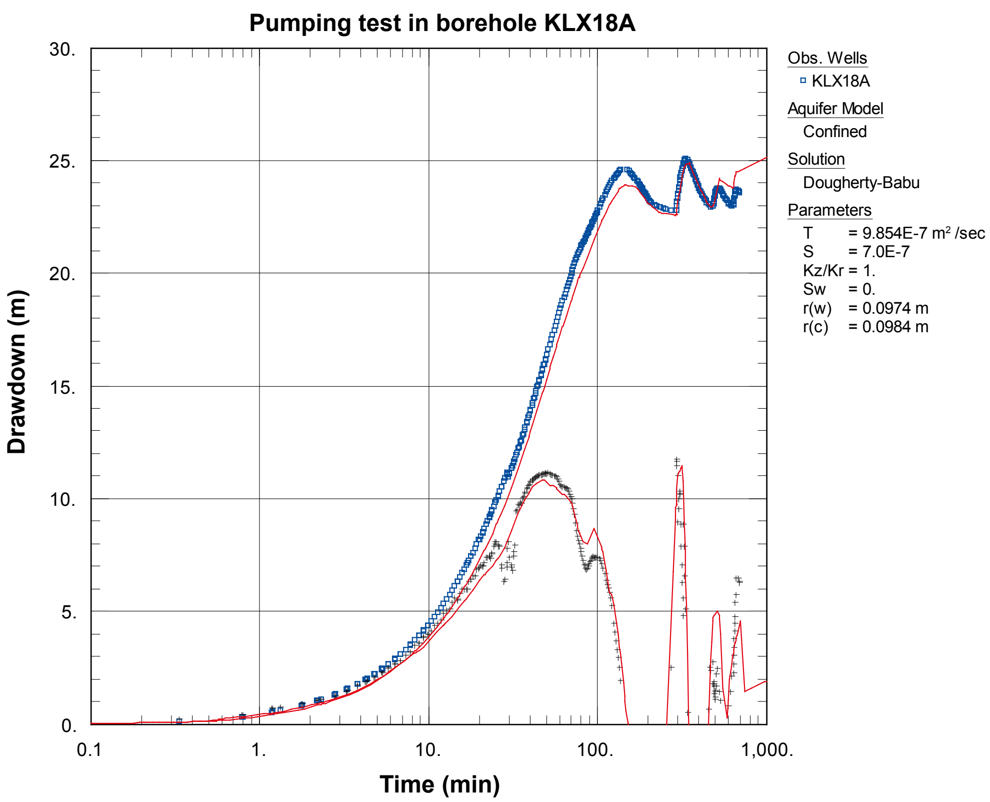


Figure A4-3. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in borehole KLX18A.*

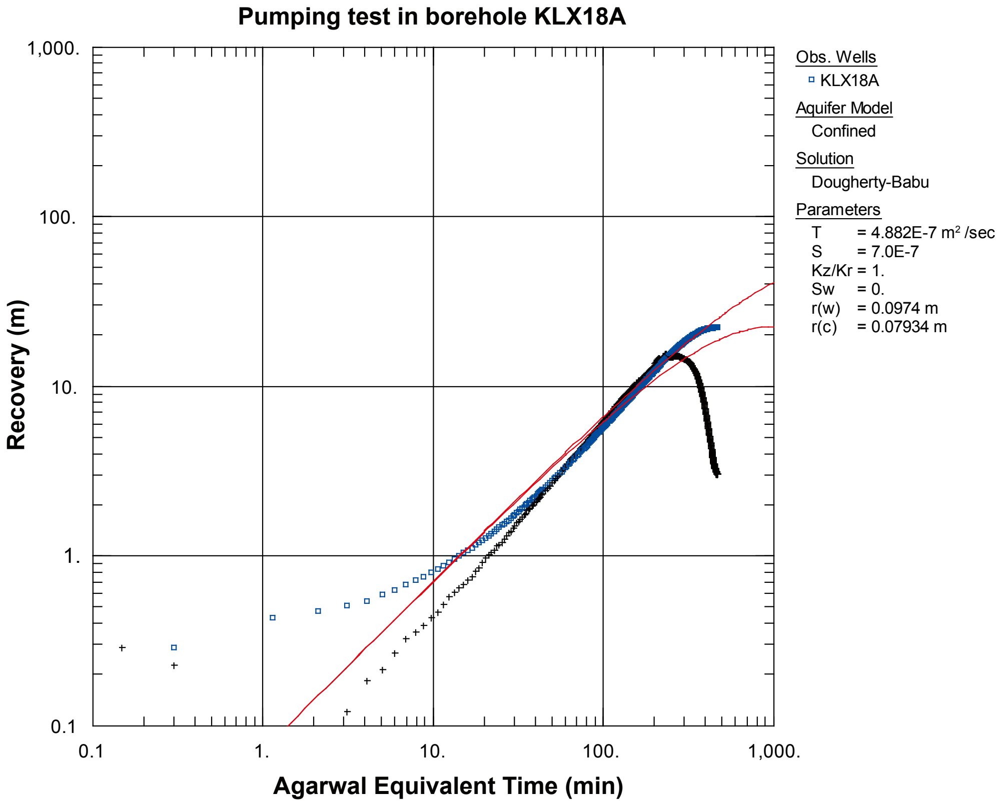


Figure A4-4. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in borehole KLX18A.*

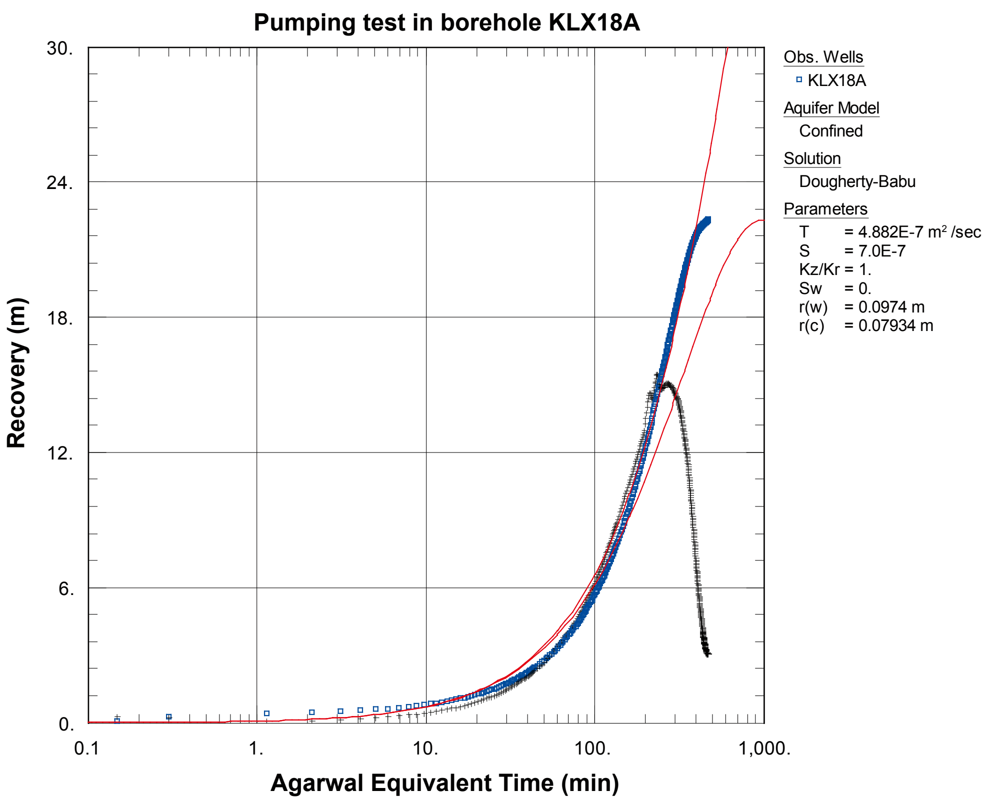


Figure A4-5. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in borehole KLX18A.*

Test diagrams for the interference test in KLX19A

Nomenclature in AQTESOLV:

T = transmissivity (m^2/s)

S = storativity (–)

K_Z/K_r = ratio of hydraulic conductivities in the vertical and radial direction (set to 1)

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

b = aquifer thickness

Interference test in KLX19A: 6.3–99.3 m

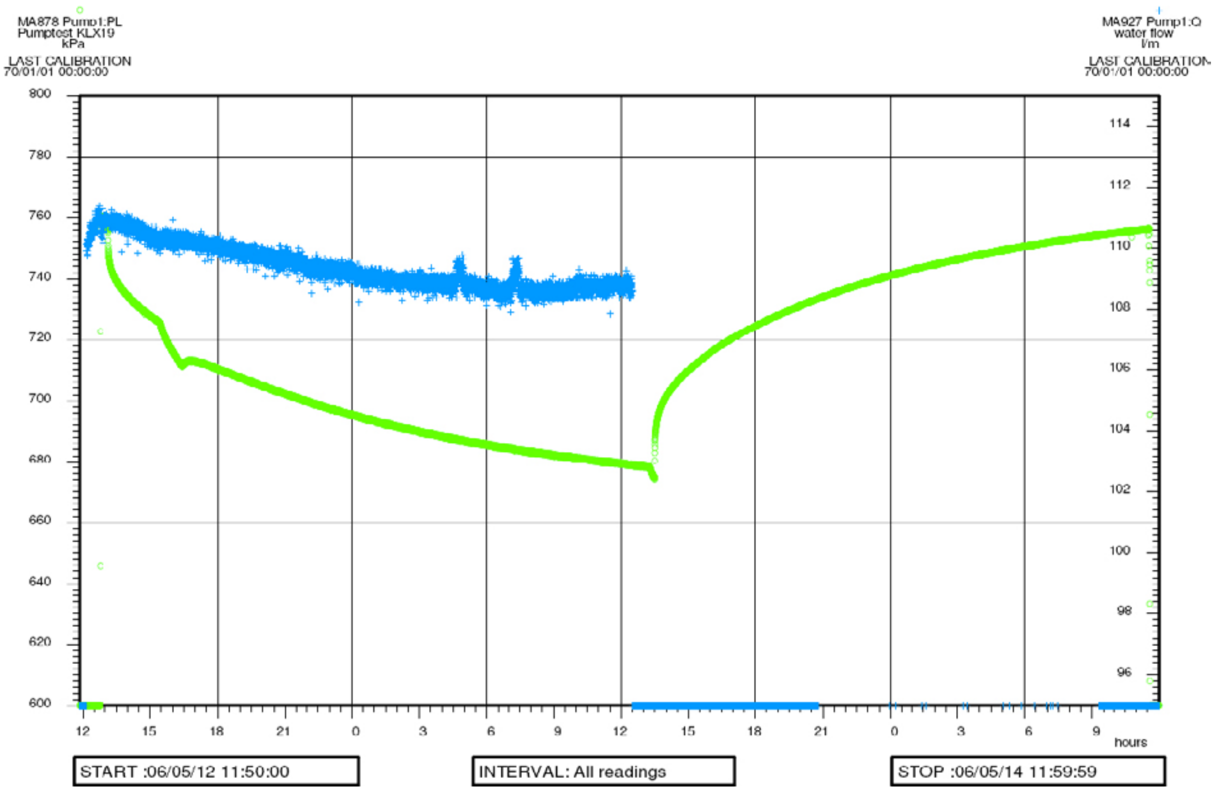


Figure A5-1. *Linear plot of flow rate and pressure versus time in the pumping borehole KLX19A.*

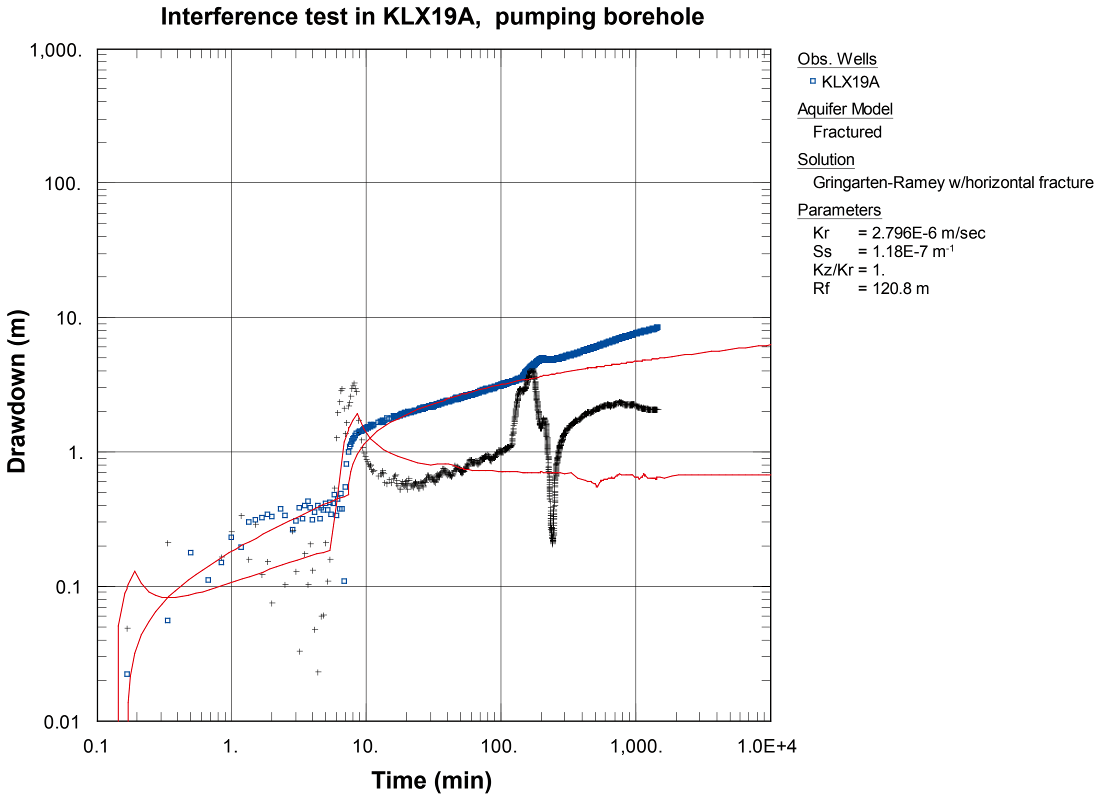


Figure A5-2. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the pumping borehole KLX19A.*

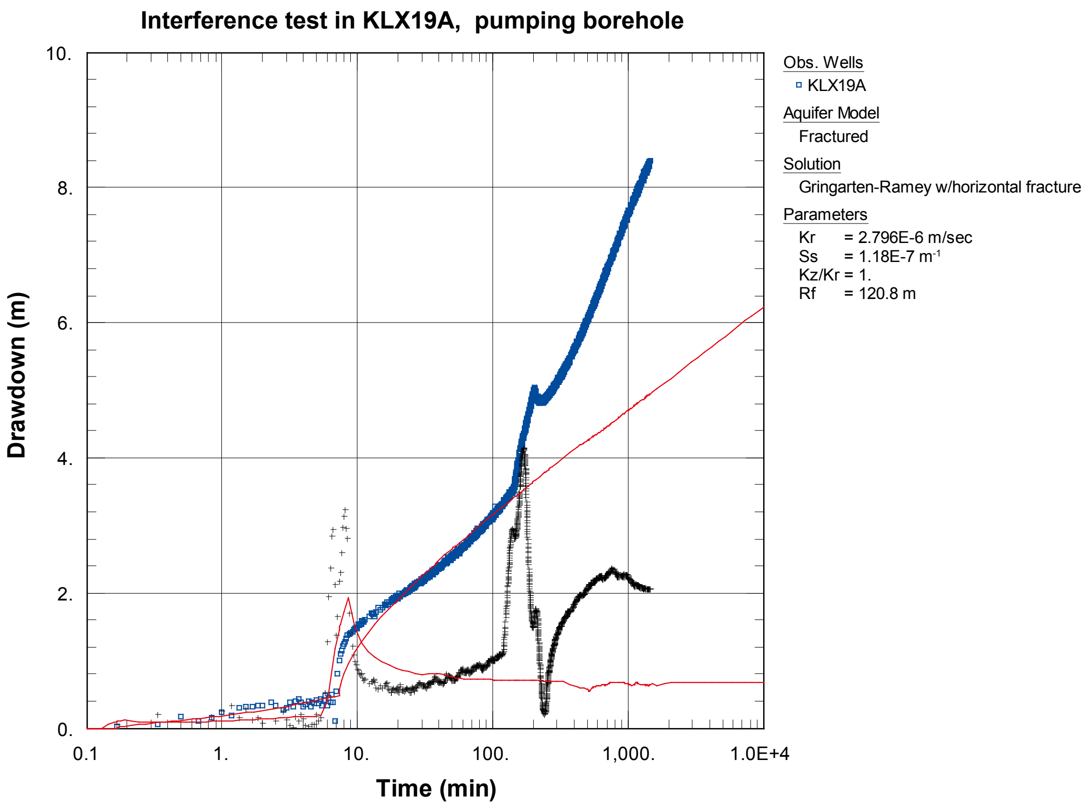


Figure A5-3. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the pumping borehole KLX19A.*

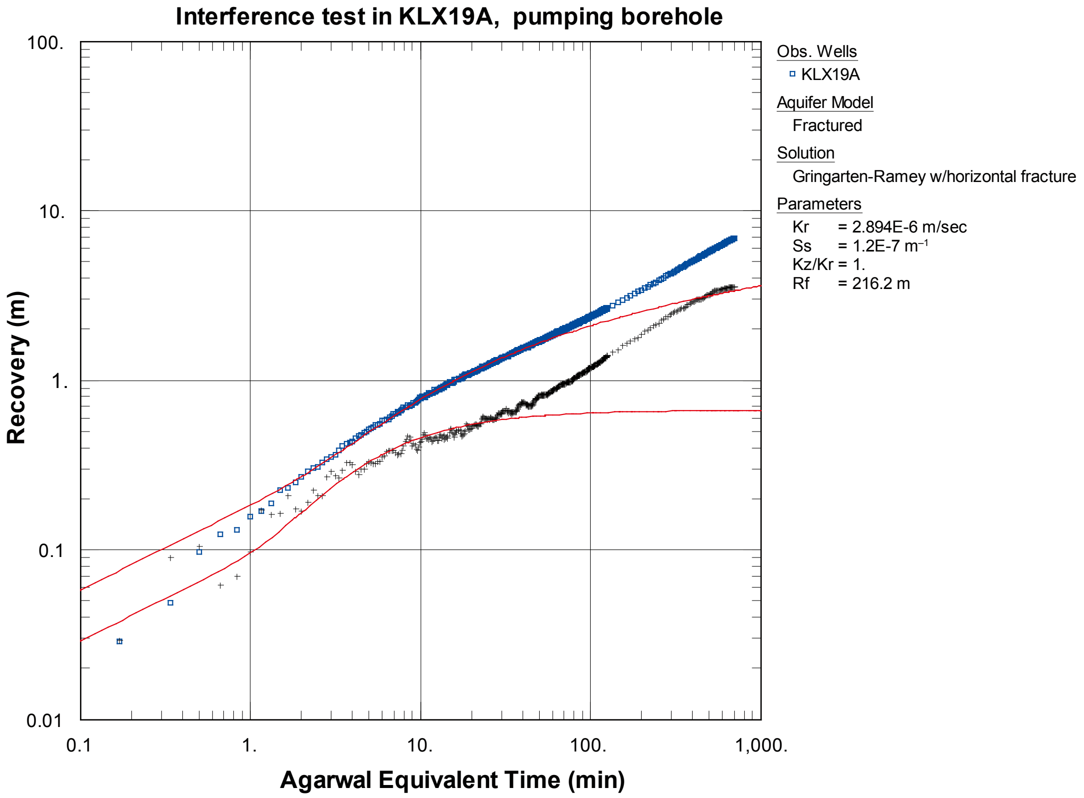


Figure A5-4. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the pumping borehole KLX19A.*

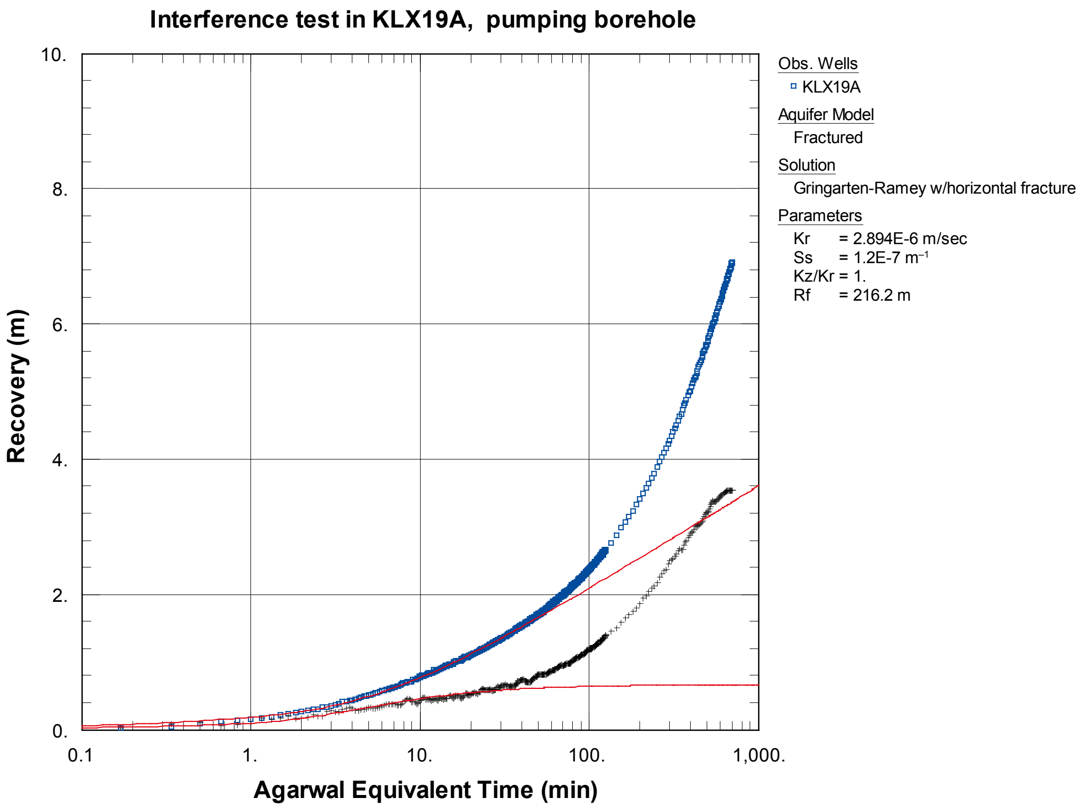


Figure A5-5. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the pumping borehole KLX19A.*

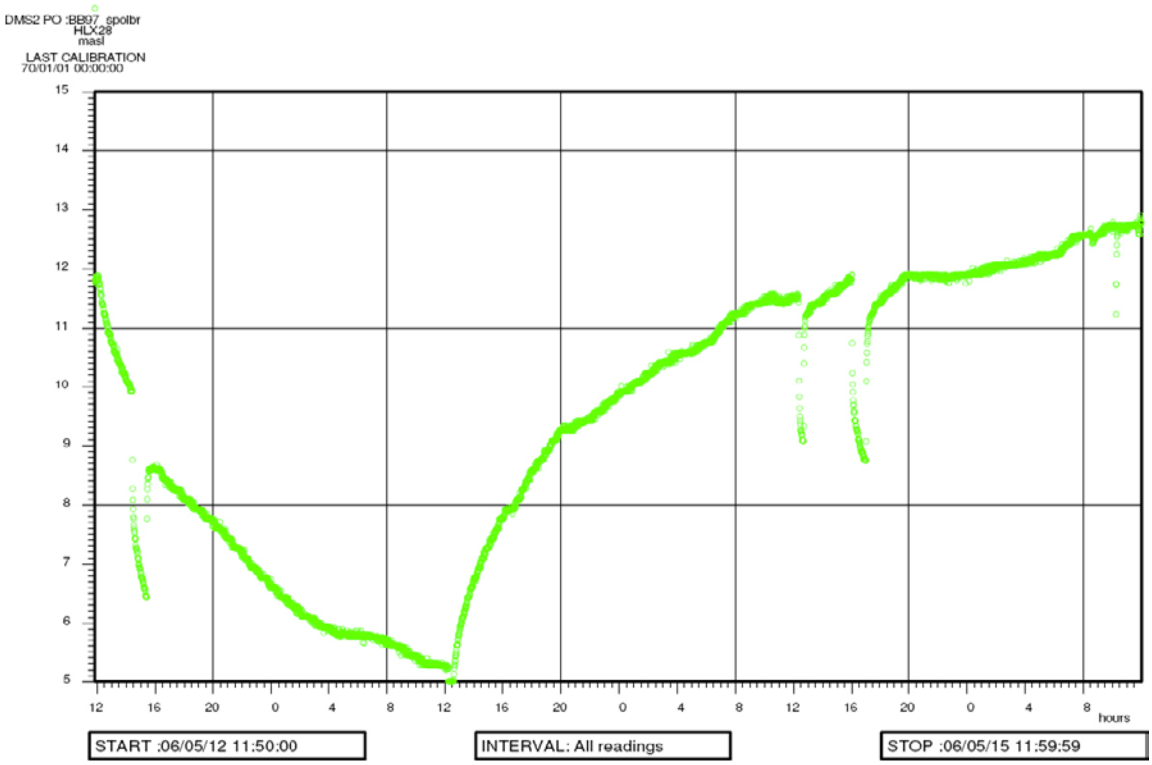


Figure A5-6. *Linear plot of pressure versus time in the observation borehole HLX28 during pumping in borehole KLX19A.*

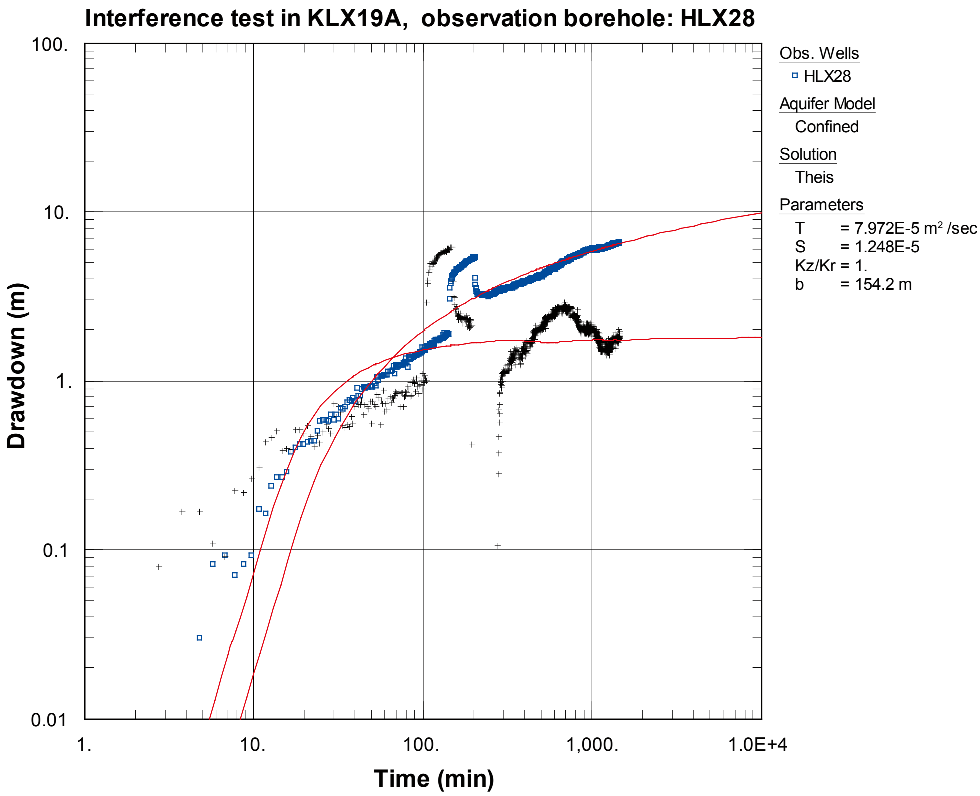


Figure A5-7. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the observation borehole HLX28 during pumping in borehole KLX19A.*

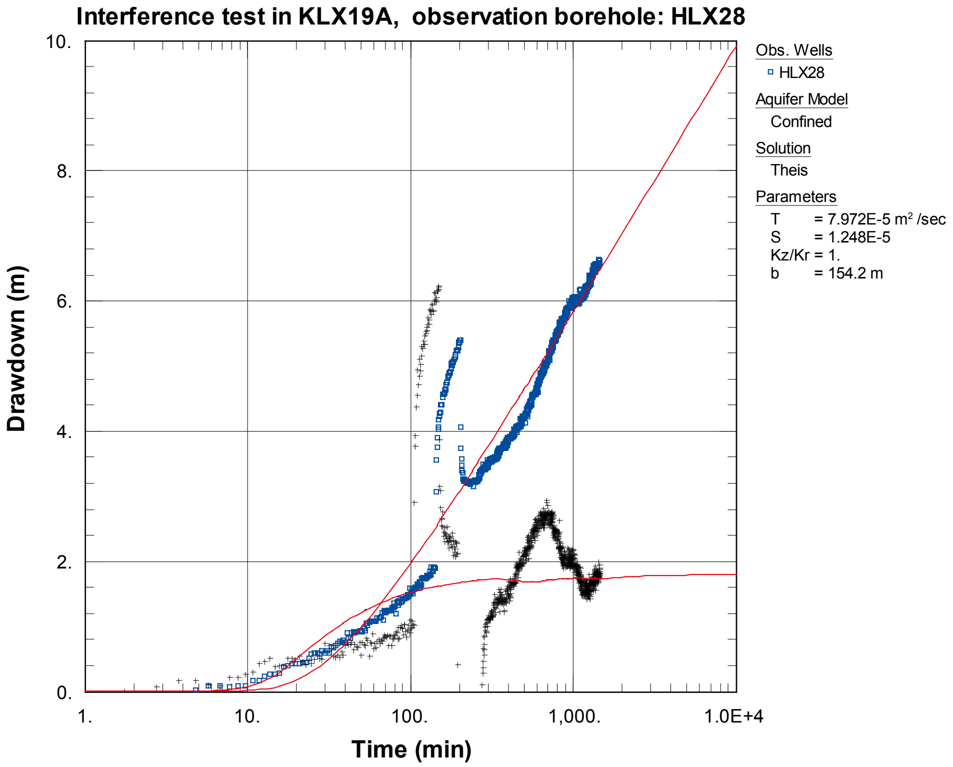


Figure A5-8. Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the observation borehole HLX28 during pumping in borehole KLX19A.

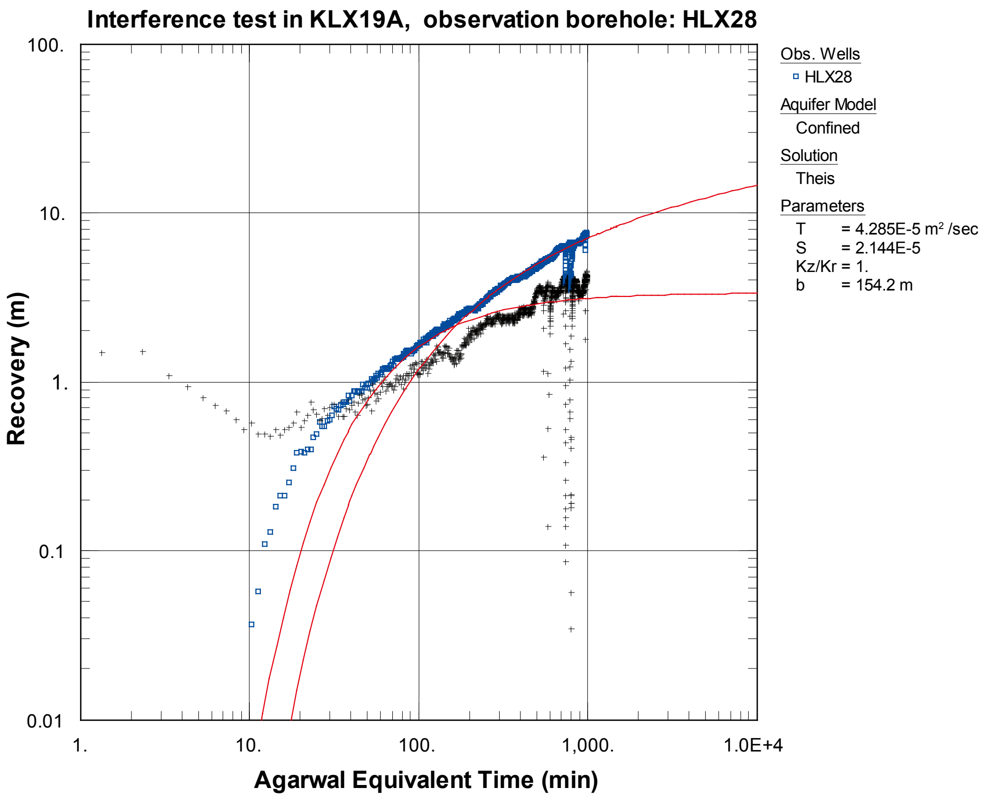


Figure A5-9. Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the observation borehole HLX28 during pumping in borehole KLX19A.

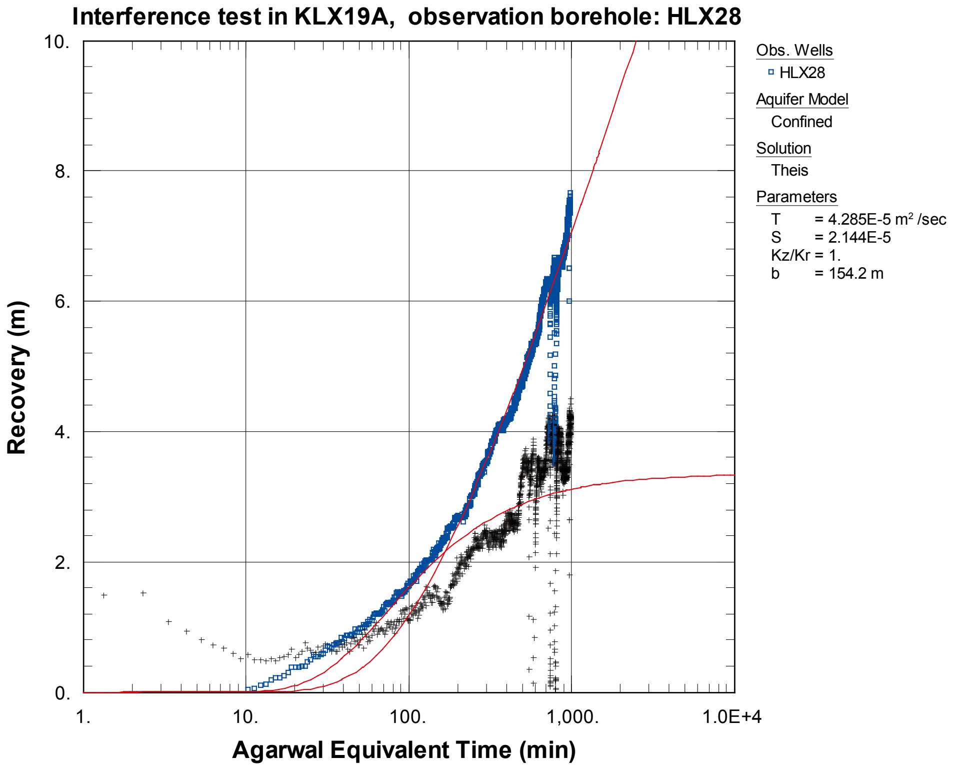


Figure A5-10. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the observation borehole HLX28 during pumping in borehole KLX19A.*

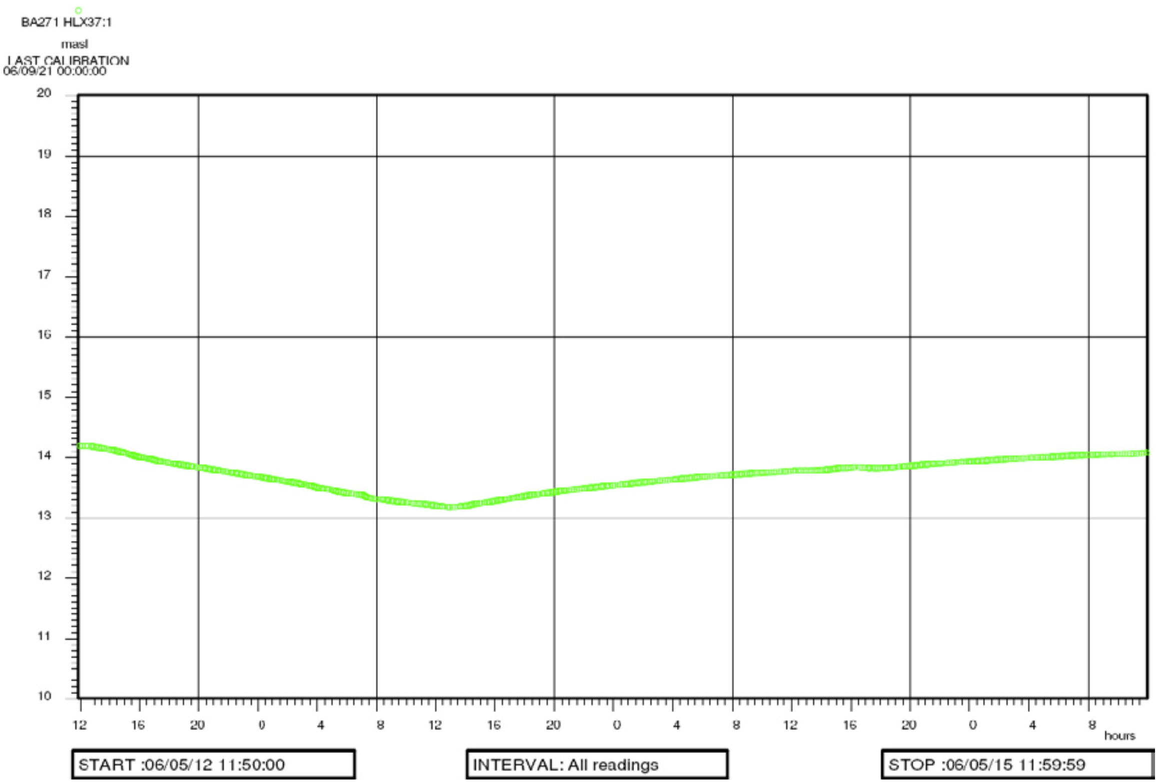


Figure A5-11. *Linear plot of pressure versus time in the observation borehole HLX37 during pumping in borehole KLX19A.*

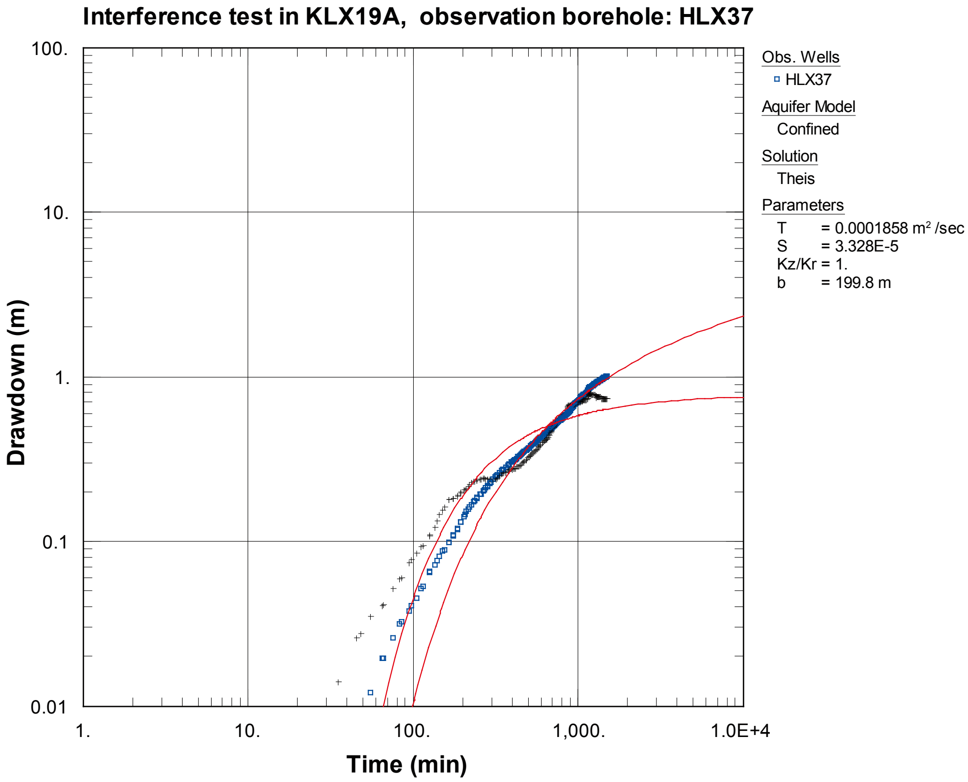


Figure A5-12. Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the observation borehole HLX37 during pumping in borehole KLX19A.

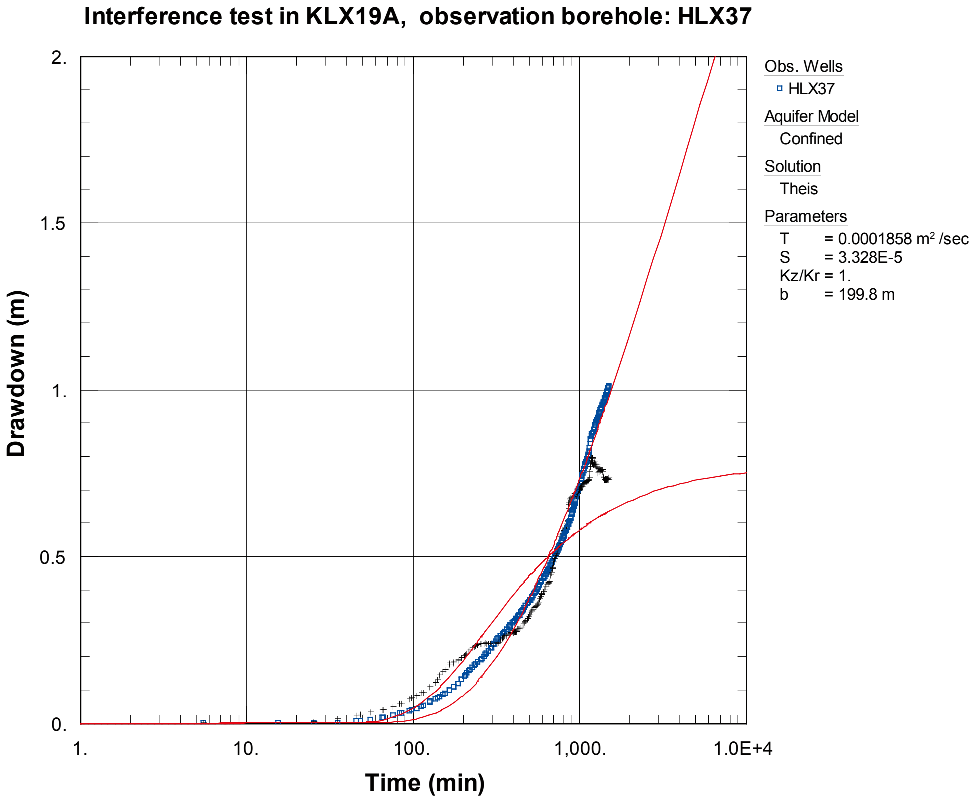


Figure A5-13. Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the observation borehole HLX37 during pumping in borehole KLX19A.

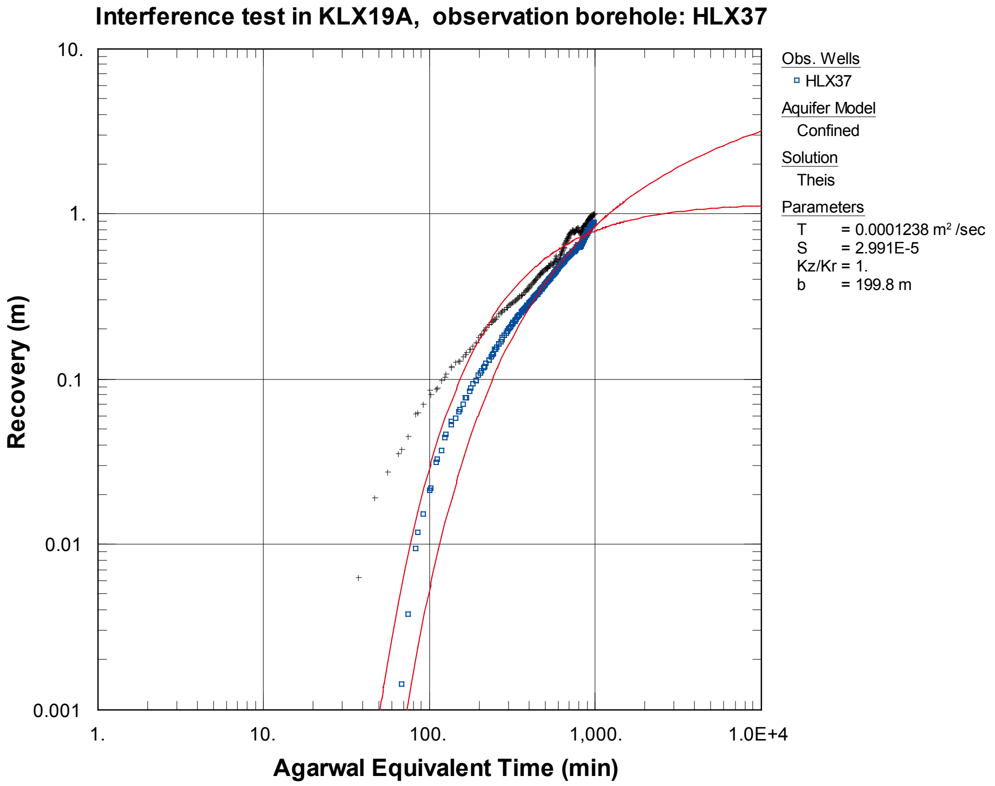


Figure A5-14. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the observation borehole HLX37 during pumping in borehole KLX19A.*

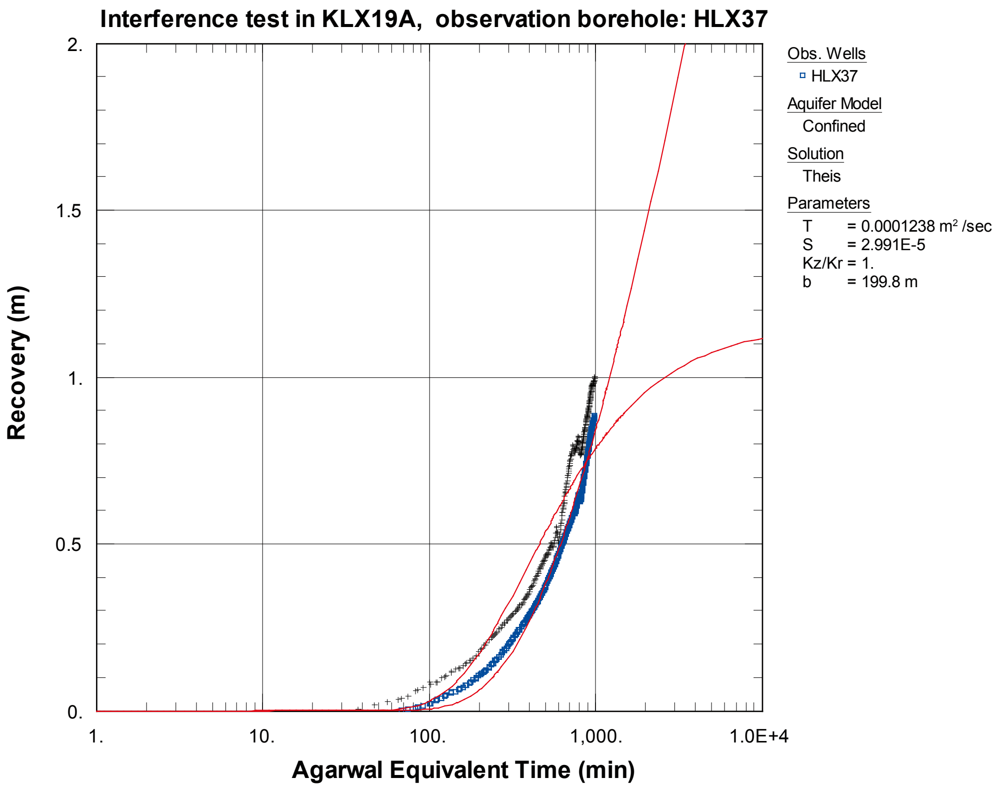


Figure A5-15. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the observation borehole HLX37 during pumping in borehole KLX19A.*

Appendix 6

Test diagrams for the interference test in HLX39

Nomenclature in AQTESOLV:

T = transmissivity (m^2/s)

S = storativity (–)

K_Z/K_r = ratio of hydraulic conductivities in the vertical and radial direction (set to 1)

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

b = aquifer thickness

Interference test in HLX39: 6.0–199.3 m

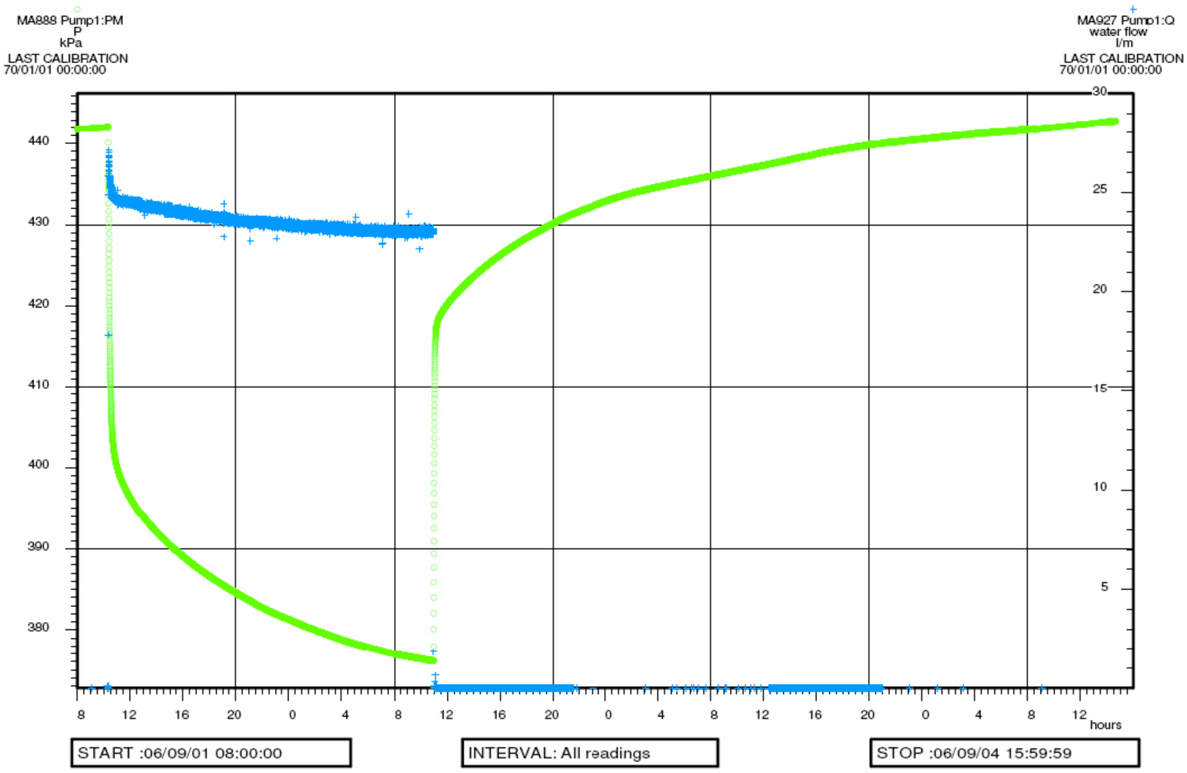


__Figure A6-1.__ Linear plot of flow rate and pressure versus time in the pumping borehole HLX39.

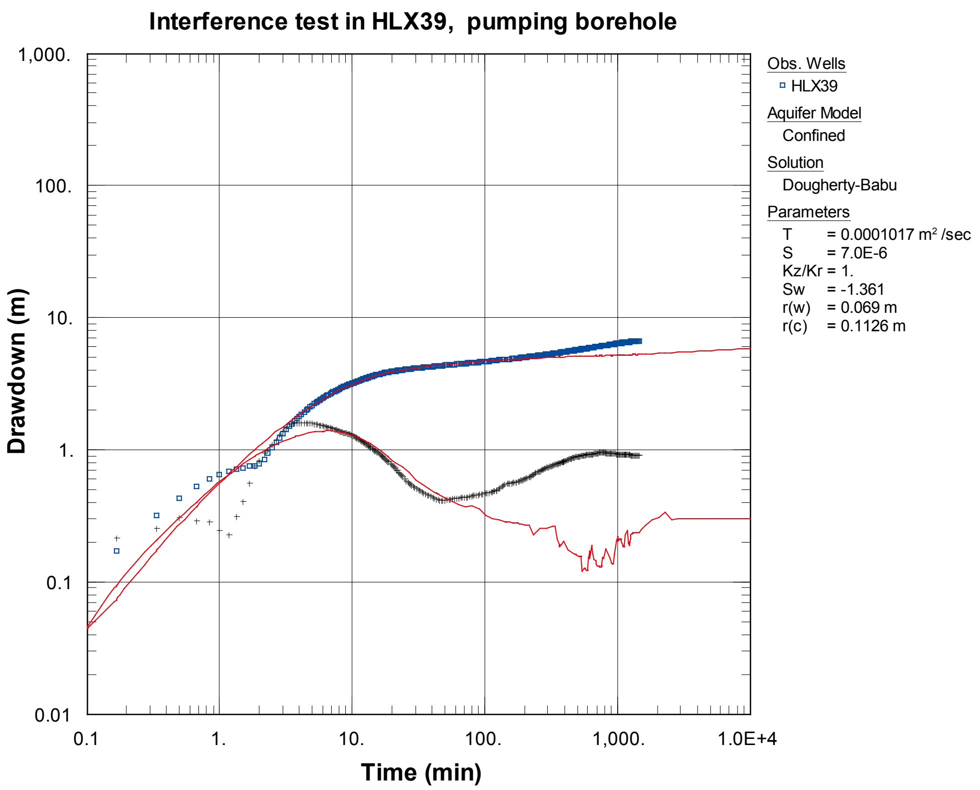


Figure A6-2. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the pumping borehole HLX39.*

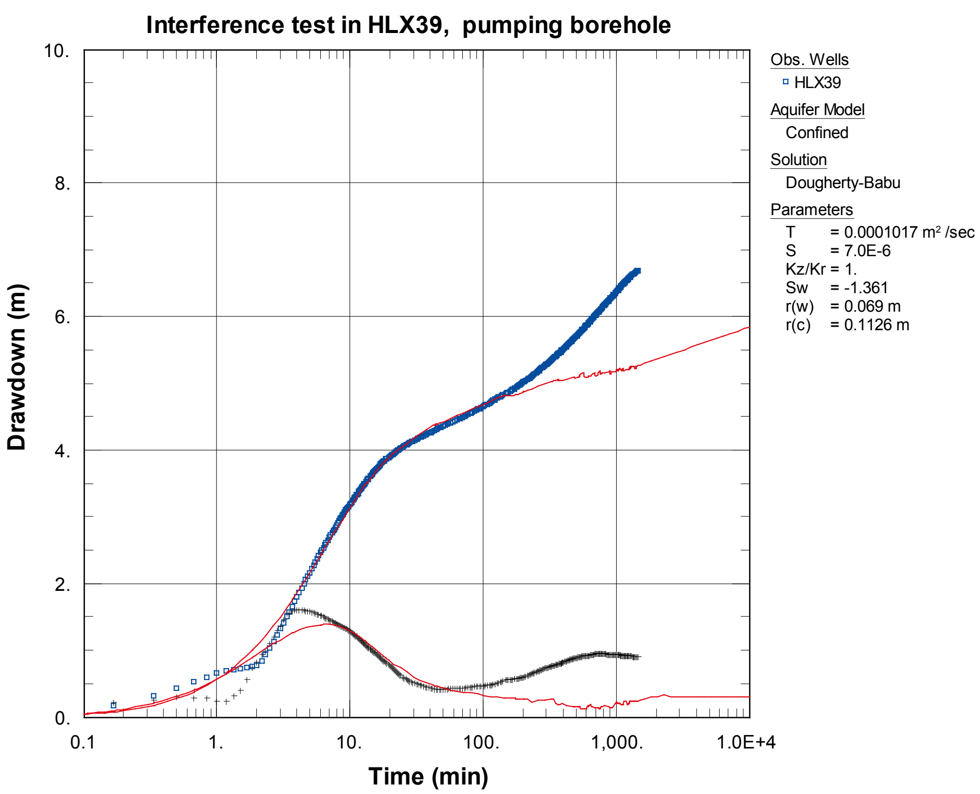


Figure A6-3. *Lin-log plot of drawdown (blue □) and drawdown n derivative (black +) versus time together with simulated curves (red) in the pumping borehole HLX39.*

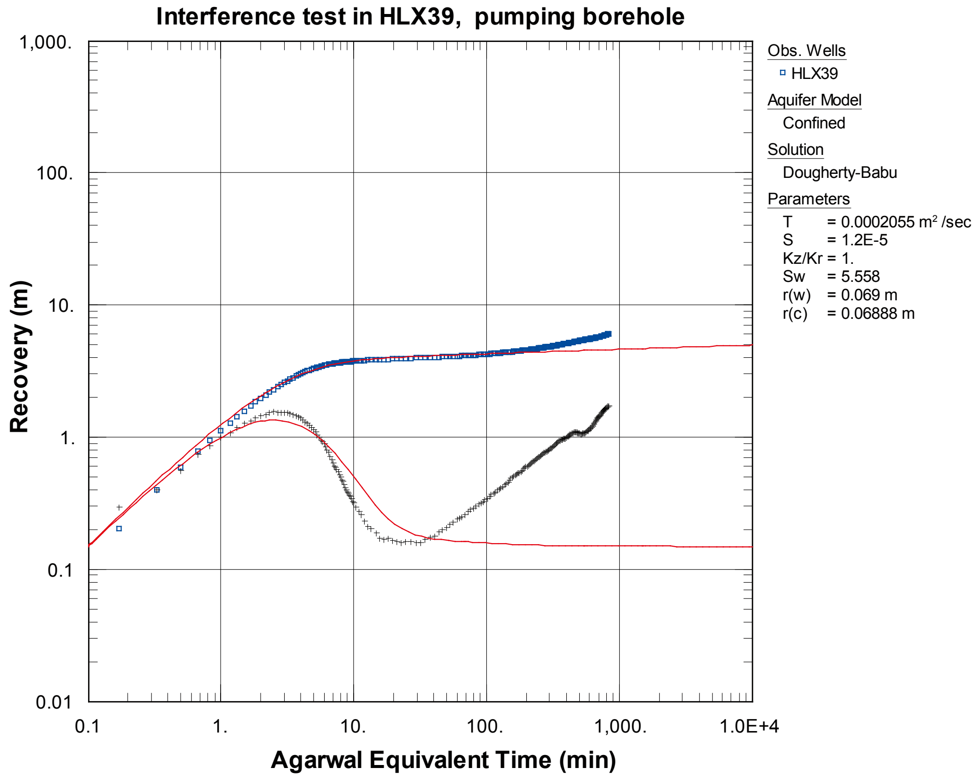


Figure A6-4. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the pumping borehole HLX39.*

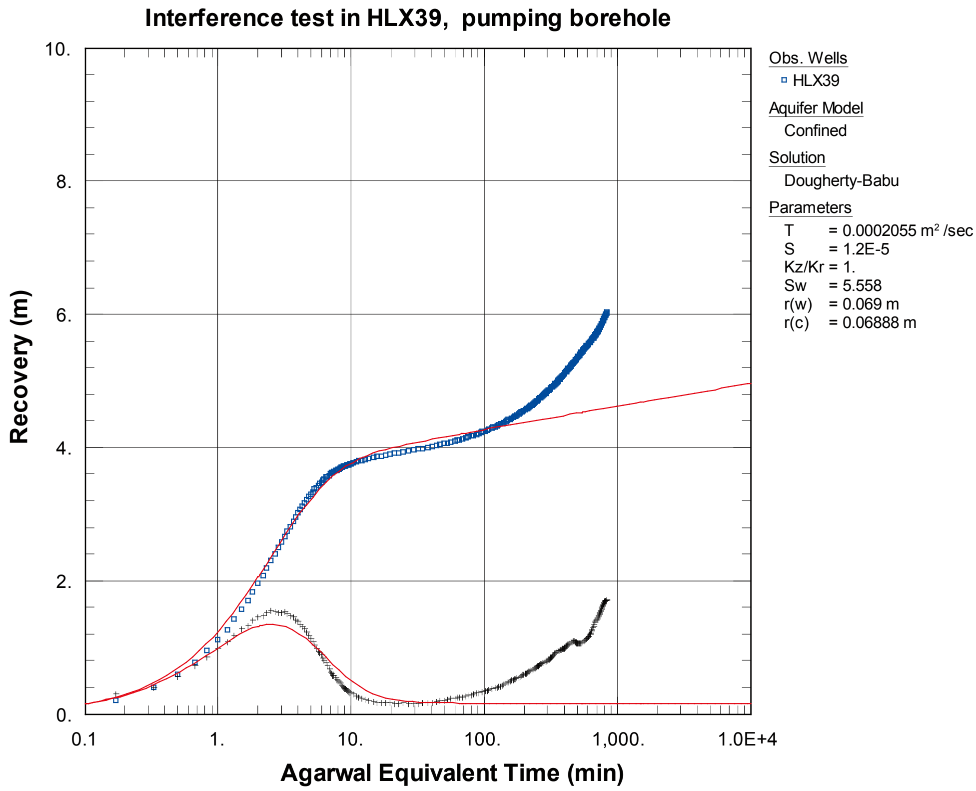


Figure A6-5. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the pumping borehole HLX39.*

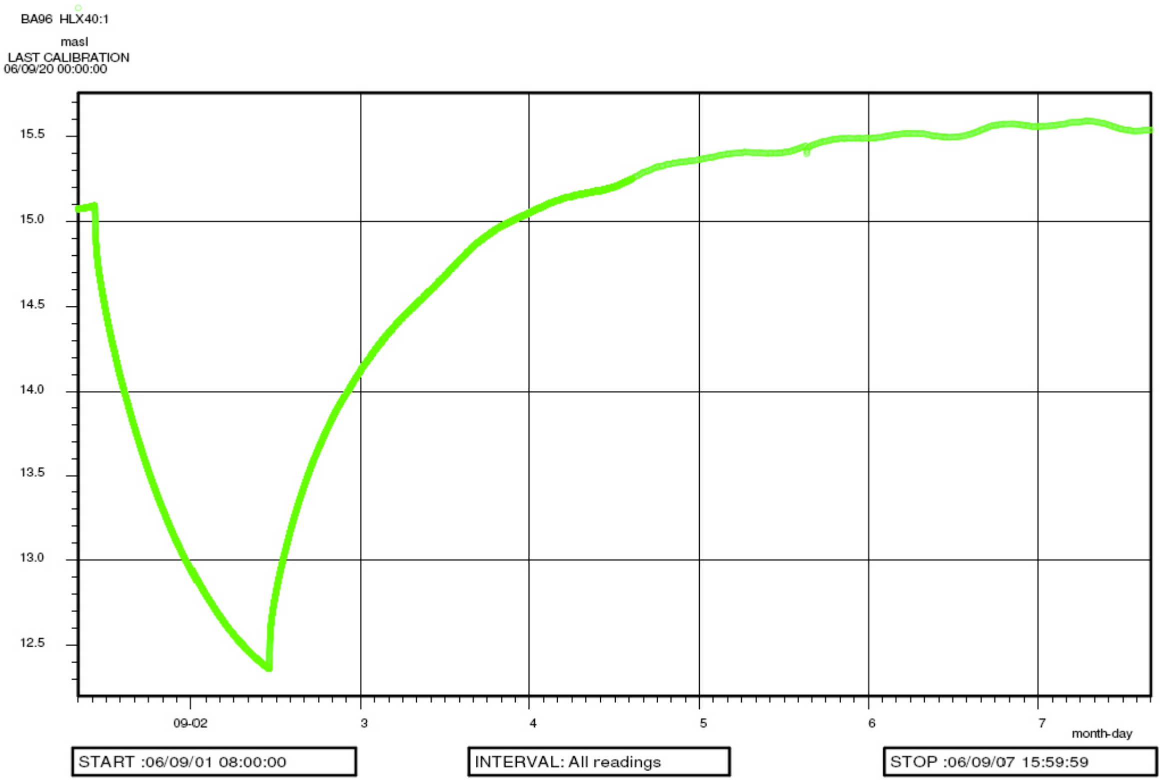


Figure A6-6. *Linear plot of pressure versus time in the observation borehole HLX40 during pumping in borehole HLX39.*

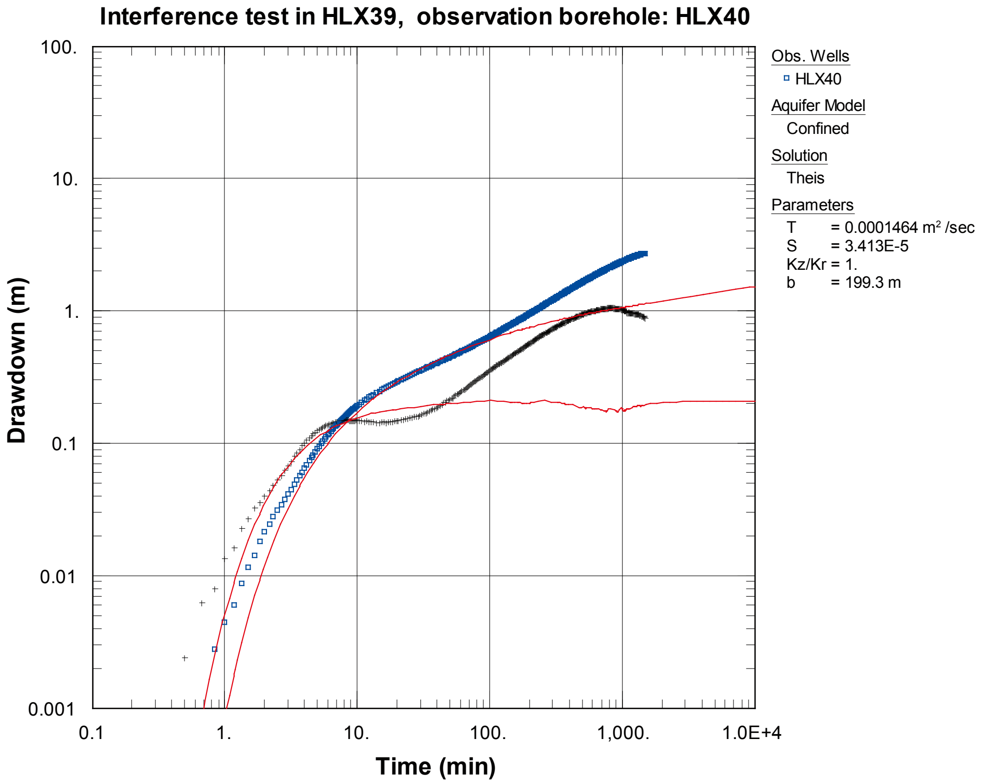


Figure A6-7. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the observation borehole HLX40 during pumping in borehole HLX39.*

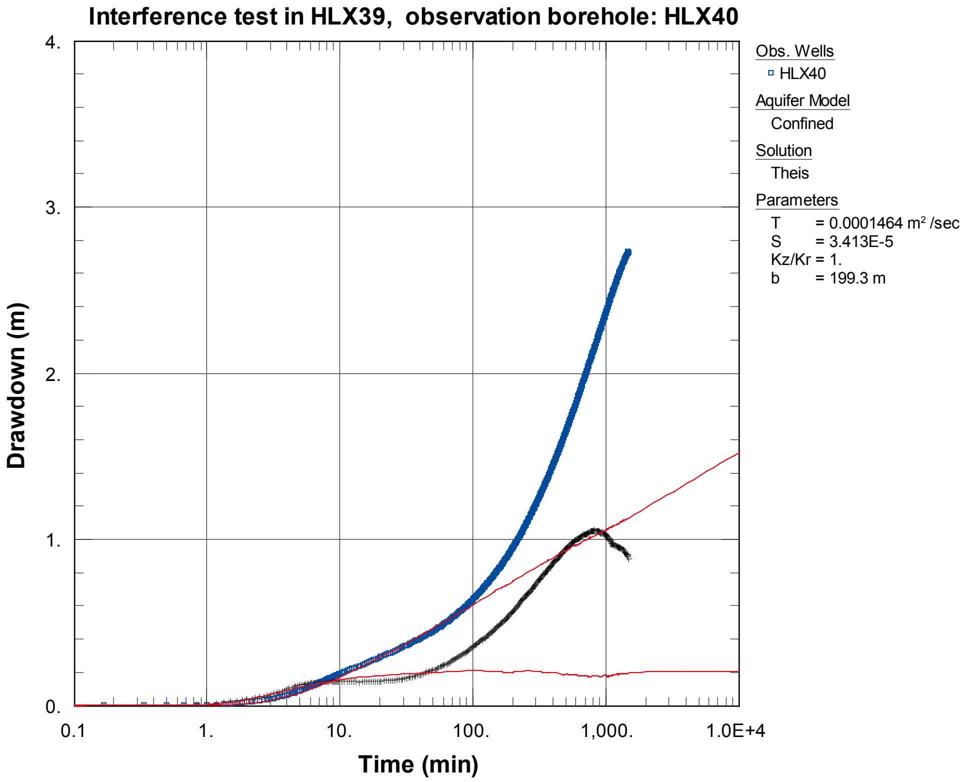


Figure A6-8. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the observation borehole HLX40 during pumping in borehole HLX39.*

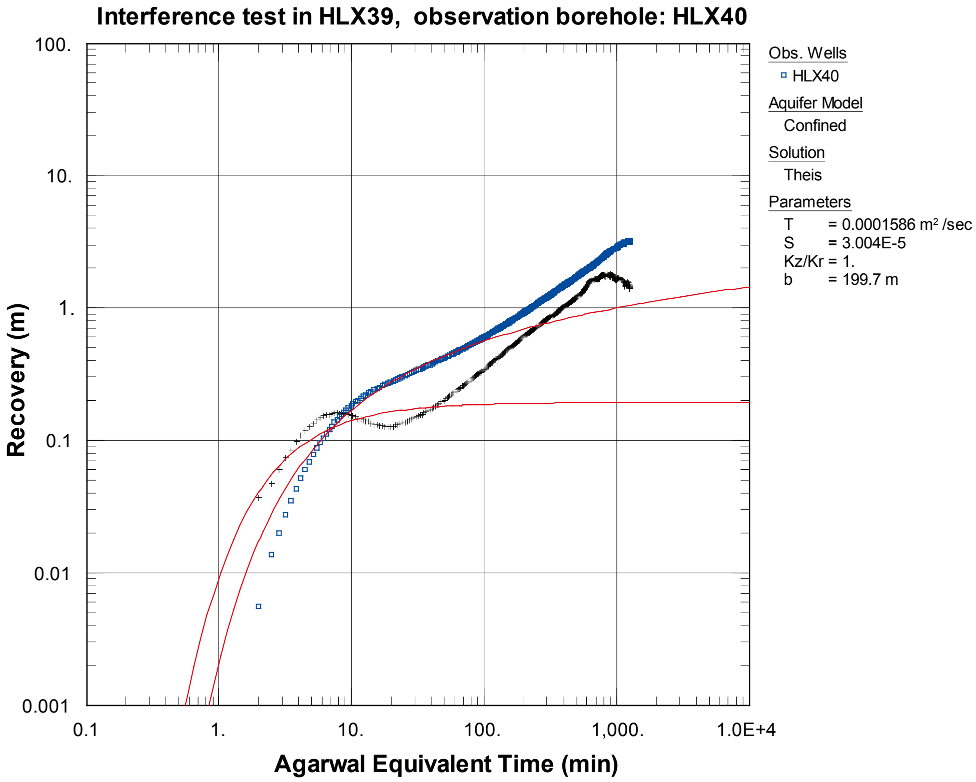


Figure A6-9. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the observation borehole HLX40 during pumping in borehole HLX39.*

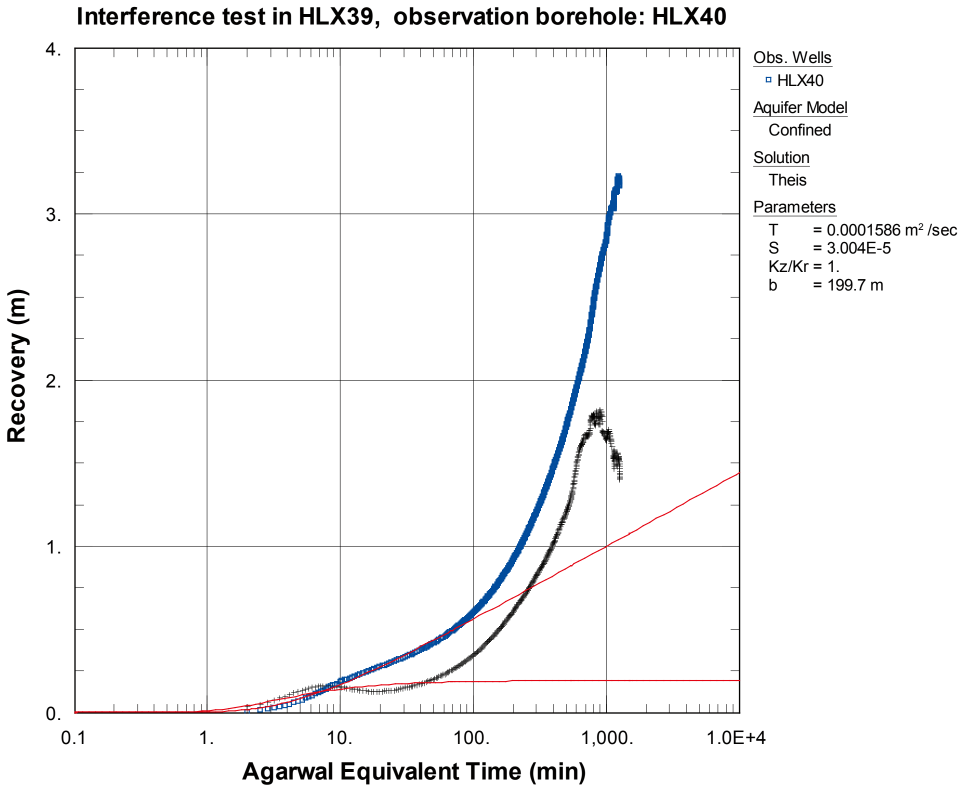


Figure A6-10. Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the observation borehole HLX40 during pumping in borehole HLX39.

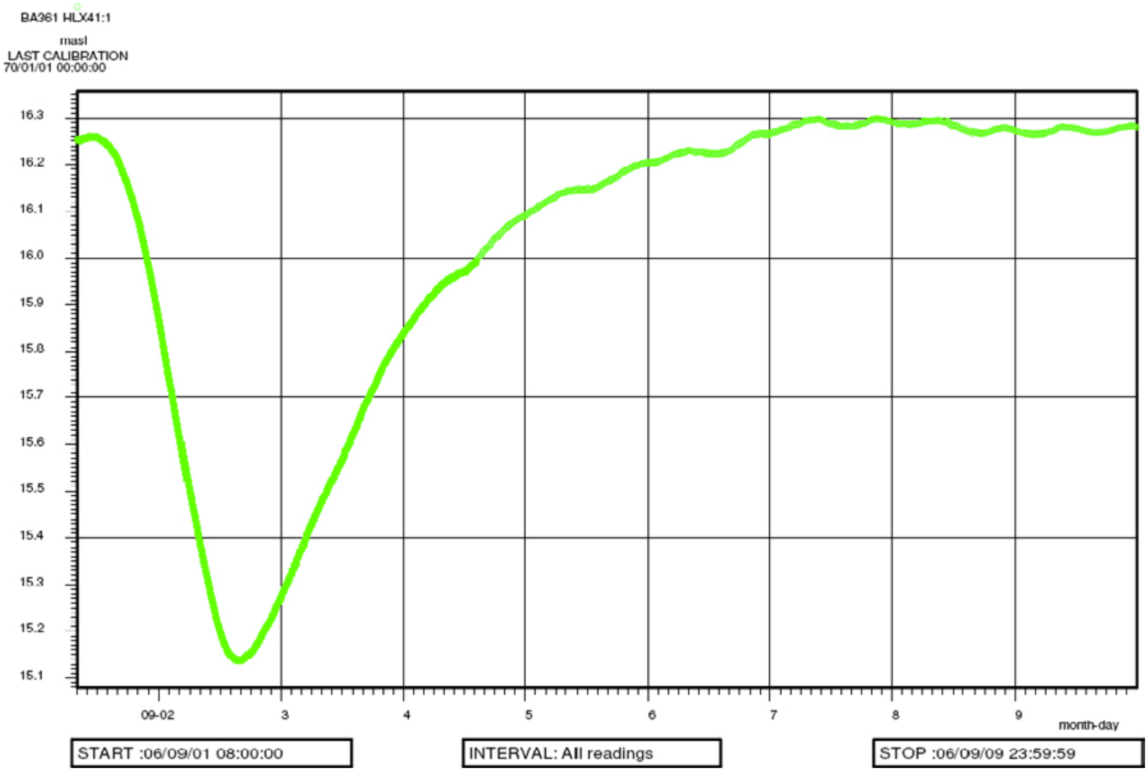


Figure A6-11. Linear plot of pressure versus time in the observation borehole HLX41 during pumping in borehole HLX39.

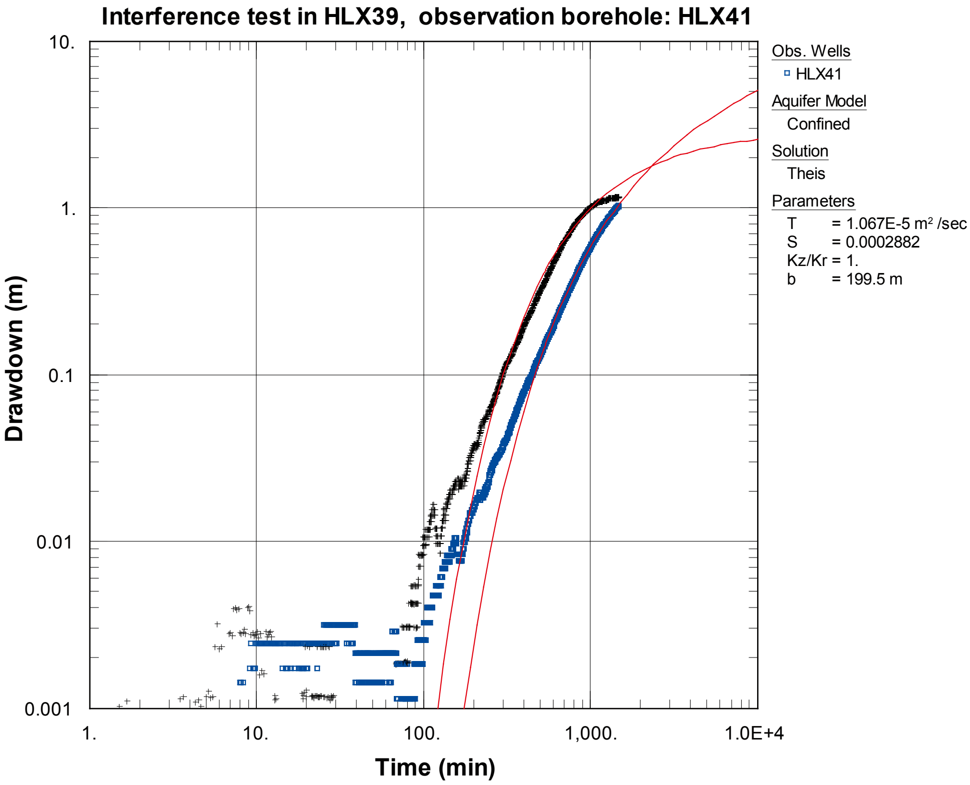


Figure A6-12. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the observation borehole HLX41 during pumping in borehole HLX39.*

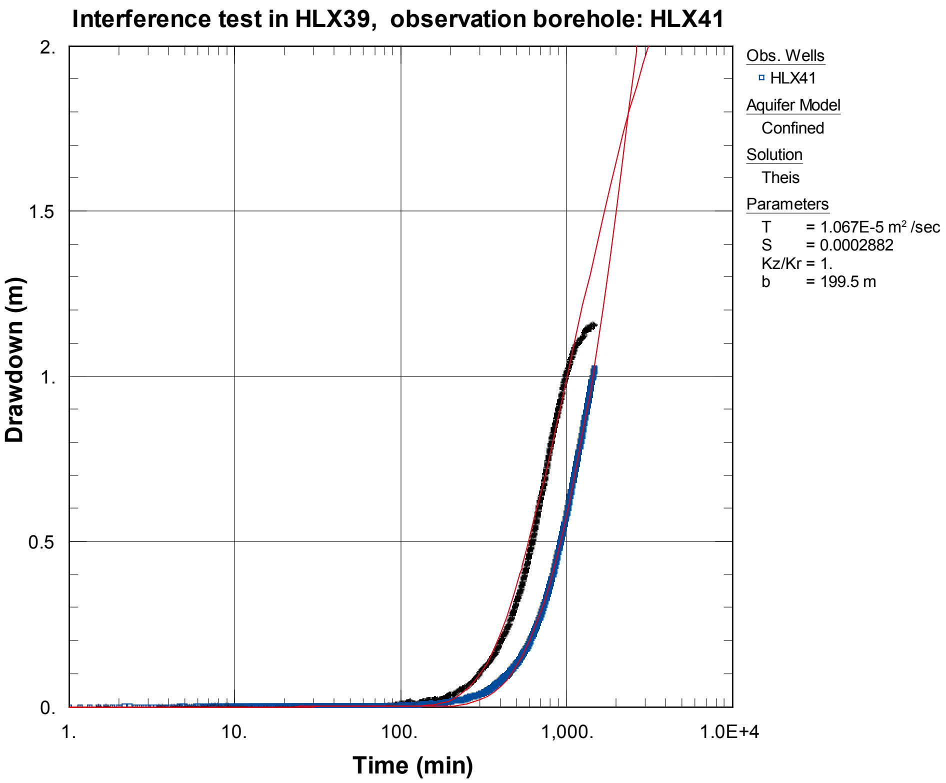


Figure A6-13. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time together with simulated curves (red) in the observation borehole HLX41 during pumping in borehole HLX39.*

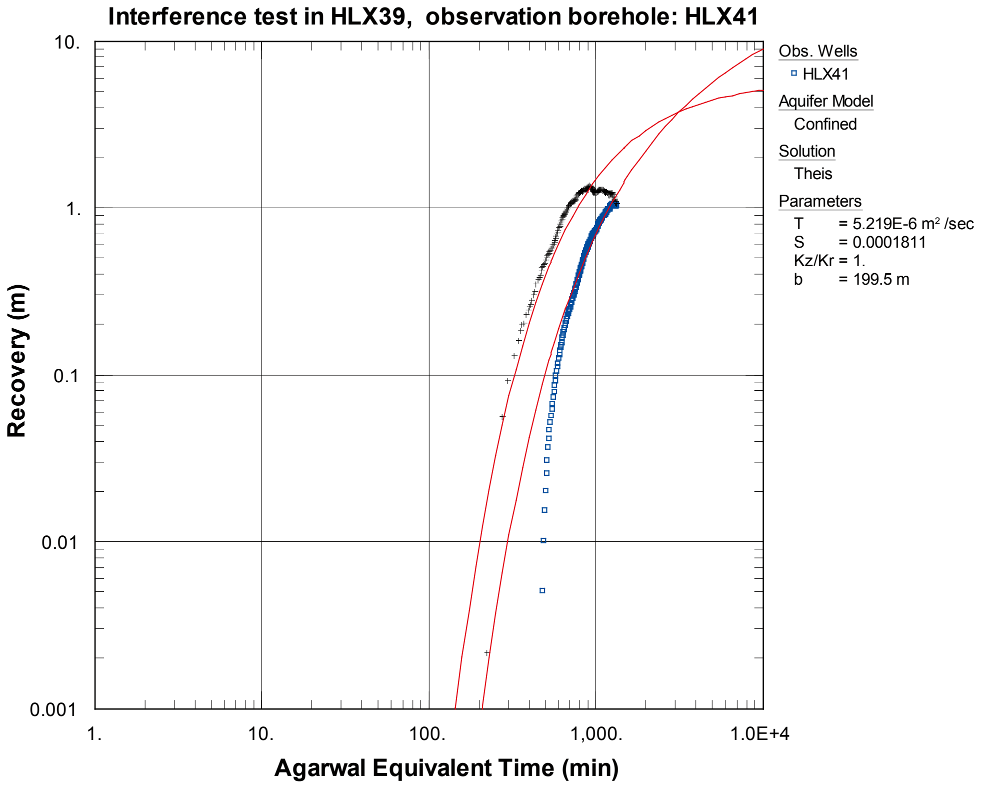


Figure A6-14. Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the observation borehole HLX41 during pumping in borehole HLX39.

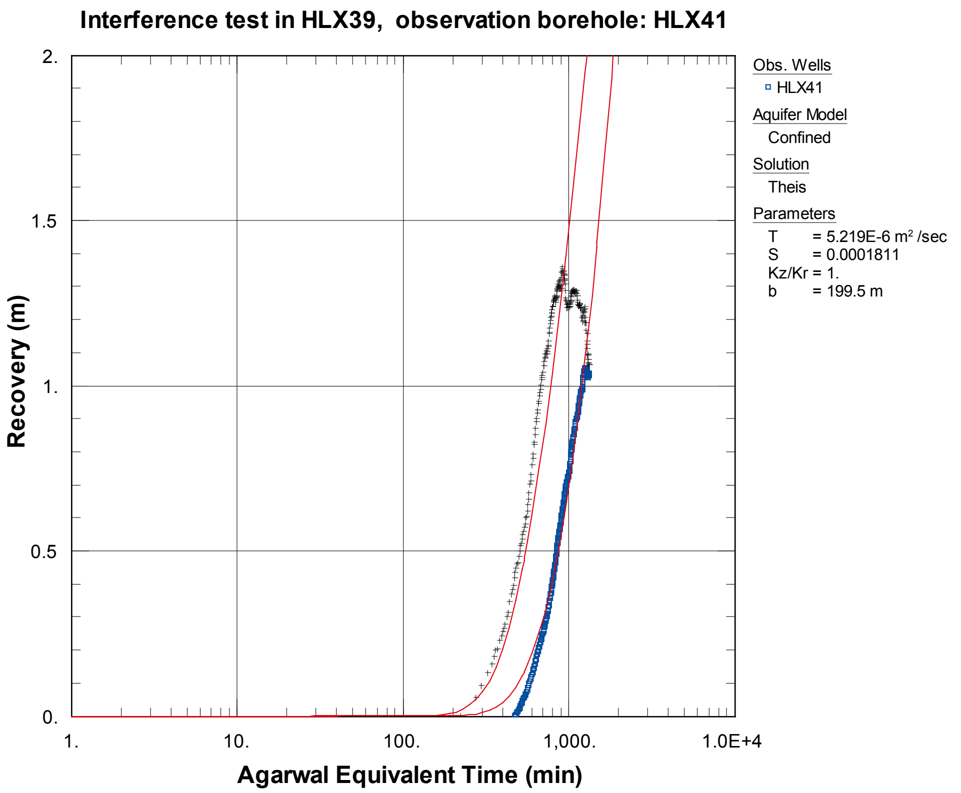


Figure A6-15. Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) together with simulated curves (red) in the observation borehole HLX41 during pumping in borehole HLX39.

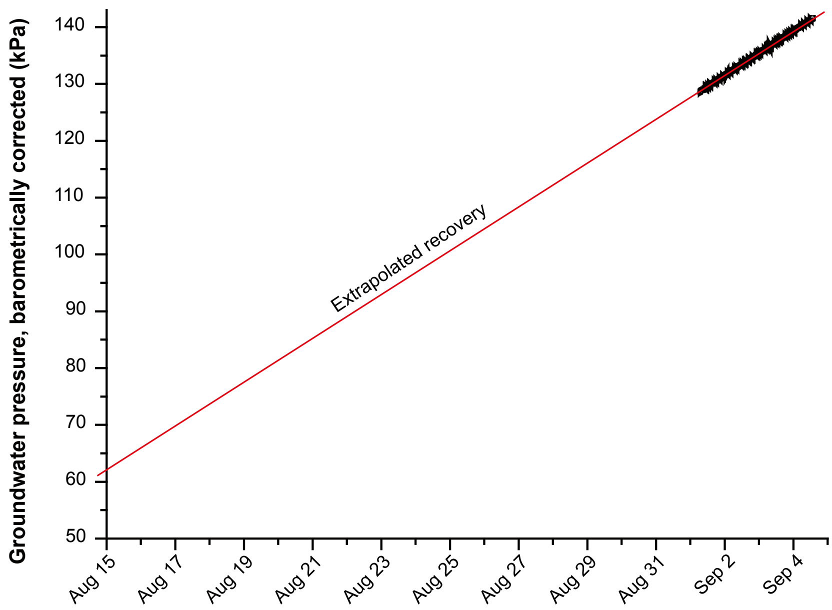
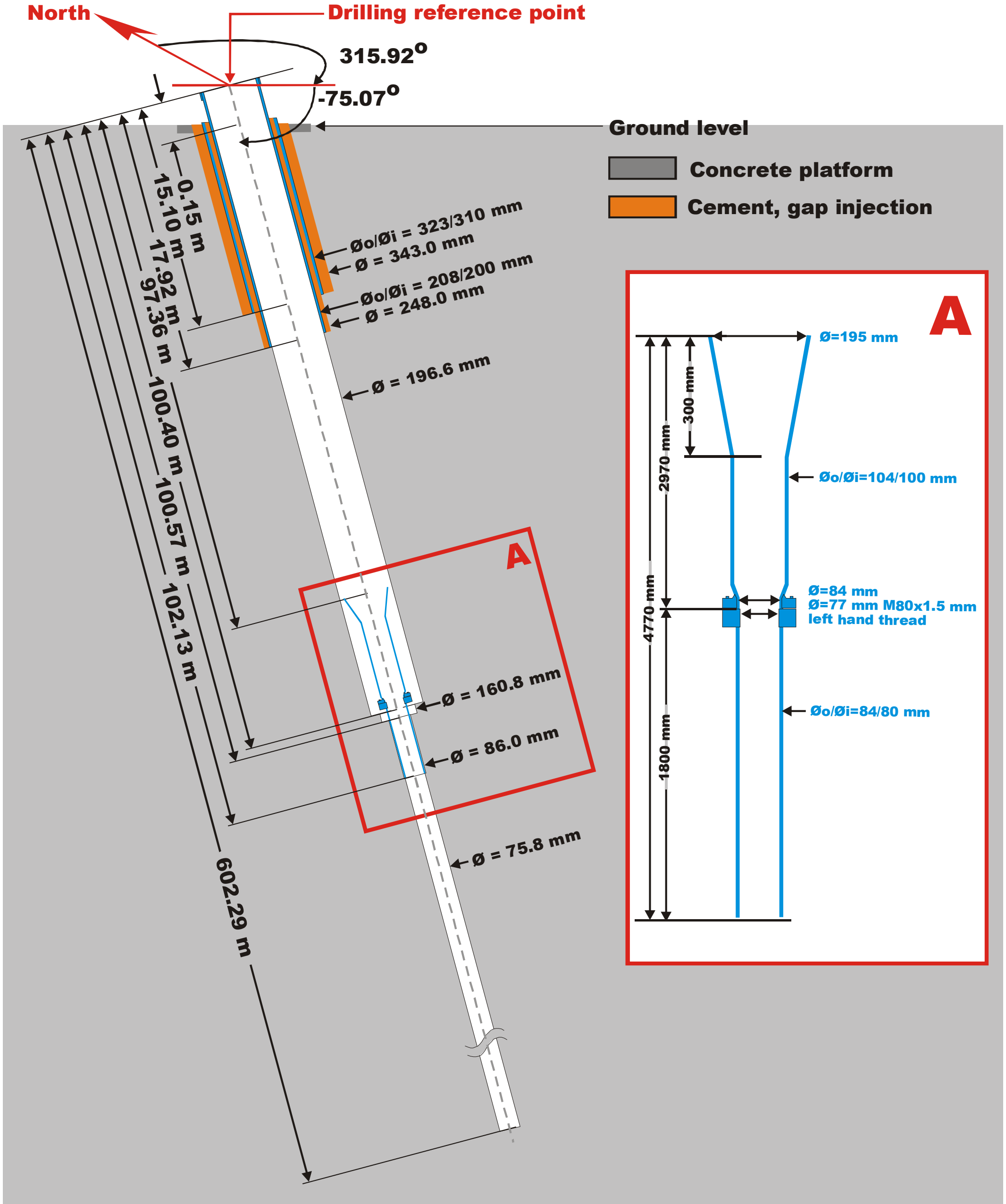


Figure A6-16. *Water level in observation hole KLX17A 0–65.35 m when pumpning HLX39Gauge at 65.35 m b ToC Last air lift flusing after drilling was performed 15/8-06 kl: 17.15. No response observed for HLX39 pumping.*

Borehole construction details

Technical data

Borehole KLX12A



Drilling reference point

Northing: 6365630.78 (m), RT90 2,5 gon V 0:-15
Easting: 1548904.44 (m), RT90 2,5 gon V 0:-15
Elevation: 17.74 (m), RHB 70

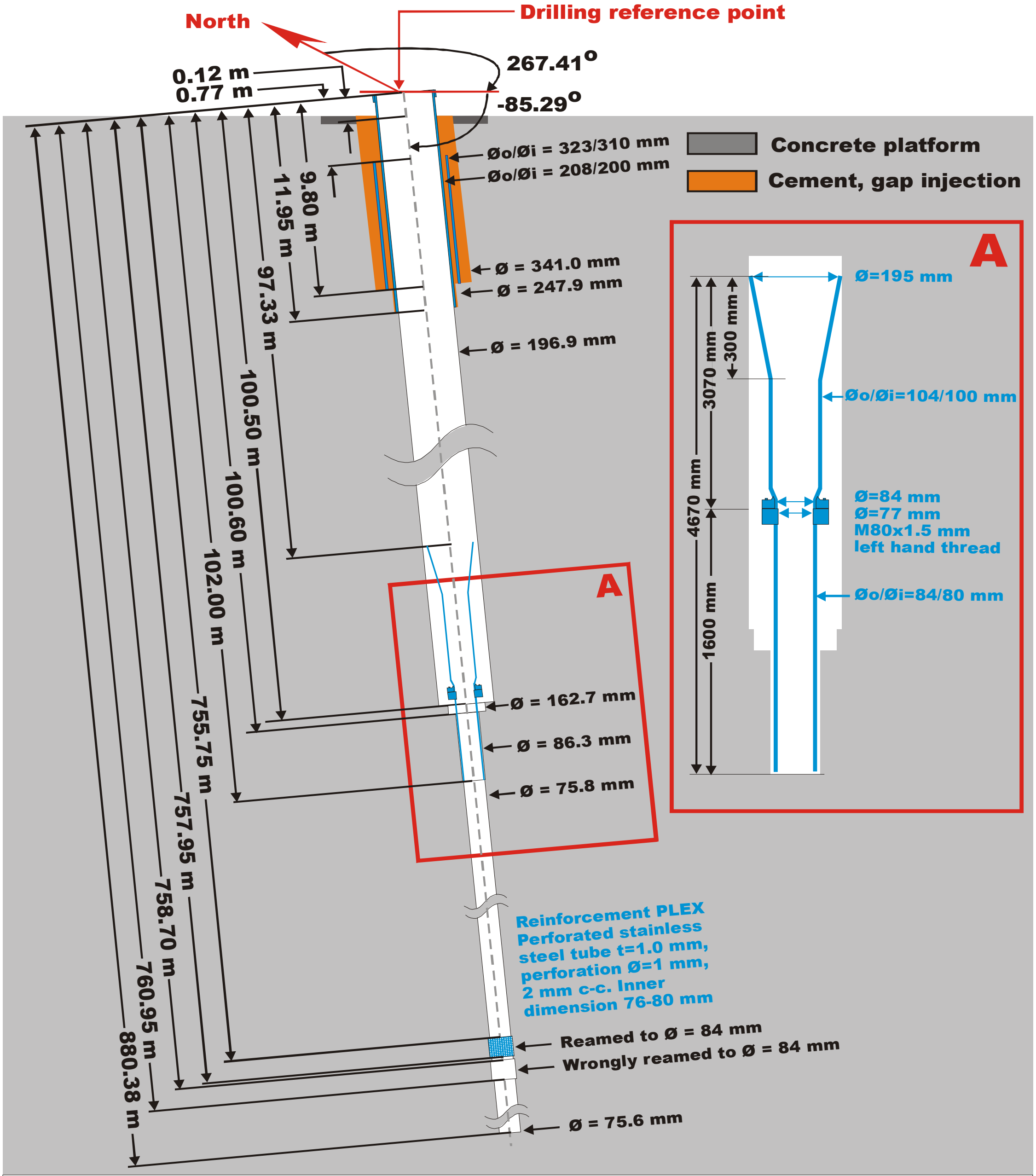
Drilling period

Drilling start date: 2005-10-19
Drilling stop date: 2006-03-04

Ver 2007-02-15

Technical data

Borehole KLX09



Drilling reference point

Northing: 6367323.45 (m), RT90 2,5 gon V 0:-15

Easting: 1548863.18 (m), RT90 2,5 gon V 0:-15

Elevation: 23.45 (m), RHB 70

Drilling period

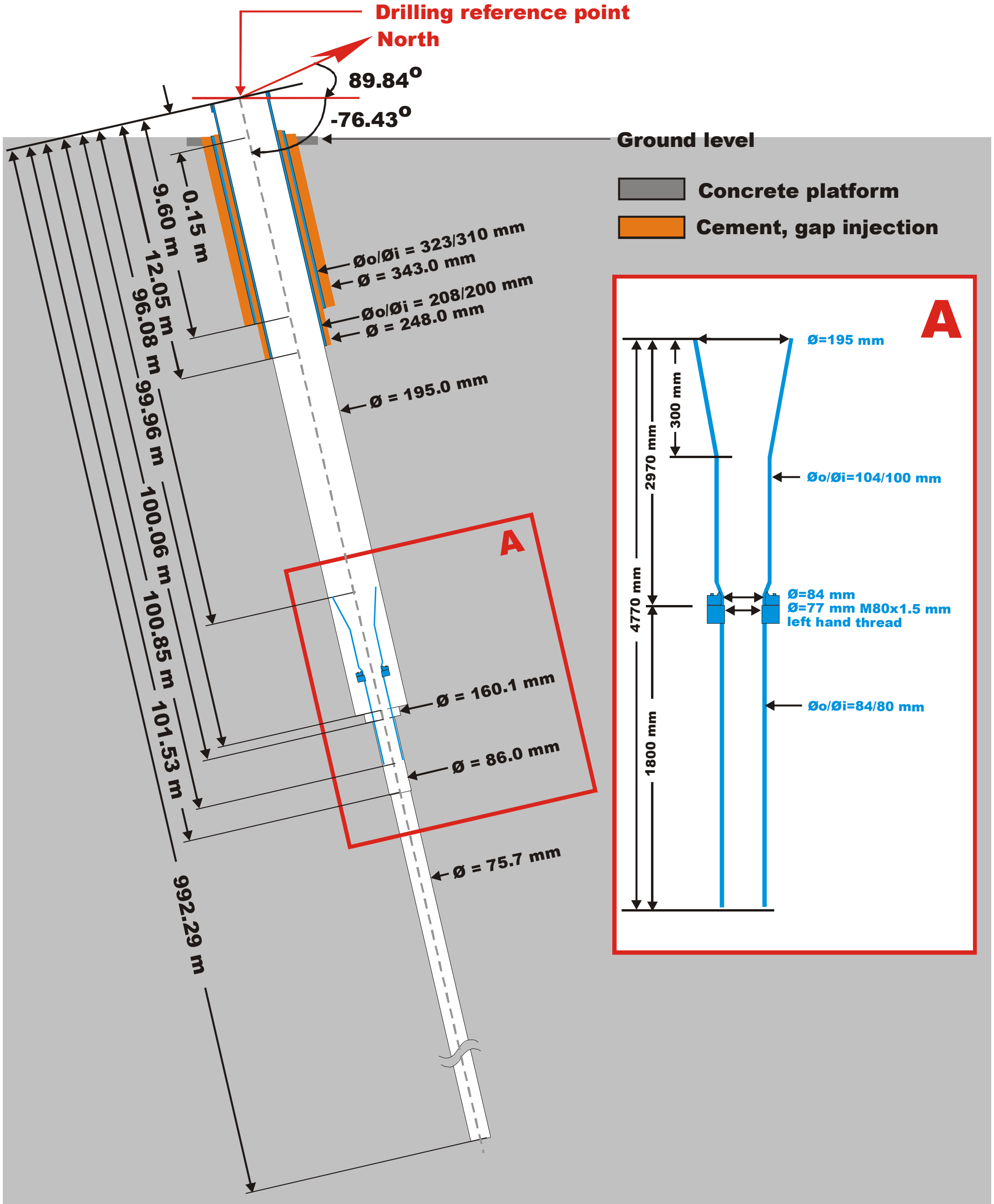
Drilling start date: 2005-06-02

Drilling stop date: 2005-10-15

Ver 2006-03-21

Technical data

Borehole KLX11A



Drilling reference point

Northing: 6366339.72 (m), RT90 2,5 gon V 0:-15

Easting: 1546608.49 (m), RT90 2,5 gon V 0:-15

Elevation: 27.14 (m), RHB 70

Drilling period

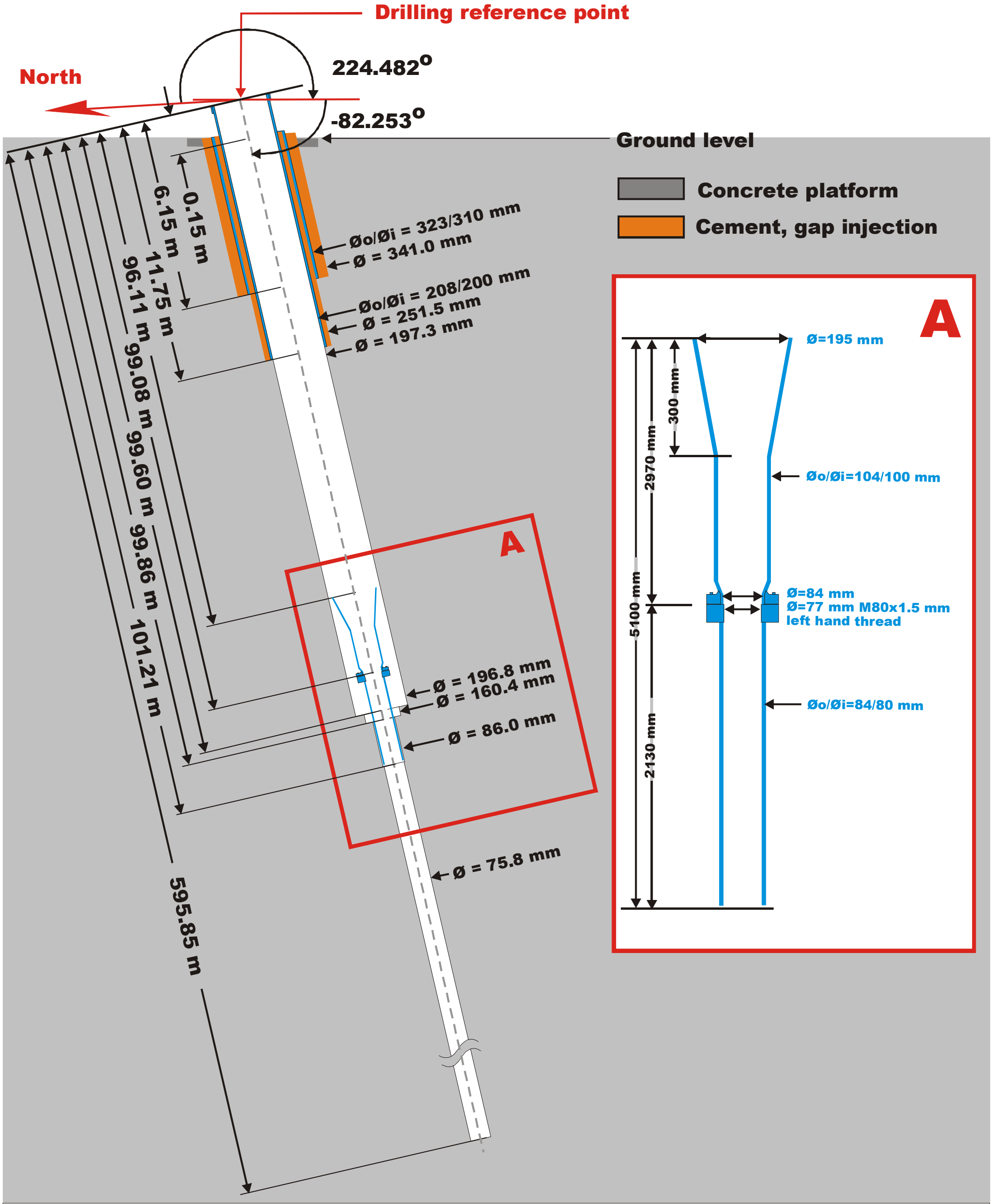
Drilling start date: 2005-11-24

Drilling stop date: 2006-03-02

Ver 2007-03-08

Technical data

Borehole KLX13A



Drilling reference point

Northing: 6367547.144 (m), RT90 2,5 gon V 0:-15

Easting: 1546787.363 (m), RT90 2,5 gon V 0:-15

Elevation: 24.153 (m), RHB 70

Drilling period

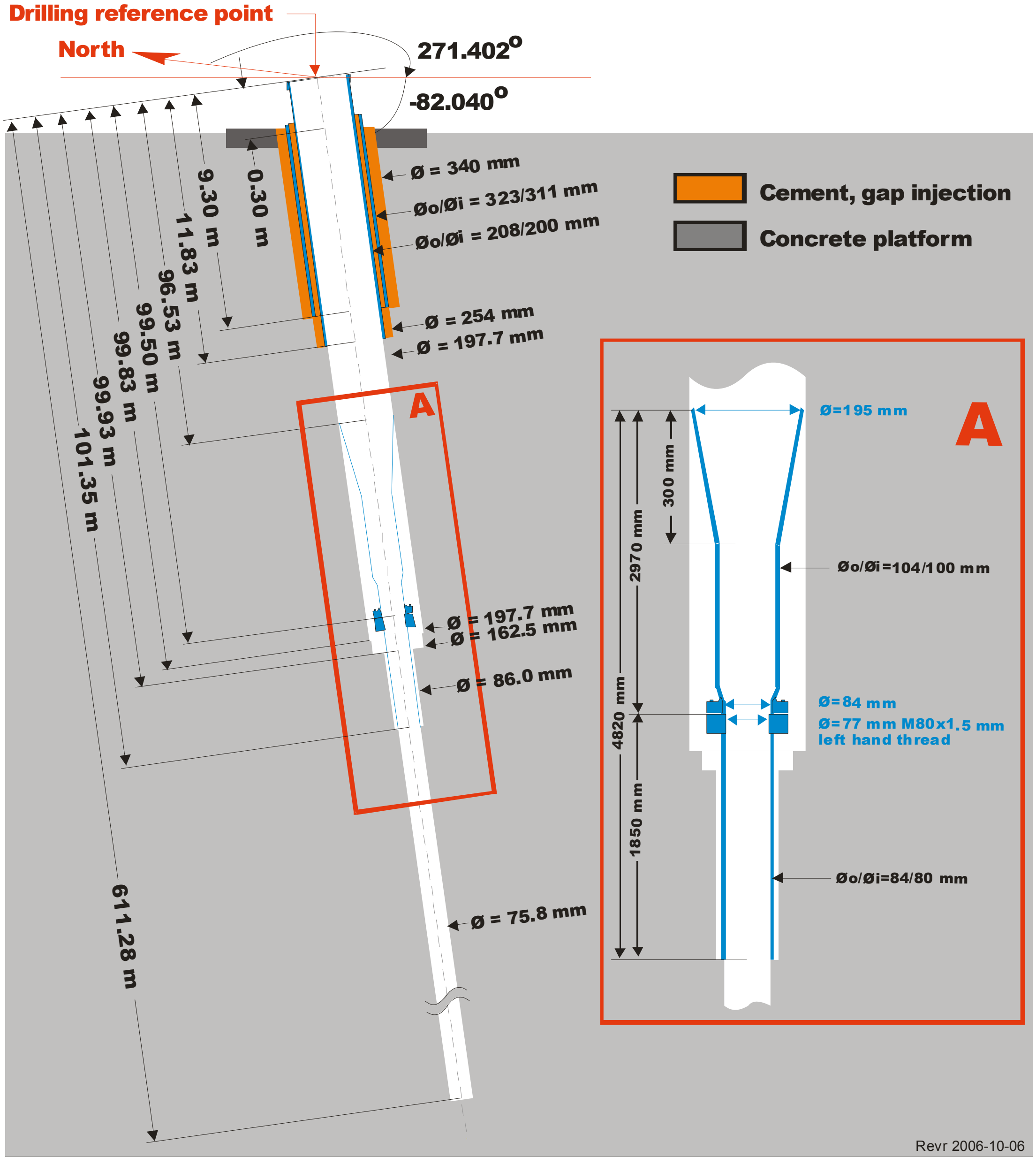
Drilling start date: 2006-05-19

Drilling stop date: 2006-08-16

Ver 2007-04-12

Technical data

Borehole KLX18A



Drilling reference point

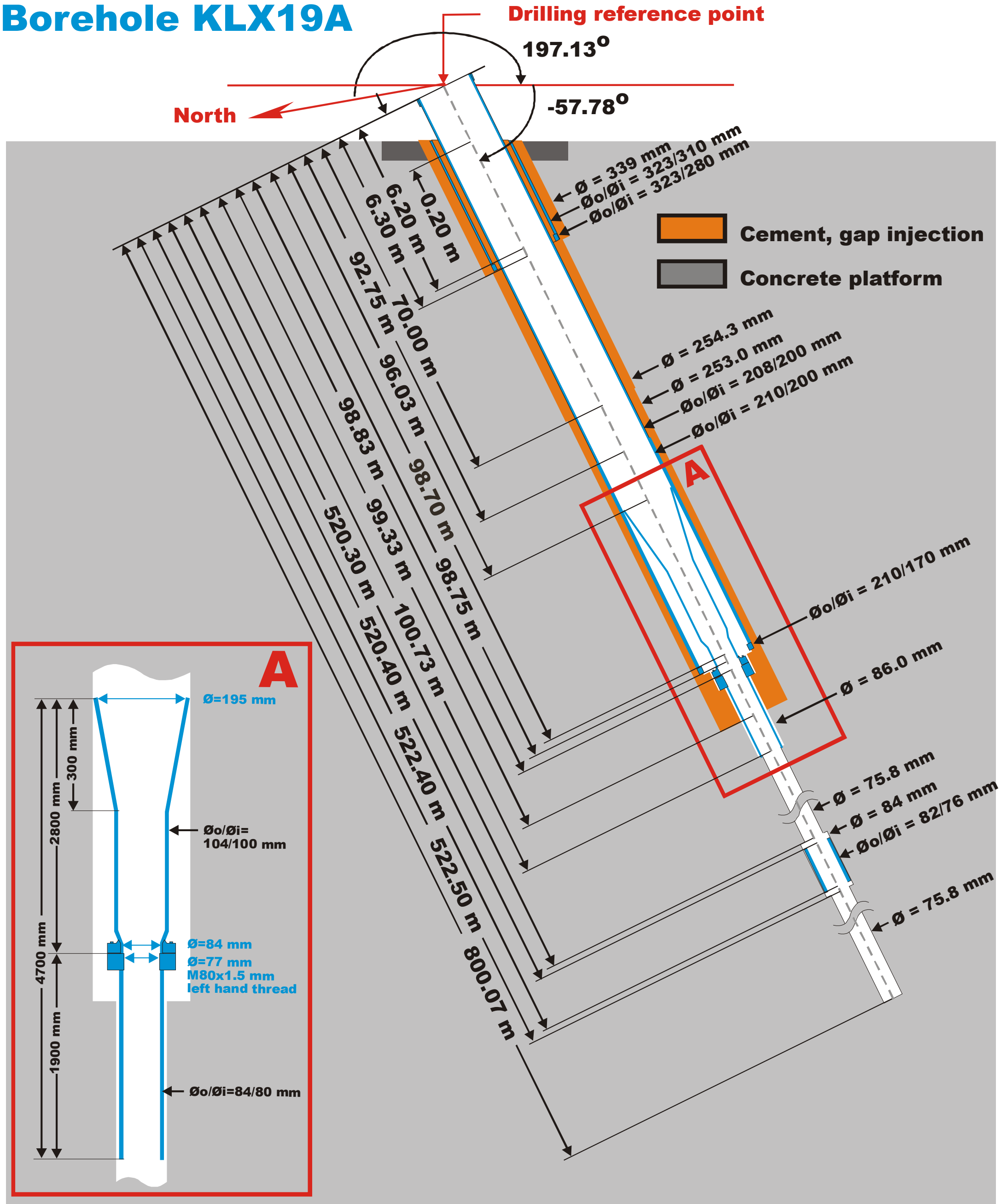
Northing: 6366413.39 (m), RT90 2,5 gon V 0:-15
Easting: 1547966.35 (m), RT90 2,5 gon V 0:-15
Elevation: 21.01 (m), RHB 70

Drilling period

Drilling start date: 2006-02-15
Drilling stop date: 2006-05-02

Technical data

Borehole KLX19A



Drilling reference point

Northing: 6365901.42 (m), RT90 2,5 gon V 0:-15

Easting: 1547004.62 (m), RT90 2,5 gon V 0:-15

Elevation: 16.87 (m), RHB 70

Drilling period

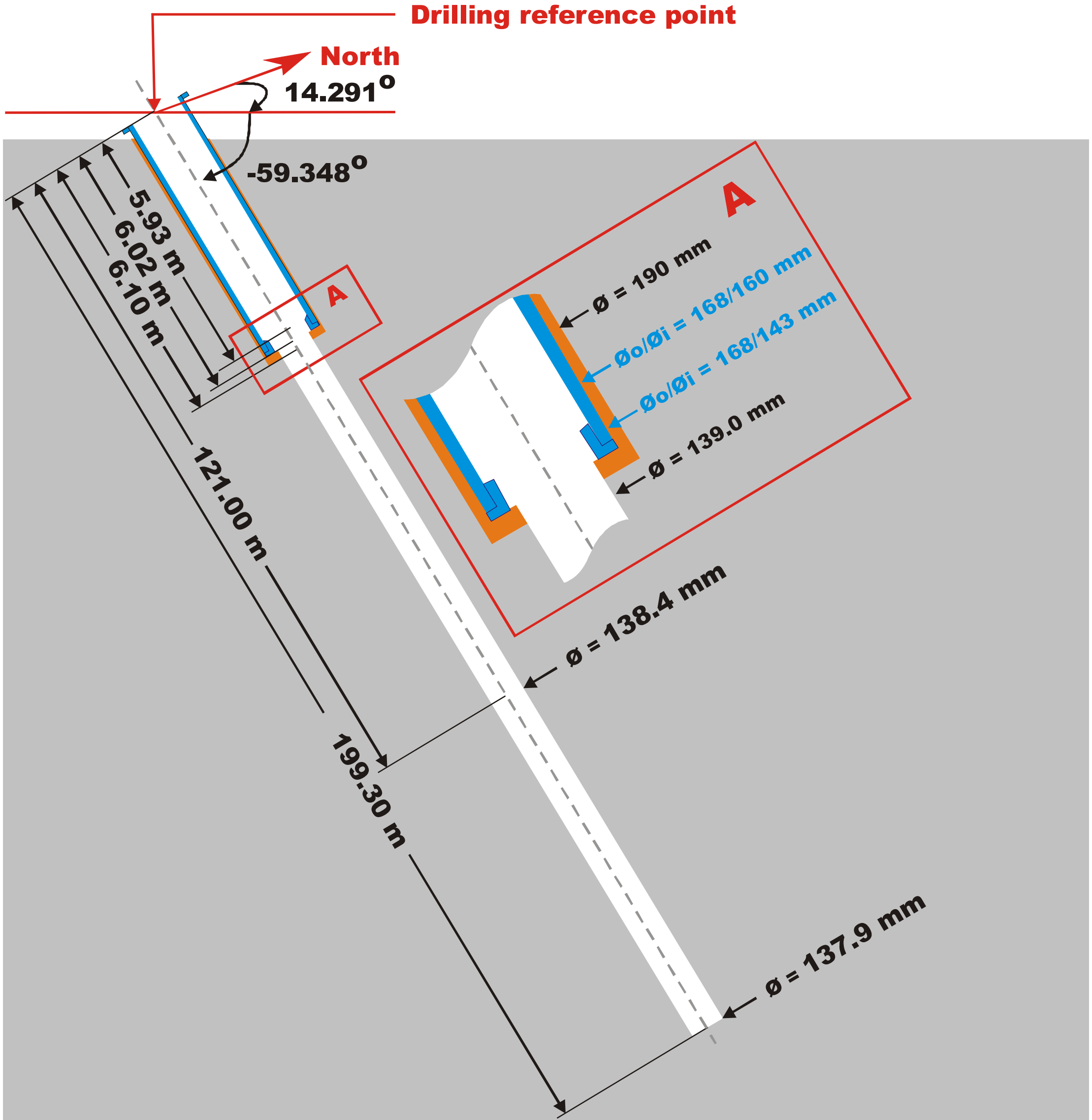
Drilling start date: 2006-05-10

Drilling stop date: 2006-09-20

Ver 2007-04-24

Technical data

Borehole HLX39



Drilling reference point

Northing:	**6366887.869 (m), RT90 2,5 gon V**
Easting:	**1546880.479 (m), RT90 2,5 gon V**
Elevation:	**27.044 (m), RHB 70**

Drilling period

Drilling start date:	**2006-06-07**
Drilling stop date:	**2006-06-14**

Rev 2006-12-21