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Keywords: Forsmark site investigation, Hydrogeology, Well yield.

Abstract

The water yield of the percussion-drilled boreholes within the Forsmark candidate area is exceptional compared to the water yield of domestic bedrock wells in northern Uppland. The former data set stems from SKB's site investigation programme and is recorded in SKB's database Sicada, whereas the latter data set is stored in the Archive of Wells, a national database for groundwater wells operated by the Geological Survey of Sweden (SGU).

The comparisons presented here reveal that the median value of the water yield of the percussion-drilled boreholes within the Forsmark candidate area is c. twenty (20) times greater than the median value of the water yield of the domestic bedrock wells outside the candidate area in northern Uppland. This difference is statistically significant and suggests that the superficial bedrock within the Forsmark candidate area is much more transmissive than the superficial bedrock outside this area. Reasons for this difference are discussed in the report.

Sammanfattning

Brunnskapaciteten hos hammarborrade bergborrhål inom kandidatområdet i Forsmark är exceptionell jämförts med brunnskapaciteten hos privata bergbrunnar i norra Uppland. Data för de förstnämnda brunnarna härrör från SKB:s platsundersökning i Forsmark och finns lagrat i Sicada, SKB:s databas för platsundersökningsdata. Data för det andra datasetet kommer från Brunnsarkivet, en nationell databas för brunnar i jord och berg som administreras av Sveriges geologiska undersökning (SGU).

Jämförelsen visar att brunnskapacitetens medianvärde är ca tjugo (20) gånger högre för borrhålen inom kandidatområdet jämfört med de privata bergbrunnarna utanför kandidatområdet i norra Uppland. Skillnaden är statistiskt signifikant och indikerar att ytberget inom kandidatområdet i Forsmark är mycket mer transmissivt än ytberget utanför detta område. I rapporten diskuteras möjliga förklaringar till detta förhållande.

Contents

1 Introduction

1.1 Background

The median value of the well yield for all bedrock wells in Sweden is c. 600 L/h /Berggren 1998/. Many percussion-drilled boreholes within the Forsmark candidate area have an exceptional water yield. For instance, Figure 1-1 shows the well yield of the percussion-drilled borehole HFM02 while air flushing during the completion of the well. The estimated well yield at this instant exceeded 48,000 L/h.

1.2 Scope and objectives

The work reported here analyses well yield data from twenty-two percussion-drilled bedrock boreholes, HFM01–22, drilled in the Forsmark candidate area between May 2002 and June 2005 (data freeze 2.1). The data used are stored in SKB's database Sicada. A statistical comparison is made with the well yield data from 1,945 domestic bedrock wells drilled in northern Uppland close to Forsmark candidate area. The latter data set is stored in the Archive of Wells, which is a national database operated by the Geological Survey of Sweden (SGU). The Archive of Wells contains information from more than 210,000 wells, out of which c. 1,600 are found in the municipality of Östhammar where the Forsmark candidate area is located.

The statistical significance of the observed difference in the median yield is tested by a H_0-test of the difference in $\log_{10}(Q)$ and $\log_{10}(Q/D)$, where Q is the well yield (flow rate, L/h) during flushing and D is the borehole penetration depth (m). The report also presents borehole transmissivity data in intervals of 50 m based on the hydraulic testing with the HTHB unit, and point-water heads in the uppermost part of the bedrock.

Figure 1-1. *Picture showing the flushing of the percussion-drilled borehole HFM02 during completion. The estimated well yield at this instant exceeded 48,000 L/h.*

1.3 Setting

Figure 1-2 shows a geological map of the bedrock surface in the Forsmark area with its rock domains and deformation zones. Superimposed are public roads and the location of the twenty-two (22) percussion-drilled boreholes, HFM01–22. The geological map represents the 1.2 geological model /SKB 2005/. The drilling, geological mapping, hydraulic testing and chemical sampling of the percussion-drilled boreholes are documented in Sicada, SKB's database. The P-reports with data from the air flushing and the hydraulic testing with the HTHB unit, respectively, are listed in Table 1-1.

1.4 Division of data into sets

Figure 1-3 shows a map of the surroundings of the candidate area and the boreholes analysed in this report. The SKB boreholes (22) are shown in red and the SGU boreholes (1,945) shown in black (1,664) and in green (281). In the work reported here, the data set comprising the twenty-two SKB boreholes is denoted by FA (Forsmark Area), the data set comprising the 1,664 SGU wells is denoted by ÖM (Östhammar Municipality) and the data set comprising the 281 SGU wells is denoted by (GZ) (Guard Zone). Statistical comparisons for these three sets of data are shown in Chapter 2.

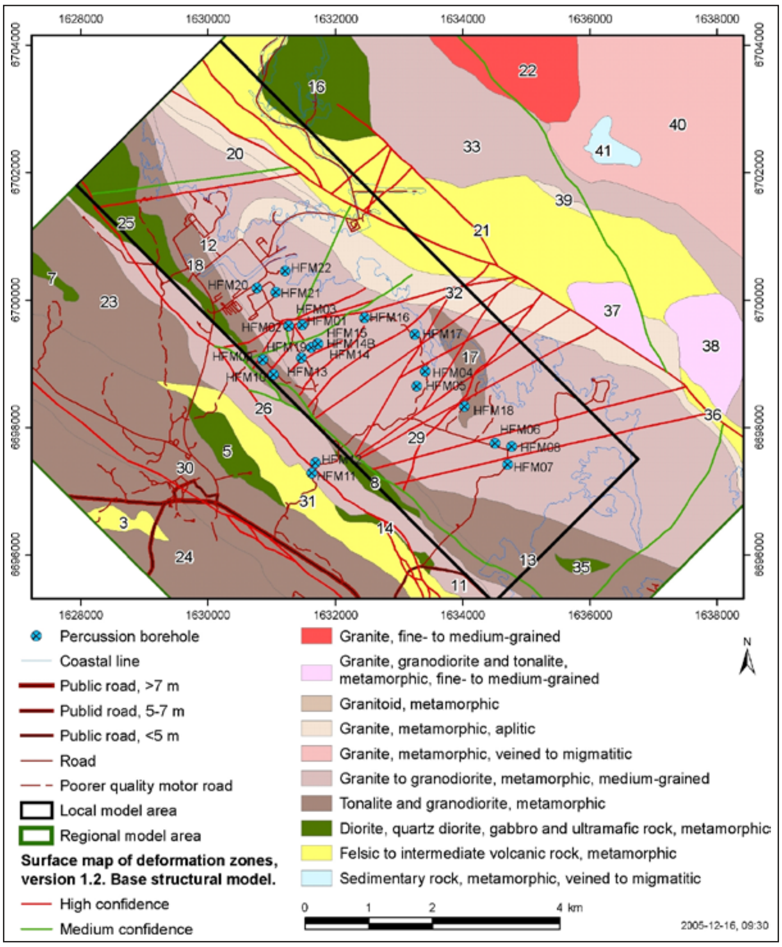


Figure 1-2. Geological map of the bedrock surface showing rock domains, deformation zones, public roads and the location of the 22 percussion-drilled boreholes, HFM01–22.

Table 1-1. A list of the P-reports that describe (a) the drilling and air flushing and (b) the pumping and impeller flow logging of the percussion-drilled boreholes HFM01–HFM22.

Borehole	P-report	Borehole	P-report	Borehole	P-report
HFM01	(a) P-03-30 (b) P-03-33	HFM09	(a) P-04-76 (b) P-04-74	HFM17	(a) P-04-106 (b) P-04-72
HFM02	(a) P-03-30 (b) P-03-33	HFM10	(a) P-04-76 (b) P-04-74	HFM18	(a) P-04-106 (b) P-04-72
HFM03	(a) P-03-30 (b) P-03-33	HFM11	(a) P-04-106 (b) P-04-64	HFM19	(a) P-04-106 (b) P-04-72
HFM04	(a) P-03-51 (b) P-03-34	HFM12	(a) P-04-106 (b) P-04-64	HFM20	(a) P-04-245 (b) P-05-14
HFM05	(a) P-03-51 (b) P-03-34	HFM13	(a) P-04-85 (b) P-04-71	HFM21	(a) P-04-245 (b) P-05-14
HFM06	(a) P-03-58 (b) P-03-36	HFM14	(a) P-04-85 (b) P-04-71	HFM22	(a) P-04-245 (b) P-05-14
HFM07	(a) P-03-58 (b) P-03-36	HFM15	(a) P-04-85 (b) P-04-71		
HFM08	(a) P-03-58 (b) P-03-36	HFM16	(a) P-04-94 (b) P-04-65		

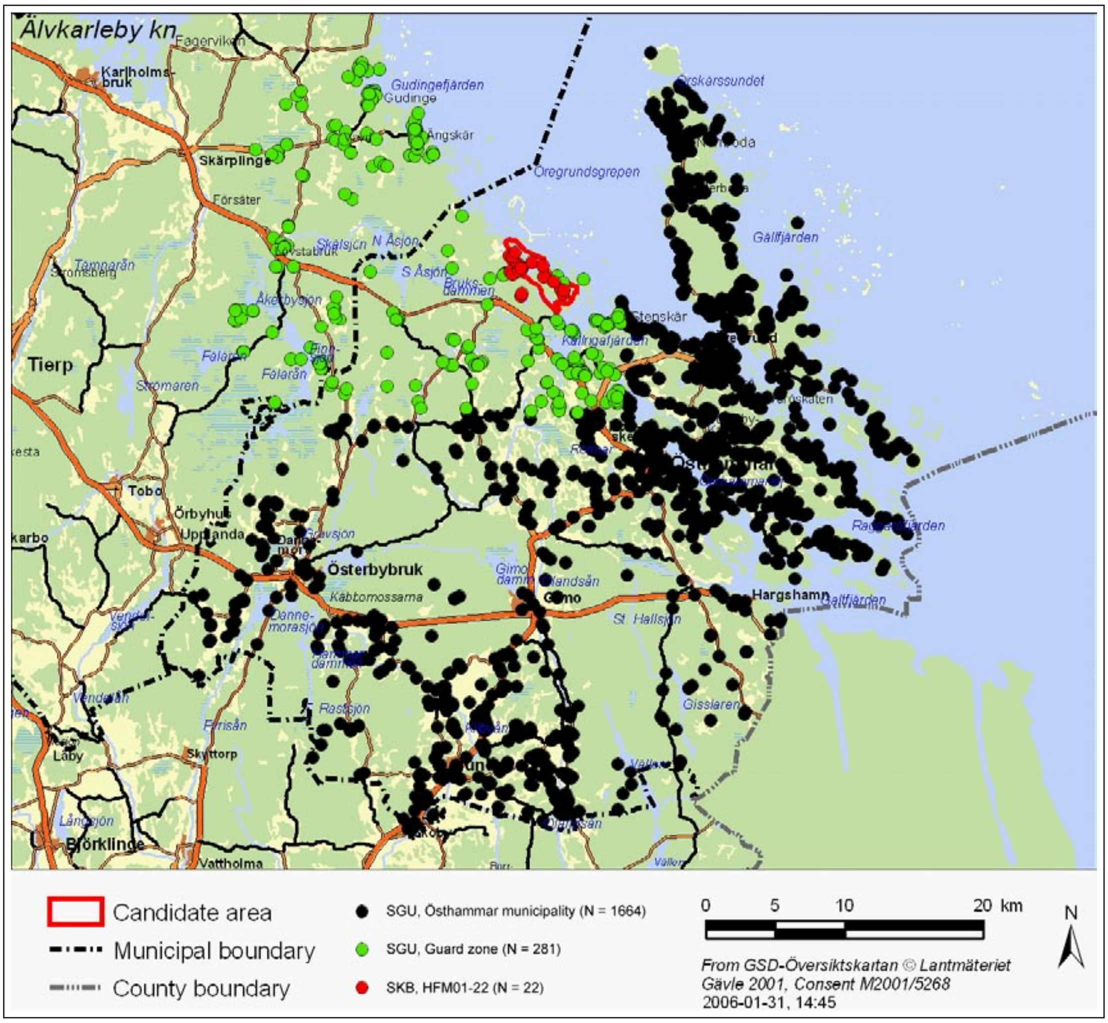


Figure 1-3. *Map showing the twenty-two boreholes, HFM01–22, drilled by SKB (red) and the 1,945 percussion-drilled domestic wells extracted from SGU's Archive of Wells. 1,664 of these are shown in black and 281 are shown in green. Statistical comparisons are made for the three sets of data (red, green and black) in Chapter 2.*

2 Statistical analysis

2.1 Univariate statistics

As described in Section 1.3 and illustrated in Figure 1-3, the data treated in this report have been divided into three sets:

- Domestic bedrock wells in the municipality of Östhammar (ÖM; N = 1,664).
- Domestic bedrock wells in a “guard zone” surrounding the Forsmark site investigation area (GZ; N = 281).
- Percussion-drilled SKB boreholes in the Forsmark area (FA; N = 22).

Table 2-1 presents a summary of the geometrical data of the wells in the three data sets. The shallower borehole penetration depths of the domestic data sets (ÖM and GZ) compared to the site investigation data set (FA) are due to the risk of saltwater intrusion and/or upconing. It is assumed that all SGU wells, ÖZ and GZ, are vertical. For the FA wells, the penetration depths have been determined with the help of the borehole deviation measurements.

Table 2-2 shows univariate statistics for the penetration depth, D, the well yield, Q, and the quotient Q/D. Here, Q/D is used as estimate for the quotient Q/s, where s is the drawdown while pumping (or flushing) the well. The quotient Q/s is often referred to as the specific capacity and has the same unit as transmissivity (m^2/s). SGU wells with no yield (Q = 0) have been assigned a yield of 1 L/h. This assumption affects c. 2% of the ÖM data set and c. 1.5% of the GZ data set.

Table 2-2 suggests that the median yield of the wells in the FA data set is c. 20 times greater than the median yield the ÖM and GZ data sets (Figure 2-1). The median of the quotient Q/D is c. 8 times greater for the FA data set. The data sets $\log_{10}(Q)$, $\log_{10}(D)$ and $\log_{10}$(Q/D) are approximately normal distributed, see Figure 2-2, Figure 2-3 and Figure 2-4 for examples. Figure 2-5 suggests that the range in the yield of the wells in the FA data set exceeds the maximum capacity of the air flushing (“mammut pumping”) method (Figure 1-1).

Figure 2-4 suggests that the range in the yield of the wells in the FA data set exceeds the maximum capacity of the air flushing (“mammut pumping”) method, cf. Figure 1-1.

Table 2-1. Summary of geometrical data. *D* = borehole penetration depth (m). ∅ = borehole diameter (mm). Wells from SGU´s Archive of Wells (ÖM and GZ) are drilled before 2002. The SKB boreholes (FA) are drilled between 2002-05-01 and 2005-06-30.

Variable	Data set	Number of data	Median	Average	Min	Max
D (m)	ÖM	1,664	52	58.6	7	180
	GZ	281	50	52.5	7	131
	FA	22	143	144	26	300
∅ (mm)	ÖM	1,664	113	119	65	200
	GZ	281	112	119	100	165
	FA	22	140	140	140	140

Table 2-2. Univariate statistics for the yield, *Q*, the penetration depth, *D* and the quotient *Q/D* for the three data sets, ÖM, GZ and FA.

Variable	Category	Number of data	Median	Average	$(\log_{10})_{median}$	$(\log_{10})_{ave}$	$(\log_{10})_{std\ dev}$
Q	ÖM	1,664	500	1,184	2.70	2.67	0.675
Q	GZ	281	700	1,467	2.85	2.85	0.617
Q	FA	22	12,300	19,141	4.09	3.97	0.630
D	ÖM	1,664	52.0	58.6	1.72	1.72	0.213
D	GZ	281	50.0	52.5	1.70	1.68	0.210
D	FA	22	143	144	2.16	2.11	0.229
Q/D	ÖM	1,664	9.21	30.8	0.964	0.956	0.754
Q/D	GZ	281	15.0	46.0	1.18	1.17	0.721
Q/D	FA	22	71.0	197	1.85	1.86	0.735

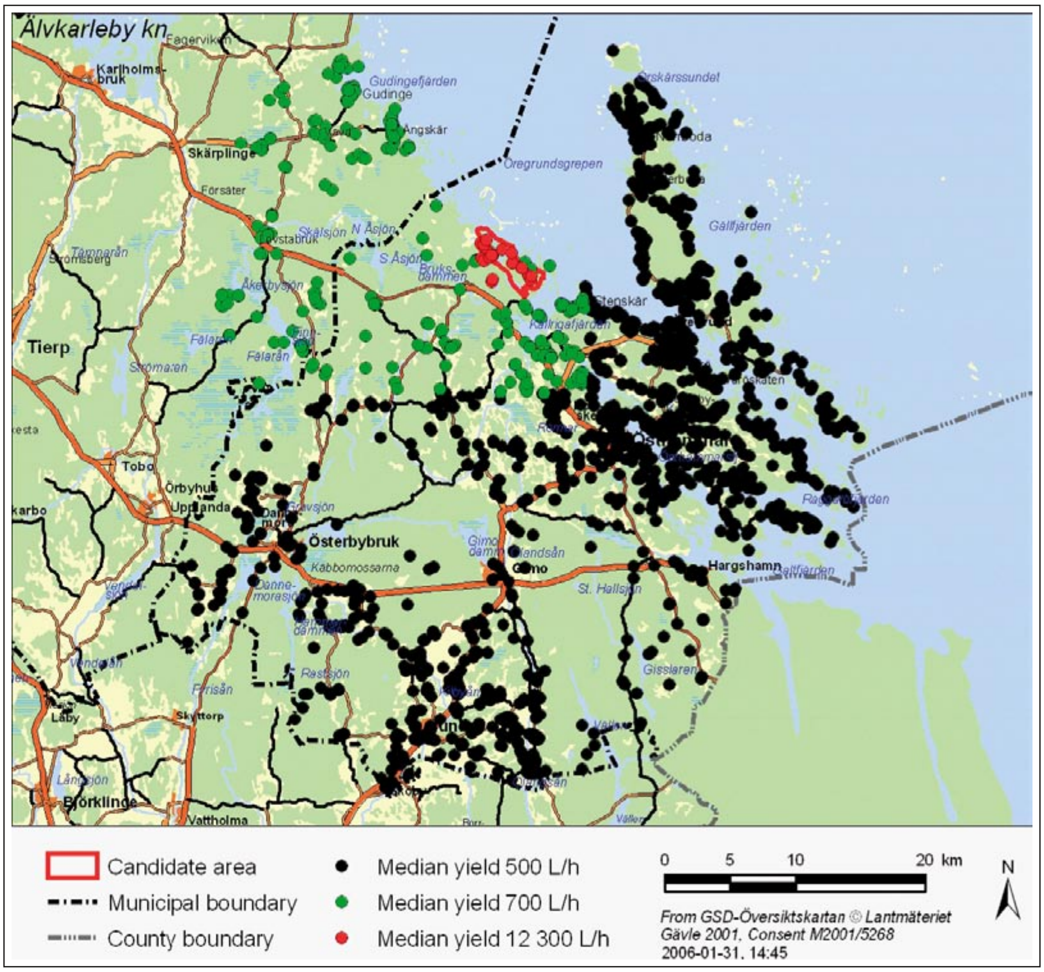


Figure 2-1. The median yield of the HFM01–HFM22 boreholes (red dots) is c. 20 times higher than the median yield of the nearby domestic wells (green and black dots).

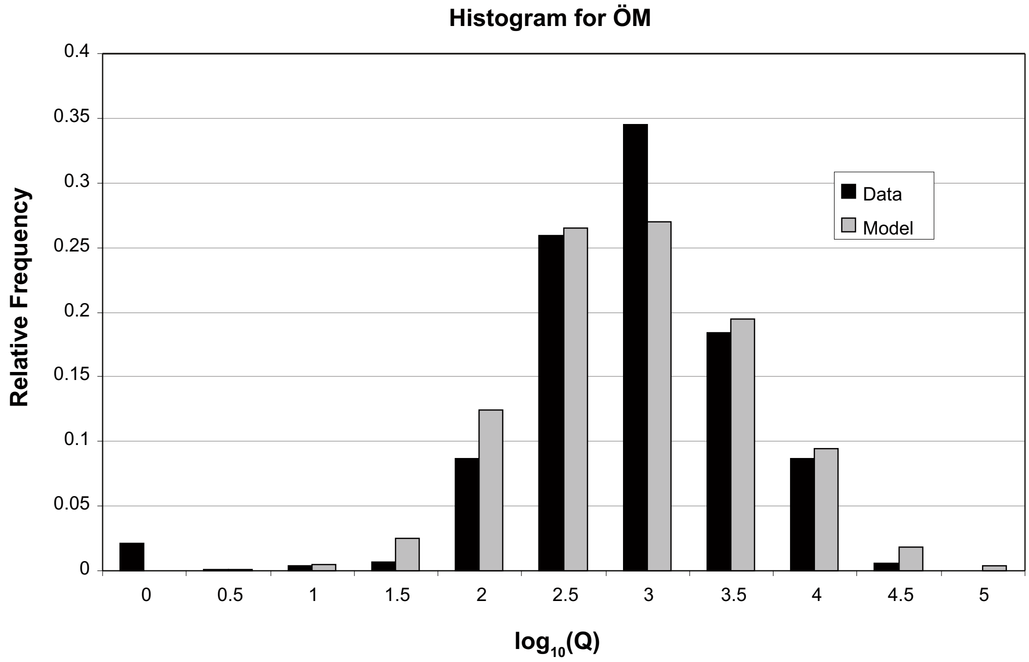


Figure 2-2. *Histogram for the ÖM data set and an example realisation of the model* $\log_{10}(Q) \in \mathbf{N}[2.67, 0.675]$. *Q is given in L/h.*

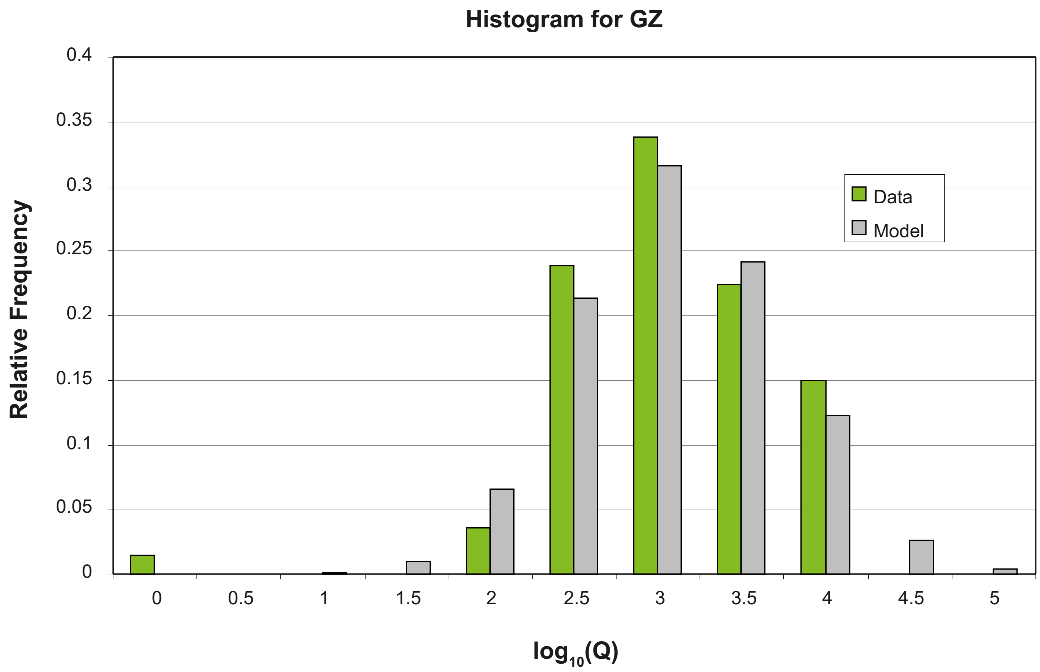


Figure 2-3. *Histogram for the GZ data set and an example realisation of the model* $\log_{10}(Q) \in \mathbf{N}[2.85, 0.617]$. *Q is given in L/h.*

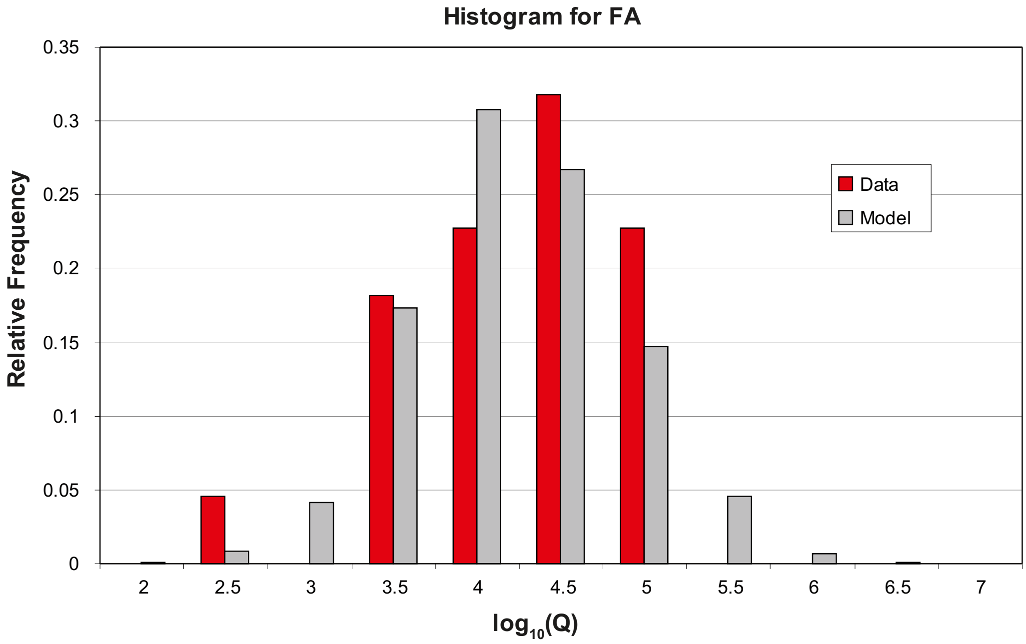


Figure 2-4. *Histogram for the FA data set and an example realisation of the model* $\log_{10}(Q) \in \mathrm{N}[3.97, 0.629]$. *Q is given in L/h.*

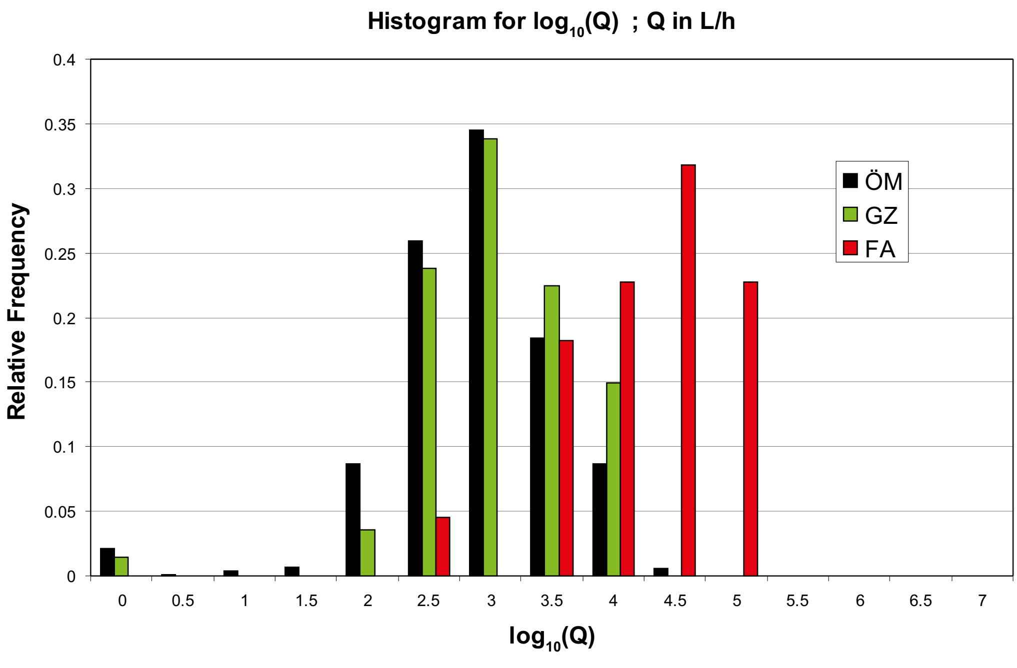


Figure 2-5. *A plot showing the three histograms of* $\log_{10}(Q)$. *Q is given in L/h.*

2.2 H_0-test of $\log_{10}(Q)_{ave}$, $\log_{10}(D)_{ave}$ and $\log_{10}(Q/D)_{ave}$

Several so-called *t*-tests were run to quantify the statistical significance of the differences observed, including the quotient *Q*/*D*.

The H_0 and H_1 hypotheses are:

H_0: *There is no difference between the three data sets*.

H_1: *There are differences between the three data sets*.

The calculated *t* values for $\log_{10}(Q)$, $\log_{10}(D)$ and $\log_{10}(Q/D)$ are displayed in Table 2-3. The *t* values were calculated using the formula:

$$t = \frac{\bar{x}_A - \bar{x}_B}{\sqrt{\frac{(s_A)^2}{n_A} + \frac{(s_B)^2}{n_B}}} \qquad (2\text{-}1)$$

where:

$\bar{x}$ = sample arithmetic mean

s = sample standard deviation

n = sample size

The degree of freedom, *DOF*, is set to 20 in the H_0-tests based on the size of the FA data set, cf. Table 2-2. A $DOF = 20$ renders a larger value of $t_{\alpha,DOF}$ than if $DOF > 20$.

The value of $t_{\alpha,DOF}$ for a significance level of 99% ($\alpha = 0.01$) and $DOF = 20$ is 2.845. The H_0 hypothesis (no difference between the populations of measurements) is rejected if $|t_{calc}| > t_{\alpha,DOF}$. Since all values in Table 2.2 are larger than 2.845, H_0 is rejected for all data sets, i.e. there is evidence of a statistically significant difference between the data sets.

Table 2-3. Calculated values of the *t* statistic for the three data sets Östhammar municipality (ÖM), Forsmark guard zone (GZ) and the Forsmark area (FA).

Data sets	*t*		
	$\log_{10}(Q)$	$\log_{10}(D)$	$\log_{10}(Q/D)$
FA vs. GZ	8.04	8.53	4.25
FA vs. ÖM	9.61	7.94	5.73
GZ vs. ÖM	4.46	2.95	4.57

3 Borehole transmissivity in 50 m intervals

3.1 HTHB data

By May 2005, 22 percussion-drilled boreholes were completed and hydraulically tested with the so-called HTHB unit in the Forsnark area (FA). Basic borehole data are shown in Table 3-1. The HTHB consists of submersible pump and an impeller flow logging device (Figure 3-1). Simultaneous pumping and impeller flow logging has been performed in the 22 boreholes in order to infer the positions and transmissivities of 55 flow anomalies with large inflow rates. The results of the flow logging measurements are presented in Table 3-2, which shows the inferred flow rate, *Q*, and the transmissivity value, *T*, of each flow anomaly. Figure 3-2 shows a histogram of the impeller flow logging flow rates and a histogram of the inferred transmissivities, respectively.

3.2 Map of ΣT versus depth for 50 m thick depth intervals

The sum of the flow rates and transmissivities in each of the 22 boreholes HFM01–HFM22 were calculated and divided into four 50 m thick depth intervals. Table 3-3 shows the mean and the standard deviation of $\log_{10}(\Sigma Q_{50m})$ and $\log_{10}(\Sigma T_{50m})$ of each depth interval. Figure 3-3 shows a map of the Forsmark area with the logarithm of the cumulative transmissivity in HFM01–HFM22 divided into four 50 m thick depth intervals.

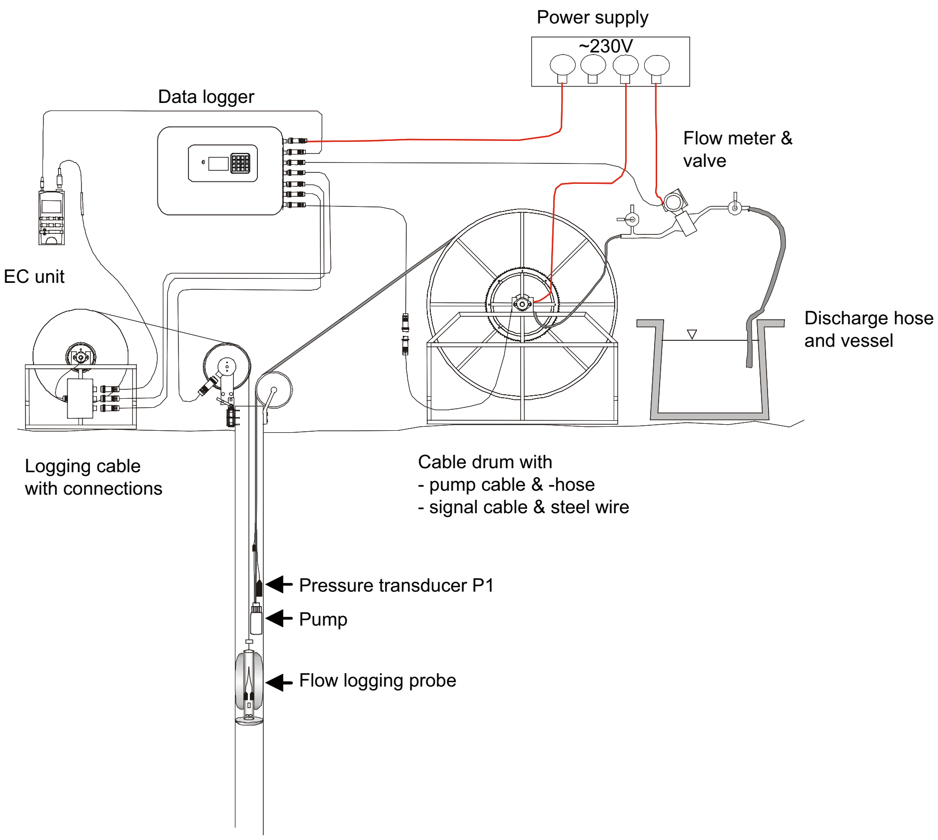


Figure 3-1. *Test set-up for a pumping test in an open borehole in combination with impeller flow logging with the HTHB unit. Reproduced from (SKB MD 326.001) (SKB internal document).*

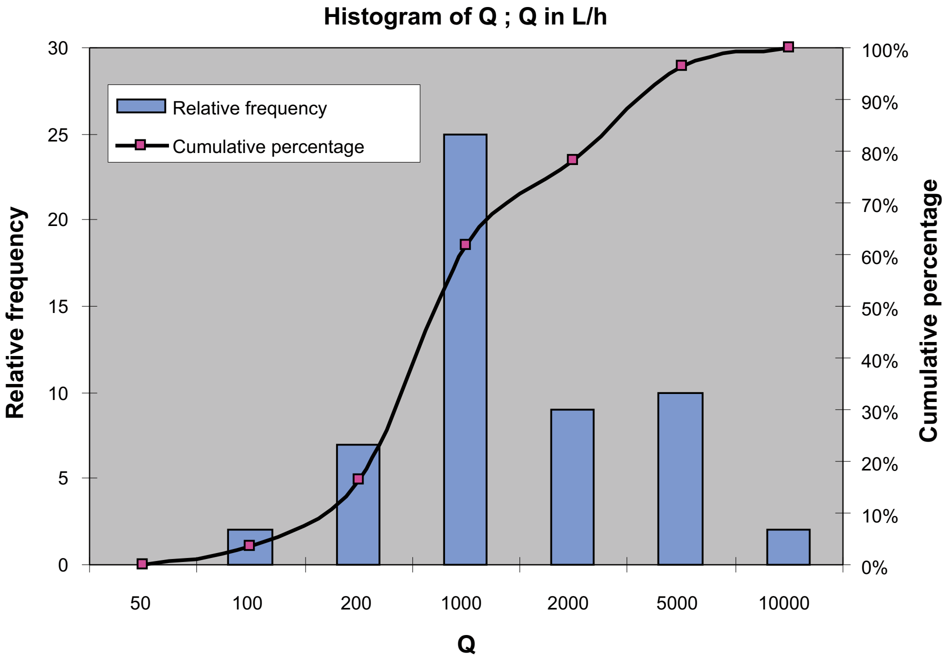
Table 3-1. Borehole data of the percussion-drilled boreholes HFM01–HFM22.

Borehole	Northing (RT 90)	Easting (RT 90)	Elevation (m RHB 70)	Bearing	Inclination	Borehole length (m)	Vertical Depth (m)	Length of casing above ground level (m)	Distance from TOC* to bedrock surface (m)	Length of Quaternary deposits in borehole (m)
HFM01	6699605.181	1631484.552	1.731	34.1	–77.5	200.2	197.1	0.21	11.51	11.30
HFM02	6699593.212	1631268.674	3.053	6.5	–87.8	100.0	99.9	0.25	12.45	12.20
HFM03	6699592.812	1631272.626	3.148	264.5	–87.3	26.0	26.0	0.23	12.45	12.00
HFM04	6698878.968	1633420.733	3.873	336.9	–84.3	221.7	218.0	0.28	1.08	0.80
HFM05	6698647.275	1633289.721	7.672	335.6	–85.0	200.1	197.6	0.30	4.30	4.00
HFM06	6697752.012	1634522.188	6.637	2.4	–84.6	110.7	109.9	0.28	2.28	2.00
HFM07	6697416.248	1634715.687	5.781	342.3	–84.5	122.5	121.6	0.30	6.90	6.60
HFM08	6697703.275	1634777.502	7.132	348.7	–84.4	143.5	142.4	0.30	5.40	5.10
HFM09	6699064.648	1630869.120	5.150	139.4	–68.9	50.3	46.5	0.30	4.90	4.60
HFM10	6698834.785	1631037.188	4.986	92.9	–68.7	150.0	139.1	0.24	2.65	2.41
HFM11	6697283.402	1631636.333	7.559	63.5	–49.3	182.4	125.4	0.30	2.80	2.50
HFM12	6697446.459	1631695.671	7.025	245.2	–49.1	209.6	143.6	0.36	4.00	3.64
HFM13	6699093.678	1631474.404	5.687	51.2	–58.8	175.6	152.5	0.30	4.05	3.75
HFM14	6699313.139	1631734.586	3.912	331.7	–59.8	150.5	131.2	0.33	0.60	0.27
HFM15	6699312.444	1631733.081	3.878	314.3	–43.7	99.5	69.3	0.30	1.10	0.80
HFM16	6699721.098	1632466.182	3.210	328.0	–84.2	132.5	131.7	0.30	2.60	2.30
HFM17	6699461.952	1633261.310	3.750	318.6	–84.2	210.7	207.6	0.14	0.50	0.36
HFM18	6698326.858	1634037.374	5.039	313.3	–59.4	180.7	147.8	0.33	1.70	1.37
HFM19	6699257.585	1631626.925	3.656	280.9	–58.1	185.2	146.5	0.30	5.90	5.60
HFM20	6700187.496	1630776.681	2.966	354.4	–85.4	301.0	300.6	0.28	3.00	2.72
HFM21	6700125.566	1631074.054	3.979	88.8	–58.5	202.0	157.4	0.26	3.10	2.84
HFM22	6700456.184	1631217.635	1.539	90.1	–58.9	222.0	157.1	0.30	3.90	3.60

*TOC = Top Of Casing

Table 3-2. Inferred flow rates and evaluated transmissivities of percussion-drilled boreholes HFM01–HFM22 determined by means of impeller flow logging.

Borehole	Start of flow anomaly (m)	End of flow anomaly (m)	Vertical depth (m)	Measured flow rate (m^3/s)	Corrected flow rate (m^3/s)	Transmissivity of flow anomaly (m^2/s)
HFM01	34.50	43.00	37.83	7.07E–04		4.50E–05
HFM01	48.00	50.00	47.84	8.33E–05		5.00E–06
HFM01	60.50	63.50	60.53	4.33E–05		2.50E–06
HFM01	64.00	64.50	62.73	1.67E–04		1.10E–05
HFM02	42.00	44.50	43.22	1.90E–03		5.90E–04
HFM03	21.00	21.50	21.23	1.61E–03		3.90E–04
HFM03	22.00	22.50	22.22	1.42E–04		3.40E–05
HFM04	60.00	63.50	61.44	5.58E–04	4.93E–04	7.87E–05
HFM05	150.50	156.50	152.91	2.40E–03	1.08E–03	3.96E–04
HFM06	20.50	23.00	21.65	1.15E–04	1.50E–04	5.00E–05
HFM06	42.50	44.00	43.06	1.22E–04	1.63E–04	5.30E–05
HFM06	60.00	64.00	61.72	1.00E–04	1.34E–04	4.40E–05
HFM06	69.00	71.00	69.69	4.17E–04	5.52E–04	1.85E–04
HFM08	89.50	90.00	89.33	6.67E–05	4.71E–04	5.70E–05
HFM08	137.50	139.50	137.85	1.47E–03	1.04E–03	1.20E–03
HFM09	22.00	29.00	23.79	8.28E–04		3.26E–04
HFM09	46.50	49.00	44.55	1.19E–04		4.67E–05
HFM10	114.50	121.00	109.71	8.33E–04		3.11E–04
HFM11	37.70	38.70	28.97	1.17E–04		7.27E–06
HFM11	40.70	43.70	32.00	2.43E–04		1.52E–05
HFM11	108.20	110.20	82.81	1.65E–04		1.03E–05
HFM11	135.70	136.70	103.29	4.67E–05		2.91E–06
HFM11	141.20	143.70	108.03	1.63E–04		1.02E–05
HFM11	146.20	147.30	111.29	7.33E–05		4.57E–06
HFM12	110.20	112.20	84.33	1.60E–05		1.36E–06
HFM12	123.20	123.80	93.28	7.73E–05		6.51E–06
HFM13	105.50	106.00	90.49	2.97E–05	7.17E–05	2.11E–05
HFM13	162.50	163.50	139.48	5.66E–04	9.87E–04	2.91E–04
HFM15	22.90	24.50	16.37	2.39E–04	2.13E–04	6.88E–05
HFM15	67.00	68.50	46.81	2.85E–04	2.56E–04	8.24E–05
HFM15	71.90	74.50	50.57	2.28E–04	2.04E–04	6.58E–05
HFM15	88.00	89.00	61.14	3.53E–04	3.16E–04	1.02E–04
HFM16	41.00	41.50	41.04	2.40E–04		1.18E–04
HFM16	56.00	56.50	55.96	8.33E–05		4.08E–05
HFM16	58.50	59.50	58.70	6.33E–04		3.10E–04
HFM16	69.00	69.50	68.90	1.17E–04		5.72E–05
HFM17	30.00	32.50	31.09	2.58E–04	5.20E–04	3.93E–05
HFM18	36.50	38.00	32.05	4.17E–04		7.78E–05
HFM18	46.00	46.50	39.79	3.17E–04		5.91E–05
HFM18	48.00	48.50	41.51	1.33E–04		2.49E–05
HFM19	100.00	102.00	85.75		1.08E–04	4.02E–05
HFM19	148.00	150.00	126.50		4.17E–05	1.55E–05
HFM19	160.00	163.00	137.11		1.67E–05	6.18E–06
HFM19	170.00	182.50	149.63		7.42E–04	2.75E–04
HFM20	22.50	28.00	25.17	7.89E–04	9.18E–04	5.73E–05
HFM20	77.00	78.00	77.26	3.33E–05	2.83E–05	1.78E–06
HFM20	118.00	118.50	117.88	1.33E–04	1.63E–04	1.03E–05
HFM21	26.00	27.00	22.59		1.57E–04	1.01E–04
HFM21	38.90	42.90	34.87		5.50E–05	3.54E–05
HFM21	67.00	69.00	57.97		5.33E–05	3.43E–05
HFM21	97.50	99.00	83.75		4.69E–04	3.01E–04
HFM21	157.00	163.00	136.39		3.23E–04	2.08E–04
HFM22	28.00	29.00	24.39	7.37E–05	9.17E–05	1.49E–05
HFM22	42.00	44.00	36.80	2.57E–05	3.17E–05	5.16E–06
HFM22	60.50	64.00	53.27	7.11E–04	8.82E–04	1.44E–04



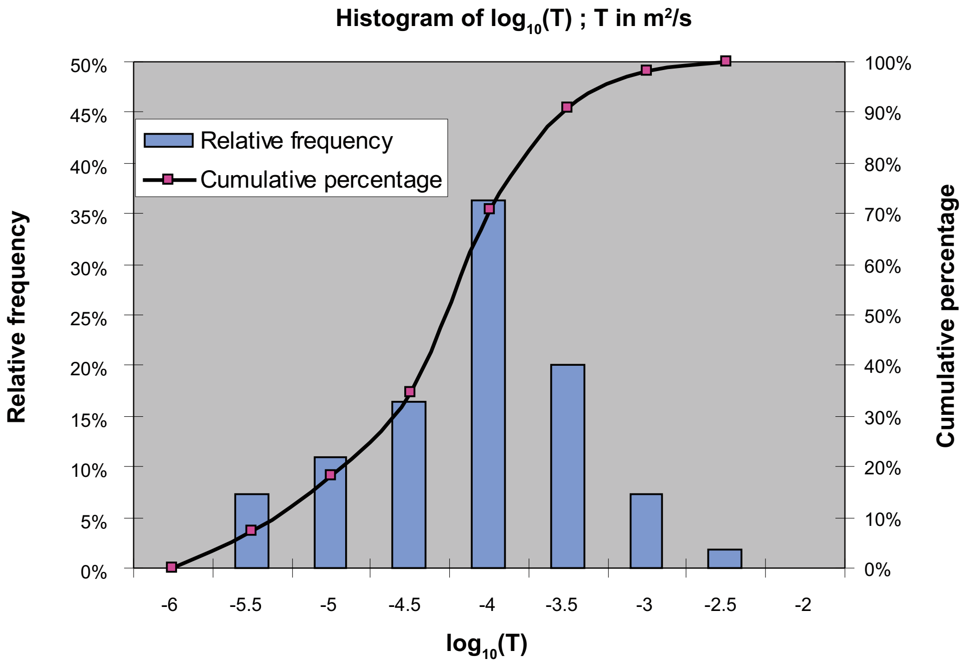


Figure 3-2. *A histogram of the 55 individual flow anomaly flow rates (above) and transmissivities (below) determined by pumping and flow impeller logging with the HTHB unit in HFM01–HFM22. The lower limit of* $\log_{10}(T)$ *of the HTHB unit is c. –6.*

Table 3-3. Mean and standard deviation of $\log_{10}(\Sigma Q)$ and $\log_{10}(\Sigma T)$ in HFM01–HFM22 divided into four 50 m thick intervals. T in m^2/s and Q in m^3/s.

Depth interval (m)	Number of values	Mean of ($\log_{10}\Sigma T_{50m}$)	Std dev of ($\log_{10}\Sigma T_{50m}$)	Mean of ($\log_{10}\Sigma Q_{50m}$)	Std dev of ($\log_{10}\Sigma Q_{50m}$)	95% conf interval of the median of T
0–50	13	–4.00805	0.470584	–3.08452	0.986177	5.5E–05–1.8E–04
50–100	13	–4.30313	0.721268	–3.56369	0.482717	2.0E–05–1.2E–04
100–150	7	–3.84478	0.743751	–3.2845	0.319229	4.2E–05–5.1E–04
> 150	1	–3.4023	–	–2.96658	–	–

Depth = vertical depth

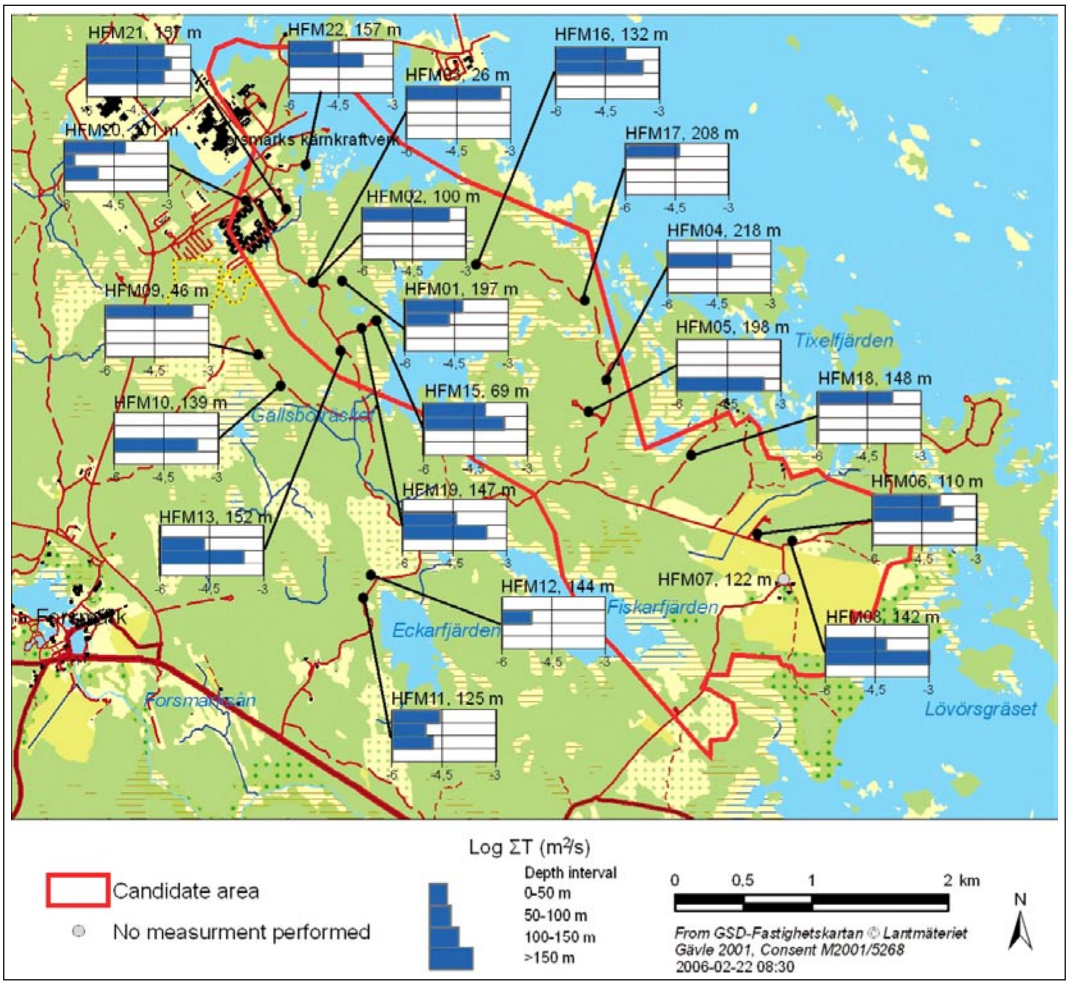


Figure 3-3. *A map of the Forsmark area with the logarithm of the cumulative transmissivity in HFM01–HFM22 divided into four 50 m thick depth intervals. The horizontal scale in each histogram ranges between –6 (10^{-6} m²/s) and –3 (10^{-3} m²/s).*

4 Discussions and conclusions

The data analyses carried out reveal that the median value of the water yield of the percussion-drilled boreholes within the Forsmark candidate area is c. twenty (20) times greater than the median value of the water yield of the domestic bedrock wells outside the candidate area in northern Uppland. This difference is statistically significant and suggests that the superficial bedrock within the Forsmark candidate area is much more transmissive than the superficial bedrock outside this area. An observation that supports this interpretation is the point-water measurements in the uppermost 150 m of bedrock.

Figure 4-1 shows an overview of the percussion and core drillings at Forsmark from the start of the site investigations up to the 2.1 data freeze. The progress of the Hydro Monitoring System (HMS) installations is also shown. The installations began in January 2004 and represent an important step in the site investigation programme in Forsmark.

Figure 4-2 shows the recordings available in Hydro Monitoring System (HMS) for the percussion-drilled boreholes HFM01–HFM22 between the beginning of December 2002 and the end of June 2005. Figure 4-2 reveals that the point-water heads are quite disturbed for most of the time because of the intense drilling, flushing and pumping activities. Apparently, these disturbances are readily transmitted across large distances due to exceptionally high transmissivities encountered in the uppermost part of the bedrock (cf. Figure 3-3). According to /Juston et al. 2006/ there are few periods, if any, when several boreholes measure natural conditions simultaneously. For instance, there is a fairly good but short period during the second half of July 2004.

During this period the horizontal component of the point-water head gradient in the uppermost part of the bedrock within the candidate area is quite flat, which is indicative of permeable conditions in the uppermost part of the bedrock, see Figure 4-3.

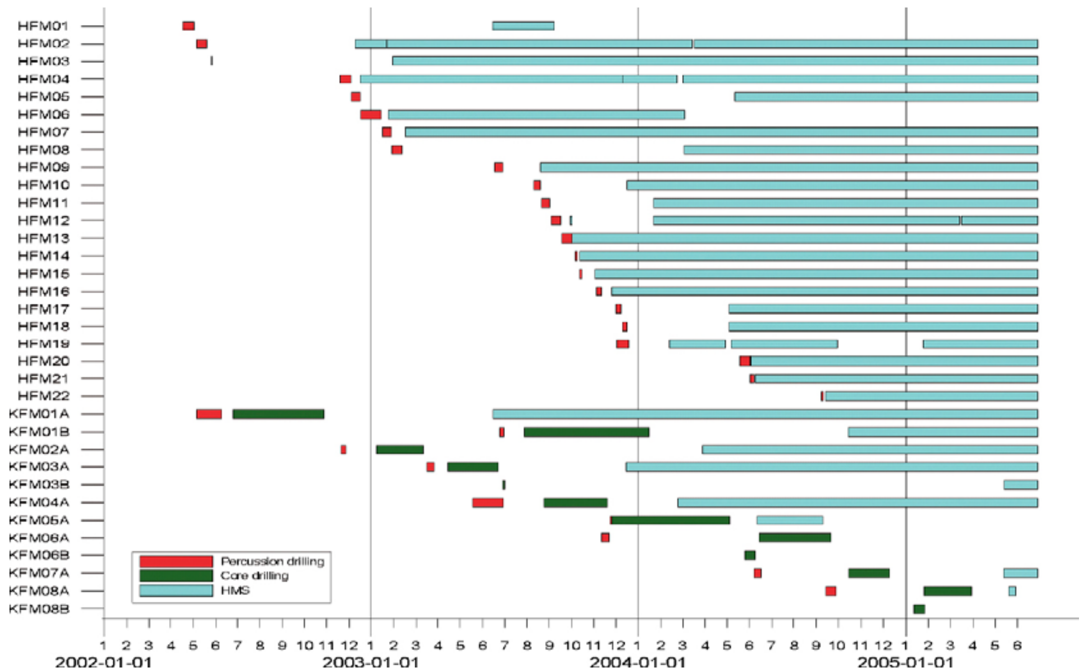


Figure 4-1. Overview of the percussion and core drillings at Forsmark from the start of the site investigations up to the 2.1 data freeze. The progress of the Hydro Monitoring System (HMS) installations is shown in blue.

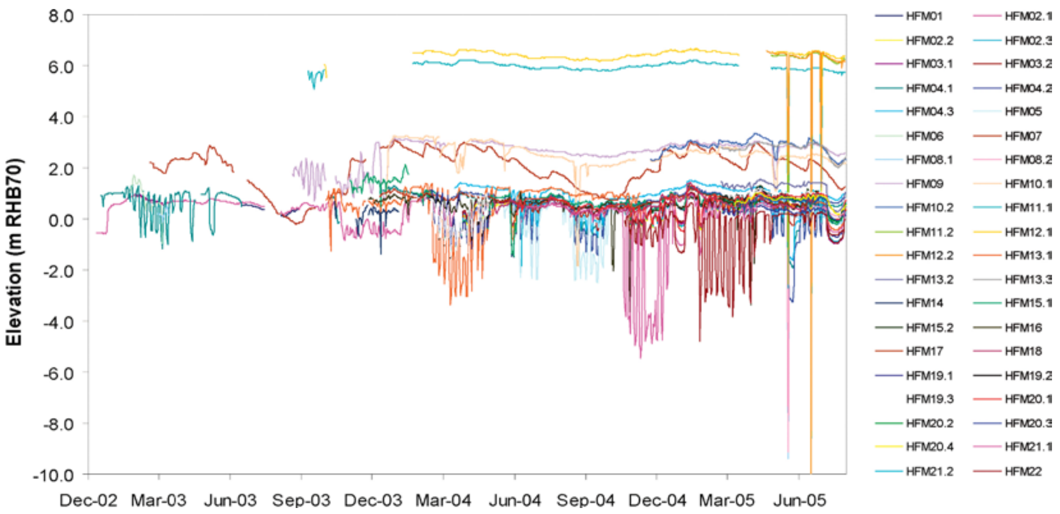


Figure 4-2. *Point-water heads available in HMS for the percussion-drilled boreholes HFM01–HFM22 between the beginning of December 2002 and the end of June 2005. Large head disturbances are due to drilling operations /Juston et al. 2006/.*

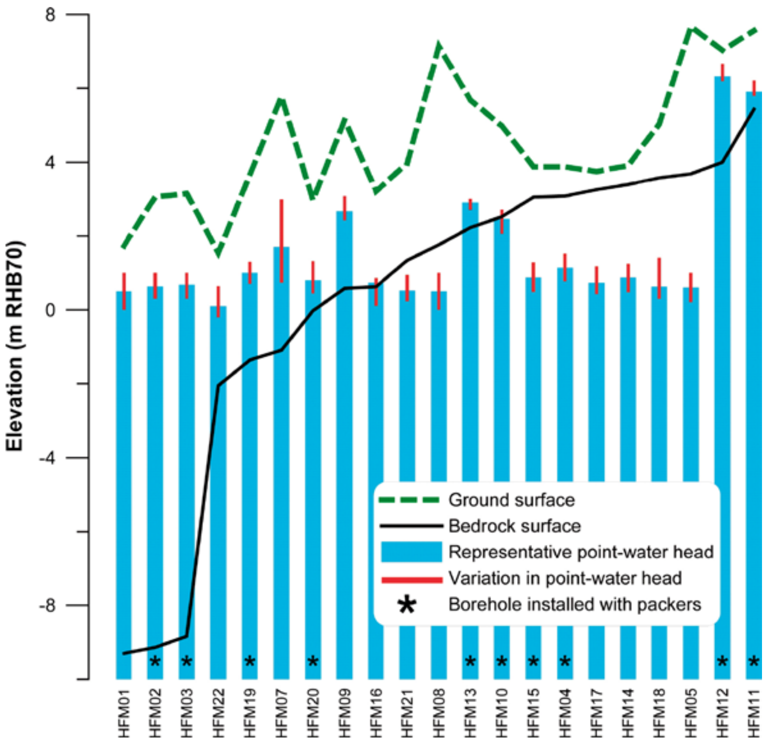


Figure 4-3. *Compilation of the best undisturbed point-water head data available from the uppermost packer sections in the monitored percussion-drilled boreholes in the 2.1 data freeze. HFM09–HFM12 are located outside the tectonic lens, see Figure 1-2. The monitored intervals in HFM07 and HFM13 are dry, see Figure 3-3.*

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