



Öppen

Promemoria (PM)

DokumentID 1372883	Version 1.0	Status Godkänt	Reg nr	Sida 1 (52)
Författare Jan-Olof Selroos			Datum 2012-12-10	
Kvalitetssäkrad av Allan Hedin			Kvalitetssäkrad datum 2012-12-20	
Godkänd av Helene Åhsberg			Godkänd datum 2012-12-21	

Reply to questions by SSM

In this PM, answers are provided to questions raised by Georg Lindgren, SSM in a request for clarifications (dated 2012-05-29 with SSM's reference number SSM2011-2426).

The answers are produced and collated by Jan-Olof Selroos, SKB and Sven Follin, SF GeoLogic AB with additional help from Urban Svensson, CFE AB, Steve Joyce and Lee Hartley, Amec, and Patrik Vidstrand, TerraSolve AB.

The PM first handles questions originally raised by SSM 2011-11-01 by providing SKB's original answers (dated 2011-12-07) and SSM's follow-up questions followed by SKB's new replies. In the second section of the PM, new questions by SSM are listed followed by SKB's answers.

Fråga 1

SSM:s fråga 2011-11-01:

SKB R-09-19 sida 34 tredje stycket:

Parametern α_{min} sätts till 10^{-10} s^{-1} . På sidan 46 i R-09-22 beskrivs att α_{max} sätts till 10^{-3} s^{-1} . Finns det en referens som visar vad dessa värden baseras på?

SKB:s svar 2011-12-07: The reference is found in report R-07-38 on pages 26 and 35.

SSM:s fördjupande fråga:

I den angivna referensen finns en härledning av parametern men inte en förklaring till valet av α_{min} och α_{max} . Myndigheten har noterat att diffusionsparametrarna ändras för det periglaciala fallet jämför med det så kallade hydrogeological base case (R-09-22 sida 87 och R-09-21 sida 51).

- Var finns det beskrivet var dessa parametriseringar baseras på, dvs. varför just de redovisade värdena har använts?*
- På sida 51 i R-09-21 och på sida 34 i R-09-19 anges att de använda parametervärdena är preliminära eller "conditional", var redogörs för de slutgiltiga värdena?*
- Ingår det ytterligare parametrar i diffusionsberäkningarna och vilka värden har de i så fall och vad baseras de på?*

SKB's elaborated reply to #1, December 2012

a) α_{min} and α_{max}

In principle, the values assigned to the exchange rate coefficients should reflect the time scale of the problem in mind. The values used for matrix diffusion modelling during the Excavation and operational phases (R-09-19) and during Periglacial and glacial climate conditions (R-09-21) are different since the time scales in these studies are different.

Excavation and operational phases, p 46 in Selroos and Follin (2010, R-09-22):

The time constant governing the short-term diffusion into/out of the stagnant pools of water nearby the flowing fractures is set to $1 \cdot 10^{-3} \text{ s}^{-1}$, whereas the time constant governing the long-term diffusion into/out of the less permeable rock matrix is set to is set to $1 \cdot 10^{-10} \text{ s}^{-1}$. The chosen settings imply a time scale of less than one hour for the fast diffusive exchanges and approximately 300 years for the slow diffusive exchanges. These values of the time constants are consistent with the time frame modelled by Svensson and Follin (2010).

Periglacial and glacial climate conditions, p. 87 in Selroos and Follin (2010, R-09-22):

Ten time constants (exchange rate coefficients) are used to model the diffusion process. The model parameter governing the short-term diffusion into/out of the stagnant pools of water nearby the flowing fractures is set to $4 \cdot 10^{-7} \text{ s}^{-1}$, whereas the parameter governing the long-term diffusion into/out of the less permeable rock matrix away from the fracture is set to is set to $4 \cdot 10^{-12} \text{ s}^{-1}$. The latter value implies a time scale of approximately 8,000 years for the remotest diffusive exchange. [Comment: The former value implies a time scale of approximately 1 month]

b) Conditional values

The usage of the word “conditional” reflects two things:

- the experience of using the multi-rate diffusion model is not extensive, and
- the exchange rate coefficients cannot be readily derived from traditional single-rate diffusion experiments.

c) Other parameters

See p. 46 in Selroos and Follin (2010, R-09-22):

A detailed description of the concepts and methodology of the implementation of the multi-rate diffusion model in DarcyTools is found in (Svensson et al. 2010 [Comment: R-10-72]). It is noted that the void space in the matrix is assumed to be ten times greater than the void space in the fractures in the work by Svensson and Follin (2010).

See also p. 111 in Selroos and Follin (2010, R-09-22).

Fråga 2

SSM:s fråga 2011-11-01:

SKB R-09-19 sida 35 andra stycket:

Under första punkten hänvisas till tabell 4-1. Finns det en referens till var värdena i tabellen kommer ifrån?

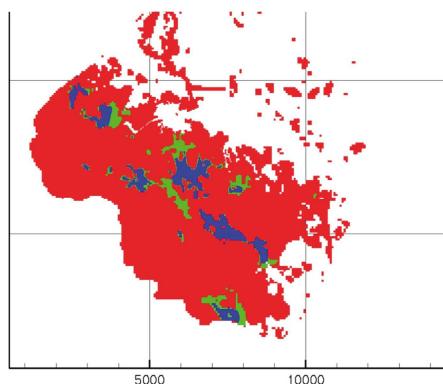
SKB:s svar 2011-12-07: The properties for the top 20 metres are found from the calibration of the ground water level for undisturbed conditions. The relation to field data is given by Figure 4-5.

SSM:s fördjupande fråga:

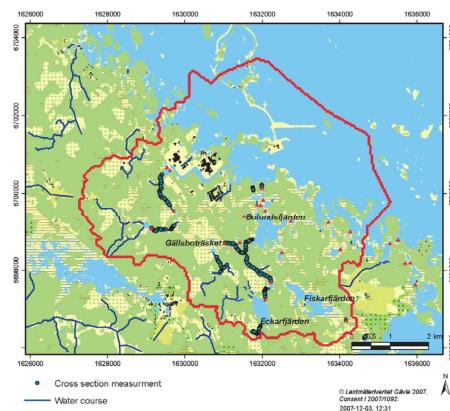
- Var finns kalibreringen av grundvattennivåerna redovisade?
- Vilka data baseras figur 4-5 sida 40 på och var finns det redovisat?

SKB's elaborated reply to #2, December 2012

a) Calibration



p. 60 in Svensson and Follin (2010; R-09-19):
Figure 5-2. Areas with a predicted groundwater table (hydraulic head) above ground surface are marked blue, whereas areas with a predicted groundwater table below, but very close, ground surface are marked green. The latter may be perceived as wetlands, cf Figure 4-7. In the red areas the groundwater table is significantly below the ground surface.



p. 41 in Svensson and Follin (2010; R-09-19):
Figure 4-7. Location of major streams, major lakes (blue areas) and wetlands (white coloured areas) in the Forsmark area. (Modified after Figure 2-13 in /Bosson et al. 2008/.)

b) Data for Figure 4-5

The hydraulic properties data shown in Figure 4-5 originate from Table 2-2 and Table 2-3 in Bosson et al. (2009; R-08-09). A compilation of this information is shown in Table 3-7 and Table 3-8 in Follin et al. (2008; R-08-23).

Fråga 3

SSM:s fråga 2011-11-01:

SKB R-09-19 sida 35: under sista punkten står det att tryck- och salinitetsvärden på modellranden är härledda från en simulerings av strandlinjeförskjutningen. Finns det en referens till denna härledning?

SKB:s svar 2011-12-07: The conditions at 2000 AD are first calculated by simulating transient boundary conditions between 8000 BC and 2000 AD. The initial conditions for this simulation are provided in Table 4-2 in R-09-19. Second, flow during open repository conditions is simulated with the pressure and salinity solutions at 2000 AD as initial conditions.

SSM:s fördjupande fråga:

Svaret pekar på att initialvillkoren har beräknats utifrån givna randvillkor. Figur 4-6 på sida 41 visar strandlinjeförskjutningen, men det är inte redovisat hur denna har implementerats i modellen.

- a) *Hur har strandlinjeförskjutningen tillämpats i modellen, var redovisas det?*
- b) *Hur har initiala trycken räknats fram från den initiala salinitetsfördelningen?*
- c) *Har beräkningarna av initialvillkoren genomförts med DarcyTools, var finns det redovisat?*

SKB's elaborated reply to #3, December 2012

a) Implementation of the shoreline displacement

The simulation of the shoreline displacement is made in the same fashion as in SDM-Site, e.g. Follin et al. (2007; R-07-49) and Follin et al. (2008; R-08-23). As stated on pp. 35-36 in Svensson and Follin (2010; R-09-19), all boundary conditions are fixed in time except the boundary conditions on the top surface. Here, the displacement (retreat) of the shoreline implies that the terrestrial part of the model area grows.

b) Initial pressures

The initial pressure distribution is calculated from the initial density distribution which in turn is calculated from the initial salinity distribution as specified by equations (3-3), (3-5), and (3-7) in Svensson and Follin (2010; R-09-19).

c) The initial salinity distribution

The assumed salinity distribution at 8000 BC is specified in Table 4-2 in Svensson and Follin (2010; R-09-19).

Fråga 4

SSM:s fråga 2011-11-01:

SKB R-09-19 sida 36: Referensen till SDM arbetet med tabell 4-2 är oklar med tanke på att de data som beskrivs i tabellen inte återfinns i Selroos och Follin (2010). Det beskrivs värden ner till 2300 m djup i tabellen, men modellen som används i rapporten har en domän som endast går ner till 1200 m djup. I R-09-22 beskrivs på sidan 47 randvillkoren och ett värde på 3 % är givet för 1200 m djup. Tabell 4-2 indikerar en högre salinitet vid detta djup. Finns det en referens som samlat redovisar rand- och initialvillkor med referenser till de data de är baserade på?

SKB:s svar 2011-12-07: First, the reference for the initial conditions shown in Table 4-2 is R-08-95, see Figure 2- 11 and Table 2-3 (to be used in combination). It is noted that Table 4-2 is identical to Table 5-2 in R-09-21 (glacial modelling). R-09-21 uses a much deeper model domain than R-09-19, D=2.1 km vs D=1.2 km. The reason for this difference is the thickness of the ice sheet primarily. D=1.2 km is used in R-09-19 since the DZ model and the DFN simulations used in R-09-19 come from R-09-20, which uses D=1.2 km.

Table 4-2 says that the salinity at D=1.2 km is approximately 5.3% in the footwall bedrock, whereas it is approximately 2.8% (~3%) outside this volume. The information provided on page 47 in R-09-22 is correct but obviously refers to the latter volume. However, as a consequence of our follow up investigation, the following mistake in the boundary condition assignment has been discovered in the model setup of R-09-19, see the figures below.

The uppermost figure shows the two volumes of bedrock associated with the initial conditions specified in Table 4-2. We use here the letter ‘F’ to denote the footwall bedrock below the gently dipping zone A2 and the letter ‘E’ to denote the bedrock elsewhere, i.e., above this zone as well as outside the tectonic lens.

The lower most figure shows the mistake made. The model domain ends at 1.2 km depth but the Footwall bedrock below zone A2 ends at 1.1 km (= the depth of model domain used in SDM-Site).

However, in R-09-19, the computational grid ends at D=1.2 km. Far away from the repository, including the bottom boundary, the grid resolution is coarse, i.e., large grid cells are used (= 128 m). Hence, the bottom most grid cell node, where the BC for salt is assigned, is not located at D=1.2 km, but higher up, i.e., $\frac{1}{2}$ cell size up to be correct. At $(1200 - \frac{1}{2} * 128 = 1136\text{m})$ the salinity is around 5%.

The algorithm used in R-09-19 for implementing the initial conditions shown in Table 4-2 used the “Elsewhere” condition for the bottommost layer since FFM01 ends at 1.1 km.

SSM:s fördjupande fråga:

Har SKB genomfört eller planerar SKB beräkningar med det korrigrade initialvillkoret?

SKB's elaborated reply to #4, December 2012

4. Erroneous boundary condition

The effects of the erroneous boundary condition setting are deemed negligible in the context of inflow calculations. Only calculated salinity levels may be somewhat affected by the error in the boundary conditions.

The calculations presented in R-09-19 are presently being complemented by corresponding calculations in ConnectFlow (using the correct boundary condition). Thus, the calculations are repeated, but with a different code.

Fråga 5

SSM:s fråga 2011-11-01:

SKB R-09-19 sida 36 första punkten: Finns en referens som visar var värdet för nettonederbörd kommer ifrån?

SKB:s svar 2011-12-07: On page 35 in SKB R-08-95 it is stated that in SDM-Site a maximum value of the specified flux of 150 mm/y was used based on the results reported in SKB R-08-08. In R-09-19, the net precipitation was set to 130 mm/y. Using a lower value implies that the radius of influence and salt water upconing effects should not be underestimated.

SSM:s fördjupande fråga:

SKB R-08-08 är en rapport på över 200 sidor, det är inte uppenbart från svaret vilken information i rapporten som föranleder en nettonederbörd på 150 mm/år. Det är inte uppenbart att det lägre värdet som används i SKB R-09-19 är konservativt i alla avseenden. I SKB R-04-54 räknas andra värden för nettonederbörd fram.

- a) *Finns en diskussion redovisad varför 150 mm/år har valts och andra resultat inte är lämpliga? Denna fråga relaterar även till FEP hanteringen:*

SKB TR-10-45 Appendix 8 sida 145 punkt M1.3.01: Tabellen visar hur NEA FEP:arna har överförts till SKB FEP:en Ge03. Referenserna som ges i FEP databasen under FEP Ge03 leder till synes inte till en diskussion om exempelvis effekterna av tidsvariationen i nederbördens som omfattas av NEA FEP:en M1.3.01.

- b) *Var är diskussionen kring betydelsen av förändringar i nederbördens för säkerhetsanalysen redovisad?*

SKB's elaborated reply to #5, December 2012

a) Net precipitation, conservativeness

The net precipitation is commented on six different pages in Johansson (2008; R-08-08) beginning with the first page of the Summary, see p 5:

A long-term overall water balance of the area may be estimated based on 30-year precipitation data from SMHI-stations surrounding the site investigation area and the relatively short-term site specific meteorological and hydrological monitoring data, as follows: precipitation = 560 mm/year, actual evapotranspiration = 400–410 mm/year, and runoff = 150–160 mm/year.

The other pages are: 20, 56, 71, 133, and 212

Conservativeness in every regard is not claimed in Svensson and Follin (2010; R-09-19). However, since the net precipitation used in Svensson and Follin (2010; R-09-19) is 14–19% less than the data range specified in Johansson (2008; R-08-08), it is pessimistic to assume 130 mm/y when it comes to drawdown and upconing effects. Mårtensson and Gustafsson (2010; R-10-18) draw the conclusion that the overall hydrogeological set-up used in Svensson and Follin (2010; R-09-19) exaggerates the drawdown effects of the modeled open repository.

It is emphasized that the water balance calculations presented in Johansson (2008; R-08-08) is the key reference for SDM-Site in this regard together with the near-surface hydrology flow modelling presented in Bosson et al. (2008; R-08-09). The mentioned report by Jarsjö et al. (2004; R-04-54) is not referenced by Johansson (2008; R-08-08). However, other reports by Jarsjö et al. are listed in Johansson (2008; R-08-08); one from 2005 and another from 2007.

b) FEP

When deep rock hydrogeology is discussed, temporal variability (which is annual if no trends are invoked) is of no relevance. This is why annual mean values are used. Within the Excavation and Operational phase, which is on the order of 100 years, trends are not relevant.

Effects of changes in climate (including temperature and precipitation) are addressed in the near-surface hydrogeological simulations presented in R-10-02 (Modelling of present and future hydrology and solute transport at Forsmark. SR-Site Biosphere).

Fråga 6

SSM:s fråga 2011-11-01:

SKB R-09-19 sida 36: Vilken tidsmässig upplösning har modellen? Hur relaterar den till tidsmässiga upplösningen av data den har kalibrerats mot, exempelvis figur 4-8?

SKB:s svar 2011-12-07: Note that the model has not been calibrated against the data in Figure 4-8; only the steady state situation was considered for the comparison with surface hydrology data, see Figure 5-3. Generally, the model was used in a transient mode for the different stages of the repository. However, as a small value of specific storativity was used, the pressure response due to changes is probably too fast. The main effect of time evolution is therefore expected in the salinity field.

SSM:s fördjupande fråga:

Frågan om modellens tidsupplösning besvaras inte och ytterligare förtydligande önskas.

- a) *Vilken tidsupplösning körs modellen med?*
- b) *Finns det redovisat att denna tidsupplösning är lämplig rent numeriskt?*

SKB's elaborated reply to #6, December 2012

a) Chosen time discretization

8000 BC – 2000 AD: 10 years

Operational phases A, B , and C: 10 days

Saturation of the backfill: 10 days

(Personal communication with Urban Svensson, Nov. 2012)

b) Relevance of chosen time discretization

The chosen time discretization is considered relevant if the iterative solution of the flow equations converge. Different time discretization were used for the three periods of interest, cf. above.

Fråga 7

SSM:s fråga 2011-11-01:

SKB R-09-19 sida 110 första stycket:

Vilka parametrar har man skruvat på för att kalibrera?

SKB:s svar 2011-12-07: The following conditions were used for the calibration:

- grouting efficiency according to level II (Table 4-3) was found suitable
- the extended DFN was used as delivered
- The HSD below the Baltic was given a value that gave a total drawdown (see Table D-2) in some agreement with measured drawdown.

SSM:s fördjupande fråga:

- a) Var finns kalibreringen av modellen redovisad?
- b) Vilka parametrar har man varierat i kalibreringen?

SKB's elaborated reply to #7, December 2012

a) Documentation of calibration

It is stated on p 111 in bullet B1 that a homogeneous porous medium (CPM) is assumed for the bedrock outside the investigated candidate area. Hence, the simplified calibration procedure employed a single value of the hydraulic conductivity of the bedrock outside the candidate area. The value used is $1 \cdot 10^{-8}$ m/s and it is c. ten times lower than the Fractured bedrock. However, the value is not explicitly stated in the report.

(Personal communication with Urban Svensson, Nov. 2012)

b) Parameters

See the reply to issue a).

Fråga 8

SSM:s fråga 2011-11-01:

SKB R-09-20 sida 55 tredje stycket

Det saknas en referens till var rand- och initialvillkoren beskrivs. Jag har spårat från R-08-05 till R-07-49 sida 94 men där finns inte konkreta siffror och inte allt beskrivet. Exempelvis beskrivs inte de hydrauliska initialvillkoren. Det finns en hänvisning till en parameterisering av en tidigare modell (R-07-20), men det är oklart om den modellen stämmer överens med SDM modellen i alla delar. Var finns beskrivningarna av de fullständiga rand- och initialvillkoren och hänvisningar till de data de är baserade på?

SKB:s svar 2011-12-07: The initial conditions are described in /Follin et al. 2008/ (R-08-23), section 3.6 and the boundary conditions in section 3.6.1.

SSM:s fördjupande fråga:

Det verkar inte framgå ur SKB R-08-23 hur de initiala trycken har definierats. Hur är förhållandet mellan salinitet och tryck som tillämpas i modelleringen? Observera att samma fråga ovan relaterar till DarcyTools modelleringen.

SKB's elaborated reply to #8, December 2012

8. The relationship between salinity and pressure in R-09-20/R-08-23

In principle, the reply to issue 3b is also valid here, i.e.:

$$\rho(S) = \rho(S=0) + a S$$

where $a = dp/dS$ is a coefficient (kg/m^3) and S is salinity (-)

The initial conditions for the salinity are defined on p 51 in Follin et al. (2008; R-08-23):

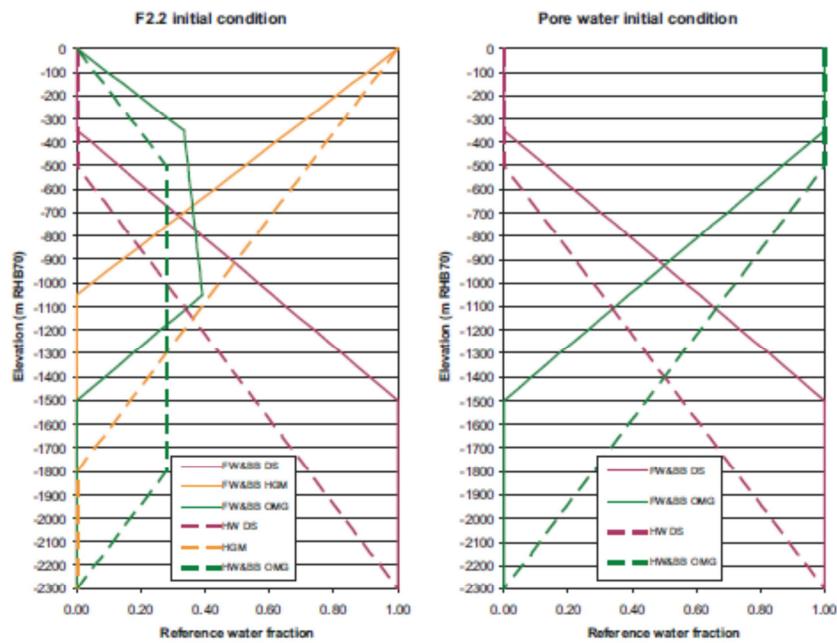


Figure 3-30. Initial mixes of reference waters in the stage 2.2 base model simulation. Left: the fracture water chemistry at 8000 BC was assumed a mixture of Deep Saline Water (DS), Holocene Glacial Melt Water (HGM) and Old Meteoric-Glacial Water (OMG). Right: the initial pore water was assumed a mixture of Deep Saline Water (DS) and Old Meteoric-Glacial Waters. In both systems, different profiles were assumed for the footwall (FW) and border borehole (BB) regions of deformation zone A2 compared to the hanging wall (HW) bedrock of A2. Reproduced from /Follin et al. 2007c/.

The hydrostatic pressure is, as always, defined as:

$$dp = -g \rho(z) dz$$

where $\rho(z)$ is the water density

Thus, the pressure at elevation z may be calculated as:

$p(z) = -g \int \rho(z) dz$, where the integral runs between the elevation of interest ($=z$) and the elevation of the water table. Thus, if the salinity increases linearly with depth, the pressure increase is quadratic.

Nya frågor 2012-05-29

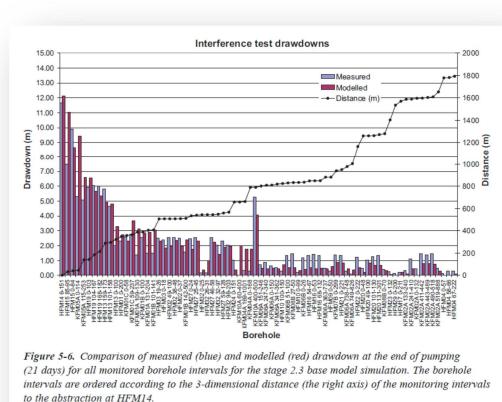
Fråga 9

Finns det några resultat som visar en jämförelse mellan uppmätta tryckdata (eller motsvarande) och modellerade tryck annat än för de förhållandevis små djup som visas i ECPM kalibreringen mot grundvattendjup och tryck i det ytliga berget?

SKB's reply to #9

9. Measured and modeled groundwater levels at depth

The sparse fracturing at depth inside the target volume together with a general depth trend of decreasing transmissivity make it difficult to find sufficiently transmissive sections that show anything but tidal and barometric responses. The greatest head responses are observed during the interference tests and these are documented and analyzed in the report, e.g. Figure 4.9 and Figure 5.6 in Follin et al. (2008; R-08-23). In the latter figure, measured and modelled responses are shown for 74 monitoring sections. Fifteen of these represent groundwater levels that are measured in deep monitoring sections i.e. that have the lowermost packer below 300 m borehole length:



KFM01B 142-500	KFM10A 60-400
KFM04A 169-1001	KFM10A 400-500
KFM06A 247-340	KFM06A 341-362
KFM06A 363-737	KFM06A 738-748
KFM06A 749-826	HFM20 131-301
KFM02A 241-410	KFM02A 411-442
KFM02A 443-489	KFM02A 490-518
KFM02A 519-888	

A few examples of the responses seen at depth during the interference test conducted in HFM14 in 2006 are shown in Appendix H in Follin et al (2007; R-07-48). One such example is shown below.

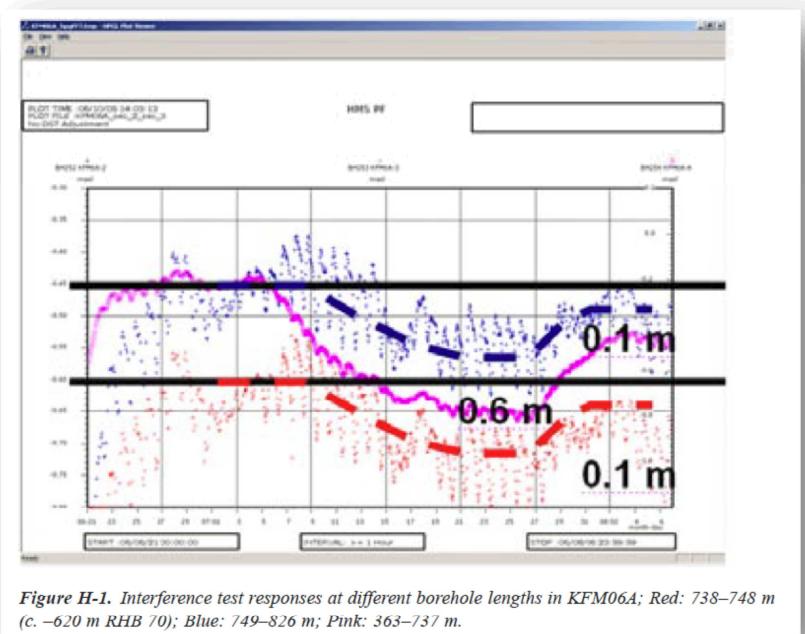


Figure H-1. Interference test responses at different borehole lengths in KFM06A; Red: 738–748 m (c. –620 m RHB 70); Blue: 749–826 m; Pink: 363–737 m.

Fråga 10

SKB R-08-23 figur 1-1 sida 10:

- Hur har bedömmningen dokumenterats att deformationszonmodellen och hydro-DFN modellen är konsistenta?*
- Hur har bedömmningen dokumenterats att den sammantagna modellen är konsistent med de bekräftande hydrogeologiska testerna?*

SKB's reply to #10

a) Consistency in the handling of structural-hydraulic data

The concluded coupling between structural-hydraulic data is shown in Follin et al. (2007; R-07-48), Table 5-1 to Table 5-20, see the image below.

Table 5-1. Compilation of PFL-f transmissivity data gathered in KFM01A.

RFMxxx	ZFMxxxx	FFMxx	Sec-up	Sec-low	Elev-up	Elev-low	No. PFL-f	$\Sigma T PFL-f$
RFM029		FFM02	102	203	-98	-199	23	$1.92 \cdot 10^{-7}$
RFM029		FFM01	203	216	-199	-212	0	0
RFM029	Possible (G)		216	224	-212	-220	0	0
RFM029		FFM01	224	267	-220	-262	2	$7.09 \cdot 10^{-10}$
RFM029	ZFMENE1192		267	285	-262	-280	2	$7.79 \cdot 10^{-10}$
RFM029		FFM01	285	386	-280	-380	7	$4.76 \cdot 10^{-9}$
RFM029	ZFMENE1192		386	412	-380	-406	0	0
RFM029		FFM01	412	639	-406	-630	0	0
RFM029	ZFMENE2254		639	684	-630	-674	0	0
RFM029		FFM01	684	1,001	-674	-982	0	0

Table 5-2. Compilation of PSS transmissivity data gathered in KFM01C.

RFMxxx	ZFMxxxx	FFMxx	Sec-up	Sec-low	Elev-up	Elev-low	No. PSS 5 m	$\Sigma T PSS 5m$
RFM029		FFM02	12	23	-6	-15	23	$4.19 \cdot 10^{-6}$
RFM029	ZFMA2, ZFMENE1192		23	48	-15	-34	5	$4.82 \cdot 10^{-4}$
RFM029		FFM02	48	62	-34	-44	3	$4.02 \cdot 10^{-7}$
RFM029	ZFMA2		62	99	-44	-72	8	$1.13 \cdot 10^{-3}$
RFM029		FFM02	99	121	-72	-89	4	$4.70 \cdot 10^{-7}$
RFM029	Possible DZ (G)		121	124	-89	-91	2	$9.03 \cdot 10^{-8}$
RFM029		FFM02	124	235	-91	-175	23	$1.96 \cdot 10^{-7}$
RFM029	ZFMENE0060A		235	252	-175	-187	5	$3.48 \cdot 10^{-9}$
RFM029		FFM01	252	305	-187	-227	10	$4.23 \cdot 10^{-9}$
RFM029	ZFMENE0060C		305	330	-227	-245	6	$3.37 \cdot 10^{-9}$
RFM029		FFM01	330	450	-245	-332	22	$3.36 \cdot 10^{-9}$

b) Confirmatory testing

This is the **core** of the GWF modelling carried out in SDM-Site. The documentation provided in Follin et al. (2007; R-07-49), Follin et al. (2008; R-08-23), and Follin (2008; R-08-95) is centered on this subject. For example, see Chapter 5 and Chapter 6 in Follin et al. (2007; R-07-49).

Fråga 11

R-09-22 sida 24 ekvation (2-1): det antas ett djupavtagande av transmissiviteten för branta deformationszoner. Detta parametriseras baserat på data från flacka zoner (R-07-48 sida 122). Till synes finns ingen uppenbar djuptrend för branta zoner (se exempelvis figur 2-4 R-09-20 sida 17 där exempelvis NNW-zondata visar ökande transmissivitet med djupet). Vad är argumentet för att parametrisera ett djupavtagande av transmissiviteten för alla branta zoner?

SKB's reply to #11

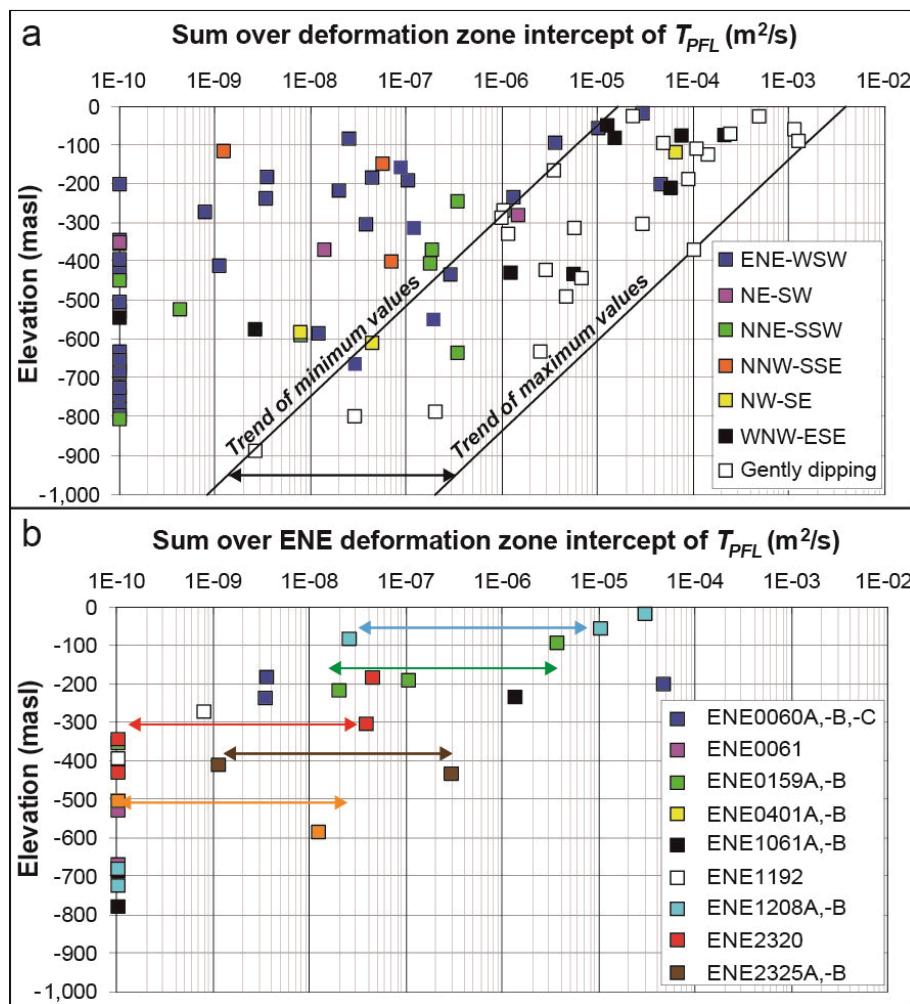
11. Depth dependency for steeply dipping deformation zones

The relevant equation for SR-Site is not Eq. (2-1) but Eq. (2-3) on p. 24 in Selroos and Follin (2010; R-09-22). Thus, the deterministic depth trend model shown in Eq. (2-1) is for the mean T value versus depth only and it should be noted that different zone may have different T(0) values. In the case of several measurements in the same zone (including data at or below the measurement limit, and effective value of T(0) is used equal to the geometric mean of the individual values of T(0). In the simulation stage, the effective value of T(0) is used. The local values of T are used to make conditioned stochastic simulations as described in Follin et al. (2008; R-08-23).

Follin et al. (2007; R-07-48) concludes that the lateral heterogeneity in each zone is considerable and that the deformation zone transmissivity is locally uncertain, thus a random deviate should be superimposed, e.g. as suggested by Eq. (2-3).

Figure b below is a replicate of Figure 9-4 in Follin et al. (2007; R-07-28). This plot shows values of T for the ENE steeply dipping deformation zones, which is the most frequent steeply dipping deformation zone set. The lateral spread at each elevation is approximately equal to the lateral spread of the gently dipping zones shown in Figure a which is a replicate of Figure 9-1 in Follin et al. (2007; R-07-48).

The three data that represent NNW-SSE zones in Figure a represent two different zones, where the two leftmost values come from the same zone. Indeed, these data reveal that there is a lateral heterogeneity also for the NNW-SSE zones and that each zone has its own T(0) value. Thus, the postulated deterministic depth trend model for the mean is not necessarily falsified.



Fråga 12

SKB R-07-49 sida 195:

- a) *Har konditioneringsmetoden för hydro-DFN modellen som beskrivs använts i SR-Site? Om så är fallet,*
- b) *hur säkerställs att de införda sprickorna leder till samma konnektivitet som det ursprungliga stokastiska nätverket?*
- c) *Hur bestäms vilken storlek de detekterade sprickorna ska ha i modellen?*
- d) *Var finns redovisningen av resultaten av konditioneringen som används i SR-Site?*

SKB's reply to 12

Below, is assumed that the question raised by SSM concerns p. 195 in Follin et al. (2007; R-07-48) and not Follin et al. (2007; R-07-49) as stated in the question.

a) Usage of proposed conditioning procedure in SR-Site

Not implemented

b) Representativeness of artificially introduced fractures

N/A

c) Size of detected fractures

N/A

d) Documentation in SR-Site

N/A

Fråga 13

SKB R-07-49 sida 62 första stycket:

- a) Hur hanteras situationer där mätvärden ligger på detektionsgränsen, dels när det finns ett mätvärde för en zon, dels när det finns flera mätvärden för en zon?
- b) Blir exempelvis transmissiviteten för fall där den enda transmissivitetsmätningen för en zon ligger på eller under detektionsgränsen större än detektionsgränsen på mindre djup än mätningen, eller ansätts ett minimivärde som är djupberoende?
- c) Hur bestäms m för mätvärden som ligger under detektionsgränsen om de behövs för att beräkna det aritmetiska medelvärdet som används när det finns flera mätningar?
- d) För vissa zoner är det djupare transmissivitetsvärdet större än det grundare (exempelvis ZFMNW1200). Antas djupavtagande transmissivitet också vid modelleringen av zoner med sådana mätresultat?

SKB's reply to #13

a) Handling of data lying on the detection limit

The detection limit for PFL tests is c. 10^{-9} m²/s, but T_{obs} was set to 10^{-10} m²/s where there were no values above the detection limit.

b) A single value at or below the detection limit

If there is only a single value in a zone and this is above or at the detection limit the value observed is retained as is. If there is no T-value measured where the borehole intersects the zone, a single value of 10^{-10} m²/s is assigned. In either case, m is calculated using the single value measured/assigned.

If we understand the reviewer correctly, the answer is yes, i.e., the modelled transmissivity at shallower depths are greater than the detection limit (10^{-9} m²/s). This is because the trend in transmissivity for the mean of log(T) increases an order of magnitude every 232.5 m, cf. Follin et al. (2007; R-07-48).

c) How is m determined if one or several data are at or below the measurement limit?

Values below the detection limit are ignored.

d) Handling of situations where the lowermost data among several data gathered in the same zone is the greatest data

For each value, an m value is calculated and an average value of the calculated m -values is used.

Fråga 14

SKB R-08-23 sida 42 sista stycket: För någon eller några zon(er) är det djupare mätvärdet mindre än det grundare.

- a) *Har man vid konditioneringen valt det uppmätta värdet vid respektive djup eller det värde vid mätdjupet som djupavtagandeekvationen (3-1a) ger?*

SKB's reply to #14

a) How is conditioning affecting the calculated depth trend?

The actual measured values at each depth are retained.

The calculated depth trend value described by Eq. (3-1) in R-08-23 is only used if there is no measured value within that zone and within that 100m depth interval.

Fråga 15

SKB R-08-23 sida 80 andra punkten i listan: Varför antas ”Else if $T_u < T_b$, use T_u ” och inte ”Else if $T_u < T_b$, use T_l ”?

SKB's reply to #15

15. Why “Else if $T_u < T_b$, use T_u ” and not “Else if $T_u < T_b$, use T_l ”?

It is basically saying that you should use the unconditioned value providing it is not above the detection limit, otherwise you would have measured a value of T_c above the detection limit T_l . Setting every value to T_l would be overly pessimistic if your best estimate is a continued reduction in T with depth beneath the detection limit.

Fråga16

SKB R-08-23 sida 80: Ändras vid konditioneringen värden i andra element än de som skärs av borrhål där testdata finns så att den statistiska fördelningen tillgodoses även efter konditioneringen?

SKB's reply to #16

16. Are the values in other elements also changed besides those that are intersected by boreholes with measured data such that the statistical distribution is maintained despite the conditioning?

No, but Figure 5-5 illustrates that it is a very small part of the overall area of DZ that is conditioned.

Fråga 17

Sida 80 hänvisning till Appendix C sida 137:

- a) Vad betyder 0.00 i tabellen, att det inte har konditionerats utan att T_u används?
- b) Har det beaktats att transmissiviteten inte ska vara mindre än transmissiviteten för HRD (punkt 5 sida 128 i R-07-49)?
- c) Hur förhåller sig tabellen till tabellen i appendix L i R-07-49?

SKB's reply to #17

a) What does 0.00 in Table C mean? That T_l has been applied or that the measurement is not used?

The measured value is below the detection limit, and so the 2nd and 3rd bullets on p. 80 in Follin et al. (2008; R-08-23) apply, i.e.:

- If $T_c \geq T_l$, use T_c ;
- Else if $T_u < T_l$, use T_u ;
- Else, Use T_l .

b) Has it been taken into account that the HCD transmissivity should not be less than the HRD transmissivity (cf. bullet 5 on page 128 in R-07-49)?

Yes, in a sense through specifying a minimum conductivity for the HCD, see #13. However, HRD is heterogeneous, and so HCD values are only above typical HRD values.

c) What is the relationship between Table C-1 in R-08-23 and Table L-1 in R-07-49?

Table L-1 gives the values used in defining the overall depth trend in each zone for a homogeneous case, or the mean values for a heterogeneous case, i.e. these govern T_u above. The values in C-1 are the values used only to condition local values at borehole intercepts, T_c .

Fråga 18

SKB R-08-23 sida 20: Enligt andra stycket går den lokala modellen ner till –1100 m. Hydromodellen i R-09-19 går ned till –1200 m och modellen i R-09-21 till –2300 m. Hur hanteras de olika djupen med avseende på parametriseringen av spricknätverket, antas samma egenskaper för de djupare modellerna som för de nedre delarna av de grundare modellerna?

SKB's reply to #18

18. How is the Hydro-DFN handled in R-09-19, R-09-20 and R-09-21 below –1,100 m elevation?

The fractures were generated afresh for SR-site in deeper volumes. The appropriate depth zone is that below –400m, and so it has the same properties below –1100m as above. In theory, one could assume that the properties below –400 m could be extended downwards indefinitely, however it is noted that the investigated depth extends down to c. –1,000 m elevation.

R-09-20: The bottom is extended to –1,200 m and the properties below –400 m elevation are also extended.

R-09-19: The model settings are imported from R-09-20, thus identical.

R-09-21: The interval below –1,100 and the bottom (–2,300) assumed a homogeneous medium with properties as specified in Table B-3 in Vidstrand et al. (2010; R-09-21). This setting was used since there is no information deeper than approximately –1,000 m elevation.

Fråga 19

SKB R-08-23 sida 118 tabell 7-4 visar $K_h = K_v/100$ men på sida 122 är $K_h/K_v = 100$. Vilket uttryck har tillämpats i beräkningarna?

SKB's reply to #19

19. Kv/Kh=100 or Kh/Kv=100?

$K_h/K_v = 100$ is the correct notation.

Fråga 20

SKB R-09-22 figur 2-6 sida 20: Figurtexten hänvisar till SKB R-08-23 där samma figur (4-2) finns på sida 67. Enligt figurtexten är figur 4-2 en reproduktion av figur 3-14 på sida 29. Vid närmare betraktelse visar sig figurerna inte vara lika. I figur 3-14 finns exempelvis en så kallad "possible deformation zone" med som inte finns i figur 3-14 (en WNW zon på ca 550 m djup med drygt 1e-6 m²/s transmissivitet). Enligt figurtexten till figur 3-14 är denna reproducerad från SKB R-07-48. I R-07-48 finns motsvarande figur (9-1) på sida 116. Figuren hänvisar till tabell 9-1. Det kan noteras att vissa punkter i figuren inte finns med i tabellen och tvärt om.

Enligt sida 20 i R-08-23 har alla 28 så kallade "minor deformation zones" (MDZ) tagits med i den deterministiska modellen. Det totala antalet zoner blir enligt texten således 131. I tabell 9-1 i R-07-48 listas 119 deterministiskt modellerade och testade zoner. På sida 28 i R-08-23 nämns 57 deformationszoner som har blivit hydrauliskt testade i steg 2.2. Enligt R-08-23 sida 20 ligger alla MDZ i den lokala modellen, men en koll i R-07-45 visar att så inte verkar vara fallet (exempelvis verkar NNW1209, sida A16-11 i R-07-45, ligga utanför).

R-09-22 sida 24 refererar till R-07-48 för en lista på T(z) för deformationszonerna som ingår i SDM-Site. I R-07-48 återfinns en lista på T mätningar i tabell 9-1 sida 114, medan en lista över konditionerade K(z) värden som baseras på 2.2 data återfinns i appendix L i R-07-49 sida 261. Sammantaget är det från redovisningen oklart vilka zoner som ingår i den deterministiska deformationszonmodellen för flödesberäkningarna och vilka egenskaper de har i flödesmodellerna.

- a) *SSM önskar att SKB klargör ovanstående oklarheter.*
- b) *Används värden i appendix L i R-07-49 även för fallet utan lateral variabilitet i HCD i SR-Site?*
- c) *Finns de deterministiskt modellerade zonerna som ingår i SR-Site basmodellen och deras egenskaper sammanhållet redovisade?*

SKB's reply to #20

a) Figure questions in R-07-48, R-08-23, R-09-22

Note that Figure 9-1 in Follin et al. (2007; R-07-48) shows data for cored boreholes only.

Figure 9-1 is correct with regard to Table 9-1. In Table 9-1 there are 55 transmissivity data > 1E-10 m²/s. The number of visible dots > 1E-10 m²/s in Figure 9-1 is 53, however, because two data points have double observations (3.40E-7 and 2.92E-5).

This means that Figure 4-2 in Follin et al. (2008; R-08-23) and Figure 2-6 in Selroos and Follin (2010; R-09-22) are also correct.

Figure 3-14 in Follin et al. (2008; R-08-23) requires some explanations however. The version pasted in Figure 3-14 differs from the correct version discussed above in that three data values representing borehole intervals with deformation zone type properties are included; see the figure shown below which is a replicate of Figure 7-2 in Follin et al (2007; R-07-48).

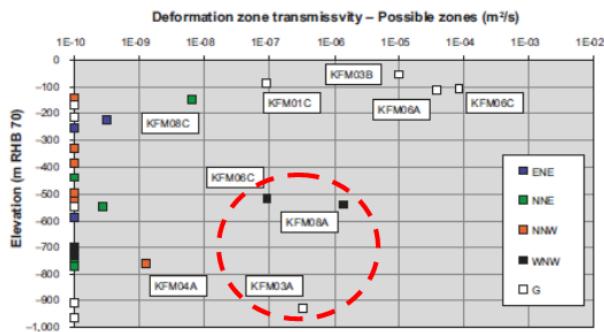


Figure 7-2. Transmissivity versus depth for the possible deformation zones observed in cored boreholes.
The transmissivities are coloured with regard to the estimated orientations of the possible deformation zones, cf. Table 3-2. Possible deformation zones with little or no flow are assigned a low transmissivity value of $1 \cdot 10^{-10} \text{ m}^2/\text{s}$.

The statement on p 20 in Follin et al (2008; R-08-23) that all of the 28 minor deformation zones are included in the local model domain is almost correct. There is at least one MDZ that is entirely outside the local model domain, see Figure 3-9 in Follin et al. (2007; R-07-49). This zone is known as Zone 6 in the hydrogeological model for the bedrock at the Forsmark-SFR site.

b) Table L-1 in Appendix L of Follin et al. (2007; R-07-49)

The data shown in Table L represent the hydraulic properties of the deformation zones in the base model simulation of stage 2.2. Table L was also used in SR-Site as the basis for all HCD modeling, see Figure 4-1 in Joyce et al. (2010; R-09-20). For the so called homogeneous variant of the hydrogeological base case model the values are used as is, for the cases with lateral heterogeneity some random variability is added about these values.

c) Documentation of the deterministically modelled deformation zones in SR-Site

The geometry of the deterministically modelled deformation zones are described in Stephens et a. (2007; R-07-45). The associated hydraulic properties are described in Appendix L of Follin et al. (2007; R-07-49). The input files to ConnectFlow (Joyce et al. 2010; R-09-20) and to DarcyTools (Svensson and Follin 2010; R-09-19 and Vidstrand et al. 2010; R-09-21) are archived and available upon request from SKB.

Fråga 21

SKB R-07-48 sida 178: *I texten beskrivs hur sprickstorleks-transmissivitetsförhållandena kalibreras.*

- a) Vilka borrrålsdata har använts i kalibreringen för de olika sprickdomänerna (för den beskrivna kalibreringen men framförallt för den kalibrering som är relevant för SR-Site)?
- b) Hur har det vid jämförelsen av flödesmätningar och modellresultat hanterats att flödesmätningarna i borrrålen innefattar flöden i deterministiskt modellerade zoner medan modellen baseras enbart på det stokastiska spricknätverket?

Fyra olika jämförelsesätt mellan modell och mätningar anges.

- c) Vilka parametrar har man vridit på när man har passat till de olika mätten?
- d) Har dessa mått viktats på något sätt, exempelvis om en bättre passning för ett mått skulle leda till ett sämre för ett annat?
- e) Finns motsvarande kalibreringar även redovisade för den modell som används i SR-Site?

SKB's reply to #21

a) Which boreholes have been used in the calibration of the different FFM's?

In terms of data, the details are given in Table 10-15 to 10-17. For the modelling, an idealized vertical borehole was used for each domain (i.e. no specific location). Borehole specific simulation was not practiced until the later stages of modelling of Laxemar.

b) How are the deformation zones handled in the Hydro-DFN calibration?

They are not included apart from guiding the lateral extent of the model domain around the boreholes to be a typical spacing between zones. Flowing fractures associated with deformation zones are not included in the calibration process.

c) Four measures of comparisons are used in the Hydro-DFN calibration. Which parameters have been changed to make the calibration?

First fracture size parameters to get the last bullet. Then, transmissivity parameters are changed to meet the other 3 measures.

d) Have the four measures been weighted or ranked in some way?

No, a reasonable match has been achieved to all 4 measures. The first two are achieved by adjusting the transmissivity parameters of the dominant sets, the third is achieved by making relative adjustments between the sets.

e) Has the same procedure been used in SR-Site?

For Forsmark, no re-calibration was performed, i.e. values are used straight from the SDM. For Laxemar, the approach was elaborated, see R-09-24.

Fråga 22

R-07-48 sida 179 sista stycket: I texten står "Two extreme assumptions...".

- a) Vad avses här med extrema antaganden?
- b) Anser SKB att det inte finns några möjliga förhållanden mellan sprickstorlek och transmissivitet som kan ge mindre fördelaktiga resultat med hänsyn till säkerhetsanalysen?

SKB's reply #22

a) On page 179 in R-07-48 it is written in the last paragraph: “Two extreme assumptions....”. What is meant here by “extreme assumptions”?

In terms of a relation between fracture size and transmissivity the “extremes” of possible assumptions are no correlation at all or a direct correlation. The word extreme does not imply anything about safety consequences, which it is difficult to speculate on a priori. One could use the word “bounding” but still in the context of this particular relationship rather safety consequence.

b) Does SKB exclude the possibility that other kind of relationships between size and T could yield less favorable results with regard to safety assessment?

These are bounding assumptions used to illustrate the sensitivities. We use the examples to demonstrate that by calibrating alternative assumptions against the same PFL data, the results of several simulated outcomes, such as F distributions, are quite similar. The bounding assumptions also demonstrate aspects that are sensitive to these assumptions, such as greater variability between realizations for a correlated model, and a slightly higher median Q_r for an uncorrelated model. Hence, the cases considered show that each model can have both favorable and detrimental attributes to safety relative to other models the consequences of which have to be evaluated. We do not claim to have considered the least favorable conceivable relation, as it may be some intermediate case, but have illustrated the various sensitivities to this assumption.

Fråga 23

SKB R-07-49 sida 127 kapitel 5:

- a) *Vad är skillnaden mellan stage 2.2 base model simulation (sida 128), central calibrated case (t.ex. sida 261) och reference calibration case (sida 162)?*
- b) *Var är parametriseringarna av dessa fall dokumenterade?*
- c) *Finns motsvarande fall för 2.3 datafrys och SR-Site basmodellen och var är dessa i så fall redovisade?*

SKB's reply to #23

a) In Follin et al. (2007; R-07-49), what is the difference between the base model simulation (p. 128), the central calibrated case (p. 261) and the reference calibration case (p. 162)?

The nomenclature is unfortunate in places. Essentially, they are all the same case, i.e., essentially the same hydrogeological properties are used, but extra settings are introduced for each type of calibration, e.g. palaeo-hydrogeology boundary and initial conditions, interference test boundary conditions.

In fact, the last part of expression “stage 2.2 base model simulation” is also unfortunate/misleading, as several different types of simulation have to be performed using the same hydrogeological properties.

b) Where are the parameters for these three cases found?

There is only one set of hydrogeological properties. R-07-49 documents an initial set of parameter settings and the adjustments made in calibrating the model. The motivation for these adjustments are documented in section 5.4 of R-07-49 and re-affirmed in section 6.2 based on regional scale ECPM modeling of site data. For example, HCD properties are in Table L-1.

Differences between the simulation cases described in different chapters of R-07-49 only relate to specific settings of e.g. boundary conditions necessary to calibration against a particular data type.

c) Does the three cases also exist in stage 2.3 (Follin et al. 2008; R-08-23) and in SR-Site, and if so where are the parameters for each case found?

The derived hydrogeological settings were then applied in R-08-23 as described in Chapter 3 of that report for stage 2.3. Two minor changes were made to the methodology of how the model was implemented as described in Chapter 5 of R-08-23. The same hydrogeological settings were applied in SR-Site.

Some changes in solute transport settings specific to simulating the regional-scale evolution of groundwater flow and composition using an ECPM model are described in Appendix C of R-09-20. Some other necessary methodological changes for representing fracturing around the repository are also described there.

Fråga 24

SKB R-07-49:

- a) *Har ändringarna som följer ur kalibreringen av ECPM modellen överförts till hydro-DFN modellen när detta är relevant (exempelvis ändrades vid kalibreringen av ECPM modellen HCD egenskaperna)?*
- b) *Hur förhåller sig resultaten av kalibreringen av DarcyTools (R-09-19 och R-09-22) till resultaten av kalibreringen av ConnectFlow ECPM som beskrivs i SDM-Site?*

SKB's reply to #24

a) Have the changes made to the ECPM model reported in Follin et al. (2007; R-07-49) affected the calibration of the Hydro-DFN model or the HCD model?

In terms of HRD, the calibration process led to the decision to use the more anisotropic Hydro-DFN as implied by the alternative orientation model with higher Fisher concentration in sub-horizontal set. In terms of HCD, it led to the prescription given in Appendix L.

b) What is the relationship between DarcyTools (R-09-19 and R-09-21) and ConnectFlow (R-09-20)?

The set-up of deformation zones and DFN realizations in the flow modeling conducted with DarcyTools in Svensson and Follin (2010; R-09-19) are imported from Joyce et al. (2010; R09-20).

The set-up of deformation zones in the flow modeling conducted with DarcyTools in Vidstrand et al. (2010; R-09-21) are imported from Joyce et al. (2010; R-09-20). The set-up of DFN realizations generated in the flow modeling conducted with DarcyTools in Vidstrand et al. (2010; R-09-21) are based on the same DFN characteristics as the modeling conducted by Joyce et al. (2010; R-09-20), i.e. Appendix C in Follin (2008; R-08-95).

Fråga 25

SKB TR-08-05 sida 260: Det beskrivs att de antaganden som görs för hydro-DFN motsvarar r_0 -fixed varianten av geo-DFN. Finns det en diskussion redovisad varför de andra antaganden som diskuteras för geo-DFN, dvs. OSM+TFM, TCM och TCMF (Sida 165 TR-08-05) inte är relevanta för DFN flödessimuleringarna?

SKB's reply to #25

25. Why are not Geo-DFN variant such as OSM+TFM, TCM and TCMF relevant for the Hydro-DFN flow simulations?

The Hydro-DFN modeling is based solely on the intensity of open and flow fractures in boreholes. The Geo-DFN modeling also considers data in boreholes but primarily data are acquired on surfaces (outcrops) and so-called linked lineaments. Furthermore, the Geo-DFN modeling includes all fractures (sealed and open) in the analysis and does not address/distinguish the statistics of open and flowing fractures in particular. In addition, there are assumptions in the Geo-DFN approach that may apply to data gathered on the surface only.

Fråga 26

SKB R-09-22 sida 59: När transmissivitetsvärdet slumpas fram är de möjliga värdena begränsade till två standardavvikeler över eller under medeltransmissiviteten (semi-korrelerade fallet) eller till den maximala transmissiviteten för zoner med motsvarande egenskaper (korrelerade fallet). Det står att värdena sampelas om och att detta leder till en annan realisering av det geometriska spricknätverket (DFN).

- a) *Vad exakt sampelas om och hur görs det? Det är inte uppenbart varför ett annat transmissivitetsvärde skulle leda till en annan geometri.*

I kalibreringen av fördelningarna beskrivs inga sådana begränsningar för transmissivitetsvärdet (eller motsvarande Q/s värden som används vid kalibreringen). Således verkar den kalibrerade och de genererade modellerna inte baseras på samma antaganden.

- b) *Var finns en diskussion om osäkerheterna som introduceras genom de olika antagandena?*

Det antas i ekvation (4-19, R-09-21 sida 49) en uniform fördelning av den slumpmässiga komponenten av spricktransmissiviteten. Enligt TR-10-52 tabell 6-74 sida 329 (och referensen ovan) antas en normalfördelning.

- c) *Hur förhåller sig begränsningarna som införs för det normalfördelade uttrycket till parametrarna för den uniforma fördelningen?*
- d) *Plockas även i fallet med uniform fördelning för höga värden bort, eller är den uniforma fördelningen begränsad genom parametervälet så att det inte behövs?*

SKB's reply to #26

- a) On page 59 in Selroos and Follin (2010; R-09-22), it is stated that re-sampling lead to another DFN- realization Exactly, what is re-sampled and how is it done? It is not obvious that another T-value leads to a different geometry?**

Fracture generation is performed by generating each fracture one at a time and sampling all the properties of each fracture. Thus, the procedure is not to generate all the fracture geometries and then generate all the hydraulic properties. Using a truncated distribution implies that if the generated value falls outside a specified range, then another random value is generated until one is found inside the allowed range. In this way the random sequence generated is used for different fractures and different parameters when truncated distributions are used.

- b) In the calibration of the fracture-size T distributions no such limitations are described for the T-values (or the corresponding Q/s values used in these calibrations). Hence, the calibrated and the generated models do not seem to be based on the same assumptions. Where is this difference and the uncertainties it implies discussed?**

The truncation of the semi-correlated model at 2 standard deviations of log(T) is encoded with ConnectFlow and so was used for both model calibration and all subsequent SDM and SR-Site applications.

The truncation of the uncorrelated model was introduced during SDM-site for Laxemar, see end of p. 246 in Rhén et al. (2008; R-08-78) as necessary to avoid generating excessively high tail values. So, yes this was a late stage change for the uncorrelated model for SR-Site for Forsmark. The motivation came from having to generate large regional scale DFN models of many millions of fractures using lognormal distributions that would inevitably sample some values orders of magnitude higher than those observed. Hence, the decision to apply limits on the regional scale DFN generation. For the model calibration, much smaller networks are generated and only sampled by linear (borehole) measures, and so the results would be less sensitive to truncation of tails of the distributions. You can see evidence of this in the fact that the calibrated values of σ are similar for the uncorrelated model (no truncation) and semi-correlated (truncated at $\pm 2\sigma$) in e.g. Table 11-20 of Follin et al. (2997; R-07-48).

c) Uniform versus normal distribution for the simulation of random heterogeneity in transmissivity

In ConnectFlow, random heterogeneity is modeled with a normal distribution with $\sigma_{\log(T)}$ as specified in Appendix C in Follin (2008; R-08-95) (see answer to Issue #33 below).

In DarcyTools, random heterogeneity is modeled with a uniformly distributed random deviate.

For SR-Site, the value of d_T in Eq. (4-19) in Vidstrand et al. (2010; R-09-21) was set to 2 standard deviations, e.g if $\sigma_{\log(T)} = 0.5$ in ConnectFlow, $d_T=1$ in DarcyTools

d) Was the uniformly random deviate in DarcyTools truncated?

No, this is not necessary for a uniform distribution.

Fråga 27

SKB R-09-22 sida 61, 5.3.8: Två ytterligare analyser beskrivs. I avsnitt 5.4.8 och 5.4.9 redogörs för resultaten av dessa analyser. Finns det någon utförligare redovisning av dessa analyser?

SKB's reply to #27

27. Additional analyses

These two sets of analyses are not presented elsewhere in more detail, but were included in R-09-22 as they provide some additional insight into model behaviour and sensitivity of the model used for the temperate simulations presented in R-09-20.

The test of the aperture proposed by (Hjerne et al., 2010) is shown also in report R-09-20, but the background of this case and discussion is more elaborated in R-09-22.

The section on Groundwater circulation and flow path characteristics serves as a confirmation of methodology used in R-09-20. Strictly this section could have been included in R-09-20; however, the motivation for these analyses was identified after completion of report R-09-20. Hence the execution of the simulations was done posterior to R-09-20, and the results included in R-09-22 instead.

Fråga 28

SKB R-09-22 sida 57 tredje punkten: vad menas med "the combined repository and site-scale models"? Är detta site-scale modellen som beskrivs i figur 3-6 på sida 36 eller finns det ytterligare en modell som kopplar repository-scale modellen till regional-scale modellen?

SKB's reply to #28

28. “The combined repository and site-scale models”

This is indeed the site-scale model described in Figure 3-6. By “combined repository and site-scale models” is implied that particle tracking is performed in the repository scale model, and continued in the site scale model. Hence, the models are combined.

Fråga 29

SKB R-09-22 sida 95 första stycket: Varför används ett relativt mått som indikator på när utspädda vatten når förvaret, är inte lererosionen kopplad till ett absolut mått?

SKB's reply to #29

29. Relative versus absolute measure of diluted water

The analysis of the number of canisters that will experience dilute waters during glacial conditions is presented in section 6.4.4. Here a relative measure is used, but it is related to the actual threshold concentration values for erosion. It is noted that the model used in the analysis in section 6.4.4 is the detailed model presented in R-09-20.

The analysis described on page 95 relates to the super-regional model used in R-09-21. The results here are not used directly to assess whether deposition holes will experience dilute conditions, but rather illustrate the large-scale salinity behaviour during a glacial passage.

Fråga 30

SKB R-09-22 sida 110 fjärde stycket: Det beskrivs att man i figur 7-1 kan se hur inflödeskriterier som tillämpas istället för FPC eller EFPC påverkar huruvida deponeringshål med höga flöden utesluts. Denna information verkar saknas i figur 7-1.

SKB's reply to #30

30. Missing information

We are not completely sure exactly which sentence the reviewer refers to here. However, what Figure 7-1 illustrates is a positive correlation between inflow during open conditions and Darcy flux during saturated conditions (albeit with a scatter such that correlation is not perfect). Hence, if one defines an inflow threshold value for accepting deposition holes, e.g. 0.1 L/min, one will, in a statistical sense, also avoid deposition holes with high fluxes during saturated conditions.

Fråga 31

SKB TR-10-52 sida 323: I listan som visar källorna för informationen som används i datakvalificeringen återfinns rapporten R-09-22. Den sammanfattar de undersökningar som har gjorts för SR-Site inom hydrogeologiområdet. Med andra ord verkar källan för de data som ska kvalificeras i datarapporten vara samma rapport som de kvalificerade data används i. Datarapportens roll för kvalificering av data inom hydrogeologiområdet är för myndigheten något oklar i och med att det inte finns ett tydligt gränssnitt mellan SR-Site och SDM-Site i rapporteringen. Vad har SKB:s utgångspunkt varit med hänsyn till datakvalificering vid framtagande av datarapportens kapitel 6.6?

SKB's reply to #31

31. Role of TR-10-52 in SR-Site

The intention of section 6.6 of the Data report is to qualify (subsets of) the relevant hydrogeological data provided by SDM-Site. However, it is noted that section 6.6 primarily deals with data related to parameterization of the fractured rock mass; clearly, SDM-Site provides other types of hydrogeological data as well. A decision was made within SR-Site that emphasis in the data qualification procedure was given data related to parameterization of the fractured rock mass since this data have the largest consequences for subsequent calculations within the safety assessment.

As stated right above Table 6-70, R-09-22 provides a description of the chosen methodology for groundwater flow modelling in SR-Site. Hence, R-09-22 is not input data to SR-Site, but rather part of SR-Site, and should thus strictly not be listed in Table 6-70. However, R-09-22 also provides a comprehensive summary of SDM-Site providing the key input to SR-Site. This is the information and data implied when references to R-09-22 are given in section 6.6 of the Data report. In retrospect, we acknowledge that this may be perceived as a circular argument, and that it would have been better to strictly reference (and qualify) data listed in SDM-Site reports.

Fråga 32

TR-10-52 sida 335: Ekvation 6-19 ger ett samband mellan apertur och transmissivitet. Den diskuteras här i samband med sprickor i hydro-DFN modellen. Enligt R-09-21 sida 49 sätts e_T för modelleringen under periglaciala förhållanden till $1e-4$ m för stokastiska sprickor, vilket inte verkar framgå av datarapporten.

- a) Används ekvation 6-19 även för de deterministiska zonerna i DFN flödesberäkningarna, dvs. antas ett djupberoende av aperturerna?
- b) Har aperturdata för zonerna från borrhålsundersökningarna beaktats i beräkningarna?
- c) Varför antas konstanta aperturvärden för det stokastiska spricknätverket i den periglaciala modelleringen?

SKB's reply to #32

Transport apertures in Vidstrand et al. (2010; R-09-21)

- a)** Eq. (6-19) in SKB (2010; TR-10-52) is used in Vidstrand et al. (2010; R-09-21) for modeling of deformation zone apertures at all depths. Note that the geometry and hydraulic properties of the deformation zone model used in Vidstrand et al. (2010; R-09-21) are provided by Joyce et al. (2010; R-09-20).
 - b)** Aperture data estimated from hydraulic tracer tests are not used in Vidstrand et al. (2010; R-09-21).
 - c)** The module in DarcyTools used for stochastic generation of DFN cannot readily use functions such as Eq. (6-19). There are means to get around this limitation, e.g. in terms of post-processing. However, it was decided to use a simpler approach in Vidstrand et al. (2010; R-09-21) since DarcyTools is primarily an ECPM flow modeling code and not a DFN flow modeling code.
-

Fråga 33

TR-10-52 sida 337 tabell 6-75: I tabellen listas parametrarna för hydro-DFN för FFM01 och FFM06. I R-09-19 om byggnads- och driftfasen listas andra värden för samma sprickdomäner i tabell 2-3 på sida 25. Samma värden listas i R-09-20 i tabell 2-3 på sida 23, i R-09-21 i tabell 3-3 på sida 41, medan tabell 2-2 på sida 25 i R-09-22 visar samma värden som i datarapporten. Således verkar värdena som ges i datarapporten inte användas för de hydrogeologiska beräkningarna i de tre tidsfaserna (i appendix B i R-09-21 sida 106 ges dock samma värden som i datarapporten i motsats till värdena som ges på sida 41 i samma rapport). Alla tabeller hänvisar till Appendix C till R-08-95 sida 161 som källa för värdena (förutom appendix B i R-09-21 som hänvisar till R-09-22). Värdena som listas i tabell C1 är samma som i datarapporten. Dock har tabell C1 uppdaterats med errata (maj 2009). Den uppdaterade tabellen visar varken samma värden som tabellerna i R-09-19 till 22 eller datarapporten. Den uppdaterade tabellen C1 hänvisar till appendix F i R-07-49 tabell F1 sida 227. Värdena för k_r är inte samma i de två tabellerna. Enligt tabelltexten är tabell F1 reproducerad från R-07-48. I R-07-48 återfinns värdena i tabell 11-20 på sida 182 (orienteringsseten återfinns på sida 192), värdena för r_0 och k_r är dock olika i tabellerna.

- SSM önskar förtigligande information om vilka hydro-DFN parametrar som har använts i SR-Site modelleringarna*
- Var redovisas härledningarna eller kalibreringarna som resulterar i de parametervärdena som har använts i SR-Site modelleringarna?*

SKB's reply to #33

a) Hydro-DFN parameterization for SR-Site

SSM's reviewer is acknowledged for noting several ambiguities in the documentation. As a result, SKB has conducted an internal review in order to clarify whether there are any serious disagreements between the Hydro-DFN parameterization used for SDM-Site and for SR-Site, respectively. The short answer is that there is no serious disagreement in the actual data used, but in order to clarify the errors made in the reporting, Errata will be compiled and published for the following reports as soon as possible:

SDM-Site

- Follin et al. (2007; R-07-48)
- Follin et al. (2007; R-07-49)
- Follin et al. (2008; R-08-23)
- Follin (2008; R-09-95)
- SKB (2008; TR-08-05)

SR-Site

- Svensson and Follin (2010; R-09-19)
- Joyce et al. (2010; R-09-20)
- Vidstrand et al. (2010; R-09-21)
- Selroos and Follin (2010; R-09-22)
- SKB (2010; TR-10-52)

Summary of results of SKB's internal review

The hydrogeological DFN-modeling and groundwater flow modeling for SDM-Site was conducted by flow modelers working at Serco TAS, UK, using the ConnectFlow code. The same flow modelers and

the same software were used also for SR-Site. This was made to assure continuity and consistency in the data handling and modeling.

The flow modelers in charge have confirmed that the Hydro-DFN and deformation zone parameterization set-up used for SR-Site is the same as the final data set-up concluded for SDM-Site. Unfortunately, these settings used were not properly communicated to the operational modeling coordinator/report manager, neither during SDM-Site, nor during SR-Site, which explains the number of reports that requires an Erratum, cf. above.

Tables with essentially appropriate Hydro-DFN figures for SDM-Site and SR-Site are reported in Appendix C of Follin (2008; R-08-95), which is the key reference on Bedrock Hydrogeology of the SDM-Site stage. Note that an Erratum was released in May 2009. The updated version of Follin (2008; R-08-95) has been available at www.skb.se since.

Critical reading by the flow modelers during November 2012 has revealed that some additional adjustments to the Erratum of Appendix C of Follin (2008; R-08-95) are required in order to reflect what was actually used in stage 2.2 and stage 2.3 of SDM-Site as well as for SR-Site. These changes are briefly summarized below.

The following changes should be made to Table C-1 of R-08-95:

- A $\mu_{\log(T)}$ of -8.8 rather than -8.3 for the uncorrelated distribution below -400 m elevation

The following changes should be made to Table C-2 of R-08-95:

- Set, Trend, Plunge, Fisher conc.
 - NS: 83, 10, 16.9
 - NE: 143, 9, 11.7
 - NW: 51, 15, 12.1
 - EW: 12, 0, 13.3
 - HZ: 71, 87, 20.4

Table C-3 of R-08-95 requires no changes.

b) Documentation of the derivations and calibrations of the Hydro-DFN settings used for SR-Site

The initial derivations and calibrations of the Hydro-DFN parameters used for SR-Site are documented in Chapter 11 of Follin et al. (2007; R-07-48). In conclusion, recommended alternative Fisher distribution settings used for groundwater flow modeling in SDM-Site (Follin et al. 2007; R-07-48 and Follin et al. 2008; R-08-23) as well as in SR-Site are shown Table 11-26. However, Table 11-26 is only applicable for fracture domains FFM01, FFM03-06. For fracture domain FFM02, the orientation data listed above apply.

Fråga 34

SKB TR-10-52 sida 339 stycket "Conceptual uncertainties": Det beskrivs att hydro-DFN modellen är förknippad med konceptuella osäkerheter.

- a) Hur beaktas dessa osäkerheter i SR-Site, förutom att tre olika samband mellan sprickstorlek och transmissivitet används i beräkningarna?
- b) Har exempelvis effekterna av osäkerheterna kring hydro-DFN modellens geometri kvantifierats i SR-Site?

SKB's reply to #34

Conceptual uncertainties in SR-Site

a) The conceptual uncertainties discussed relate to the basic assumptions made in the Hydro-DFN model derivation. These uncertainties are primarily assessed by applying a different conceptual model for calculation of the performance measures. Hence, a channel network model has been applied as described in R-10-69 (A safety assessment approach using coupled NEAR3D and CHAN3D – Forsmark).

b) If the reviewer by geometrical uncertainties imply e.g. fracture distributions for orientation, length and location, these attributes are analyzed in the Hydro-DFN derivation presented in report R-07-48. In the SDM work, it is shown that the fracture size-transmissivity relationship remains the main uncertain feature of the parameterization.

Uncertainties in orientations are of lesser significance.

Fråga 35

SKB TR-10-52 sida 340 under 6.7: det står att parametrarna har "essentially" erhållits genom numerisk simulation av grundvattenflöde med modellerna som beskrivs i 6.6. Vad menas med "essentially", har även annan information beaktats?

SKB's reply to #35

35. "Essentially"

The choice of wording is unclear and somewhat unfortunate in the introduction of this section. What is implied, and described in the sections below, is that groundwater flux, advective velocity, and flow-related transport resistance are obtained from the groundwater flow simulations. However, values on longitudinal dispersion and penetration depth are obtained from other sources.

Fråga 36

SKB TR-10-45: Förvarstunnlarna och deponeringshålen ingår inte explicit I FEP:arna för initialtillståndet. Till synes verkar det bero på att initialtillståndet för geosfären definieras som tillståndet innan byggnadsfasen påbörjas. FEP:ar för avvikeler i initialtillståndet för tunnelnsystemet och deponeringshålen (initialtillstånd i mening av tillståndet för deponeringshål strax efter deponering och för deponeringstunnlar och andra tunnlarna när återfyllnaden är på plats) kan anses betydelsefulla för säkerhetsanalysen. Har sådana FEP:ar beaktas systematiskt i analysen?

SKB's reply to #36

36. FEP

It is correct that deviations in tunnel and deposition hole geometries not are handled directly by any FEPs. This is motivated by the fact that tunnels and deposition holes do not have any barrier function; this is discussed in section 5.1.3 of TR-11-01. The initial state of tunnels and deposition holes is discussed in section 5.2 of TR-11-01.

The initial states of engineered barriers are given by the Design premises. Any deviations from the design premises are analyzed within the safety assessment. It is noted that the effect of deviations in deposition hole geometry primarily implies a deviation in buffer density. This issue is thoroughly addressed in report TR-10-15 (Design, production and initial state of the buffer).

Groundwater flow and radionuclide transport analyses addressing tunnels with deviations from expected properties are provided in report R-09-20. Here cases with increased EDZ and a crown space under the tunnel roof are analyzed. The subsequent impact on radionuclide transport is analyzed in TR-10-50.

The motivation for the EDZ and crown space variants is simply to evaluate whether the design premises presented in TR-09-22 (Design premises for a KBS-3V repository based on results from the safety assessment SR-Can and some subsequent analyses) were strict enough.

Fråga 37

SR-Site huvudrapporten sida 49 första stycket sjätte punkten: Relaterat till konstruktionsförutsättningarna står att den tillåtna transmissiviteten på EDZ i deponeringstunnlarna på $10^{-8} \text{ m}^2/\text{s}$ är rimlig och inte behöver sänkas. Var redovisas resonemangen som leder till denna slutsats?

SKB's reply to #37

37. EDZ

This statement is based on arguments collected in report TR-09-22 (Design premises for a KBS-3V repository based on results from the safety assessment SR-Can and some subsequent analyses). The arguments specifically related to EDZ transmissivities is based on simulations performed as pre-modelling studies to SR-Site (R-08-108; SR-Site Pre-modelling: Sensitivity studies of hydrogeological model variants for the Laxemar site using CONNECTFLOW).

The effect of an EDZ with higher T-values is assessed in SR-Site in R-09-20, and it is verified that the chosen T value on $10^{-8} \text{ m}^2/\text{s}$ is adequate. See also reply to question above.

Fråga 38

SR-Site huvudrapporten sida 89 tredje stycket: Det exemplifieras att fel orsakade av den mänskliga faktorn kan minimeras genom att använda alternativa förenklade modeller. Har sådana använts när det gäller framtagandet av prestandamåtten i den hydrogeologiska modelleringen? Var har de i så fall redovisats?

SKB's reply to #38

38. Alternative simplified models

Alternative simplified models to assess effects of human factors are not used within the hydrogeological modelling. However, the effect of deviating tunnel properties and abandoned boreholes are addressed in R-09-20 using the same model as for the other cases, but modifying relevant properties.

The effect of abandoned open tunnels is addressed in R-10-41 (Groundwater flow modelling of an abandoned partially open repository); however, this is not a simplified model, but rather a variant of the model used for the open repository simulations (R-09-19).

Fråga 39

SR-Site huvudrapporten sida 130 sista stycket: Det diskuteras att gradienter som tolkats från mätningar ger högre värden än de modellerade. I R-08-103 diskuteras att transmissiviteten är en viktig felkälla när det gäller beräkning av gradienterna. Rekommendationen i TR-08-05 sida 291 är att uppdatera transmissivitetsdata med företrädesvis PFL-f data. Har uppdaterade transmissivitetsdata användts i SR-Site och har de osäkerheter i transmissivitetsdata som indikeras av resultaten i R-08-103 beaktats i SR-Site beräkningarna?

SKB's reply to #39

39. Uncertainties in gradients and transmissivities

Due to precisely the problems indicated above, and other challenges related to estimation of transmissivity values from pumping tests in fractured rock, an alternative method has been used in SDM-Site and SR-Site. The procedure is described in detail in R-07-48, but basically implies that instead of using T values derived from pumping tests, the T values are assigned in the DFN model by matching a number of metrics related to measured inflows detected by the PFL flow logging tool. Thus, the T values used in subsequent modelling are not based on values deduced from pump tests, but are calibrated values that honour the flow distribution in the discrete fracture network.

Fråga 40

SR-Site huvudrapporten sida 354:

- a) *Var finns beräkningarna som ligger bakom figur 10-34 dokumenterade?*
- b) *Till synes förutsätter beräkningarna att spjälkningen inte påverkar flödet i hydro-DFN modellen (eller verkligheten den avbildar). Har ökningen av konnektiviteten kring deponeringshålen som skulle kunna orsakas av spjälkningen uppskattats?*

SKB's reply to #40

Spalling

a) Figure 10-34 is presented in the Main report only. However, the calculations supporting the figure are made in connection to the erosion and corrosion calculations presented in TR-10-66. The documentation of the calculations is detailed in Appendix 2 of TR-10-66.

b) The hydraulic effect of the spalled zone is not included in the groundwater flow models. However, the volume of the spalled zone is small, see Table 6-69 of the SR-Site Data report (TR-10-52). Furthermore, in the Data report, page 300, the following is noted concerning the hydraulic conductivity of the spalled zones: "If this conductivity cannot be shown to be small in relation to the transmissivity of the fracture intersecting the deposition hole, or if there is no fracture intersecting the deposition hole, it is sufficient to note that the hydraulic conductivity of the spalled zone is "high". In the Data report, table 6-69 "Recommended data for deposition hole walls", the hydraulic conductivity of the spalled zone is subsequently given as "High".

Fråga 41

SR-Site huvudrapporten sida 358 fjärde stycket: Det beskrivs att det inte är motiverat att ta upp de andra SDM-Site varianterna i den fortsatta analysen. Finns det en mer utförlig diskussion kring hantering av alla olika varianter i SDM och grunderna för att inte följa upp dem i SR-Site, exempelvis i form av en tabell som listar alla varianterna?

I R-06-98 som redovisar hydrogeologin för Forsmark i SR-Can finns exempelvis sådana listor (tabell 3-4 sida 92 och tabell 3-6 sida 144) även om anledningarna till att vissa varianter förkastas där inte uttryckligen förklaras.

SKB's reply to #41

41. SDM variants

The SDM-Site report on Hydrogeology (R-08-95) discusses the different SDM variants and their importance. The ones found most important are propagated to SR-Site and listed under the heading “SDM-Site related model variants” in section 10.3.6 of the SR-Site Main report.

The section the reviewer refers to we believe is on page 354, not 358. Here it is concluded, after assessment of the quantitative results and associated uncertainties, that out of the SDM variants analyzed, the only one that needs to be propagated to subsequent assessment within the compliance calculations is the variant assuming other transmissivity-size relationships.

In summary, the most important SDM variants identified in R-08-95 are propagated to SR-Site, and the analysis summarized on page 354 results in the conclusion that only the size-transmissivity variant is propagated further down the assessment chain.

Fråga 42

SR-Site huvudrapporten sida 513 figur 10-147: Var finns beräkningarna som ligger bakom figuren dokumenterade?

SKB's reply to #42

42. Figure 10-147 in SKB (2011; TR-11-01)

The calculations supporting this figure are done based on the results in R-09-21. The resulting figure is only shown in the Main report. The calculations are performed by the author of R-09-21 and stored with all other data and results stemming from this report.