R-10-69

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December 2010

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ISSN 1402-3091
SKB R-10-69

Updated 2018-08

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Update notice

The original report, dated December 2010, was found to contain factual errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2018-08

Location	Original text	Corrected text
Page 7, Chapter 1, paragraph 1	/Liu et al. 2010/	Reference deleted
Page 7, Chapter 1, paragraph 2	In the Laxemar report /Liu et al. 2010/,	In the safety assessment of Laxemar,
Page 7, Chapter 1, paragraph 3	/Liu et al. 2010/	Reference deleted
Page 8, Section 1.2	In an earlier report /Liu et al. 2010/,	Earlier,
Page 45, References	Liu et al. 2010	Reference deleted

Abstract

Safety assessment calculations for the Forsmark site were performed using a new code, which couples the far-field code CHAN3D and the near-field code NEAR3D. In addition, the package has a Graphical User Interface (GUI) and a code that governs the simulations (Coupling).

The simulations were performed for 90 different canister locations, which were randomly chosen. Deterministic data were used for tunnels, deposition holes, and shafts. The background fractures were stochastically generated in two HRD realizations. The F-ratio and the water travel time distributions were used to study the performance of the simulations. Near-field calculations were not performed for the Forsmark site using the new coded presented in the prevailing report. However, the obtained results in this study are compared with the results from the Task 2 model of the ConnectFlow report /Joyce et al. 2010/. Although the results cannot be compared directly, a reasonably good agreement is obtained for the F-ratio.

Sammanfattning

Säkerhetsanalysberäkningar har utförts för Forsmark varvid ett nytt simuleringsverktyg har använts som kopplar ihop fjärrzonskoden CHAN3D och närzonskoden NEAR3D. Mjukvarupaketet har dessutom ett grafiskt användargränssnitt (GUI) och ett program (Coupling) som hanterar simuleringarna.

Simuleringarna utfördes för 90 olika slumpvist valda kapselpositioner. Deterministiska data användes för tunnlar, deponeringshål och schakt. Bakgrundssprickorna genererades stokastiskt för två realisationer av HRD. Fördelningar av F-kvoten och gångtiden för vatten användes för att studera egenskaperna av simuleringarna. För Forsmark utfördes inte några närzonsberäkningar med det nya simuleringsverktyget som presenteras här. Resultaten i denna studie är jämförda med de från Task 2 modellen i ConnectFlow rapporten /Joyce et al. 2010/. Även om resultaten inte kan jämföras direkt så har en relativt god överensstämmelse för F-kvoten erhållits.

Contents

1 Introduction

SKB has proposed the use of a new code, which couples the far-field code CHAN3D and the new near-field code NEAR3D, for performing safety assessment calculations. In an earlier safety assessment the new code was applied to the Laxemar site. In that assessment, two deterministic cases were studied for comparison purposes, one was representing the near field and the other was representing the far field. For the far field, a stochastic case was also performed.

In the safety assessment of Laxemar, the release from the near field calculated using NEAR3D agreed very well with the releases obtained by /SKB 2006a/ (updated results). There, it was assumed that spalling exists around the deposition hole and the equivalent flowrate for Q_1 was taken to be $2.25 \cdot 10^{-4}$ m^3/y /SKB 2006a/. The values used for the other equivalent flowrates were: $1.0 \cdot 10^{-5}$ m^3/y for Q_2 and $1.94 \cdot 10^{-4}$ m^3/y for Q_3 /SKB 2006a/.

The far-field transport was addressed in two ways in the Laxemar study. First, a deterministic case, where the release from the near field, calculated by NEAR3D, was used as input to a deterministic far-field model. Thereafter, a stochastic model was set up to calculate the release from a number of canisters.

For the deterministic model, an excellent agreement between the different modelling tools was obtained. In the stochastic simulations, the F-ratio and the water travel time were used to discuss the performance of these simulations. The results compared quite well with the results from SKB /Hartley et al. 2006/ particularly in the mean values. However, the standard deviations of our results are smaller than those from SKB. For the F-ratio the standard deviation in our case was in the range 0.37–040, while in the SKB calculations /Hartley et al. 2006/ was 0.77 for the Path Q_1 and 0.97 for Path Q2. For the water travel time, the differences in standard deviation were larger. Several reasons were considered to explain these differences, but no conclusive causes were found.

The present report describes the results for the Forsmark site, and only stochastic cases are considered. This study concerns only F-ratio and water travel time distributions, and hence near-field calculations were not performed for the Forsmark site.

Data for the calculations was taken from R-09-20 /Joyce et al. 2010/ for the base case. The underlying report by /Follin et al. 2007/ adds information not transferred to the main report. Repository design data was mainly taken from R-07-33 /SKB 2007/.

1.1 Objectives

The objective of the report is to present the result of simulations calculating the release from a repository located at the Forsmark Site using the code CHAN3D. In these simulations, the F-ratio and the water travel time distributions were determined for a large number of stochastically chosen canister locations (90 canister locations). Two different HRD realizations of the background fractures were employed, but deterministic data were used for tunnels, deposition holes, and shafts. The results were compared with results from the Task 2 model of the performed ConnectFlow simulations /Joyce et al. 2010/.

CHAN3D and NEAR3D have been coupled and together they cover both the near field and the far field. In the present report, only the code CHAN3D will be used, since only the far-field release will be studied.

1.2 Approach

Earlier, the new code was validated using the conditions and data from the Laxemar site. The same or at least comparable results as obtained in SKB's previous calculations were obtained. The near field results were compared for the same input data as used in SKB's calculations. The far-field results were compared using the same input data as used in SKB's calculations.

In the present report, CHAN3D is used to generate one or more far-field realisations based on data from the Forsmark site. Water travel time and the F-ratio distributions are determined and compared to SKB results. These data are the essential underlying data needed for radionuclide transport calculations.

2 The Simulation Tools

An integrated model with capability to follow the transport of nuclides all the way from the damaged canister to the biosphere has been developed. It couples the near-field and the far-field models in a transparent and simple way. It uses reasonable computer time and all operations to transfer information are handled automatically.

The new package is based on the codes NUCTRAN /Romero et al. 1999/ for near-field calculations and CHAN3D /Gylling et al. 1999/ for far-field calculations. Since the code for the near-field calculations has been considerably modified, we preferred to use a new code name, NEAR3D. For CHAN3D the original name was kept.

These new codes have important improvements compared to the original codes. The most important improvements are:

- New algorithms have been developed in order to increase the transparency in the calculations performed with the codes.
- The memory handling has been significantly improved, in particular in the code for near-field calculations (NEAR3D)
- The flexibility of the code for the far-field calculations has also been significantly improved. At present, the code can handle several embedded fields where the properties of each field may be specified independently.
- A GUI (Graphical User Interface) has been included to aid in defining the modelled system and to generate the input data to the codes. The GUI also handles the calculations of the response curves, the breakthrough curves, and other required outputs.

The package comprises four parts: the near-field code (NEAR3D), the far-field code (CHAN3D), the coupling code (COUPLING) and the GUI (Graphical User Interface). The last routine controls the function of the other parts of the package (NEAR3D, CHAN3D, and COUPLING). The main characteristics of these elements are described in the following sections.

The presentation of the package will start with the descriptions of the codes NEAR3D and CHAN3D. The code COUPLING and the GUI will be discussed at the end, since they connect the other parts of the package.

2.1 The Near-Field Code NEAR3D

The original code (NUCTRAN) was designed specifically for the near field of a repository. The length scale of the near field is only a few tens of meters. The near field is complex both in structure and in geometry. It consists of the canister, the bentonite clay, the tunnel, the disturbed zone, the fractures intersecting the deposition hole, and nearby fractures or fracture zones.

NEAR3D calculates the release of radionuclides into the fractured rock, which is used as source term for the far-field calculations. The processes included in the model comprise radionuclide dissolution within the canister, escape of the radionuclides from the canister, diffusion in the bentonite surrounding the canister and the sand-bentonite mixture in the tunnel, advection in the fractures or fracture zones, as well as adsorption and radioactive decay.

The boundary conditions are defined as a function of the "Equivalent Flowrate", in the points were the radionuclides are released from the near field. The term Equivalent Flowrate is the flow of water that carries with it a concentration equal to that at the interface between the buffer/backfill and the seeping water /Neretnieks 1979/. It depends on several entities such as the water flowrate in the fracture, the flow porosity or fracture aperture, and the diffusion coefficient. A schematic picture of the near field is shown in Figure 2-1.

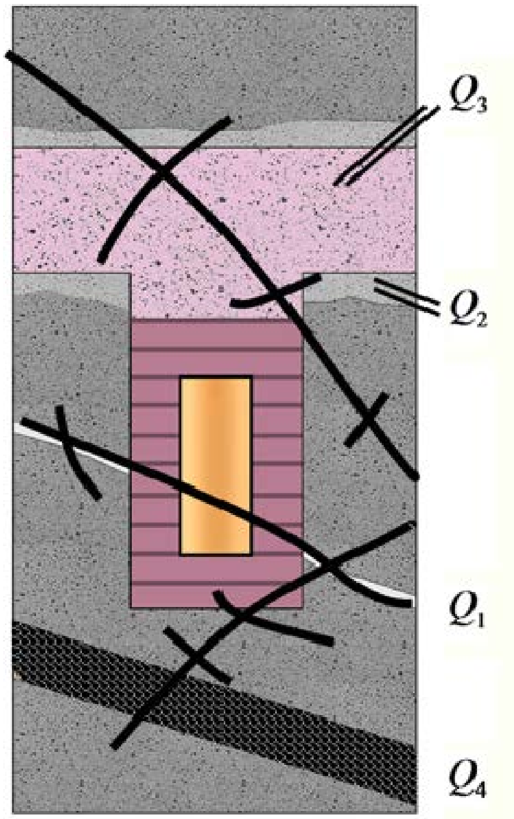

Figure 2-1. *Schematic picture of the near field showing the 4 possible release points (Equivalent flowrates).*

In the repository, radionuclides leaking out through the damaged on the canister wall diffuse into the bentonite clay and then may migrate through various pathways into the flowing water in rock fractures. Figure 2-1 shows four possible pathways: directly into a fracture intersecting the deposition hole Q_1, through the rock to a nearby fracture or fracture zone Q_4, up to the disturbed zone around the tunnel Q_2, into the tunnel backfill and further to a fracture (zone) intersecting the tunnel Q_3.

NEAR3D uses a compartment concept. Compared to other codes, based on finite elements or other techniques, the system in NEAR3D is divided into a smaller number of compartments (15–20 compartments), in order to calculate radionuclide transport. The smaller numbers of compartments is made possible by using analytical expressions in some critical points where other codes typically use a very fine discretization. The transient advection-dispersion equation including radioactive chain decay is applied within each compartment.

2.1.1 The main improvements in the new code NEAR3D

The original code (NUCTRAN) was significantly improved, in particular to increase its transparency and decrease the use of memory. The most important improvements are:

- The new code considers all isotopes to determine the nuclide solubilities. Therefore a general expression is used for all of the radionuclides, which considers the fraction of the nuclides embedded in the fuel matrix, the fraction that has precipitated, and the fraction that is dissolved in the solution. Knowing the concentrations in each of these fractions at a given time step, the value at the following time step can be calculated. In the original code several subroutines were required for the same task.
- The memory usage has been reduced considerably. The new code handles systems with a large number of compartments and radionuclides. Taking into account the connection between compartments in a more efficient way does this. No large matrices are used to define the connection between compartments, since they are defined directly.

2.2 The Far Field Code CHAN3D

As indicated above, the code used for the far-field calculations is based on CHAN3D /Gylling et al. 1999/, which is an implementation of the Channel Network Model /Moreno and Neretnieks 1993/. The model assumes that fluid flow takes place in a network of interconnected flow channels in the rock. Each member of the channel network is assigned a hydraulic conductance. This is the only entity required to calculate the flow. Conductances together with boundary conditions determine the pressures/head field and the flows in the system. A schematic picture of the network is shown in Figure 2-2.

In CHAN3D, a cubic grid is used for illustration purposes. In reality, the channels can have orientations that are not aligned with the regular grid. In addition, the channels can have different lengths. Up to six channels can meet at a grid point. Not all channels must be hydraulically conductive. The transmissivity distribution, the channel density, and flow-wetted surface of the rock are chosen so that they agree with field observations.

The model considers solute transport in a suite of single channels. Each channel has a rock matrix of a given thickness on each side, into which the radionuclides may diffuse and be adsorbed. The model includes advective flow in channels, linear sorption on the fracture surfaces, diffusion into the rock matrix and linear sorption onto micro-surfaces within the rock matrix. Radioactive chain decay is also included. The solution for each path is calculated in Laplace space. To obtain breakthrough curves, the solution is numerically inverted in Laplace space.

The main improvements in the current CHAN3D code are:

- Chain decay is included in the model.
- The code may handle a large number of embedded fields (rock domains), where each field may represent different characteristics, e.g., hydraulic conductivities, channel lengths, flow wetted surfaces, sorption properties, etc. This provides great flexibility to the new code and allows descriptions of complex situations.
- Memory usage is made more efficient. The code runs easily on a normal laptop for systems of 10^6 channel intersections. This is due to a new description of the connections between channels and intersection points.

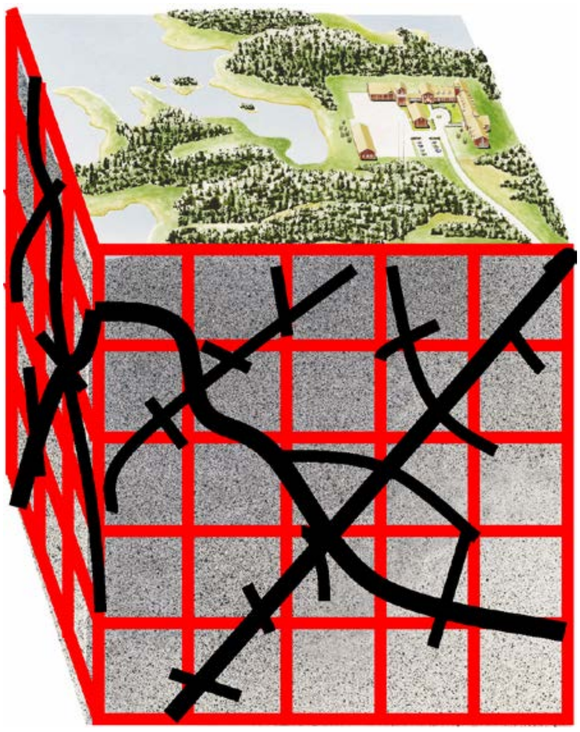

Figure 2-2. *Schematic picture of the channel network used to describe the modelled system.*

The main task is concentrated in the flow part of CHAN3D. The most important input data are the conductances of the channels forming the network and the boundary conditions. This requires a large amount of information; e.g., the geometry and hydraulic properties of the features found in the volume of rock modelled. This includes information about fracture zones, main tunnels, deposition tunnels, excavation disturbed zones (EDZ), shafts, etc. These features are then mapped onto the channel network. Finally, the stochastic properties of the background channels are needed.

Once the conductances of all the channels are specified, deterministically or stochastically generated, the pressure field is calculated for the assigned boundary conditions. The linear system of equations is solved by using a standard solver for sparse matrices. When the pressure field is calculated, the flowrate field is determined.

A particle tracking method is used in the transport part to determine the different paths from the damaged canister to the biosphere. Properties of the channels through which the particles travel are also recorded. The sum of the tracer residence times in each channel and the sum of the ratio of flow-wetted surface to flowrate in each channel (so-called F-ratio) are used to describe the retardation in the matrix. In many cases, an infinite matrix is used. However, if the matrix thickness is finite an additional entity is needed; the matrix thickness.

2.3 The COUPLING code

The main function for this code (COUPLING) is to control the program execution. Each of the codes NEAR3D and CHAN3D, is run only once for each call. Therefore the requirements of memory for save intermediate results are eliminated. A typical simulation arrangement could be CHAN3D-flow, CHAN3D-transport, and NEAR3D, but other sequences are also possible.

The most important function of the code is to handle the calculations of the radionuclide release to the recipient e.g. the ground surface. This is done firstly by calculating the response for each path starting from the same location; e.g. the paths starting at Q_1; the fracture intersecting the deposition hole. This response is calculated by using the residence time for the specific path and the F-ratio. The calculations are done by numerical inversion of the Laplace transform. Once the responses for all paths are known they can be added to get the response corresponding to all paths starting from a given location (in this case; Q_1). The same procedure is used to calculate the responses for the paths starting at the other locations, e.g., Q_2 and Q_3.

Now, the response for paths starting from a given location is coupled to the nuclide release at that location and the breakthrough curves for all paths starting from that location is determined. The same procedure is done for the other paths. Once the breakthrough curves for the paths starting at Q_1, Q_2, and Q_3 are known, the radionuclide release from that canister into the biosphere can be calculated.

2.4 The Graphical User interface

The Graphical User Interface (GUI) consists of three panels. The first is the control panel where one can select or specify the tasks one wish to perform, such as defining the near field, the far field, the fractures, the repositories, the nuclides, the materials, etc. Then one chooses to run the near and far-field models separately or coupled. The second panel is the work panel, where dialogues are used to specify the input data and the plotting of simulation results. The third panel is the note panel that gives information about which task is being performed. The GUI is shown in Figure 2-3.

The main functions of the GUI are to:

- Help the user to create the input data for the near and far-field models (NEAR3D and CHAN3D) and also for the COUPLING code.
- Use the results from the simulations to prepare the output data. These data comprise release curves, distribution of the F-ratio and tracer residence times, and other required output data.

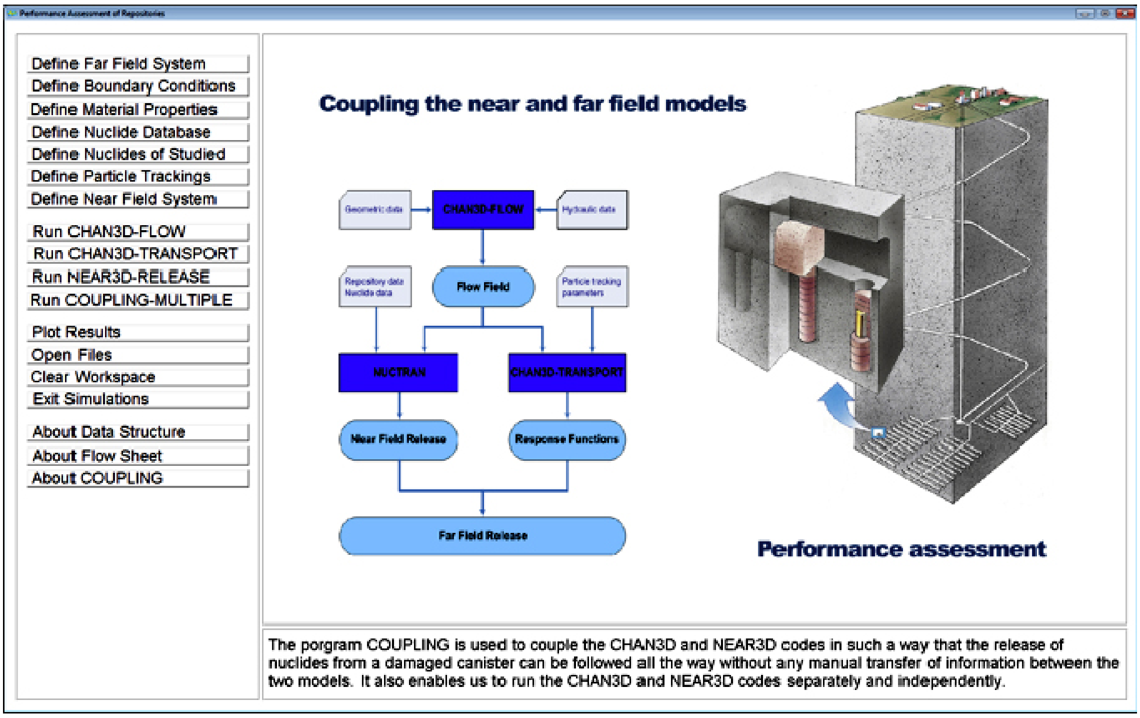

Figure 2-3. *The Graphical User Interface, GUI.*

The data used for both NEAR3D and CHAN3D are generated by the GUI. The user has to provide the GUI with all the data required to create the input data. These include, e.g.:

- The geometry of the system
- The radionuclides or chains to be modelled
- The initial damage in the canister, initial size, growth rate, time for collapse
- Fuel dissolution rate
- Flowrate in the tunnel

Nuclide specific data is also included in the model. These data are available from the GUI, but they can be modified if needed.

The user has to choose what output data and what kind of plots that are desired. There are a lot of alternatives available.

3 Release from the Far Field

Since the objective of this study is solely to address the far field, the results are studied by means of the F-ratio and the water travel time distributions. As a platform for this, a large-scale model is set up using data from Forsmark to calculate the properties of the release paths from a number of canisters. Here, conditions from the reference case in /Joyce et al. 2010/ are used. A summary of the site description of Forsmark can be found below.

According to the data report /SKB 2010a/, the following flow related performance measures are requested for deposition hole locations within the repository:

- Darcy flux q (m/yr) for the Q1, Q2, and Q3 release paths. Also equivalent flow rates Q_{eq} (m^3/year) corresponding to the Q1, Q2, and Q3 release paths (Q_{eq1}, Q_{eq2}, and Q_{eq3}) are needed, which in turn are related to the groundwater flow rates for the Q1, Q2, and Q3 release paths.
- Recharge and discharge coordinates in the biosphere along flow paths from the Q1, Q2, and Q3 release paths.
- Advective travel time t_w (yr) along flow paths to the recharge and discharge locations for the Q1, Q2, and Q3 release paths.
- Flow related transport resistance F (yr/m) along flow paths to the recharge and discharge locations for the Q1, Q2, and Q3 release paths.

In the prevailing report, advective travel times (yr) and the flow related transport resistance F values (yr/m) are calculated for release paths Q1 and Q2.

3.1 Summary of the site description of Forsmark

This section is a summary of the site description of Forsmark that is reported in /Follin 2008/. The Forsmark area is located in northern Uppland within the municipality of Östhammar, about 120 km north of Stockholm (Figure 3-1). The candidate area for site investigation is located south-east of the Forsmark nuclear power plant. It is approximately 6 km long and 2 km wide. The north-western part of the candidate area was selected as the target area for the complete site investigation work which is shown in Figure 3-2.

The Forsmark area consists of crystalline bedrock that belongs to the Fennoscandian Shield, one of the ancient continental nuclei on the Earth. It has been affected by both ductile and brittle deformation. The ductile deformation has resulted in large-scale, ductile high-strain belts and more discrete high-strain zones. Tectonic lenses, in which the bedrock is less affected by ductile deformation, are enclosed between the ductile high strain belts. The candidate area is located in the north-westernmost part of one of these tectonic lenses. This lens extends from north-west of the nuclear power plant south-eastwards to the area around Öregrund (Figure 3-3). The brittle deformation has given rise to reactivation of the ductile zones in the colder, brittle regime and the formation of new fracture zones with variable size.

The current ground surface in the Forsmark region forms a relatively flat topographic surface with a gentle dip towards the east. The candidate area at Forsmark is characterised by a small-scale topography at low altitude (Figure 3-4). The most elevated areas to the south-west of the candidate area are located at about 25 m above current sea level (datum RHB 70). The whole area is located below the highest coastline associated with the last glaciation and large parts of the candidate area emerged from the Baltic Sea only during the last 2,000 years. Both the flat topography and the still ongoing shore level displacement of about 6 mm per year strongly influence the current landscape (Figure 3-4). Sea bottoms are continuously transformed into new terrestrial areas or freshwater lakes, and lakes and wetlands are successively covered by peat.

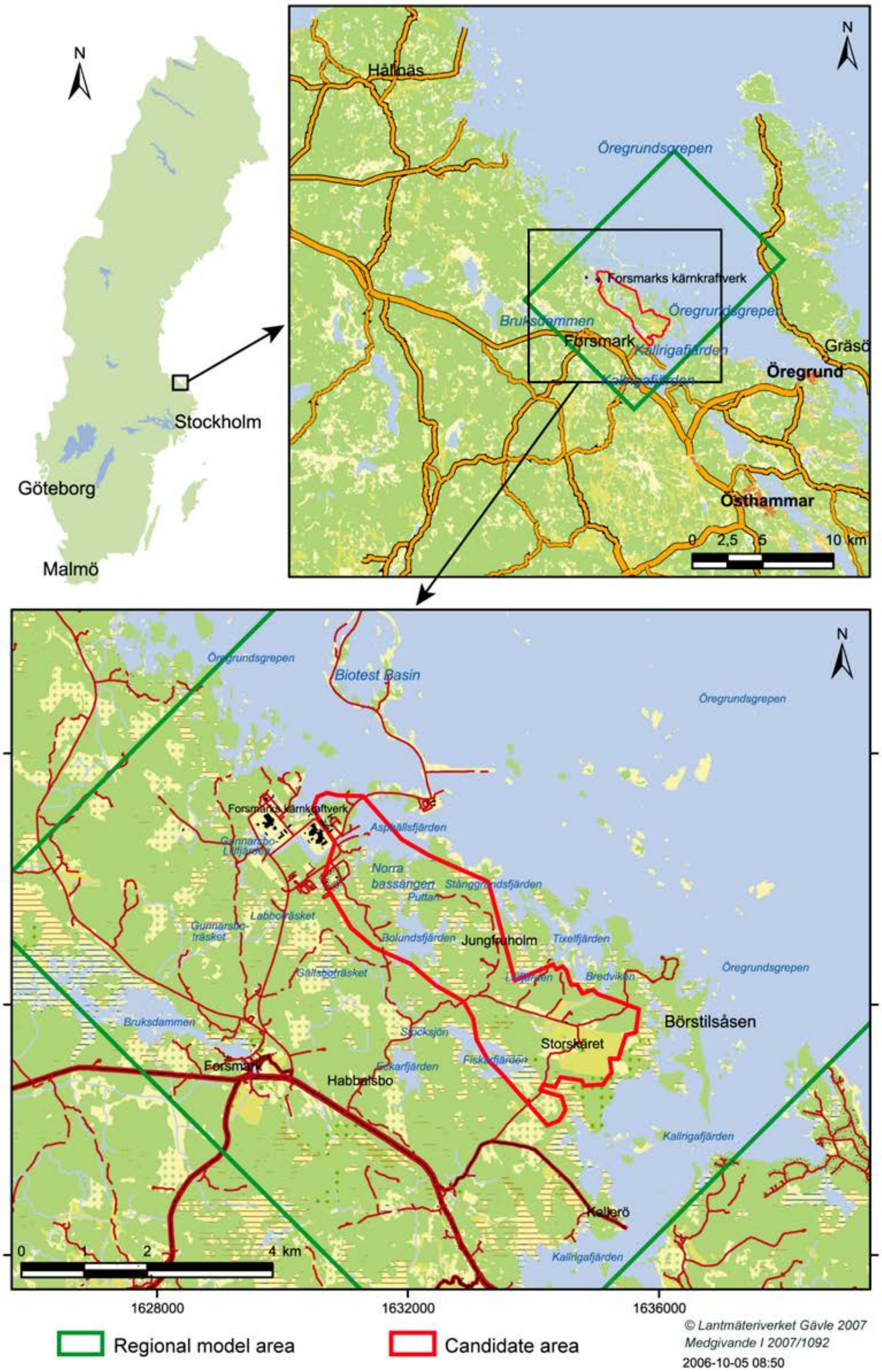

Figure 3-1. *The red polygon shows the size and location of the Forsmark candidate area for site investigation. The green rectangle indicates the size and location of the associated regional model area /SKB 2008, Figure 1-3/.*

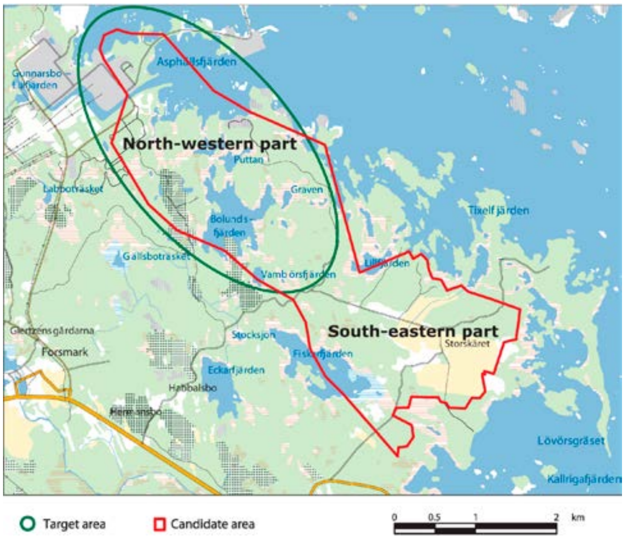

Figure 3-2. *The north-western part of the candidate area was selected as the target area for the complete site investigation work. Modified after /SKB 2008, Figure 2-15/.*

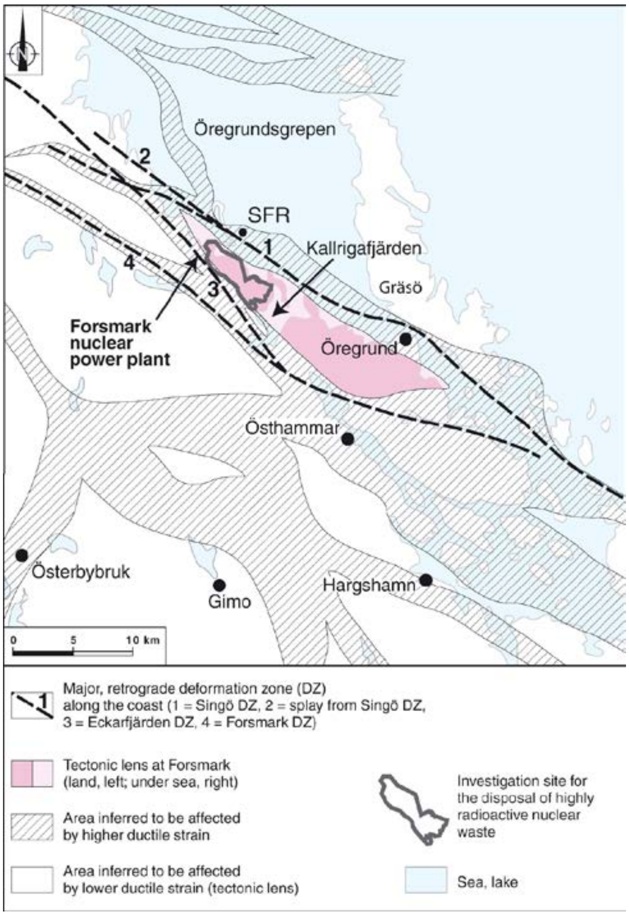

Figure 3-3. *Tectonic lens at Forsmark and areas affected by strong ductile deformation in the area close to Forsmark /Stephens et al. 2007, Figure 4-1/.*

Figure 3-4. *Photos from Forsmark showing the flat topography and the low-gradient shoreline with recently isolated bays due to land uplift /Follin 2008, Figure 1-7/.*

3.1.1 Summary of the hydrogeological model

The bedrock in the Forsmark area has been thoroughly characterised with both single-hole and cross-hole (interference) tests. Constant-head injection tests and difference flow logging pumping tests have been used in parallel to characterise the fracture properties close to the boreholes, and interference tests have been used for larger-scale studies. The overall experience from these investigations is that spatial variability in the structural geology significantly affects the bedrock hydrogeology and associated hydraulic properties at all depths. There is a considerable depth trend in deformation zone transmissivity and in the conductive fracture frequency in the bedrock between the deformation zones, where the uppermost part of the bedrock is found to be significantly more conductive than the deeper parts. In conclusion, the strong contrasts in the structural-hydraulic properties with depth encountered inside the target volume suggest a hydraulic phenomenon that causes a short circuit of the near-surface groundwater flow system. The short circuit phenomenon probably contributes to the observed slow transient evolution of fracture water and porewater hydrochemistry at repository depth, although the slow evolution is mainly due to the very low permeability at these depths.

In the site descriptive modelling of Forsmark, it is common to divide the rock into two hydraulic domains (see e.g. /Follin 2008/):

- HCD (Hydraulic Conductor Domain) represents deformation zones, and
- HRD (Hydraulic Rock Domain) represents the less fracture rock in between the deformation zones.
- The HRD can in turn be divided into fracture domains denoted by FFM in Forsmark. The fracture domains are defined in the geological DFN modelling based on spatial differences in the fracture frequency of all fractures.

3.1.2 The hydraulic conductor domain (HCD)

The following hydrogeological model has been suggested for the deterministically modelled deformation zones (Figure 3-5):

- The geological division of the deterministically modelled deformation zones into major sets and subsets is useful from a hydrogeological point of view. Most of these structural entities are steeply dipping and strike WNW-NW, NNW and NNE-NE-ENE; one is gently dipping (denoted by G in Figure 3-5).
- All deformation zones, regardless of orientation (strike and dip), display a substantial decrease in transmissivity with depth. The data suggest a contrast of about 20,000 times in the uppermost one kilometre of the bedrock, i.e. more than four orders of magnitude. There is a lack of hydraulic data below this depth (Figure 3-6).
- The lateral heterogeneity in transmissivity is also substantial (a few orders of magnitude) but more irregular in its appearance.
- The highest transmissivities within the candidate area, regardless of depth, were found among the gently dipping deformation zones. The steeply dipping deformation zones that strike WNW and NW have, relatively speaking, higher mean transmissivities than steeply dipping deformation zones in other directions.

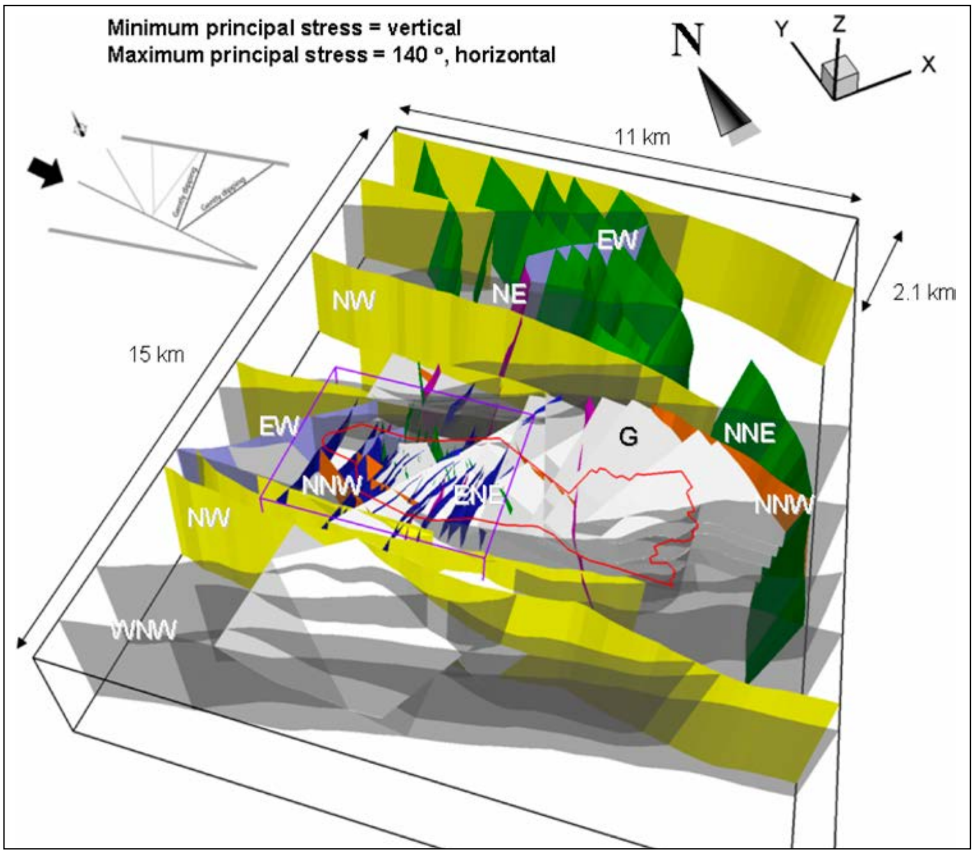

Figure 3-5. *3D visualisation of the regional model domain and the 131 deformation zones modelled deterministically for Forsmark stage 2.2. The steeply dipping deformation zones (107) are shaded in different colours and labelled with regard to their principle direction of strike. The gently dipping zones (24) are shaded in pale grey and denoted by a G. The border of the candidate area is shown in red and regional and local model domains in black and purple, respectively. The inset in the upper left corner of the figure shows the direction of the main principal stress /Follin 2008, Figure 3-4/.*

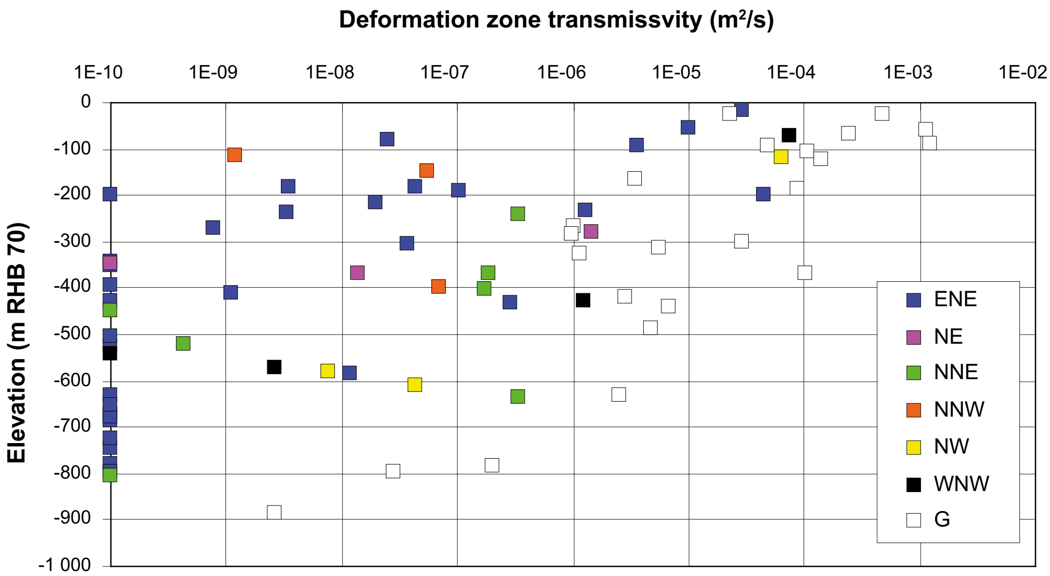

Figure 3-6. *Transmissivity data versus depth for the deterministically modelled deformation zones. The transmissivities are coloured with regard to the orientations of the deformation zones, where G means gently dipping. The deformation zones with no measurable flow are assigned an arbitrary low transmissivity value of $1 \cdot 10^{-10}$ m²/s in order to make them visible on the log scale /Follin 2008, Figure 5-1/.*

3.1.3 The Hydraulic Rock Domain (HRD)

The following hydrogeological model has been suggested by /Follin 2008/ for the fractured bedrock between the deterministically modelled deformation zones (Figure 3-7 and Figure 3-8):

- The bedrock between the deterministically modelled deformation zones is divided into six fracture domains, FFM01-06, and five fracture sets, NS, NE, NW, EW and HZ. This geological division is useful from a hydrogeological point of view.
- Since the conductive fracture frequency shows very strong variations with depth, the adopted discrete network model for the conductive fractures, within the target volume, splits into three layers; above 200 m depth, between 200 and 400 m depth, and below 400 m depth.
- The hydraulic character of the fracture domains is dominated by the gently dipping HZ fracture set, and with only a small contribution from the steeply dipping NS and possibly NE fracture sets. However, the depth trend in fracture transmissivity for the fracture domains is not as conclusive as for the deformation zones.
- The sparse number of steeply dipping flowing features at depth within the target volume suggests that fractures associated with the gently dipping HZ fracture set may be fairly long (large) in order to form a sufficiently connected network.

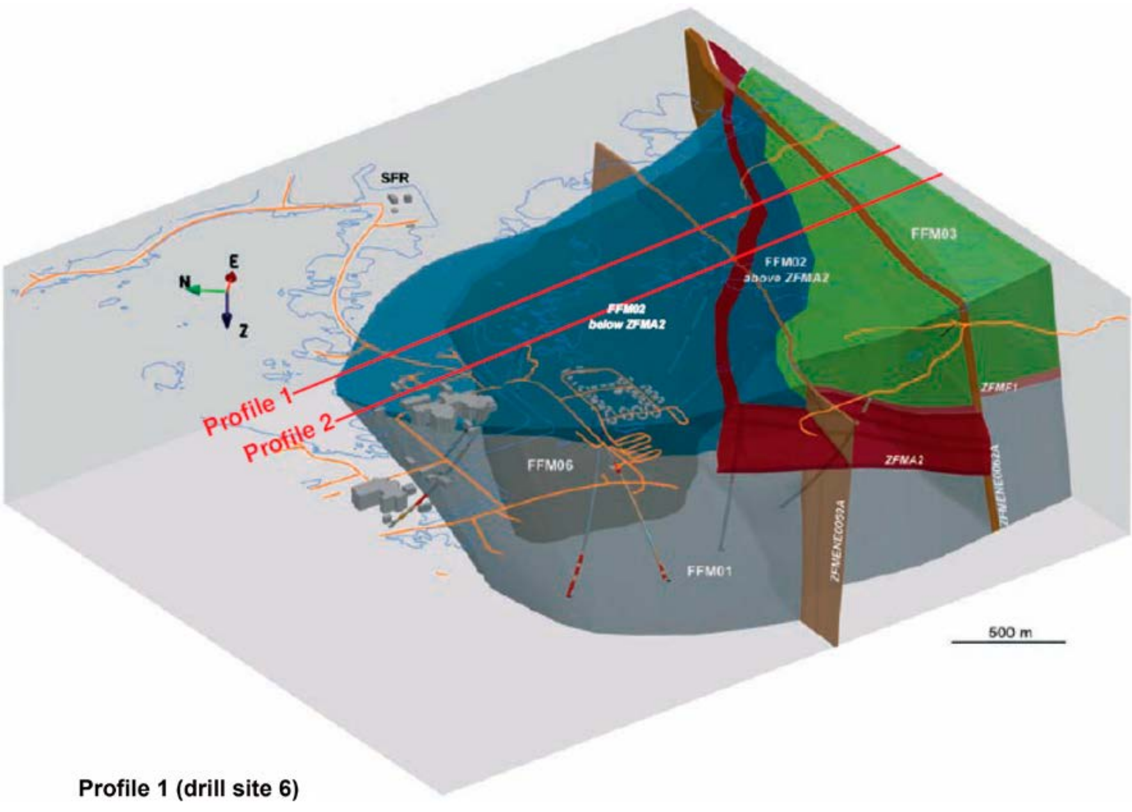

Figure 3-7. Three-dimensional view to the east-north-east showing the relationship between the gently dipping deformation zone A2 (red) and fracture domain FFM02 (blue). Fracture domains FFM01, FFM03 and FFM06 are coloured grey, green, and dark grey, respectively. The sub-horizontal zone F1 as well as the steeply dipping deformation zones ENE0060A and ENE0062A are also shown. Profile 1 and 2 are shown as cross-sections in Figure 3-8 /Follin 2008, Figure 3-11/.

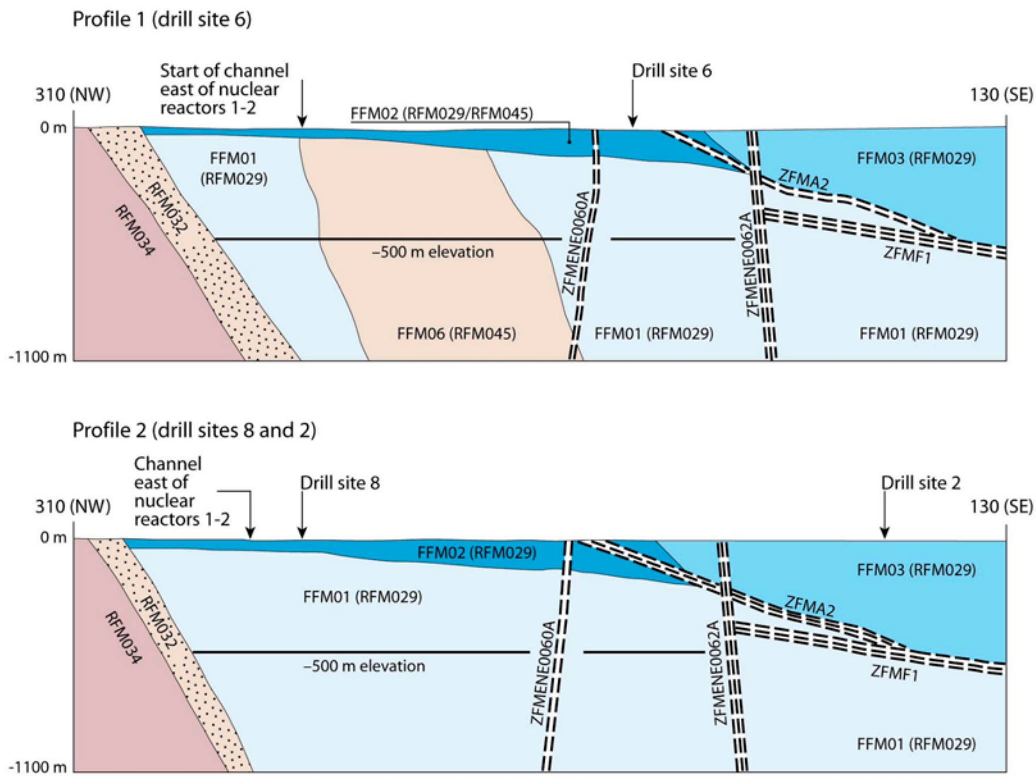

Figure 3-8. *Simplified profiles in a NW-SE direction that pass through the target volume. The profiles are shown in Figure 3-7. The key fracture domains, FFM01, -02 and -06, for a final repository at Forsmark occur in the footwall of zones A2 (gently dipping) and F1 (sub-horizontal). The major steeply dipping zones ENE0060A and ENE0062A are also included in the profiles /Olofsson et al. 2007, Figure 5-4/.*

3.1.4 The target volume

The cross-section in Figure 3-9 summarises the key components of the conceptual model of the bedrock hydrogeology in the target volume at Forsmark:

- The flow at repository depth in fracture domains FFM01 and FFM06 is probably channelized in the sparse network of connected fractures, **D**, which is dominated by two fracture sets, HZ and NE. The HZ fracture set is interpreted to be longer and probably more transmissive than the NE set.
- **D** connects to **A** and **C**, where **A** represents the steeply dipping NNE-ENE deformation zones, which are abundant but hydraulically heterogeneous, and **C** represents the intensely fractured fracture domain FFM02, which lies on top of **D**.
- The groundwater flow in **C** is dominated by the HZ fracture set, which occurs with a high frequency. More importantly, **C** is intersected by several extensive, horizontal fractures/sheet joints, **B** (Figure 3-10), which can be very transmissive.
- **B** and **C** and the outcropping parts of **A** probably form a shallow network of water flowing fractures. The network is interpreted to be highly anisotropic, structurally and hydraulically. Together with **D**, which is close to the percolation threshold (critical value to create a continuous path), the network creates a hydrogeological situation that is referred to as a shallow bedrock aquifer on top of a thicker bedrock segment with aquitard type properties.

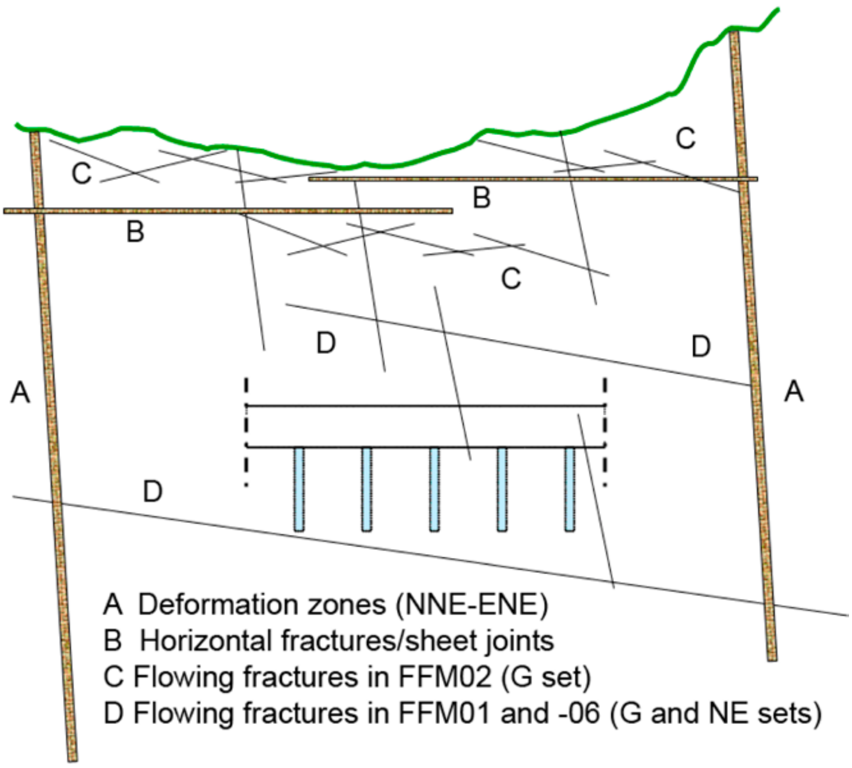

Figure 3-9. *A two-dimensional representation facing NE that summarises the hydrogeological conceptual model of the bedrock within the target volume at Forsmark /Follin 2008, Figure 10-3/.*

Figure 3-10. *Picture from the construction of the 13 m deep and more than one kilometre long canal between the Baltic Sea and the nuclear power reactors in Forsmark. Horizontal fractures/sheet joints are encountered along the entire excavation. The sheet joints follow the undulations of the bedrock surface implying that many of them do not outcrop, but stay below the bedrock surface as this dips under the Baltic Sea. There are several "horizons" of extensive sheet joints on top of each other according to the hydraulic interference tests /Follin 2008, Figure 5-14/.*

3.2 Stochastic simulations

In this simulation task, we have tried to adopt the conditions used in the reference case of SR-Site Forsmark /Joyce et al. 2010/ that are summarised above. The following items were considered:

1. Conductivities for fracture zones and their depth dependency /Follin et al. 2007/.
2. Fracture distribution data for the background rock /Follin et al. 2007, Rhén et al. 2009, Joyce et al. 2010/.
3. Boundary conditions, trying to mimic what was used in the SR-Can Forsmark model /Follin et al. 2007/.
4. Repository design data /SKB 2007, 2010b, c/.

Information regarding these points is given below.

3.3 Data for far-field calculation

The bedrock hydrogeological model addresses the hydraulic properties of the target volume and its boundaries. The structural segments treated in stage 2.2 are /Follin et al. 2007/:

1. The deterministically modelled deformation zones within the candidate area.
2. The superficial bedrock above repository depth (FFM02).
3. The bedrock bordering the target volume (FFM04–05).
4. The bedrock at repository depth (FFM01 and FFM06).

The fracture zones are described in a file that is very similar to what was used in the ConnectFlow model. Since the geometries of the different HRD volumes are rather complicated they were simplified in this study. The boundary condition file is identical.

3.3.1 Transmissivity distribution for fracture zones

Information on T-values and widths of fracture zones are available. Information on depth dependency of T for zones and standard deviation of T are also available. Based on this information, an input file was created with the same properties as the input used in hydrological modelling for SR-Site /Joyce et al. 2010/.

3.3.2 Hydraulic Rock Domains

Since the geometries of the different HRD volumes are rather complicated they were simplified in this study. In SR-Site the volumes for the different rock types are described by voxel data i.e. volumetric pixel data. The properties for the different rock domains are obtained by up scaled DFN simulations /Rhén et al. 2009/. In general there is a change in the hydraulic properties at 200 and 400 m below sea level. /Follin et al. 2007, p 66/ gives illustrations of FFM01-6. More details about the hydraulic rock domains are given in Appendix A.

The HRD correspond to the six defined fracture domains, FFM01–FFM06, together with the remaining rock for which there is no borehole information. Each finite-element with the ECPM is assigned to one of the FFM or the remaining rock based on a 3D geological model, as illustrated in Figure 3-11.

Upscaling the Hydrogeological DFN to an ECPM

The power-law fracture size distribution and fracture transmissivity distribution parameters derived through the calibration /Joyce et al. 2010/ to measured data are intended for use in modelling flow and transport using a DFN concept. However, much of the hydro-geological modelling for Forsmark uses equivalent porous continuum medium (ECPM) modelling based on up scaling the underlying

DFN model. In the upscaling methodology, a model containing stochastically generated fractures based on the calibrated hydrogeological DFN (Hydro-DFN) parameters can be converted to a model with equivalent block properties.

The up scaling methodology produces a directional hydraulic conductivity tensor, fracture kinematic porosity and other transport properties (such as the connected fracture surface area per unit volume). In ConnectFlow a flux-based upscaling method is used that requires several flow calculations through a DFN model in different directions.

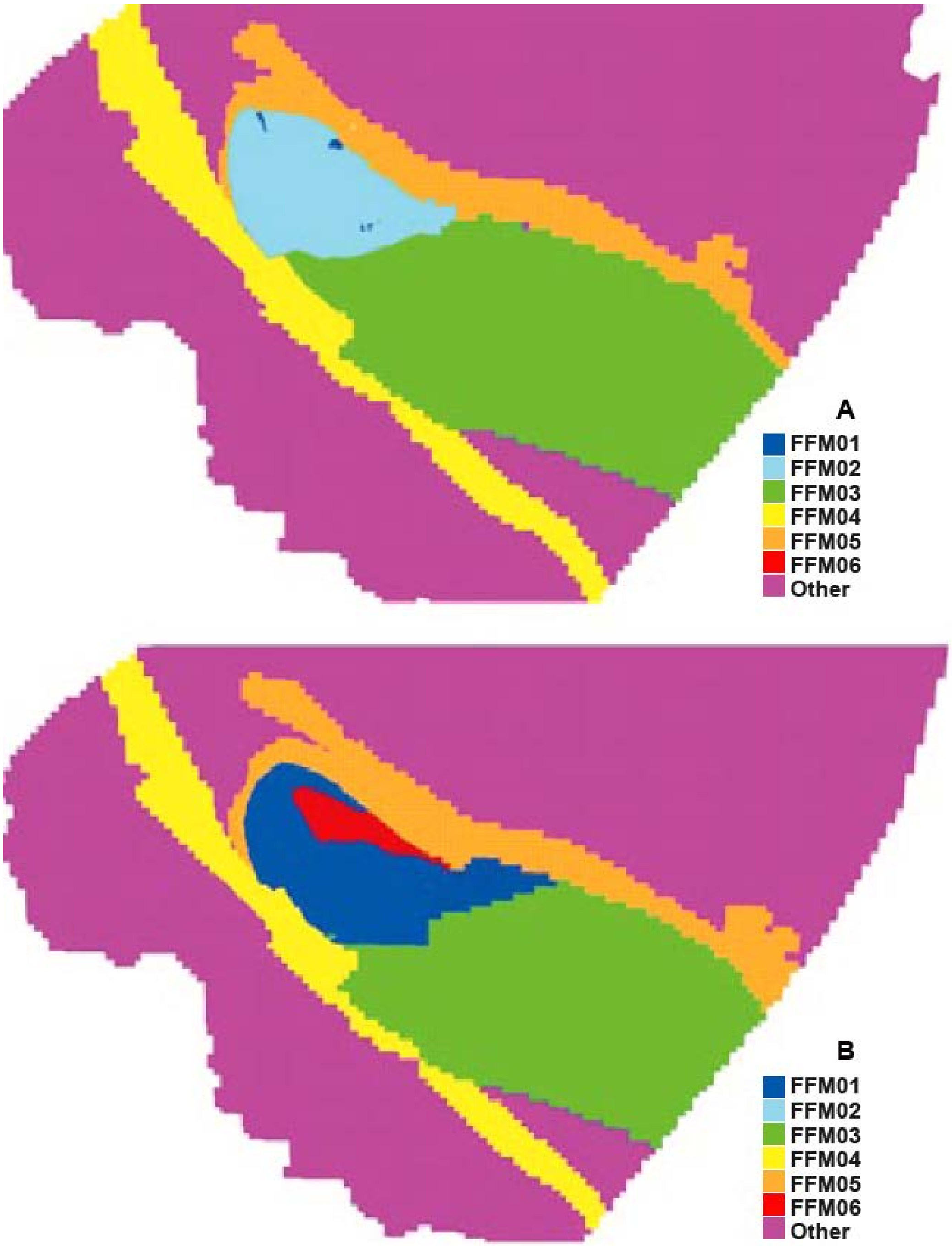

Figure 3-11. *The implementation of fracture domains, FFM01–FFM06 in the ECPM model. Horizontal slices through the fracture domains are shown at –30 m RHB 70 (a) and at –500 m RHB 70 (b). Only the southern half of the regional model is shown. Definitions of the fracture domain volumes were supplied on a 20 m regular grid within the local model area and on a 100 m grid elsewhere /Follin et al. 2007, Figure 3-39/.*

The use of a 'guard-zone' is a refinement of the up scaling methodology. The aim is to simulate flow through a slightly larger domain than the block size required for the ECPM properties, and then calculates the flux responses through the correct block size. The reason for this is to avoid over-prediction of hydraulic conductivity from flows through fractures that just cut the corner of the block but that are unrepresentative of flows through the in situ fracture network. The use of a guard-zone can reduce the calculated hydraulic conductivity of a block significantly. The sensitivity of the regional and block up scaling results to the use of a guard-zone are considered in Appendix 7 of /Rhén et al. 2009/.

The results of the up scaling calculations on the block scale are displayed in Figure 3-12 and Figure 3-13. The results of the regional upscaling are shown in Table 3-1. The effect of including a guard zone in the calculations is to reduce the hydraulic conductivities by up to a factor of 3. The variation in hydraulic conductivities between blocks is also increased, while the percentage of blocks that are hydraulically active is decreased. These effects are less pronounced in the results of up scaling the regional model compared to the block models due to a smaller guard zone being used. This was necessary in order to make the calculations tractable.

Table 3-1. A comparison of 20 m upscaling results for one realization of the Forsmark regional DFN model, with and without a guard zone. /Rhén et al. 2009, Appendix 7/. The data without a guard zone was used in the simulations. The numbers in the columns denoted "% active" is the percentage of blocks that are hydraulically active.

	Using a guard zone (10 m) Log$_{10}$ Hydraulic conductivity (m/s)			Without a guard zone Log$_{10}$ Hydraulic conductivity (m/s)		
	mean K_{eff}	std K_{eff}	% active	mean K_{eff}	std K_{eff}	% active
FFM01						
0 to –200 m.a.s.l.	–7.96	1.18	62.8%	–7.92	1.08	86.1%
–200 to –400 m.a.s.l.	–9.45	1.01	54.3%	–9.47	0.96	77.9%
–400 to –1,000 m.a.s.l.	–10.45	1.05	17.7%	–10.67	1.01	30.1%
FFM02						
0 to –200 m.a.s.l.	–8.51	0.99	84.1%	–8.22	0.84	97.3%
–200 to –400 m.a.s.l.	–8.69	0.99	79.0%	–8.29	0.79	96.8%
FFM03						
0 to –200 m.a.s.l.	–8.96	0.87	58.6%	–8.91	0.82	82.1%
–200 to –400 m.a.s.l.	–8.88	0.82	57.5%	–8.85	0.79	81.1%
–400 to –1,000 m.a.s.l.	–9.21	0.78	32.1%	–9.18	0.75	57.2%
FFM04						
0 to –200 m.a.s.l.	–8.74	0.83	59.3%	–8.67	0.81	81.0%
–200 to –400 m.a.s.l.	–8.62	0.79	55.3%	–8.60	0.78	79.6%
–400 to –1,000 m.a.s.l.	–8.76	0.70	37.6%	–8.84	0.68	59.9%
FFM05						
0 to –200 m.a.s.l.	–8.86	0.92	60.3%	–8.82	0.87	83.5%
–200 to –400 m.a.s.l.	–8.82	0.86	53.8%	–8.84	0.83	77.2%
–400 to –1,000 m.a.s.l.	–8.98	0.73	39.6%	–9.06	0.71	60.4%
FFM06						
0 to –200 m.a.s.l.	–7.62	1.36	64.2%	–7.66	1.22	87.6%
–200 to –400 m.a.s.l.	–9.49	1.07	48.2%	–9.51	1.01	75.2%
–400 to –1,000 m.a.s.l.	–10.53	0.98	19.6%	–10.74	0.96	33.0%

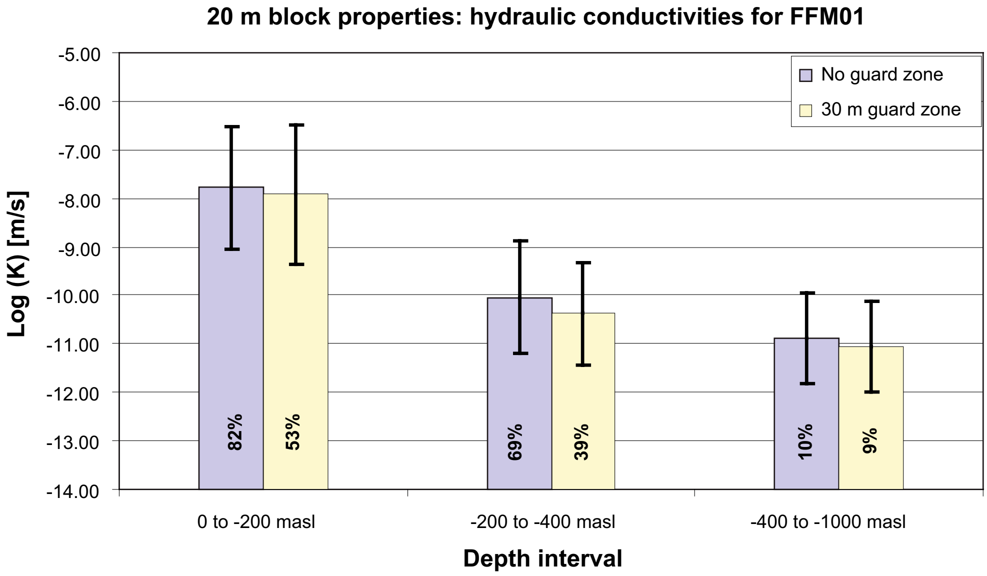

Figure 3-12. *Bar diagram comparing 20 m block–scale hydraulic conductivities by depth zone, using a guard-zone of 30 m around the block and without a guard zone. The DFN model used is for FFM01, semi-correlated transmissivity model. The height of the column is the mean Log (hydraulic conductivity) of the blocks that are hydraulically active. The error bars are the standard deviation of Log (hydraulic conductivity) of the blocks that are hydraulically active. The number in each column is the percentage of blocks that are hydraulically active in 3D /Rhén et al. 2009, Appendix 7/.*

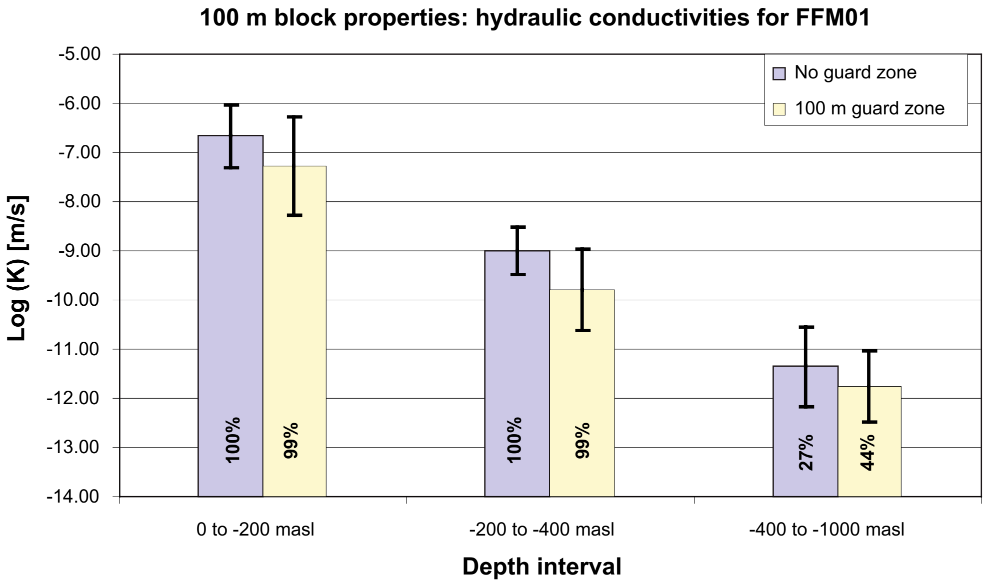

Figure 3-13. *Bar diagram comparing 100 m block-scale hydraulic conductivities by depth zone, using a guard-zone of 100 m around the block and without a guard zone. The DFN model used is for FFM01, semi-correlated transmissivity. The height of the column is the mean Log (hydraulic conductivity) of the blocks that are hydraulically active. The error bars are the standard deviation of Log (hydraulic conductivity) of the blocks that are hydraulically active. The number in each column is the percentage of blocks that are hydraulically active in 3D /Rhén et al. 2009, Appendix 7/.*

Flow porosity values for the HRDs, FFM01–FFM06, are shown in Table 3-2. The homogeneous hydrogeological properties used outside the FFM are shown in Table 3-3. These are based on Table 3-6 in /Follin et al. 2007/. The flow-wetted surface area used in the SR-Site ConnectFlow modelling for transport calculations is shown in Table 3-4. Flow wetted surface is estimated as 2×P32, and the P32 values are taken from one realisation of the up scaled Hydro-DFN. P32 is the volumetric fracture intensity, i.e. the total fracture surface area per cubic metre of rock (m^2 m^{-3}).

Table 3-2. Statistics of flow porosity for HRD FFM01–FFM06 /Joyce et al. 2010/.

Domain Dept zonation	Without a guard zone Log_{10} Flow porosity (–) mean Phi	std Phi	% active
FFM01			
0 to –200 m.a.s.l.	–3.56	0.58	86.1%
–200 to –400 m.a.s.l.	–4.25	0.41	77.9%
–400 to –1,000 m.a.s.l.	–4.55	0.34	30.1%
FFM02			
0 to –200 m.a.s.l.	–3.66	0.44	97.3%
–200 to –400 m.a.s.l.	–3.71	0.42	96.8%
FFM03			
0 to –200 m.a.s.l.	–4.08	0.42	82.1%
–200 to –400 m.a.s.l.	–4.05	0.41	81.1%
–400 to –1,000 m.a.s.l.	–4.24	0.37	57.2%
FFM04			
0 to –200 m.a.s.l.	–3.97	0.43	81.0%
–200 to –400 m.a.s.l.	–3.95	0.43	79.6%
–400 to –1,000 m.a.s.l.	–4.11	0.39	59.9%
FFM05			
0 to –200 m.a.s.l.	–4.03	0.44	83.5%
–200 to –400 m.a.s.l.	–4.05	0.42	77.2%
–400 to –1,000 m.a.s.l.	–4.20	0.38	60.4%
FFM06			
0 to –200 m.a.s.l.	–3.44	0.66	87.6%
–200 to –400 m.a.s.l.	–4.27	0.42	75.2%
–400 to –1,000 m.a.s.l.	–4.57	0.33	33.0%

Table 3-3. Homogeneous hydrogeological properties used outside the FFM based on Table 3-6 in /Follin et al. 2007/.

Elevation (m RHB 70)	K (m/s)	Kinematic porosity
FFM Other		
0 to –40 m.a.s.l.	$1\cdot10^{-6}$	$1\cdot10^{-5}$
–40 to –200 m.a.s.l.	$1\cdot10^{-7}$	$1\cdot10^{-5}$
–200 to –400 m.a.s.l.	$1\cdot10^{-8}$	$1\cdot10^{-5}$
Below –400 m.a.s.l.	$3\cdot10^{-9}$	$1\cdot10^{-5}$

Table 3-4. The used flow-wetted surface area in the SR-Site ConnectFlow modelling for transport calculations. Flow wetted surface (FWS) is estimated as 2×P32, and the P32 values are taken from one realisation of the upscaled HydroDFN /Joyce et al. 2010/.

	Flow wetted surface (m^2/m^3)		
	mean FWS	std FWS	Count
FFM01			
0 to –200 m.a.s.l.	0.1798	0.1367	26,589
–200 to –400 m.a.s.l.	0.1566	0.1216	68,487
–400 to –1,000 m.a.s.l.	0.0859	0.0815	59,092
Below –1,000 m.a.s.l.	0.0859	0.0815	59,092
FFM02			
0 to –200 m.a.s.l.	0.2676	0.1565	53,024
–200 to –400 m.a.s.l.	0.2616	0.1513	2,427
–400 to –1,000 m.a.s.l.	–	–	–
FFM03			
0 to –200 m.a.s.l.	0.1042	0.0394	5,791
–200 to –400 m.a.s.l.	0.1600	0.1237	19,930
–400 to –1,000 m.a.s.l.	0.1048	0.0929	1,364
Below –1,000 m.a.s.l.	0.1048	0.0929	1,364
FFM04			
0 to –200 m.a.s.l.	0.1434	0.1145	24,122
–200 to –400 m.a.s.l.	0.1478	0.1162	22,014
–400 to –1,000 m.a.s.l.	0.1075	0.0937	24,014
Below –1,000 m.a.s.l.	0.1075	0.0937	24,014
FFM05			
0 to –200 m.a.s.l.	0.1490	0.1161	26,069
–200 to –400 m.a.s.l.	0.1443	0.1152	28,434
–400 to –1,000 m.a.s.l.	0.1083	0.0938	37,072
Below –1,000 m.a.s.l.	0.1083	0.0938	37,072
FFM06			
0 to –200 m.a.s.l.	0.1805	0.1315	10,326
–200 to –400 m.a.s.l.	0.1440	0.1163	16,168
–400 to –1,000 m.a.s.l.	0.0880	0.0834	12,475
Below –1,000 m.a.s.l.	0.0880	0.0834	12,475
FFM Other			
0 to –200 m.a.s.l.	0.0682	0.0676	1,626
–200 to –400 m.a.s.l.	0.0817	0.0694	2,754
–400 to –1,000 m.a.s.l.	0.0638	0.0559	2,694
Below –1,000 m.a.s.l.	0.0638	0.0559	2,694

3.3.3 Summary of the hydraulic rock domains. Simplification of the HRD

In order to use the HRDs, FFM01–FFM06 are included in a simplified form in the model. Their geometries are described by boxes or by planes with a given thickness. The different HRDs may be seen in Figure 3-14.The coordinates of the boxes or the equation of the planes are shown in Appendix A

It is suggested that FFM01 is defined by the adjusted values in Table A-1, FFM02 is defined by adjusted values in Table A-2, FFM03 is defined by the adjusted values in Table A-3, and FFM06 is defined by the adjusted values in Table A-9. Furthermore, it is proposed that FFM04 and FFM05 are modelled using slabs defined by planes with a given thickness.

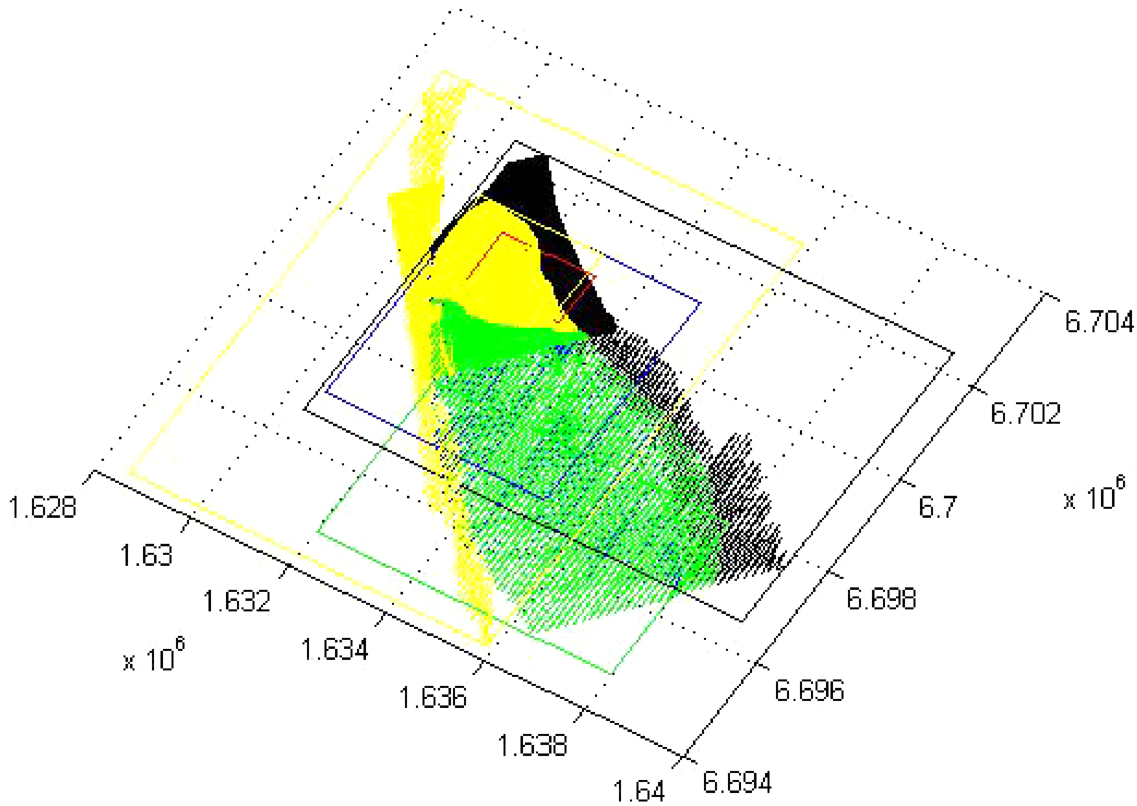

Figure 3-14. *All the domains FFM01 to FFM06 after additional RFM domains and adjustments for DZ A2.*

The approximations may cause that the domains overlap. If the inclusion of domains in the model means that a previous domain is overwritten it is suggested that FFM01 is added last.

Details about the HRDs FFM01–FFM06 are shown in Appendix A. The properties of the RMD volume that does not belong to either of FFM0–FFM06 could be obtained from Table 3-6 in /Follin et al. 2007/.

Statistics of flow wetted surface is available for transport calculations. The values are based on the upscaled HydroDFN as P_{32}. The flow wetted surface is estimated as $2 \times P_{32}$.

3.3.4 Repository information

The layout of the tunnels is based on the so-called 13% option of the SR-Site Forsmark study. The used data files, which were obtained from TRAC, are shown in Appendix D. TRAC is a database for files to be used in SR-Site. They show the co-ordinates for tunnels, deposition holes, ramp and shafts in layout D2 for Forsmark. The layout of the tunnels is shown in Figure 3-15. Table 3-5 shows the dimensions of different sections of the Forsmark repository layout as used in the model.

For the Forsmark site two alternative layouts have been developed, where one layout is based on 13% rejection of deposition positions due to anticipated intersections with fractures with too large radius, and the other on a rejection target value of 30% loss of positions, to cover for the most unfavourable outcome from an alternative DFN-models prepared by the site modelling team. The rejection of 13% is given preference as the most probable future loss when constructing the repository (see Appendix D).

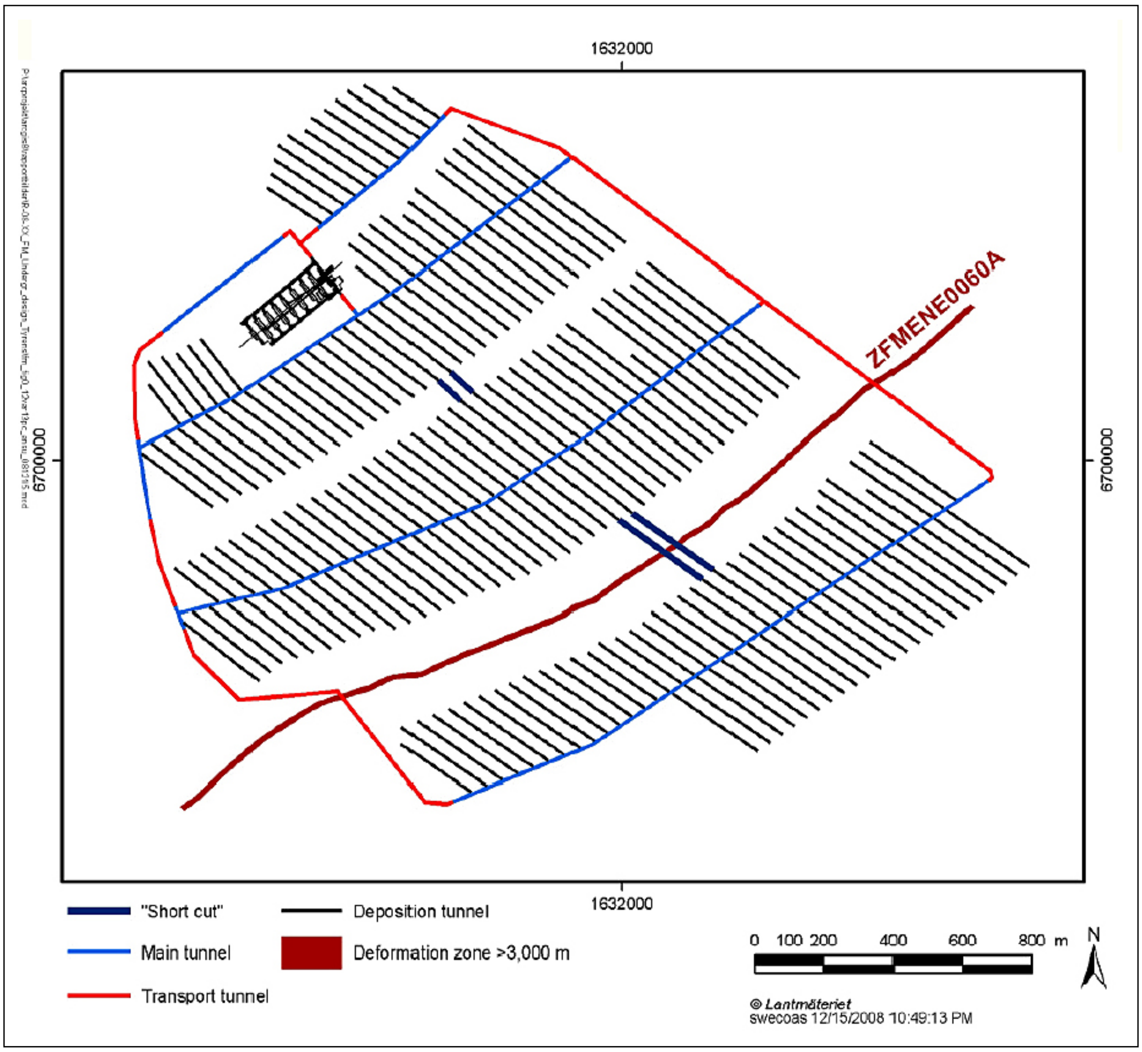

Figure 3-15. *Tunnels in the 13% option for Forsmark repository layout D2 (see Appendix D).*

Table 3-5. Dimensions of different sections of the Forsmark repository layout D2 as used in the model (see Appendix D).

Section	Width [m]	Height [m]
Deposition tunnel	4.2	4.8
Main tunnel	10.0	6.0
Transport tunnel	7.0	5.4
Ramp, straight	5.5	5.4
Ramp, curve radius 25 m	7.0	5.4
Shaft, ventilation, air in	3.5	–
Shaft ventilation, air out	2.5	–
Shaft, elevator	6.0	–
Shaft, skip	5.0	–
Deposition hole	1.75	8.0

Properties of the ConnectFlow Forsmark SR-Site Repository Scale Model

The properties of the repository used for the ConnectFlow Forsmark SR-Site Repository Scale Model are displayed in Table 3-6.

Table 3-6. Properties of the ConnectFlow Forsmark SR-Site Repository Scale Model /Joyce et al. 2010/.

Parameter description	Value
Main tunnel height, m	6.4
Main tunnel width, m	10.0
Main tunnel hydraulic conductivity, m/s	$1.0\ 10^{-10}$
Main tunnel porosity	0.45
Transport tunnel height, m	5.8
Transport tunnel width, m	7.0
Transport tunnel hydraulic conductivity, m/s	$1.0\ 10^{-10}$
Transport tunnel porosity	0.45
Deposition tunnel height, m	4.8
Deposition tunnel width, m	4.2
Deposition tunnel hydraulic conductivity, m/s	$1.0\ 10^{-10}$
Deposition tunnel porosity	0.45
Deposition hole height, m	8.2
Deposition hole diameter, m	1.75
Deposition hole hydraulic conductivity, m/s	$1.0\ 10^{-12}$
Deposition hole porosity	0.41
Ramp height, m	5.8
Ramp width, m	5.5
Ramp conductivity, m/s	$1.0\ 10^{-10}$
Ramp porosity	0.45
Height of elevator shafts in the central area, m	5.3
Width of elevator shafts in the deposition area, m	5.3
Hydraulic conductivity of elevator shafts in the central area, m/s	$1.0\ 10^{-10}$
Porosity of elevator shafts in the central area	0.45
Height of skip shafts in the central area, m	4.4
Width of skip shafts in the central area, m	4.4
Hydraulic conductivity of skip shafts in the central area, m/s	$1.0\ 10^{-10}$
Porosity of skip shafts in the central area	0.45
Height of air intake shafts in the central area, m	3.1
Width of air intake shafts in the central area, m	3.1
Hydraulic conductivity of air intake shafts in the central area, m/s	$1.0\ 10^{-10}$
Porosity of air intake shafts in the central area	0.45
Height of air exhaust shafts in the central area, m	3.1
Width of air exhaust shafts in the central area, m	3.1
Hydraulic conductivity of air exhaust shafts in the central area, m/s	$1.0\ 10^{-10}$
Porosity of air exhaust shafts in the central area	0.45
Height of air exhaust shafts in the deposition area, m	2.7
Width of air exhaust shafts in the deposition area, m	2.7
Hydraulic conductivity of air exhaust shafts in the deposition area, m/s	1.010^{-10}
Porosity of air exhaust shafts in the deposition area	0.45
Thickness of the EDZ, m	0.3
Hydraulic conductivity of the EDZ, m/s	$1.0\ 10^{-8}$
Porosity of the EDZ	$1.0\ 10^{-4}$
Hydraulic conductivity of the top ceiling. This applies to repository features at depth less than 200 m below the ground surface, m/s	$1.0\ 10^{-1}$

3.3.5 Locations of the simulated canisters

In the present report, the release of solute particles from 90 canisters was calculated. The locations of the randomly chosen canisters are shown in Figure 3-16. The location and SKB ID for the canister locations (see Appendix D). used in the simulations are shown in Appendix C, Table C1.

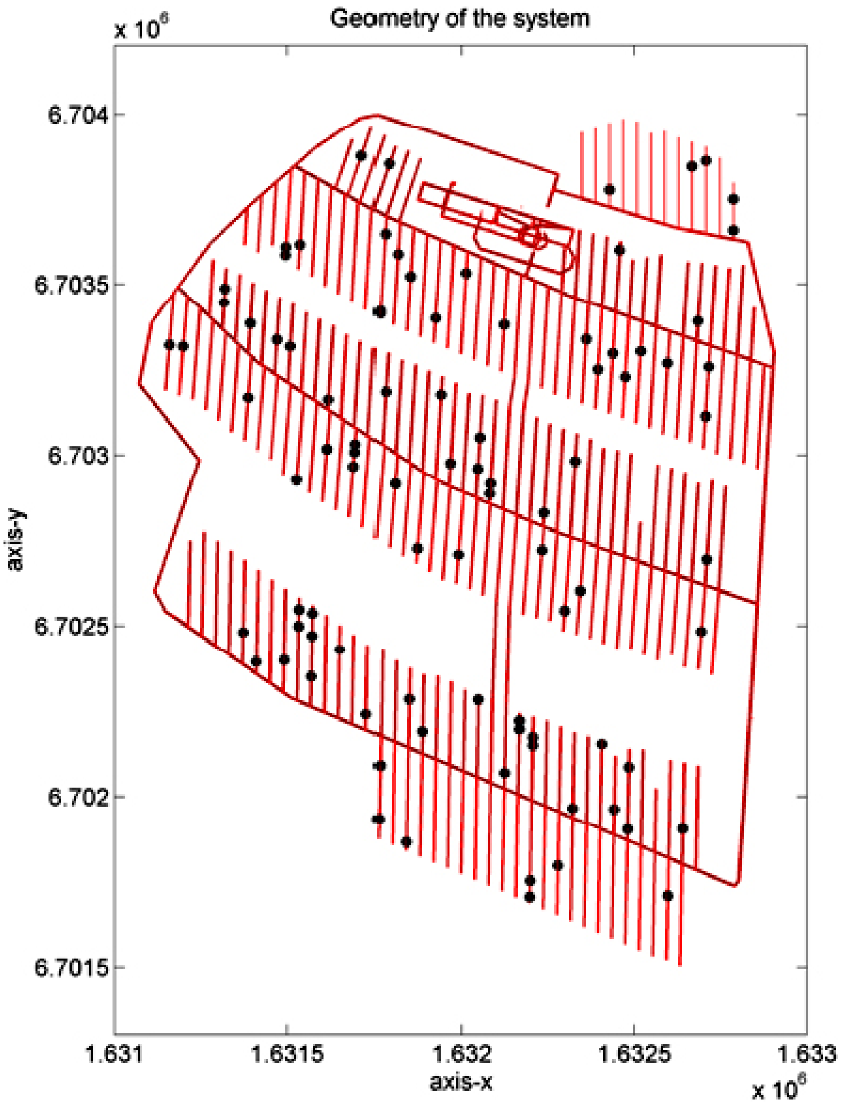

Figure 3-16. *Schematic picture showing the locations of the simulated canisters.*

4 Results of the Stochastic Simulations

The F-ratio and the water travel time will be used to discuss the performance of the stochastic simulations. The release has been calculated for 90 different randomly chosen locations. Due to the large amount of data, only summary tables are presented in this report. Detailed results are shown in Appendices. In Appendix B, the cumulative curves for F-ratio and water travel time are shown. Transport statistics for F-ratio and water travel time are shown in Appendix C.

Two realizations of the background fractures were generated and simulations for 90 canister locations were performed for each HRD realization. For each canister two sets of paths were used; one is starting in Q_1 and the other in Q_2. For each canister, 500 particles were released for each set of paths. A summary of the results for both HRD realizations is given in Tables 4-1 to 4-8.

4.1 Results for a certain canister simulation

The results for the particle release in Q_1 and Q_2 for selected canister locations are shown below. The histograms for the F-ratio, corresponding to canister location #60, are shown in Figure 4-1 and 4-2 for paths starting in Q_1 and Q_2 respectively. The histograms for the water travel time, corresponding to canister location #10, are shown in Figure 4-3 and 4-4 for paths starting at Q_1 and Q_2, respectively. Both simulations belong to the realization 1 of the HRD.

The histograms for the F-ratio in Figures 4-1 and 4-2 show two clear peaks separated by a factor three approximately. The F-ratios are within an interval of about 1.5 orders of magnitude.

The histograms for the water travel time in Figures 4-3 and 4-4 also show a range of about 1.5 orders of magnitude. The histograms also show several smaller peaks.

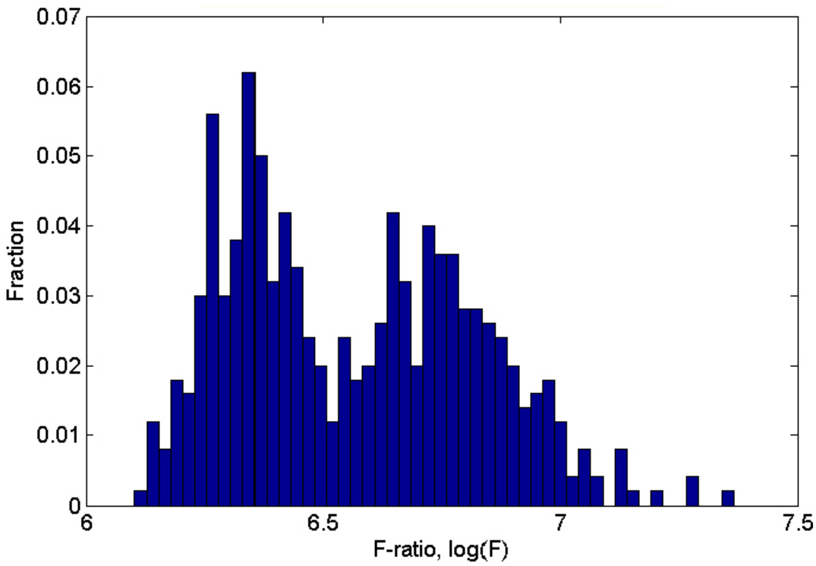

Figure 4-1. *Histogram for the log_{10} (F-ratio) for canister location #60 (HRD realization 1) for paths starting at Q_1.*

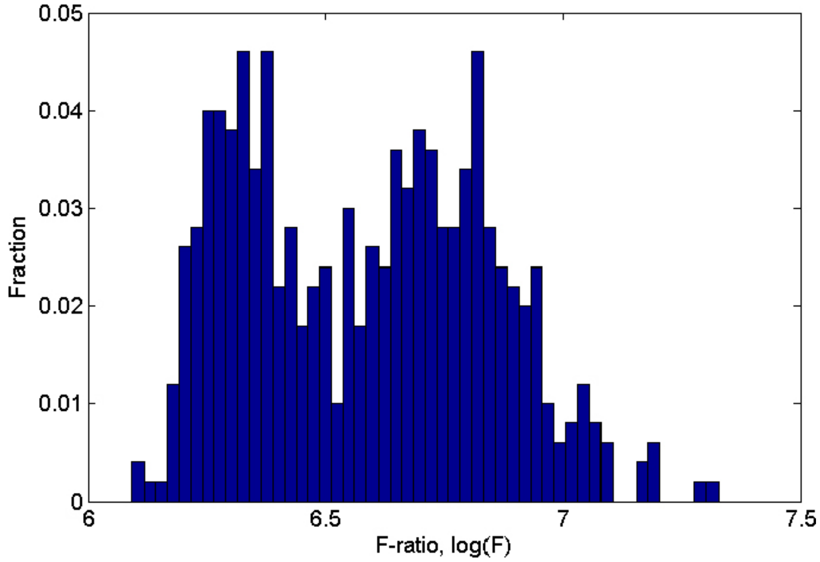

Figure 4-2. *Histogram for the log_{10} (F-ratio) for canister location #60 (HRD realization 1) for paths starting at Q_2.*

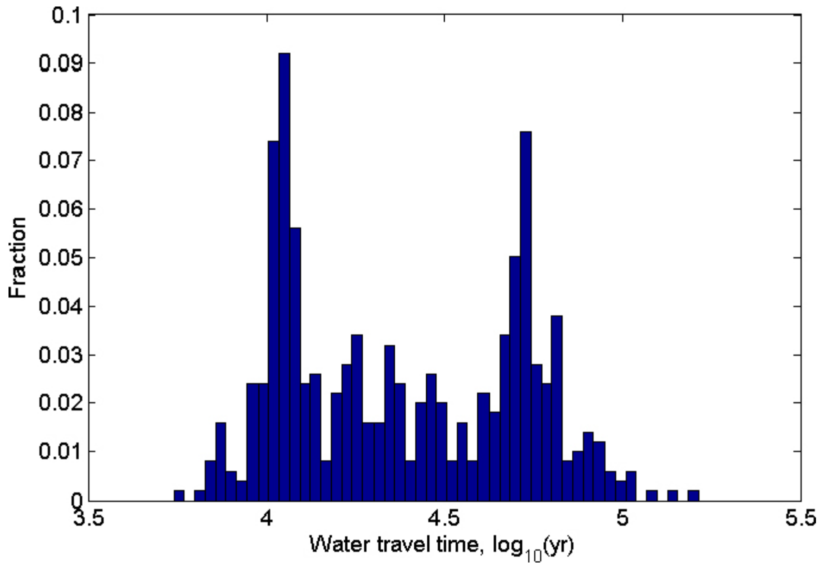

Figure 4-3. *Histogram for the log_{10} (water travel time) for canister location #10 (HRD realization 1) for paths starting at Q_1.*

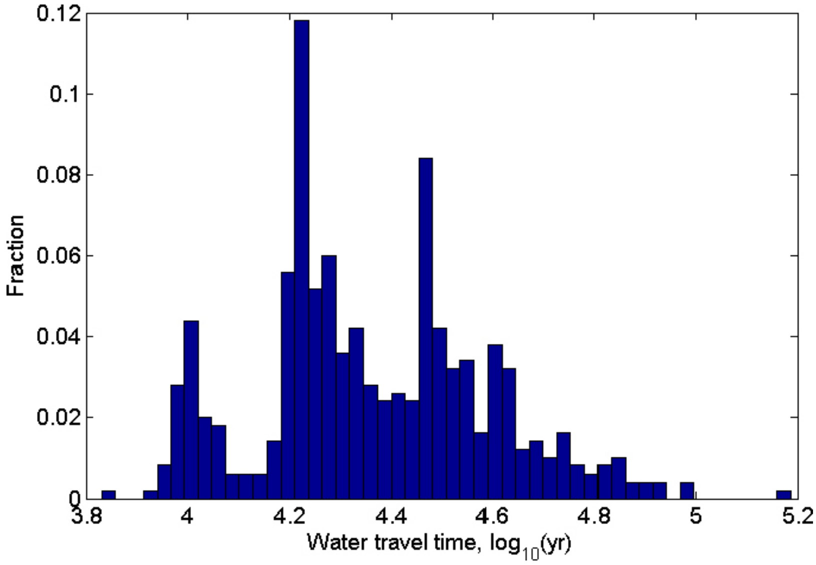

Figure 4-4. *Histogram for the log_{10} (water travel time) for canister location #10 (HRD realization 1) for paths starting at Q_2.*

4.2 Results for the two HRD realizations

Histograms for the two HRD realizations are shown in Figures 4-5 to 4-8. The values in the histograms correspond to the mean value of each of the 90 canister locations. The mean value for each canister corresponds to the mean value of the 500 particles released for paths starting at Q_1 and Q_2. Figure 4-5 shows the histogram for the mean F-ratio for paths starting at Q_1 in the HRD realizations 1 and 2. Figure 4-6 shows the mean F-ratio for paths starting at Q_2. Figures 4-7 and 4-8 show histograms for the water travel time for paths starting at Q_1 and Q_2 respectively in HRD realizations 1 and 2. Detailed statistical results for the 90 canister locations are shown in Appendix C.

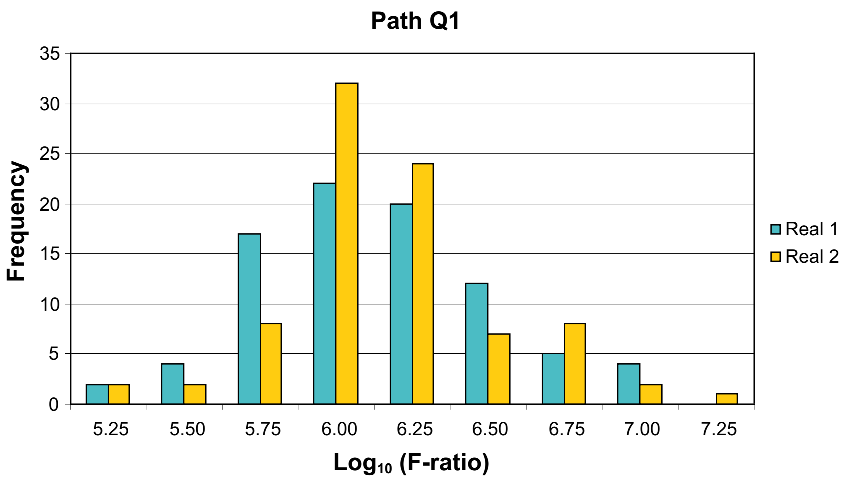

Figure 4-5. *Bar diagram for mean F-ratio for the 90 canister locations for paths starting at Q_1, HRD realizations 1 and 2.*

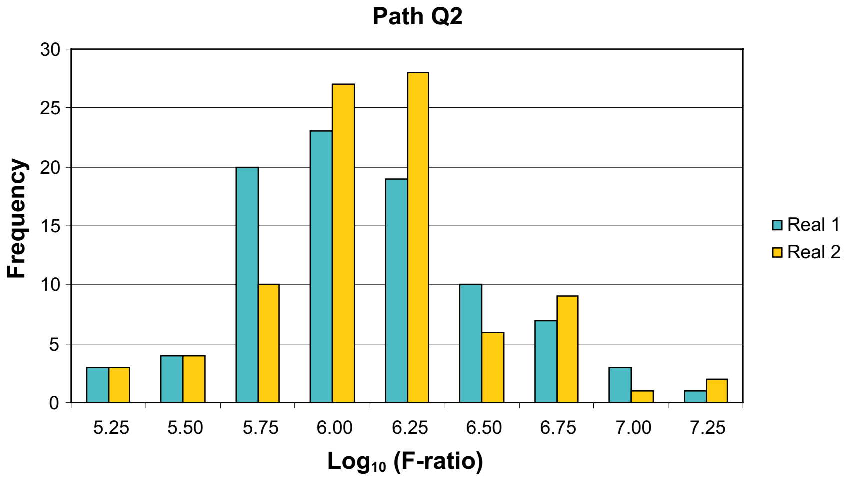

Figure 4-6. Bar diagram for mean F-ratio for the 90 canister locations for paths starting at Q_2, HRD realizations 1 and 2.

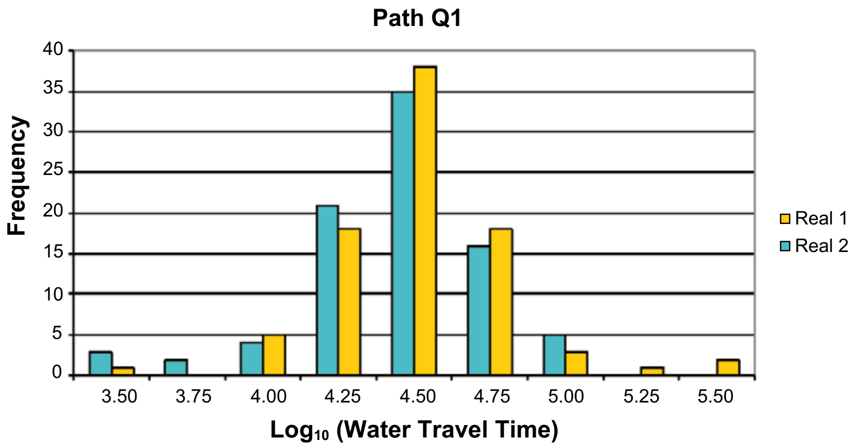

Figure 4-7. Bar diagram for mean water travel time for the 90 canister locations for paths starting at Q_1, HRD realizations 1 and 2.

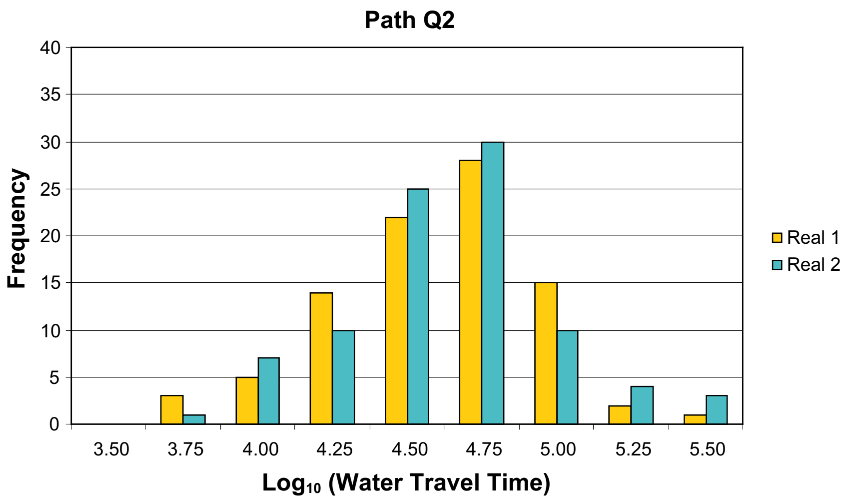

Figure 4-8. Bar diagram for mean water travel time for the 90 canister locations for paths starting at Q_2, HRD realizations 1 and 2.

The results were compared with the outcome of one HRD realization of the so-called ConnectFlow Task 2 model /Joyce et al. 2010/. The Task 2 model is built up by a DFN model, representing the repository, which is nested into a regional CPM. One particle per starting position is used, and each of the 6,619 starting positions represents a canister location. The particles can be started in a fracture intersecting the deposition hole, i.e. paths starting at Q_1, or where the EDZ intersects the deposition hole, i.e. paths starting at Q_2. In the Forsmark model the rock is rather intact around the repository, which means that many paths starting at $Q_1$are absent. Only about 20% of the particles managed to reach the ground surface. The recovery for the paths starting at Q_2 is about 80%. Presently, for the ConnectFlow results, the statistics for the water travel time is divided into three domains. The three domains are fracture rock, tunnel, and EDZ. At the moment, no statistics is presented for the full paths i.e. from the canisters to the exit locations. For the F-ratio calculations there is no contribution from the tunnel in the Task 2 model. Table 4-9 shows the results from the ConnectFlow Task 2 model /Joyce et al. 2010/

Table 4-1. A summary of the transport statistics for the $\log_{10}$ (F-ratio) – from Q_1 for HRD realization 1.

Entity	Mean	Median	Std dev.	5th per.	95th per.
Mean	6.01	5.98	0.21	5.72	6.38
Std. Dev.	0.39	0.40	0.08	0.35	0.44
5th per	5.41	5.37	0.09	5.18	5.66
95th per.	6.71	6.74	0.32	6.26	7.07
Joyce et al. 2010					
Mean	6.60				
Std. Dev.	0.77				

Table 4-2. A summary of the transport statistics for the $\log_{10}$ (F-ratio) – from Q_1 for HRD realization 2.

Entity	Mean	Median	Std dev.	5th per.	95th per.
Mean	6.05	6.02	0.20	5.86	6.40
Std. Dev.	0.37	0.38	0.07	0.33	0.41
5th per	5.48	5.43	0.10	5.32	5.76
95th per.	6.73	6.77	0.30	6.29	7.08
Joyce et al. 2010					
Mean	6.60				
Std. Dev.	0.77				

Table 4-3. A summary of the transport statistics for the $\log_{10}$ (F-ratio) – from Q_2 for HRD realization 1.

Entity	Mean	Median	Std dev.	5th per.	95th per.
Mean	5.98	5.95	0.21	5.70	6.35
Std. Dev.	0.40	0.41	0.08	0.36	0.45
5th per	5.38	5.32	0.09	5.11	5.61
95th per.	*6.71*	*6.74*	*0.37*	*6.24*	*7.05*
Joyce et al. 2010					
Mean	6.25				
Std. Dev.	0.97				

Table 4-4. A summary of the transport statistics for the $\log_{10}$ (F-ratio) – from Q_2 for HRD realization 2.

Entity	Mean	Median	Std dev.	5th per.	95th per.
Mean	6.02	5.99	0.20	5.82	6.38
Std. Dev.	0.39	0.41	0.07	0.35	0.42
5th per	5.38	5.29	0.11	5.07	5.72
95th per.	6.73	6.76	0.32	6.28	7.10
Joyce et al. 2010					
Mean	6.25				
Std. Dev.	0.97				

Table 4-5. A summary of the transport statistics for the $\log_{10}$ (water travel time) – from Q_1 for HRD realization 1.

Entity	Mean	Median	Std dev.	5th per.	95th per.
Mean	4.33	4.30	0.20	4.08	4.69
Std. Dev.	0.29	0.30	0.10	0.30	0.34
5th per	3.74	3.70	0.08	3.61	4.14
95th per.	4.76	4.75	0.38	4.46	5.18

Table 4-6. A summary of the transport statistics for the $\log_{10}$ (water travel time) – from Q_1 for HRD realization 2.

Entity	Mean	Median	Std dev.	5th per.	95th per.
Mean	4.37	4.34	0.21	4.08	4.75
Std. Dev.	0.27	0.27	0.11	0.33	0.33
5th per	3.96	3.92	0.09	3.58	4.28
95th per.	4.79	4.69	0.39	4.45	5.31

Table 4-7. A summary of the transport statistics for the $\log_{10}$ (water travel time) – from Q_2 for HRD realization 1.

Entity	Mean	Median	Std dev.	5th per.	95th per.
Mean	4.47	4.43	0.24	4.15	4.92
Std. Dev.	0.34	0.35	0.11	0.35	0.38
5th per	3.78	3.71	0.08	3.47	4.18
95th per.	4.90	4.92	0.40	4.60	5.53

Table 4-8. A summary of the transport statistics for the $\log_{10}$ (water travel time) – from Q_2 for HRD realization 2.

Entity	Mean	Median	Std dev.	5th per.	95th per.
Mean	4.52	4.49	0.25	4.17	4.97
Std. Dev.	0.34	0.35	0.10	0.35	0.38
5th per	3.91	3.86	0.10	3.55	4.28
95th per.	5.13	5.15	0.42	4.66	5.60

Table 4-9. Results from the ConnectFlow Task 2 model /Joyce et al. 2010/.

Entity	Mean	Median	Std dev.	5th per.	95th per.
F-ratio, Q1	6.60	6.60	0.77	5.39	7.92
F-ratio, Q2	6.25	6.36	0.97	4.27	7.71
Travel Time,Q1					
Fractured rock	2.21	2.24	0.43	1.41	2.84
Tunnel	6.24	6.30	1.21	4.35	8.03
EDZ	0.83	0.84	0.86	–0.50	2.22
Travel Time,Q2					
Fractured rock	2.17	2.21	0.44	1.33	2.80
Tunnel	6.22	6.32	1.36	3.86	8.16
EDZ	0.86	0.87	0.90	–0.73	2.27

5 Discussion and Conclusions

A site model, which takes into account most of the fracture zones of the Forsmark site, was developed. These features were included in the model in a deterministic way; only the background fractures were generated stochastically.

Two HRD simulations were performed where the only difference was the background fractures. No large differences were found between these simulations, since the water flow mainly is determined by the site features such as fracture zones. Moreover, the same locations were chosen when the releases from the 90 canisters were calculated.

The results from the simulations were compared with the outcome of one realization of the so-called ConnectFlow Task 2 model /Joyce et al. 2010/. However, the results are not directly comparable. In the ConnectFlow modelling, one particle per starting position is used, in total 6,619 starting positions. In the present report, 500 particles are released from each location and they can take 1,000 different paths from the canister location to the biosphere. The paths that the particles choose from a given location are stochastically determined. Therefore, the results (F-ratio and travel time) for a canister location represent average values for 500 particles per release path (see Appendix C). This could explain the smaller standard deviation for the F-ratio in these simulations compared to the simulation using the ConnectFlow Task 2 model /Joyce et al. 2010/. The values for each canister location are smoothed due to the averaging process.

For the F-ratio, a reasonably good agreement is obtained comparing the results from the Connect-Flow Task 2 model /Joyce et al. 2010/ and the present study.

In order to determine the effect on results from impact of the particles that reach the tunnel or the EDZ, simulations were performed varying properties of the tunnels and the EDZ. The flow wetted surface was increased to a very high value ($1.0 \cdot 10^6$ m^2/m^3). Therefore, the value of the F-ratio for particles travelling through the tunnels or the EDZ becomes very high and these particles can be distinguished from the particles that travel only through fractures or fracture zones.

The simulations show that for approximately 10% of the canisters, the particles, in a fraction greater than 97%, reach the biosphere without travelling through tunnels or EDZ. Considering the ensemble of the particles, it is found that for the particles released in Q_1, 47% reach the biosphere. For the particles released in Q_2, the percentage is 32%. The cumulative curve for the F-ratio fraction is shown in Figure 5-1. Similar cumulative curves may be obtained for the water travel time by removing the particles that reach the tunnels or the EDZ. These results are shown in Figure 5-2.

In the simulations, the water flowrate in the channels where the particles were released was also determined. The values shown in the histograms correspond to the sum of the flowrates in the intersection close to the release point. Figure 5-3 shows the histogram for the flowrate for the case Q_1. The flowrates for the case Q_2 are shown in Figure 5-4.

In summary, simulations were performed using a new package developed at the Department of Chemical Engineering and Technology, Royal Institute of Technology. The package contains two main codes; NEAR3D and CHAN3D. In addition, the package has a Graphical User Interface (GUI) and a code that governs the simulations (Coupling).

The updated CHAN3D can handle chain decay and allows several fields with different properties embedded in the model. NEAR3D was totally restructured in order to improve the use of computer memory. The codes were made more transparent and easier to understand in terms of how the different processes are included.

Stochastic simulations for the far field were performed, and results are shown in this report. The results are compared with the results from the Task 2 model of the ConnectFlow study /Joyce et al. 2010/. Although the results cannot be compared directly, a reasonably good agreement is obtained for the F-ratio determined with the ConnectFlow Task 2 model /Joyce et al. 2010/ and the F-ratio obtained using our model.

The main objectives of this study are:

- to perform calculations and produce performance measures for the Forsmark site using an alternative-modelling concept than the methodology used in the main SR-Site concept /Joyce et al. 2010/, and
- to test the developed package containing the coupled codes NEAR3D and CHAN3D.

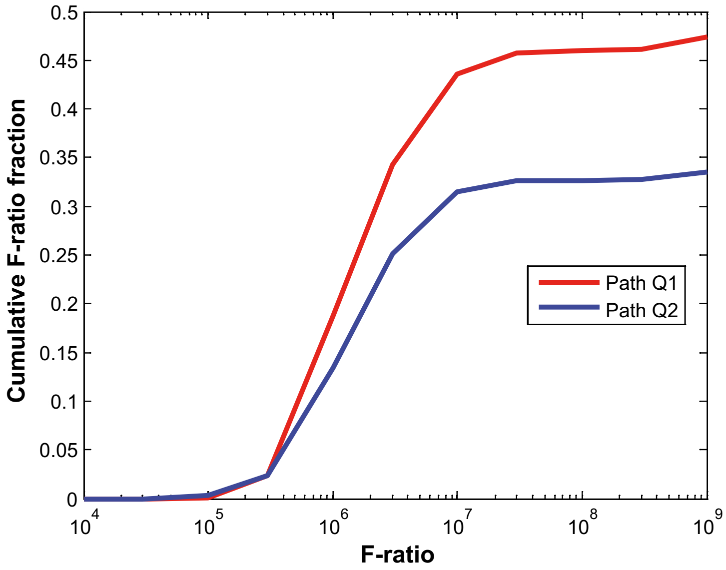

Figure 5-1. Cumulative curves for the F-ratio particles released in Q_1 and Q_2.

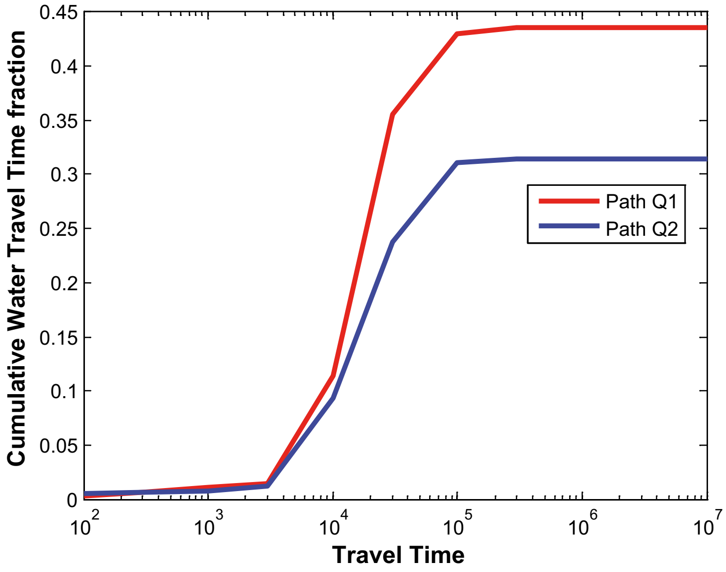

Figure 5-2. Cumulative curves for the water travel time for particles released in Q_1 and Q_2.

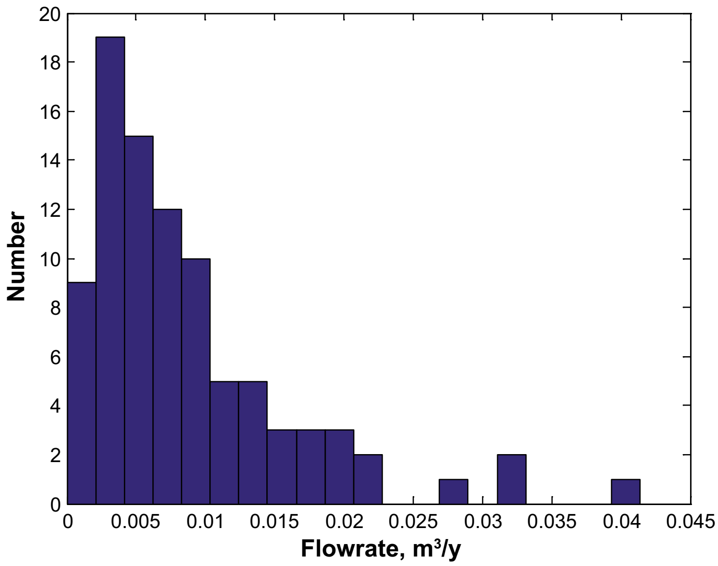

Figure 5-3. *Histogram for flowrates at the release points for the paths starting at* Q_1.

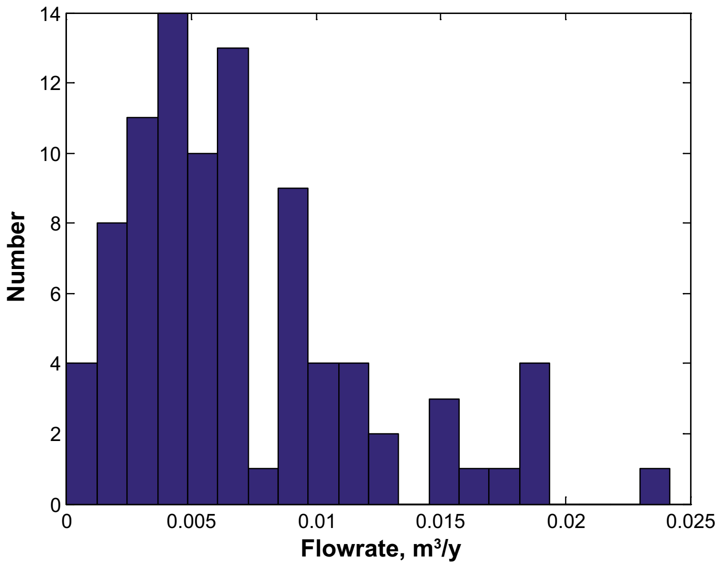

Figure 5-4. *Histogram for flowrates at the release points for the paths starting at* Q_2.

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Appendix A

Hydraulic Rock Domains

FFM01

The domains RFM029 and 17 were added in the same way as in the ConnecFlow modelling. In addition, the volume above the deformation zone A2 was moved to FFM03. Table A-1 shows the min and max values of x, y and z for the total volume of FFM01 for actual and adjusted values.

Table A-1. Min and max values of the coordinates for the total volume of FFM01, for actual and adjusted values, as Easting (X), Northing (Y), and Elevation (Z) in (m).

	Actual values		Adjusted values	
	Minimum	Maximum	Minimum	Maximum
X	1,630,530	1,638,050	1,630,530	1,635,000
Y	6,695,450	6,701,250	6,697,000	6,701,250
Z	–2,050	–30	–2,050	–30

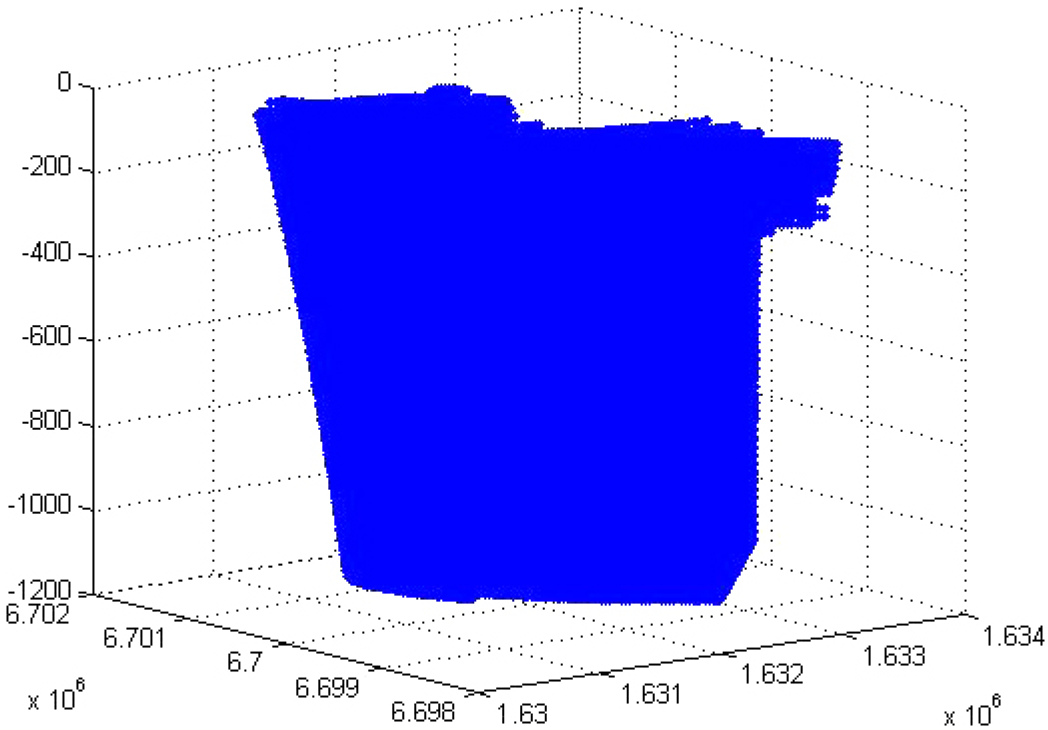

Figure A-1. Hydraulic Rock Domain FFM01 before RFM029 and 17 are added.

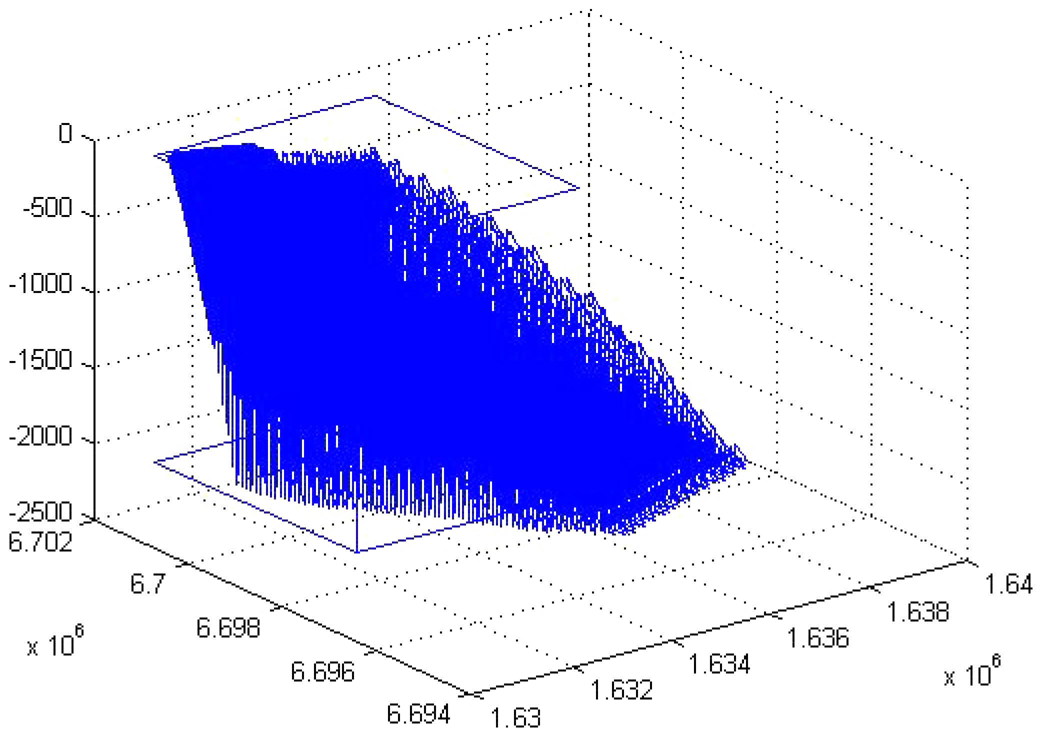

Figure A-2. *Hydraulic Rock Domain FFM01 after RFM029 and 17 are added. In addition, the volume above ZFM02 is assigned to FFM03.*

FFM02

Table A-2 shows the min and max values of x, y and z for the total volume of FFM02 for actual and adjusted values.

Table A-2. Min and max values of the coordinates for the total volume of FFM02, for actual and adjusted values, as Easting (X), Northing (Y), and Elevation (Z) in (m).

	Actual values		Adjusted values	
	Minimum	Maximum	Minimum	Maximum
X	1,630,530	1,633,750	1,630,530	1,633,000
Y	6,699,050	6,701,250	6,700,000	6,701,250
Z	–270	–10	–170	–10

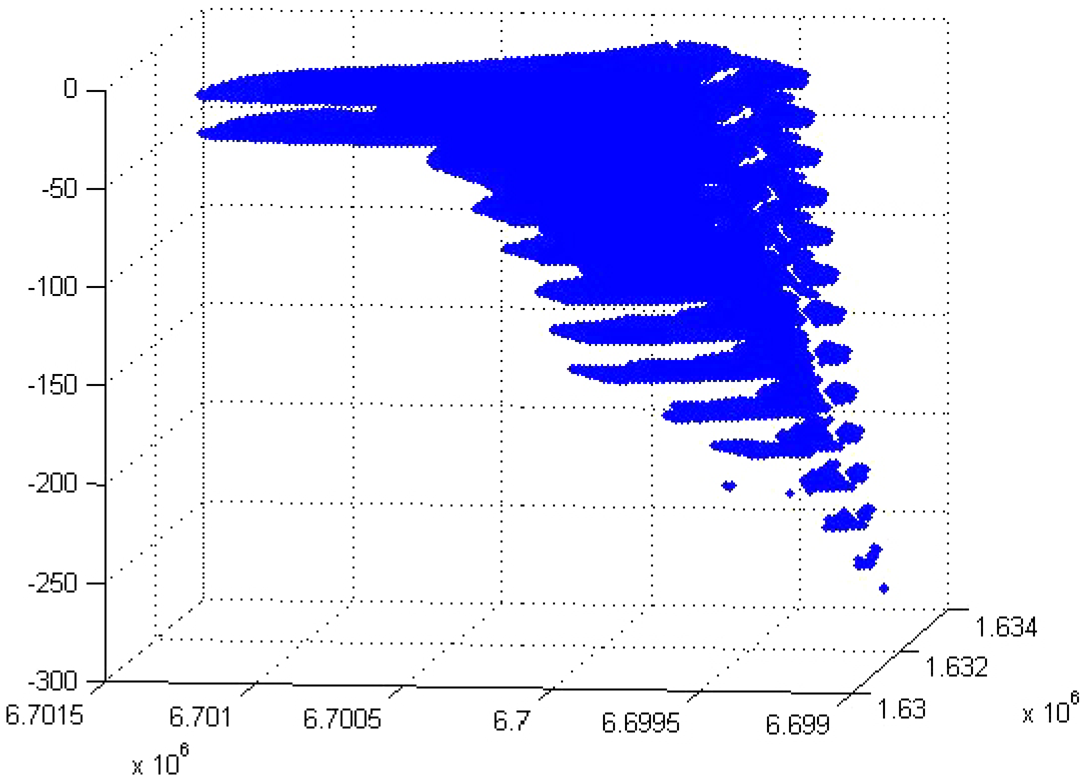

Figure A-3. *Hydraulic Rock Domain FFM02 is rather small and shallow in comparison to the other fracture domains.*

FFM03

Table A-3 shows the min and max values of x, y and z for the total volume of FFM03 for actual and adjusted values.

Table A-3. Min and max values of the coordinates for the total volume of FFM03, for actual and adjusted values, as Easting (X), Northing (Y), and Elevation (Z) in (m).

	Actual values		Adjusted values	
	Minimum	Maximum	Minimum	Maximum
X	1,631,030	1,638,450	1,632,000	1,638,000
Y	6,694,750	6,699,870	6,694,750	6,698,000
Z	–2,050	–10	–2,050	–10

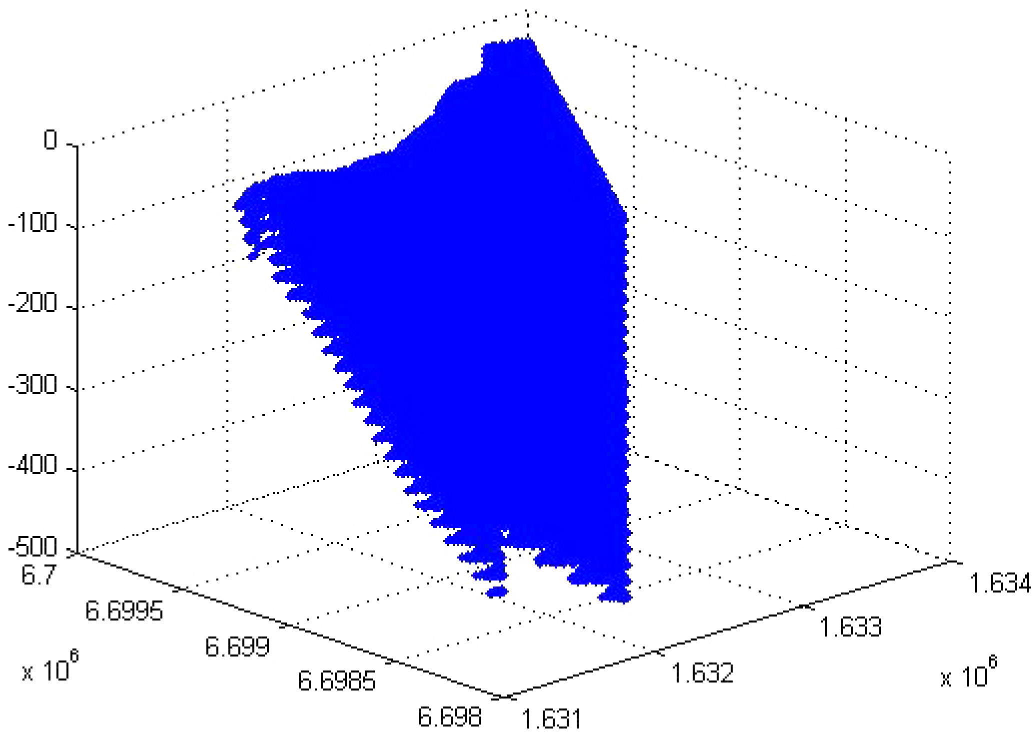

Figure A-4. Hydraulic Rock Domain FFM03 before volume is added for being above ZFMA2.

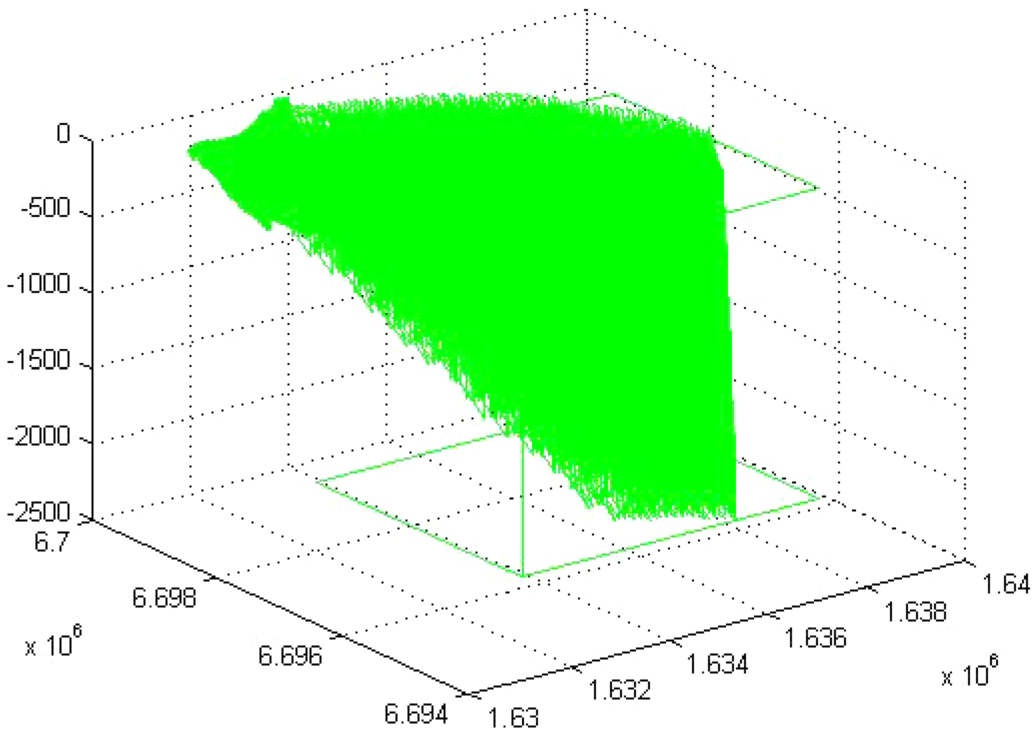

Figure A-5. *Hydraulic Rock Domain FFM03 after volume is added from FFM01 for being above ZFMA2.*

FFM04

Table A-4 shows the min and max values of x, y and z for the total volume of FFM04 for actual and adjusted values. An attempt was done to approximate FFM04 with a box shaped volume (adjusted values). However, it is suggested to use a slab instead defined with a plane and a thickness.

Table A-4. Min and max values of the coordinates for the total volume of FFM04, for actual and adjusted values, as Easting (X), Northing (Y), and Elevation (Z) in (m).

	Actual values		Adjusted values	
	Minimum	Maximum	Minimum	Maximum
X	1,628,550	1,635,850	1,628,550	1,635,850
Y	6,694,250	6,702,950	6,694,250	6,702,950
Z	–2,050	10	–2,050	10

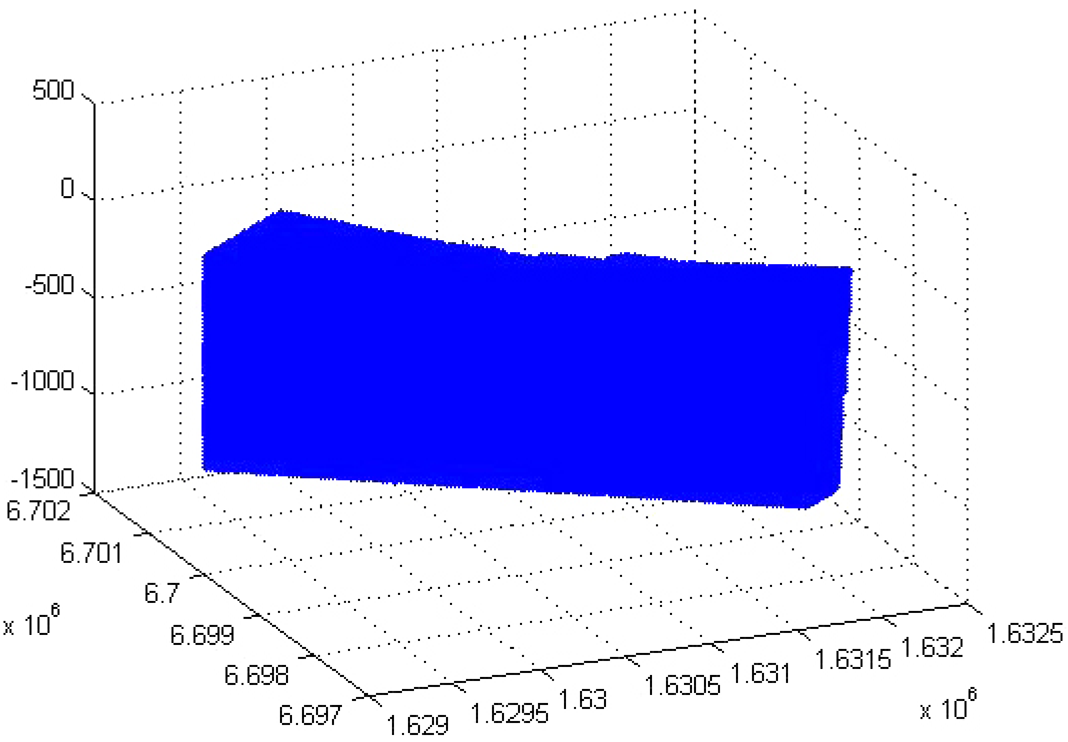

Figure A-6. Hydraulic Rock Domain FFM04 before RFM012 and 18 are added.

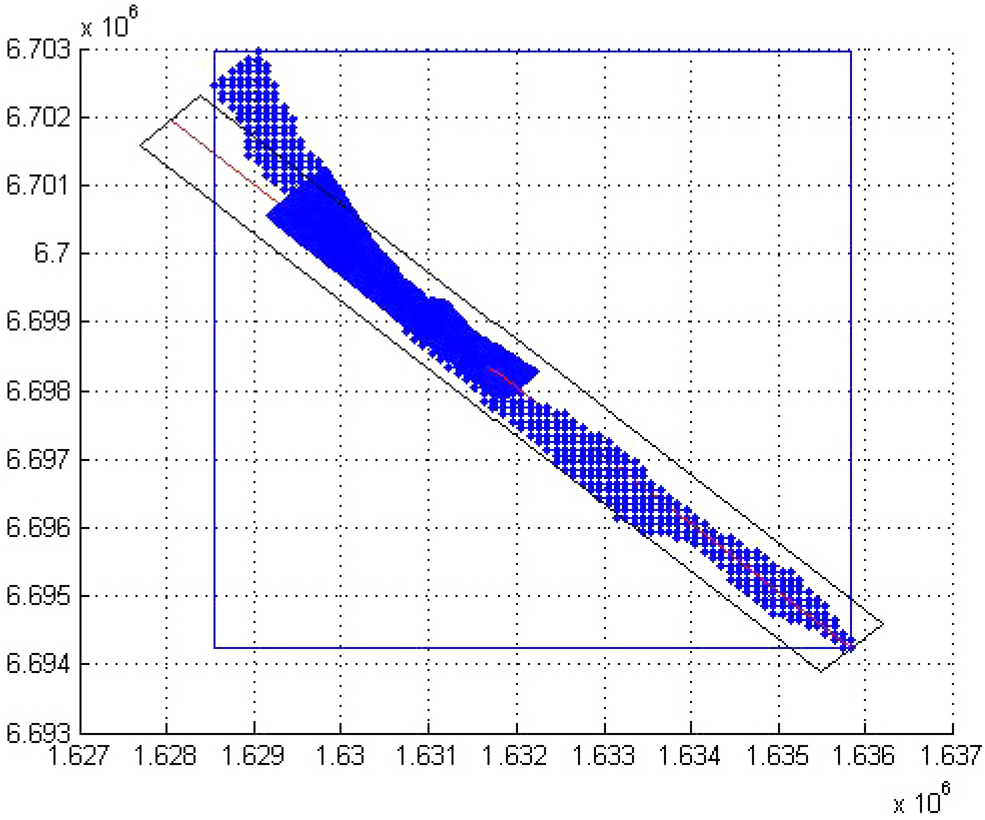

Figure A-7. *Hydraulic Rock Domain FFM04 after RFM012 and 18 are added. It is suggested to model this by using a plane with thickness.*

FFM04 with additions as approximated with a plane. Table A-5 shows the possible plane definitions.

Table A-5. Definition of the plane equation.

Plane equation on the form	Specification
ax+by+cz+1=0	abc = 1.0e–006 *(–0.1188 –0.1203 0) d = 1
Ax+By+Cz+D=0	ABC = –0.7025 –0.7117 0 D = 5.9132E+006
Polygon	1,635,850 6,694,250 10 1,628,050 6,701,950 10 1,628,050 6,701,950 –2,050 1,635,850 6,694,250 –2,050
Total thickness	L = 500 m, i.e. 250 on each side of the plane

FFM05

Also FFM05 is an elongated volume but with a branch shaped volume attached to it. Table A-6 shows the min and max values of x, y and z for the total volume of FFM05 An attempt was made to approximate using a box, which may be also seen in Table A-6 showing the adjusted values. However, it is suggested to use two slabs instead.

Table A-6. Min and max values of the coordinates for the total volume of FFM04, for actual and adjusted values, as Easting (X), Northing (Y), and Elevation (Z) in (m).

	Actual values		Adjusted values	
	Minimum	Maximum	Minimum	Maximum
X	1,630,410	1,639,350	1,630,410	1,639,350
Y	6,696,550	6,702,390	6,696,550	6,702,390
Z	–2,050	10	–2,050	10

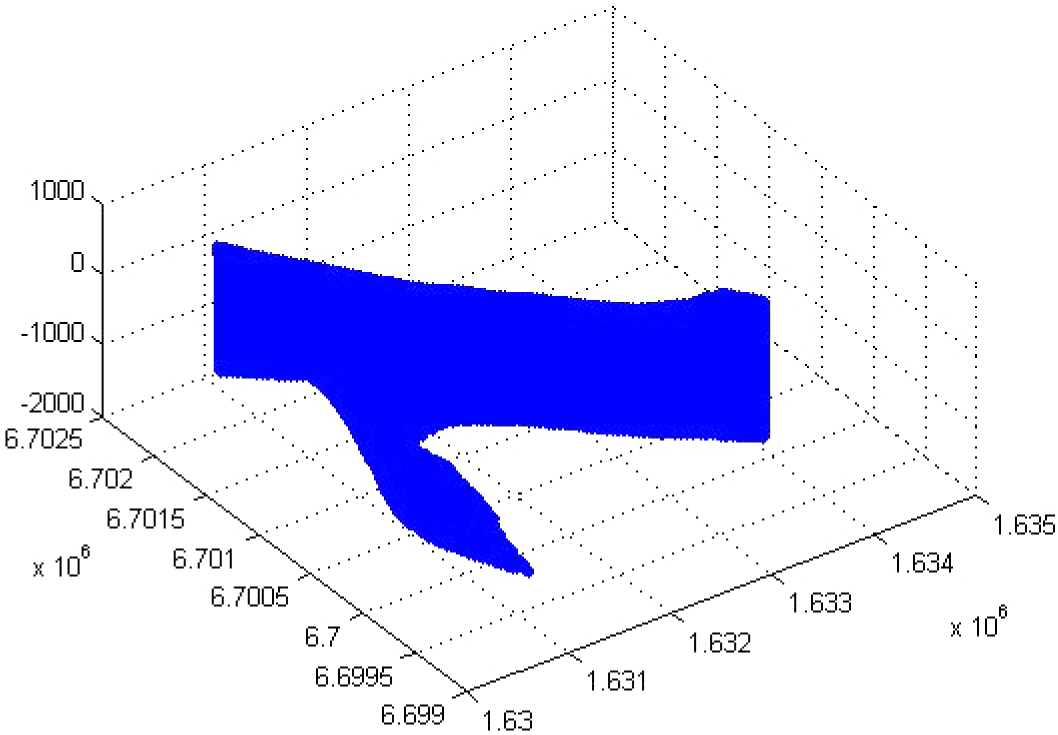

__Figure A-8.__ Hydraulic Rock Domain FFM05 before RFM032 and 44 are added.

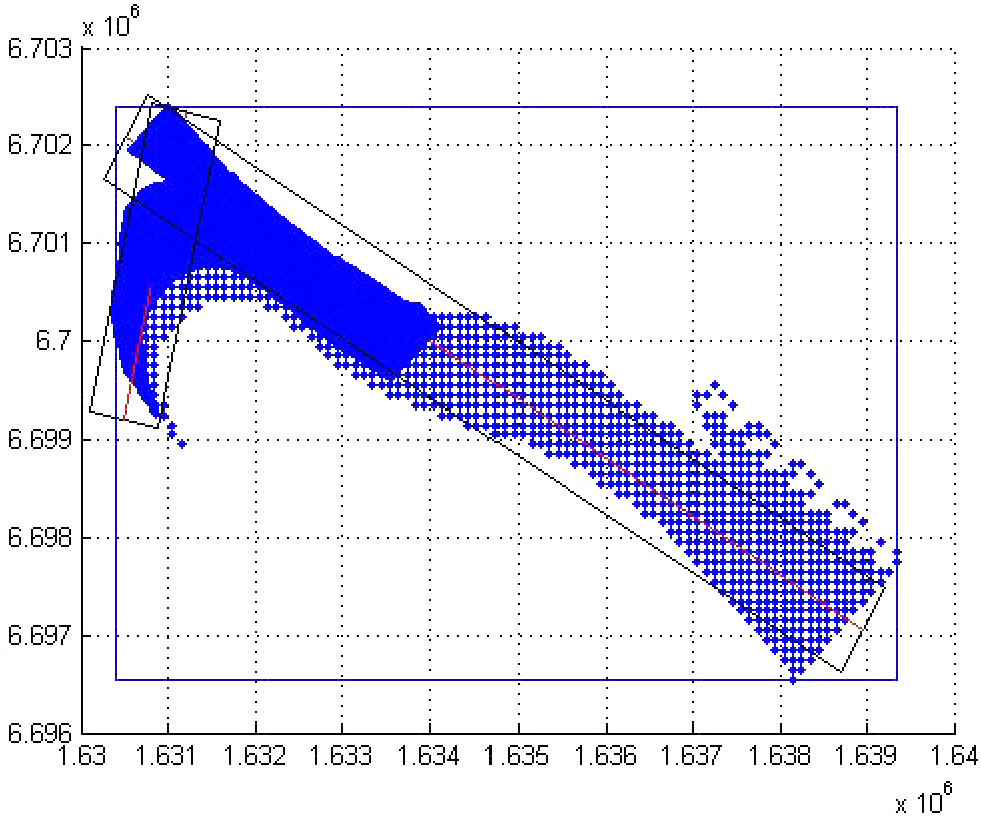

Figure A-9. *Hydraulic Rock Domain FFM05 after RFM032 and 44 are added.*

FFM05 as approximated with two planes, one large and one small. Table A-7 shows the definitions for the large plane. Table A-8 shows the definitions for the small plane.

Table A-7. Definition of the big plane.

Plane equation on the form	Specification
ax+by+cz+1=0	abc = 1.0e–006 *(–0.0778 –0.1303 0)
	d = 1
Ax+By+Cz+D=0	ABC = –0.5127 –0.8586 0
	D = 6.5902E+006
Polygon	1,638,950 6,697,050 10
	1,630,510 6,702,090 10
	1,630,510 6,702,090 –2,050
	1,638,950 6,697,050 –2,050
Total thickness	L = 500 m, i.e. 250 m on each side of the plane

Table A-8. Definition of the small plane.

Plane equation on the form	Specification
ax+by+cz+1=0	abc = 1.0e–005 *(–0.7297 0.1627 0)
	d = 1
Ax+By+Cz+D=0	ABC = –0.9760 0.2176 0
	D = 1.3376E+005
Polygon	1,630,500 6,699,200 10
	1,631,200 6,702,340 10
	1,631,200 6,702,340 –2,050
	1,630,500 6,699,200 –2,050
Total thickness	L = 400 m, i.e. 200 m on each side of the plane

FFM06

Table A-9 shows Min and Max of x, y and z for the total volume. FFM06 is also approximated with a smaller box. Table A-9 shows Min and Max of x, y and z, for adjusted values.

Table A-9. Min and max values of the coordinates for the total volume of FFM04, for actual and adjusted values, as Easting (X), Northing (Y), and Elevation (Z) in (m).

	Actual values		Adjusted values	
	Minimum	Maximum	Minimum	Maximum
X	1,631,310	1,633,650	1,631,310	1,633,150
Y	6,699,590	6,700,850	6,699,840	6,700,850
Z	–1,090	–30	–1,090	–30

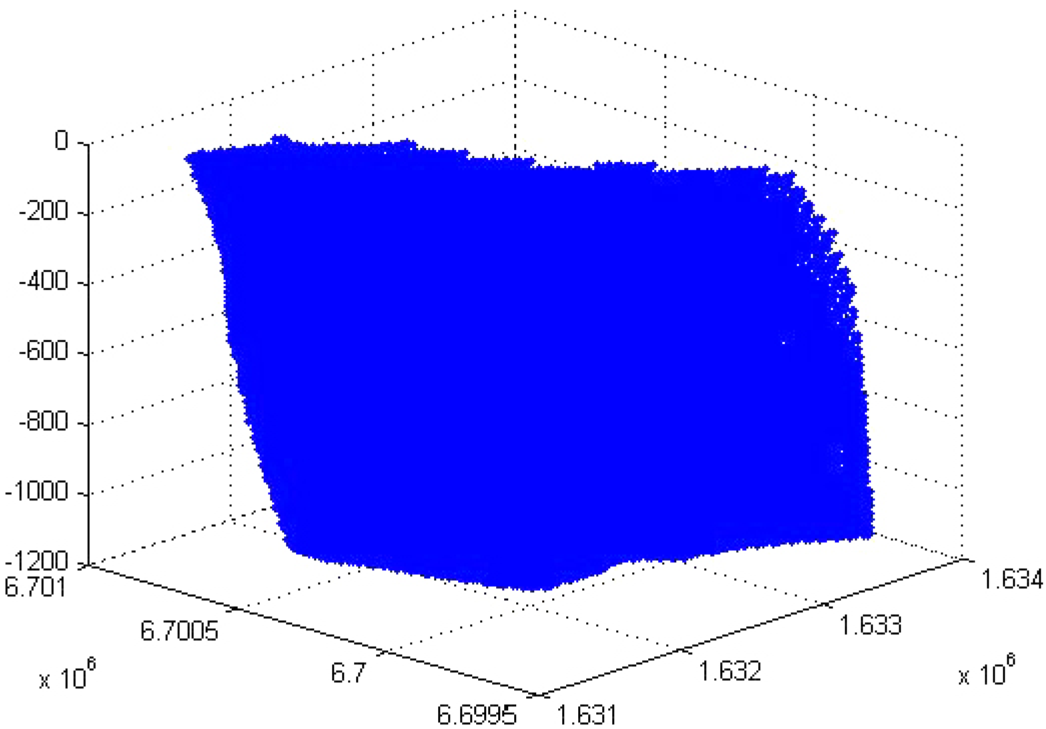

Figure A-10. *Hydraulic Rock Domain FFM06.*

Results for the far-field – distribution plots

Results for HRD realization 1

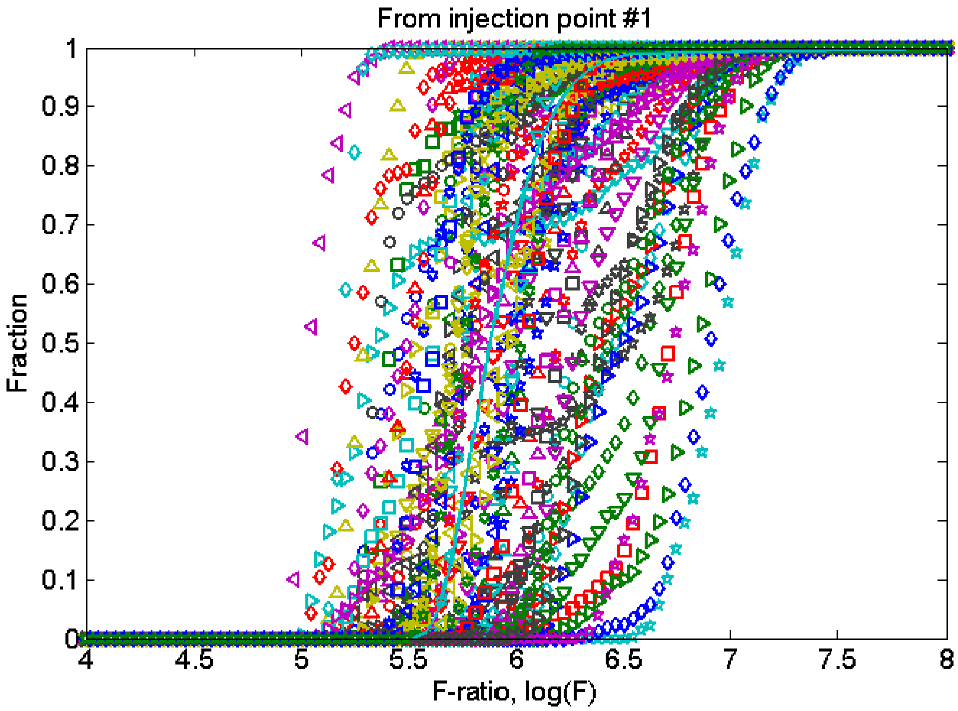

Figure B-1. *Cumulative curves for log_{10} (F- ratio) for the 90 canister locations for paths starting at Q_1, HRD realization 1.*

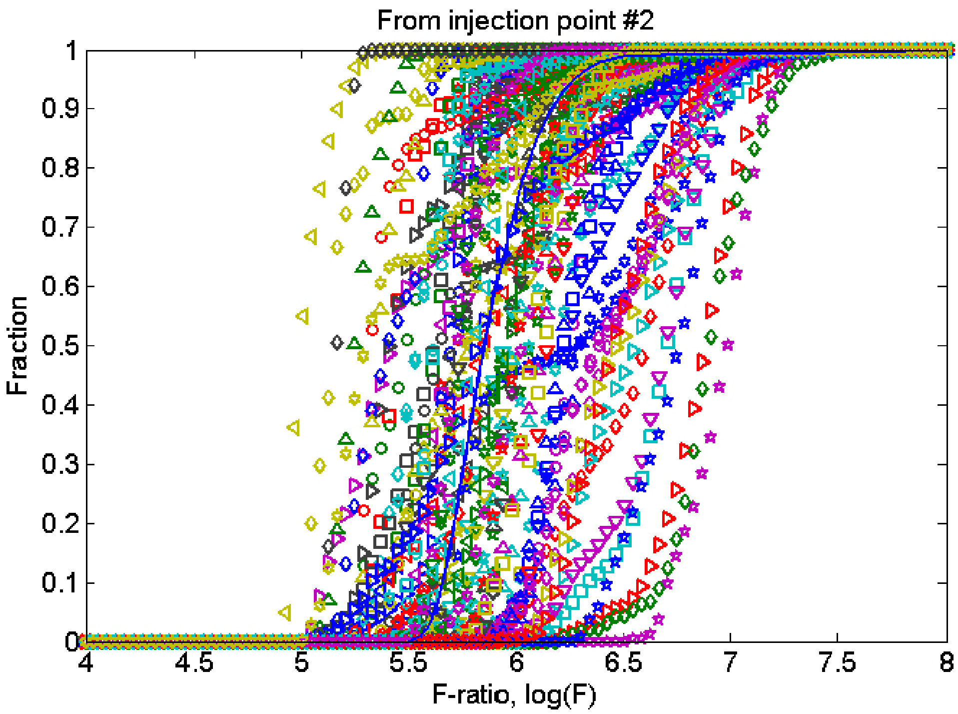

Figure B-2. *Cumulative curves for log_{10} (F- ratio) for the 90 canister locations for paths starting at Q_2, HRD realization 1.*

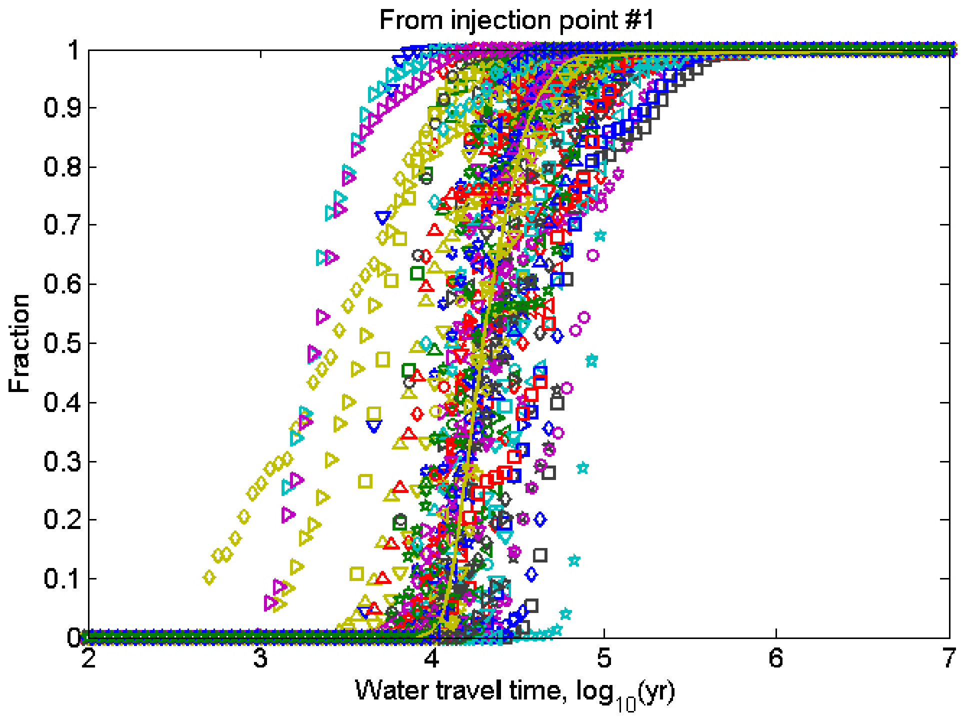

Figure B-3. *Cumulative curves for log_{10} (water travel time) for the 90 canister locations for paths starting at Q_1, HRD realization 1.*

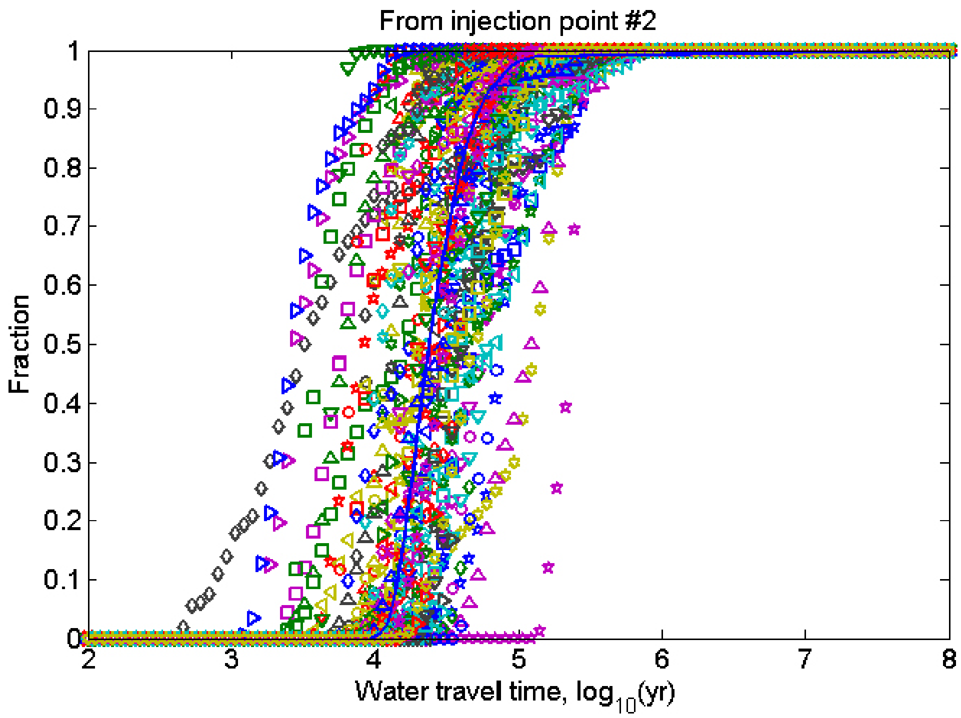

Figure B-4. *Cumulative curves for log_{10} (water travel time) for the 90 canister locations for paths starting at Q_2, HRD realization 1.*

Results for HRD realization 2

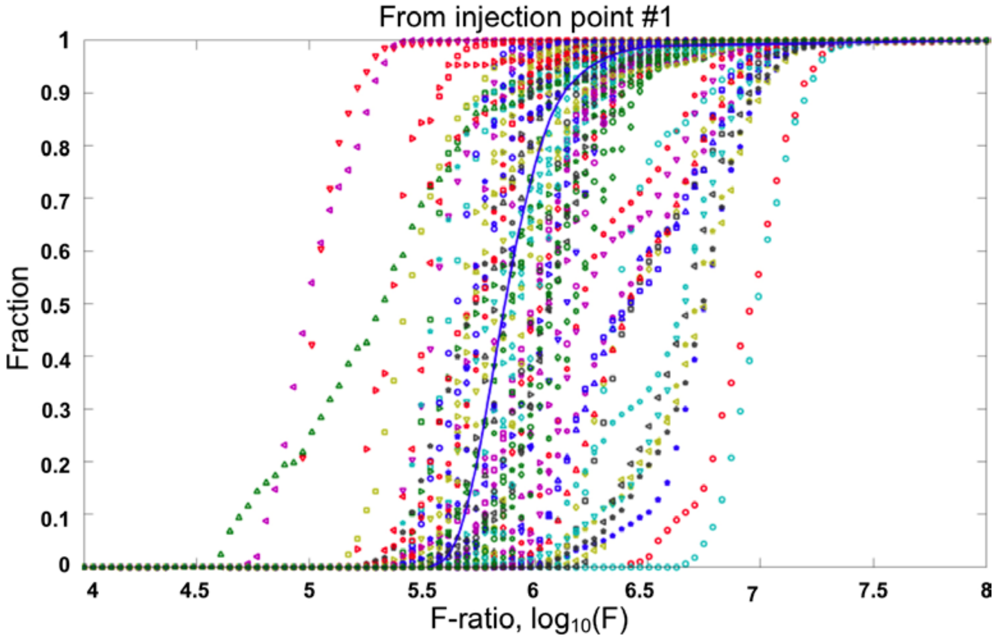

Figure B-5. *Cumulative curves for log_{10} (F- ratio) for the 90 canister locations for paths starting at Q_1, HRD realization 2.*

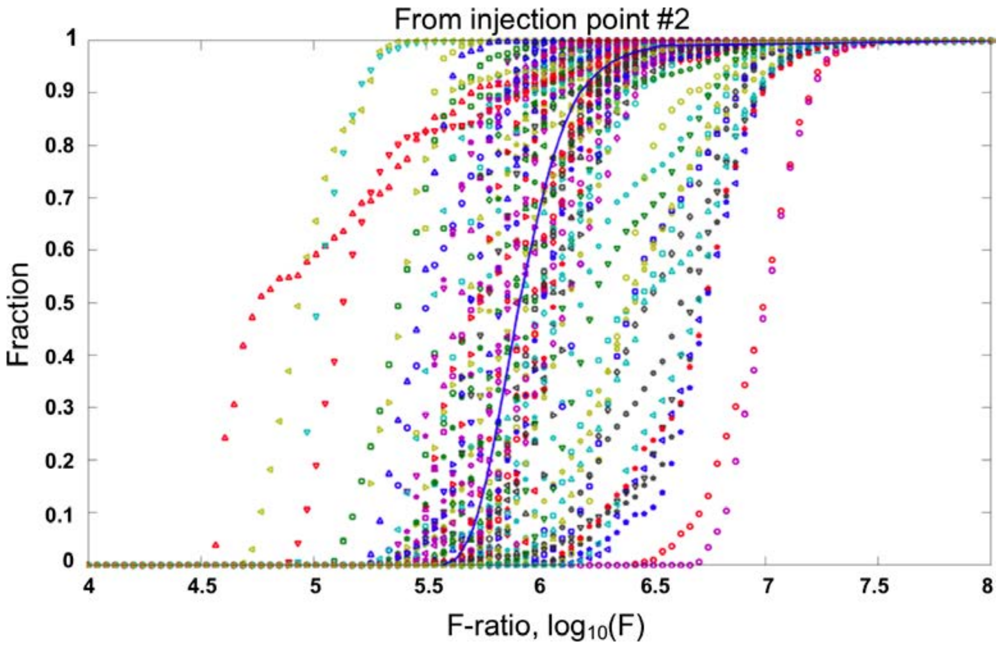

Figure B-6. *Cumulative curves for log_{10} (F- ratio) for the 90 canister locations for paths starting at Q_2, HRD realization 2.*

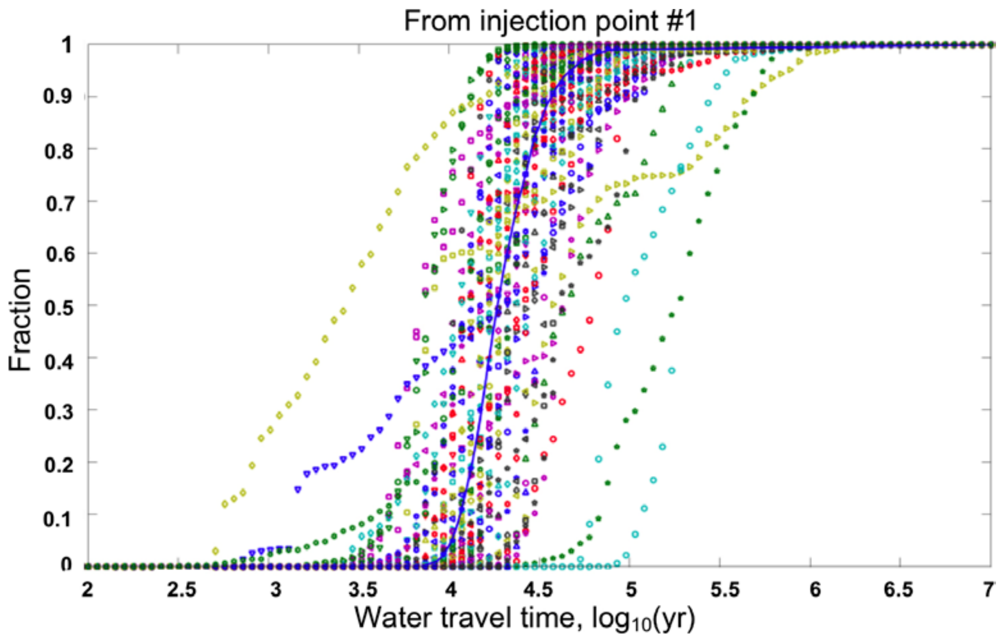

Figure B-7. *Cumulative curves for log_{10} (water travel time) for the 90 canister locations for paths starting at Q_1, HRD realization 2.*

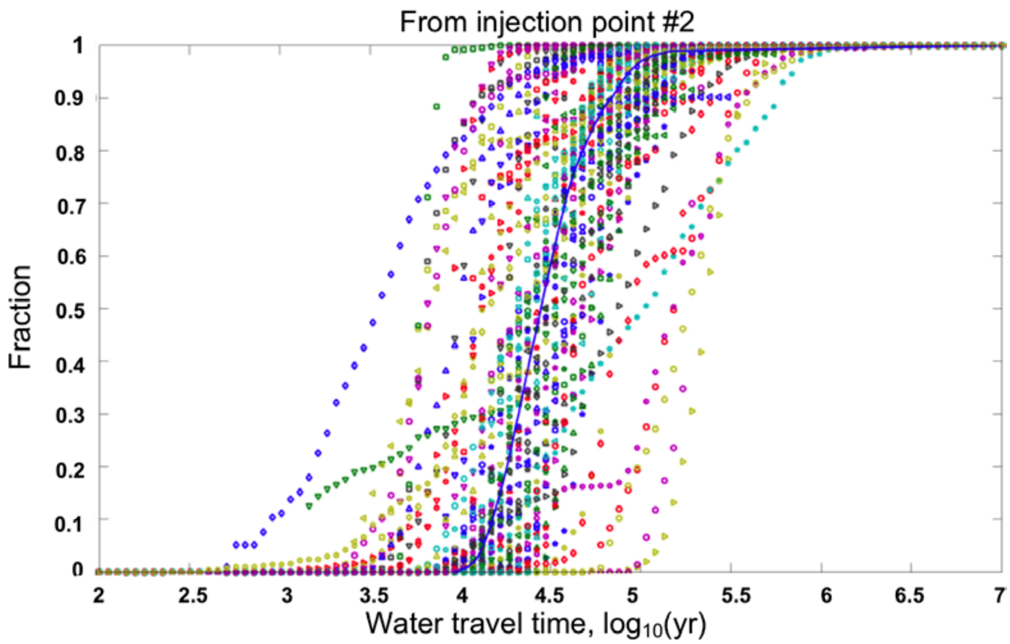

Figure B-8. *Cumulative curves for log_{10} (water travel time) for the 90 canister locations for paths starting at Q_2, HRD realization 2.*

Appendix C

Results for the far-field – tables

Identification of the canister locations used in the simulations

Table C-1. Identification of the canister locations used in the simulations.

Location No.	SKB ID	Easting, m	Northing, m	Level from the surface, m
1	57	1.6324E+06	6.7038E+06	–4.6745E+02
2	302	1.6327E+06	6.7038E+06	–4.6432E+02
3	341	1.6327E+06	6.7039E+06	–4.6449E+02
4	380	1.6328E+06	6.7037E+06	–4.6717E+02
5	395	1.6328E+06	6.7037E+06	–4.6626E+02
6	428	1.6317E+06	6.7039E+06	–4.6615E+02
7	490	1.6318E+06	6.7039E+06	–4.6516E+02
8	522	1.6315E+06	6.7036E+06	–4.6699E+02
9	526	1.6315E+06	6.7036E+06	–4.6675E+02
10	577	1.6315E+06	6.7036E+06	–4.6667E+02
11	891	1.6325E+06	6.7036E+06	–4.6439E+02
12	898	1.6318E+06	6.7036E+06	–4.6563E+02
13	925	1.6318E+06	6.7034E+06	–4.6335E+02
14	926	1.6318E+06	6.7034E+06	–4.6329E+02
15	952	1.6318E+06	6.7036E+06	–4.6479E+02
16	1,014	1.6319E+06	6.7035E+06	–4.6408E+02
17	1,150	1.6319E+06	6.7034E+06	–4.6403E+02
18	1,164	1.6327E+06	6.7034E+06	–4.6545E+02
19	1,264	1.6320E+06	6.7035E+06	–4.6656E+02
20	1,451	1.6321E+06	6.7034E+06	–4.6682E+02
21	1,628	1.6324E+06	6.7033E+06	–4.6597E+02
22	1,654	1.6324E+06	6.7032E+06	–4.6480E+02
23	1,674	1.6324E+06	6.7033E+06	–4.6500E+02
24	1,705	1.6325E+06	6.7032E+06	–4.6404E+02
25	1,726	1.6325E+06	6.7033E+06	–4.6451E+02
26	1,772	1.6326E+06	6.7033E+06	–4.6425E+02
27	1,875	1.6327E+06	6.7033E+06	–4.6581E+02
28	1,899	1.6327E+06	6.7031E+06	–4.6437E+02
29	2,037	1.6312E+06	6.7033E+06	–4.6419E+02
30	2,066	1.6313E+06	6.7034E+06	–4.6695E+02
31	2,073	1.6313E+06	6.7035E+06	–4.6653E+02
32	2,102	1.6312E+06	6.7033E+06	–4.6483E+02
33	2,201	1.6314E+06	6.7034E+06	–4.6788E+02
34	2,338	1.6315E+06	6.7033E+06	–4.6874E+02
35	2,408	1.6315E+06	6.7033E+06	–4.6842E+02
36	2,443	1.6314E+06	6.7032E+06	–4.6771E+02
37	2,590	1.6316E+06	6.7032E+06	–4.6781E+02
38	2,719	1.6315E+06	6.7029E+06	–4.6637E+02
39	2,841	1.6316E+06	6.7030E+06	–4.6689E+02
40	2,881	1.6318E+06	6.7032E+06	–4.6470E+02
41	2,976	1.6317E+06	6.7030E+06	–4.6663E+02
42	2,980	1.6317E+06	6.7030E+06	–4.6639E+02
43	2,987	1.6317E+06	6.7030E+06	–4.6597E+02
44	3,199	1.6319E+06	6.7032E+06	–4.6363E+02
45	3,217	1.6318E+06	6.7029E+06	–4.6484E+02
46	3,253	1.6320E+06	6.7030E+06	–4.6587E+02
47	3,402	1.6319E+06	6.7027E+06	–4.6346E+02

Location No.	SKB ID	Easting, m	Northing, m	Level from the surface, m
48	3,418	1.6320E+06	6.7030E+06	–4.6654E+02
49	3,433	1.6321E+06	6.7031E+06	–4.6564E+02
50	3,491	1.6321E+06	6.7029E+06	–4.6757E+02
51	3,496	1.6321E+06	6.7029E+06	–4.6727E+02
52	3,637	1.6320E+06	6.7027E+06	–4.6520E+02
53	3,792	1.6322E+06	6.7028E+06	–4.6913E+02
54	3,955	1.6323E+06	6.7030E+06	–4.6734E+02
55	4,038	1.6322E+06	6.7027E+06	–4.6889E+02
56	4,188	1.6323E+06	6.7025E+06	–4.6741E+02
57	4,244	1.6323E+06	6.7026E+06	–4.6773E+02
58	4,546	1.6327E+06	6.7027E+06	–4.6620E+02
59	4,716	1.6327E+06	6.7025E+06	–4.6559E+02
60	4,936	1.6314E+06	6.7025E+06	–4.6651E+02
61	4,969	1.6314E+06	6.7024E+06	–4.6759E+02
62	5,065	1.6315E+06	6.7024E+06	–4.6796E+02
63	5,125	1.6315E+06	6.7025E+06	–4.6717E+02
64	5,133	1.6315E+06	6.7025E+06	–4.6669E+02
65	5,148	1.6316E+06	6.7024E+06	–4.6892E+02
66	5,163	1.6316E+06	6.7025E+06	–4.6772E+02
67	5,174	1.6316E+06	6.7025E+06	–4.6706E+02
68	5,237	1.6317E+06	6.7024E+06	–4.6733E+02
69	5,283	1.6317E+06	6.7022E+06	–4.6802E+02
70	5,370	1.6318E+06	6.7021E+06	–4.6717E+02
71	5,387	1.6318E+06	6.7019E+06	–4.6561E+02
72	5,411	1.6318E+06	6.7023E+06	–4.6577E+02
73	5,456	1.6319E+06	6.7022E+06	–4.6612E+02
74	5,507	1.6318E+06	6.7019E+06	–4.6439E+02
75	5,727	1.6320E+06	6.7023E+06	–4.6277E+02
76	5,832	1.6321E+06	6.7021E+06	–4.6539E+02
77	5,919	1.6322E+06	6.7022E+06	–4.6438E+02
78	5,923	1.6322E+06	6.7022E+06	–4.6414E+02
79	5,981	1.6322E+06	6.7021E+06	–4.6511E+02
80	5,985	1.6322E+06	6.7022E+06	–4.6487E+02
81	6,097	1.6322E+06	6.7018E+06	–4.6433E+02
82	6,105	1.6322E+06	6.7017E+06	–4.6385E+02
83	6,178	1.6323E+06	6.7020E+06	–4.6773E+02
84	6,227	1.6323E+06	6.7018E+06	–4.6597E+02
85	6,355	1.6324E+06	6.7022E+06	–4.6637E+02
86	6,409	1.6324E+06	6.7020E+06	–4.6854E+02
87	6,480	1.6325E+06	6.7019E+06	–4.6939E+02
88	6,510	1.6325E+06	6.7021E+06	–4.6757E+02
89	6,777	1.6326E+06	6.7019E+06	–4.6753E+02
90	6,819	1.6326E+06	6.7017E+06	–4.6787E+02

Results for HRD realization 1

Table C-2. Summary of transport statistics for $\log_{10}$ (F-ratio) for paths starting at Q_1.

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#1	5.77	5.75	0.14	0.02	6.33	5.43	5.55	5.62	5.66	5.85	5.94	6.02
#2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#3	6.59	6.65	0.30	0.09	7.29	5.83	6.09	6.14	6.34	6.81	6.92	7.00
#4	6.18	6.16	0.16	0.02	6.89	5.86	5.97	6.00	6.06	6.25	6.35	6.50
#5	6.05	5.79	0.46	0.21	7.33	5.68	5.69	5.69	5.73	6.42	6.84	6.94
#6	5.92	5.91	0.17	0.03	6.60	5.39	5.64	5.71	5.82	5.99	6.14	6.22
#7	6.04	6.01	0.32	0.10	7.15	5.54	5.62	5.66	5.79	6.14	6.44	6.78
#8	6.43	6.59	0.49	0.24	7.44	5.71	5.74	5.76	5.83	6.84	6.97	7.08
#9	6.04	5.98	0.22	0.05	7.17	5.73	5.77	5.79	5.86	6.19	6.34	6.41
#10	5.83	5.81	0.18	0.03	6.63	5.47	5.58	5.62	5.68	5.92	6.06	6.12
#11	6.74	6.75	0.22	0.05	7.69	6.10	6.30	6.46	6.62	6.86	6.99	7.07
#12	6.53	6.51	0.28	0.08	7.38	5.88	6.13	6.19	6.29	6.76	6.90	6.96
#13	5.85	5.90	0.29	0.08	7.07	5.29	5.38	5.45	5.57	6.08	6.18	6.24
#14	5.71	5.76	0.20	0.04	6.59	5.28	5.34	5.39	5.57	5.84	5.91	5.99
#15	5.79	5.73	0.22	0.05	7.08	5.13	5.59	5.64	5.66	5.83	6.13	6.27
#16	6.04	6.01	0.14	0.02	7.02	5.85	5.90	5.91	5.95	6.07	6.22	6.28
#17	5.71	5.72	0.08	0.01	5.86	5.43	5.50	5.59	5.69	5.75	5.78	5.79
#18	6.30	6.23	0.25	0.06	7.09	5.85	6.00	6.05	6.13	6.38	6.71	6.82
#19	6.28	6.29	0.15	0.02	6.92	5.93	6.02	6.08	6.18	6.36	6.45	6.50
#20	6.21	6.19	0.15	0.02	6.92	6.00	6.04	6.05	6.09	6.29	6.38	6.47
#21	5.80	5.77	0.18	0.03	6.97	5.57	5.61	5.63	5.69	5.87	5.96	6.05
#22	6.36	6.35	0.18	0.03	7.20	5.99	6.08	6.12	6.23	6.47	6.59	6.68
#23	6.07	6.02	0.22	0.05	7.07	5.78	5.82	5.85	5.90	6.17	6.37	6.47
#24	6.86	6.89	0.23	0.05	7.40	6.19	6.40	6.54	6.74	7.01	7.11	7.17
#25	5.84	5.82	0.13	0.02	6.27	5.56	5.65	5.68	5.74	5.92	6.02	6.07
#26	7.00	7.00	0.18	0.03	7.43	6.58	6.70	6.74	6.87	7.12	7.21	7.27
#27	5.83	5.82	0.13	0.02	6.87	5.61	5.66	5.69	5.75	5.88	5.97	6.01
#28	5.73	5.75	0.16	0.03	6.21	5.44	5.47	5.50	5.59	5.84	5.93	5.99
#29	6.28	6.24	0.21	0.04	7.45	5.81	5.97	6.05	6.14	6.39	6.54	6.64
#30	6.95	6.94	0.20	0.04	7.78	6.29	6.64	6.72	6.81	7.07	7.20	7.26
#31	6.10	6.09	0.16	0.02	7.03	5.78	5.86	5.90	5.99	6.18	6.27	6.33
#32	6.00	5.95	0.23	0.05	6.97	5.63	5.68	5.73	5.82	6.12	6.31	6.44
#33	5.47	5.40	0.29	0.08	6.55	5.05	5.08	5.11	5.22	5.75	5.82	5.86
#34	5.11	5.08	0.10	0.01	5.46	4.99	5.00	5.01	5.04	5.16	5.26	5.29
#35	5.99	5.82	0.25	0.06	6.71	5.79	5.79	5.79	5.80	6.22	6.35	6.45
#36	6.41	6.32	0.30	0.09	7.37	5.86	5.99	6.06	6.17	6.68	6.83	6.90
#37	5.59	5.51	0.26	0.07	6.47	5.28	5.30	5.31	5.35	5.81	5.95	6.07
#38	5.58	5.46	0.35	0.13	7.16	5.29	5.32	5.34	5.40	5.52	6.01	6.37
#39	5.55	5.56	0.15	0.02	6.06	5.18	5.29	5.33	5.44	5.65	5.73	5.78
#40	6.07	6.04	0.18	0.03	7.08	5.72	5.82	5.87	5.94	6.16	6.28	6.38
#41	6.08	6.04	0.20	0.04	6.83	5.75	5.79	5.82	5.91	6.21	6.37	6.44
#42	5.62	5.58	0.19	0.04	6.15	5.32	5.36	5.38	5.44	5.75	5.88	5.93
#43	5.71	5.75	0.21	0.04	6.91	5.24	5.31	5.40	5.57	5.83	5.93	5.98
#44	6.16	6.13	0.25	0.06	7.22	5.78	5.84	5.88	5.96	6.30	6.48	6.59
#45	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#46	5.72	5.64	0.27	0.07	7.16	5.45	5.50	5.54	5.58	5.71	6.02	6.34
#47	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#48	5.35	5.29	0.23	0.06	7.08	5.06	5.09	5.12	5.19	5.39	5.59	5.63
#49	6.15	6.07	0.23	0.05	6.95	5.83	5.94	5.96	6.01	6.15	6.53	6.67
#50	6.38	6.32	0.24	0.06	7.16	5.90	6.08	6.12	6.18	6.54	6.74	6.84
#51	6.04	6.02	0.18	0.03	6.74	5.69	5.76	5.81	5.91	6.16	6.26	6.36
#52	5.89	5.83	0.33	0.11	6.94	5.42	5.44	5.46	5.65	6.07	6.37	6.51

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#53	6.16	6.12	0.24	0.06	7.23	5.73	5.85	5.91	6.00	6.23	6.37	6.67
#54	6.09	6.07	0.24	0.06	7.18	5.64	5.77	5.81	5.92	6.19	6.36	6.54
#55	5.82	5.84	0.22	0.05	6.52	5.37	5.44	5.49	5.67	5.96	6.09	6.16
#56	5.63	5.66	0.24	0.06	6.39	5.14	5.26	5.31	5.48	5.74	5.88	6.13
#57	5.50	5.54	0.15	0.02	5.81	5.20	5.25	5.28	5.35	5.62	5.65	5.69
#58	5.35	5.34	0.10	0.01	5.75	5.13	5.19	5.22	5.27	5.42	5.49	5.52
#59	6.19	6.17	0.17	0.03	7.06	5.74	5.88	6.01	6.11	6.28	6.37	6.44
#60	6.56	6.54	0.25	0.06	7.37	6.10	6.21	6.25	6.34	6.76	6.90	6.98
#61	5.74	5.72	0.13	0.02	6.64	5.52	5.58	5.60	5.65	5.78	5.87	5.92
#62	5.93	5.83	0.28	0.08	7.33	5.60	5.67	5.70	5.75	5.98	6.25	6.61
#63	5.85	5.82	0.15	0.02	6.63	5.63	5.69	5.72	5.76	5.88	6.02	6.17
#64	5.74	5.72	0.07	0.01	6.15	5.63	5.66	5.67	5.68	5.76	5.84	5.89
#65	5.73	5.65	0.21	0.05	6.89	5.54	5.61	5.61	5.62	5.69	5.87	6.21
#66	5.85	5.85	0.23	0.05	6.95	5.35	5.49	5.55	5.69	5.95	6.10	6.29
#67	6.09	6.04	0.17	0.03	6.95	5.65	5.88	5.91	5.97	6.19	6.34	6.40
#68	6.68	6.72	0.25	0.06	7.32	5.66	6.21	6.28	6.56	6.84	6.95	7.03
#69	6.50	6.43	0.27	0.07	7.11	6.02	6.12	6.17	6.27	6.73	6.86	6.92
#70	5.79	5.76	0.08	0.01	6.17	5.67	5.70	5.71	5.73	5.82	5.88	5.96
#71	6.77	6.78	0.20	0.04	7.32	6.32	6.44	6.48	6.62	6.92	7.01	7.07
#72	5.81	5.76	0.17	0.03	6.65	5.50	5.60	5.63	5.69	5.90	6.05	6.11
#73	5.54	5.39	0.31	0.10	7.63	5.29	5.31	5.32	5.34	5.54	6.02	6.26
#74	5.68	5.67	0.18	0.03	7.15	5.46	5.48	5.49	5.55	5.75	5.83	5.94
#75	6.49	6.48	0.29	0.09	7.40	5.77	6.05	6.12	6.24	6.72	6.88	6.94
#76	5.56	5.56	0.16	0.03	6.17	5.33	5.37	5.39	5.44	5.61	5.67	6.02
#77	6.05	6.04	0.12	0.01	6.92	5.84	5.92	5.94	5.98	6.09	6.17	6.23
#78	5.93	5.86	0.44	0.19	7.11	5.10	5.25	5.36	5.64	6.14	6.60	6.76
#79	6.00	5.98	0.21	0.04	6.76	5.69	5.71	5.74	5.84	6.13	6.27	6.38
#80	6.10	6.07	0.15	0.02	6.54	5.79	5.88	5.92	5.98	6.19	6.32	6.35
#81	5.65	5.61	0.16	0.03	6.35	5.43	5.46	5.47	5.52	5.73	5.87	5.95
#82	6.45	6.38	0.29	0.08	7.26	5.92	6.06	6.11	6.20	6.70	6.84	6.93
#83	6.11	6.09	0.16	0.03	7.40	5.78	5.86	5.93	6.01	6.18	6.31	6.35
#84	5.25	5.24	0.07	0.01	6.09	5.14	5.17	5.18	5.20	5.27	5.30	5.32
#85	6.29	6.23	0.24	0.06	7.37	5.91	5.99	6.03	6.11	6.39	6.60	6.75
#86	5.81	5.77	0.22	0.05	7.41	5.50	5.56	5.62	5.68	5.84	6.04	6.20
#87	6.49	6.44	0.24	0.06	7.23	6.01	6.16	6.21	6.29	6.65	6.83	6.95
#88	5.82	5.81	0.18	0.03	6.73	5.48	5.54	5.59	5.70	5.91	6.02	6.08
#89	5.82	5.81	0.14	0.02	6.30	5.55	5.62	5.65	5.71	5.90	6.00	6.06
#90	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Mean	6.01	5.98	0.21	0.05	6.89	5.62	5.72	5.76	5.85	6.12	6.27	6.38
Std. Dev.	0.39	0.40	0.08	0.04	0.48	0.31	0.35	0.36	0.37	0.43	0.43	0.44
5th per.	5.41	5.37	0.09	0.01	5.96	5.12	5.18	5.20	5.24	5.47	5.62	5.66
95th per.	6.71	6.74	0.32	0.10	7.44	6.10	6.26	6.37	6.59	6.85	6.98	7.07

Table C-3. Summary of transport statistics for $\log_{10}$ (F-ratio) for paths starting at Q_2.

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#1	5.75	5.74	0.14	0.02	6.19	5.39	5.53	5.62	5.65	5.83	5.92	5.99
#2	5.66	5.67	0.16	0.02	6.41	5.16	5.38	5.44	5.54	5.76	5.82	5.90
#3	6.57	6.63	0.31	0.09	7.27	5.86	6.04	6.12	6.29	6.78	6.92	7.00
#4	6.17	6.15	0.15	0.02	6.81	5.82	5.95	5.98	6.06	6.25	6.35	6.43
#5	5.96	5.80	0.37	0.14	7.21	5.70	5.70	5.70	5.73	5.88	6.62	6.85
#6	5.93	5.92	0.17	0.03	6.48	5.46	5.66	5.70	5.81	6.03	6.15	6.23
#7	6.00	6.01	0.28	0.08	7.32	5.56	5.65	5.69	5.77	6.12	6.26	6.60
#8	6.32	6.32	0.50	0.25	7.39	5.72	5.73	5.76	5.81	6.81	6.95	7.03
#9	6.05	6.00	0.22	0.05	6.97	5.74	5.79	5.81	5.87	6.19	6.35	6.46
#10	5.78	5.77	0.15	0.02	6.49	5.46	5.57	5.60	5.67	5.87	5.99	6.06
#11	6.73	6.75	0.24	0.06	7.88	6.08	6.26	6.37	6.60	6.86	6.98	7.10
#12	6.51	6.47	0.27	0.07	7.21	5.99	6.12	6.17	6.28	6.74	6.88	6.93
#13	5.81	5.84	0.29	0.08	6.64	5.29	5.36	5.42	5.55	6.05	6.16	6.25
#14	5.75	5.79	0.21	0.05	6.82	5.33	5.39	5.43	5.58	5.85	5.98	6.04
#15	5.77	5.72	0.22	0.05	7.06	5.14	5.44	5.58	5.66	5.82	6.12	6.14
#16	6.06	6.03	0.13	0.02	6.74	5.86	5.91	5.93	5.97	6.10	6.25	6.30
#17	5.70	5.70	0.07	0.00	5.89	5.40	5.53	5.66	5.68	5.73	5.76	5.78
#18	6.31	6.24	0.26	0.07	7.05	5.91	6.00	6.05	6.12	6.43	6.74	6.84
#19	6.29	6.29	0.15	0.02	7.04	5.98	6.06	6.10	6.18	6.38	6.45	6.51
#20	6.20	6.17	0.14	0.02	6.85	6.01	6.04	6.05	6.08	6.28	6.37	6.44
#21	5.80	5.76	0.18	0.03	7.14	5.57	5.62	5.65	5.69	5.85	5.93	6.00
#22	6.36	6.34	0.20	0.04	7.49	5.95	6.07	6.11	6.21	6.46	6.57	6.64
#23	6.05	6.00	0.20	0.04	6.86	5.77	5.81	5.83	5.90	6.12	6.33	6.42
#24	6.90	6.93	0.21	0.04	7.41	6.17	6.48	6.63	6.78	7.03	7.13	7.20
#25	5.83	5.82	0.13	0.02	6.46	5.57	5.63	5.66	5.73	5.90	6.00	6.06
#26	7.01	7.03	0.17	0.03	7.48	6.56	6.71	6.75	6.89	7.12	7.20	7.25
#27	5.84	5.82	0.13	0.02	7.11	5.61	5.66	5.69	5.75	5.89	5.97	6.04
#28	5.68	5.69	0.15	0.02	6.11	5.42	5.46	5.48	5.53	5.80	5.87	5.93
#29	6.30	6.26	0.19	0.04	7.15	5.86	6.03	6.08	6.16	6.41	6.58	6.64
#30	6.95	6.94	0.21	0.05	7.59	6.25	6.58	6.72	6.83	7.07	7.22	7.29
#31	6.13	6.12	0.15	0.02	6.93	5.76	5.89	5.93	6.02	6.21	6.30	6.35
#32	6.02	5.99	0.23	0.05	7.15	5.62	5.72	5.77	5.83	6.15	6.31	6.40
#33	5.51	5.46	0.28	0.08	6.44	5.06	5.11	5.14	5.27	5.76	5.83	5.90
#34	5.07	5.04	0.10	0.01	5.42	4.95	4.97	4.97	4.99	5.12	5.21	5.27
#35	5.97	5.81	0.23	0.05	6.70	5.77	5.78	5.78	5.78	6.21	6.27	6.41
#36	6.41	6.34	0.30	0.09	7.21	5.81	5.99	6.04	6.16	6.67	6.85	6.93
#37	5.60	5.53	0.26	0.07	6.71	5.27	5.30	5.32	5.36	5.82	5.96	6.04
#38	5.54	5.48	0.26	0.07	7.13	5.30	5.33	5.36	5.42	5.53	5.68	6.11
#39	5.58	5.58	0.15	0.02	6.74	5.23	5.33	5.38	5.47	5.66	5.74	5.80
#40	6.20	6.16	0.24	0.06	7.00	5.78	5.86	5.92	6.02	6.30	6.55	6.68
#41	6.08	6.04	0.23	0.05	7.15	5.75	5.78	5.81	5.90	6.22	6.38	6.49
#42	5.53	5.46	0.22	0.05	6.25	5.23	5.28	5.30	5.37	5.72	5.87	5.92
#43	5.74	5.77	0.20	0.04	6.70	5.24	5.33	5.44	5.63	5.84	5.94	5.98
#44	6.18	6.11	0.29	0.08	7.23	5.80	5.86	5.90	5.96	6.33	6.51	6.73
#45	5.52	5.34	0.39	0.15	6.60	5.02	5.11	5.15	5.22	5.84	6.14	6.30
#46	5.75	5.66	0.28	0.08	7.20	5.46	5.51	5.55	5.59	5.74	6.12	6.34
#47	5.77	5.72	0.19	0.04	6.54	5.57	5.61	5.62	5.66	5.80	5.90	6.27
#48	5.23	5.18	0.19	0.04	6.69	5.05	5.05	5.06	5.10	5.27	5.54	5.58
#49	6.06	6.01	0.21	0.05	7.07	5.73	5.87	5.90	5.95	6.06	6.27	6.60
#50	6.36	6.27	0.26	0.07	7.17	5.85	6.05	6.09	6.16	6.52	6.75	6.85
#51	6.03	6.01	0.20	0.04	6.79	5.66	5.75	5.79	5.88	6.14	6.28	6.41
#52	5.94	5.90	0.37	0.13	6.90	5.40	5.43	5.45	5.66	6.17	6.49	6.57
#53	6.13	6.10	0.25	0.06	7.22	5.72	5.80	5.85	5.95	6.22	6.43	6.64
#54	6.09	6.07	0.24	0.06	7.32	5.65	5.77	5.82	5.91	6.21	6.33	6.48

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#55	5.79	5.81	0.23	0.05	6.66	5.38	5.44	5.47	5.57	5.95	6.10	6.15
#56	5.65	5.67	0.25	0.06	6.99	5.14	5.27	5.34	5.49	5.75	5.87	6.13
#57	5.46	5.45	0.16	0.03	5.81	5.17	5.22	5.24	5.30	5.60	5.64	5.66
#58	5.31	5.29	0.11	0.01	5.62	5.12	5.16	5.18	5.23	5.38	5.46	5.51
#59	6.22	6.19	0.14	0.02	6.83	5.77	6.06	6.09	6.12	6.30	6.39	6.46
#60	6.58	6.59	0.26	0.07	7.33	6.09	6.22	6.25	6.34	6.79	6.91	6.99
#61	5.71	5.69	0.12	0.01	6.46	5.49	5.55	5.56	5.62	5.76	5.84	5.90
#62	5.99	5.91	0.27	0.07	7.12	5.62	5.69	5.72	5.80	6.09	6.29	6.62
#63	5.85	5.81	0.16	0.03	6.63	5.65	5.69	5.71	5.76	5.87	6.12	6.19
#64	5.73	5.71	0.08	0.01	6.11	5.61	5.65	5.66	5.68	5.76	5.85	5.89
#65	5.65	5.63	0.06	0.00	6.00	5.45	5.60	5.60	5.61	5.66	5.73	5.78
#66	5.89	5.90	0.21	0.04	7.12	5.38	5.55	5.63	5.79	5.96	6.06	6.23
#67	6.07	6.03	0.17	0.03	7.41	5.77	5.85	5.87	5.94	6.16	6.31	6.37
#68	6.70	6.73	0.26	0.07	7.50	5.90	6.19	6.28	6.56	6.86	6.98	7.03
#69	6.52	6.51	0.26	0.07	7.21	6.00	6.15	6.18	6.29	6.73	6.87	6.94
#70	5.76	5.74	0.10	0.01	7.13	5.68	5.68	5.69	5.70	5.77	5.83	5.86
#71	6.78	6.81	0.21	0.05	7.44	6.33	6.41	6.47	6.61	6.93	7.02	7.07
#72	5.85	5.81	0.19	0.04	6.81	5.50	5.59	5.65	5.71	5.94	6.09	6.21
#73	5.47	5.37	0.25	0.06	6.43	5.28	5.30	5.31	5.33	5.43	5.89	6.16
#74	5.68	5.66	0.15	0.02	6.99	5.48	5.51	5.53	5.60	5.71	5.77	5.81
#75	6.46	6.41	0.30	0.09	7.17	5.78	6.00	6.09	6.22	6.69	6.85	6.96
#76	5.44	5.40	0.14	0.02	6.57	5.29	5.31	5.33	5.35	5.47	5.60	5.64
#77	6.05	6.04	0.11	0.01	6.94	5.84	5.91	5.94	5.98	6.09	6.16	6.23
#78	5.92	5.87	0.42	0.18	7.12	5.06	5.27	5.36	5.64	6.09	6.59	6.76
#79	6.00	5.99	0.19	0.04	6.64	5.57	5.70	5.75	5.85	6.11	6.26	6.38
#80	6.06	6.04	0.14	0.02	6.62	5.77	5.86	5.90	5.95	6.14	6.25	6.33
#81	5.62	5.58	0.16	0.02	6.26	5.41	5.44	5.46	5.49	5.71	5.82	5.92
#82	6.47	6.43	0.31	0.09	7.33	5.87	6.05	6.09	6.19	6.74	6.88	6.95
#83	6.13	6.11	0.16	0.02	6.86	5.79	5.89	5.95	6.03	6.19	6.35	6.43
#84	5.22	5.21	0.05	0.00	5.61	5.12	5.15	5.16	5.18	5.25	5.28	5.29
#85	6.29	6.25	0.22	0.05	7.34	5.91	6.03	6.07	6.14	6.38	6.57	6.78
#86	5.81	5.77	0.19	0.04	6.99	5.49	5.59	5.63	5.70	5.84	5.99	6.18
#87	6.52	6.49	0.23	0.05	7.25	5.96	6.19	6.23	6.33	6.68	6.82	6.92
#88	5.86	5.85	0.18	0.03	7.51	5.52	5.59	5.64	5.74	5.95	6.05	6.09
#89	5.80	5.78	0.14	0.02	6.29	5.55	5.61	5.63	5.69	5.87	5.98	6.05
#90	5.52	5.34	0.39	0.15	6.60	5.02	5.11	5.15	5.22	5.84	6.14	6.30
Mean	5.98	5.95	0.21	0.05	6.86	5.60	5.70	5.74	5.83	6.09	6.25	6.35
Std. Dev.	0.40	0.41	0.08	0.04	0.48	0.33	0.36	0.37	0.38	0.43	0.44	0.45
5th per.	5.38	5.32	0.09	0.01	5.85	5.06	5.11	5.15	5.22	5.41	5.57	5.61
95th per.	6.71	6.74	0.37	0.14	7.48	6.09	6.24	6.32	6.58	6.86	6.98	7.05

Table C-4. Summary of transport statistics for log_{10} (water travel time) for paths starting at Q_1.

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#1	4.46	4.30	0.25	0.06	5.21	4.13	4.21	4.22	4.24	4.67	4.84	4.88
#2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#3	4.36	4.32	0.19	0.04	5.09	3.91	4.13	4.17	4.24	4.41	4.57	4.83
#4	4.29	4.31	0.11	0.01	5.07	3.93	4.06	4.15	4.24	4.35	4.40	4.43
#5	4.55	4.52	0.22	0.05	5.34	4.22	4.25	4.27	4.39	4.76	4.85	4.88
#6	4.17	4.18	0.16	0.03	4.88	3.75	3.88	3.96	4.05	4.28	4.35	4.41
#7	4.33	4.32	0.08	0.01	4.60	4.17	4.21	4.23	4.27	4.39	4.44	4.46
#8	4.74	4.80	0.16	0.02	5.01	4.30	4.41	4.48	4.62	4.84	4.88	4.90
#9	4.14	4.09	0.17	0.03	5.52	3.92	3.94	3.96	4.01	4.21	4.38	4.47
#10	4.38	4.35	0.33	0.11	5.21	3.74	3.96	4.01	4.06	4.69	4.80	4.87
#11	4.41	4.39	0.11	0.01	4.76	4.19	4.25	4.27	4.33	4.48	4.57	4.61
#12	4.39	4.39	0.14	0.02	4.94	4.00	4.19	4.22	4.26	4.47	4.57	4.62
#13	4.21	4.21	0.12	0.01	4.65	3.88	4.04	4.06	4.11	4.28	4.34	4.38
#14	4.11	4.11	0.20	0.04	5.44	3.67	3.79	3.85	3.96	4.23	4.32	4.38
#15	4.17	4.15	0.09	0.01	4.54	4.01	4.06	4.08	4.11	4.22	4.30	4.35
#16	4.41	4.41	0.22	0.05	5.54	4.04	4.12	4.16	4.27	4.49	4.58	4.90
#17	4.23	4.25	0.25	0.06	5.01	3.74	3.84	3.89	4.03	4.35	4.57	4.66
#18	4.22	4.22	0.10	0.01	4.62	3.89	4.03	4.08	4.15	4.28	4.34	4.37
#19	4.54	4.55	0.15	0.02	5.13	4.18	4.29	4.35	4.44	4.64	4.72	4.77
#20	4.37	4.40	0.20	0.04	4.78	3.92	4.04	4.08	4.21	4.52	4.61	4.65
#21	3.48	3.49	0.51	0.26	5.18	2.71	2.73	2.74	3.01	3.84	4.10	4.30
#22	4.36	4.41	0.18	0.03	4.77	3.92	4.04	4.09	4.20	4.51	4.55	4.57
#23	3.74	3.73	0.06	0.00	4.15	3.62	3.67	3.68	3.70	3.77	3.81	3.82
#24	4.47	4.46	0.13	0.02	5.17	4.10	4.25	4.31	4.38	4.54	4.63	4.68
#25	4.55	4.39	0.32	0.10	5.32	4.07	4.16	4.18	4.26	4.85	4.97	5.01
#26	4.98	4.99	0.08	0.01	5.21	4.56	4.83	4.86	4.92	5.04	5.08	5.09
#27	4.64	4.45	0.39	0.15	5.86	4.24	4.25	4.28	4.33	5.03	5.25	5.34
#28	4.21	4.17	0.26	0.07	5.46	3.90	3.93	3.95	4.01	4.33	4.53	4.76
#29	4.88	4.81	0.27	0.07	6.05	4.48	4.61	4.65	4.71	4.88	5.36	5.49
#30	4.78	4.77	0.14	0.02	5.43	4.25	4.58	4.62	4.68	4.86	4.96	5.01
#31	4.08	4.07	0.12	0.01	5.04	3.85	3.93	3.96	4.01	4.12	4.18	4.21
#32	4.42	4.25	0.39	0.15	6.24	3.97	4.01	4.04	4.10	4.70	5.01	5.17
#33	3.40	3.37	0.22	0.05	4.67	3.14	3.15	3.16	3.20	3.52	3.68	3.82
#34	4.36	4.29	0.30	0.09	5.35	3.73	3.91	4.00	4.19	4.57	4.63	5.03
#35	4.41	4.48	0.29	0.08	5.20	4.00	4.08	4.09	4.11	4.62	4.75	4.87
#36	4.43	4.42	0.14	0.02	4.86	4.02	4.19	4.25	4.35	4.52	4.59	4.64
#37	4.33	4.32	0.20	0.04	5.03	3.90	4.11	4.13	4.18	4.37	4.50	4.94
#38	3.97	3.93	0.13	0.02	4.56	3.82	3.83	3.85	3.87	4.00	4.09	4.23
#39	4.00	3.99	0.07	0.01	4.35	3.88	3.89	3.90	3.94	4.04	4.09	4.11
#40	4.22	4.17	0.20	0.04	5.54	3.79	3.96	4.01	4.07	4.30	4.43	4.61
#41	4.24	4.22	0.10	0.01	4.58	4.03	4.11	4.13	4.16	4.30	4.38	4.44
#42	3.74	3.66	0.47	0.22	5.62	3.14	NaN	3.22	3.42	3.87	4.58	4.69
#43	4.25	4.25	0.11	0.01	5.18	3.98	4.09	4.12	4.17	4.31	4.38	4.42
#44	4.43	4.34	0.26	0.07	6.20	4.16	4.23	4.25	4.28	4.42	4.73	5.05
#45	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#46	4.42	4.40	0.12	0.01	5.08	4.21	4.26	4.28	4.33	4.46	4.56	4.63
#47	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#48	4.68	4.58	0.30	0.09	5.92	4.23	4.38	4.40	4.43	4.97	5.08	5.18
#49	4.30	4.27	0.19	0.03	5.15	3.86	4.02	4.10	4.21	4.34	4.51	4.63
#50	4.42	4.44	0.09	0.01	4.72	4.00	4.25	4.29	4.34	4.48	4.50	4.52
#51	4.33	4.33	0.17	0.03	4.96	3.90	4.04	4.10	4.20	4.45	4.54	4.61
#52	4.39	4.39	0.25	0.06	5.29	3.77	4.07	4.10	4.20	4.54	4.60	4.99
#53	4.38	4.34	0.16	0.03	5.10	4.02	4.17	4.19	4.25	4.48	4.58	4.63
#54	4.15	4.13	0.17	0.03	4.73	3.80	3.88	3.94	4.02	4.24	4.37	4.44

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#55	4.15	4.14	0.13	0.02	4.84	3.80	4.00	4.02	4.06	4.22	4.32	4.40
#56	4.59	4.51	0.22	0.05	5.43	4.31	4.36	4.39	4.43	4.67	4.86	5.06
#57	4.38	4.36	0.27	0.07	5.18	3.86	3.91	3.97	4.20	4.55	4.71	4.80
#58	4.10	3.97	0.39	0.15	5.51	3.49	3.63	3.71	3.82	4.35	4.66	4.87
#59	4.35	4.32	0.12	0.01	4.86	4.13	4.20	4.22	4.27	4.40	4.51	4.58
#60	4.59	4.58	0.03	0.00	4.75	4.45	4.54	4.55	4.57	4.60	4.62	4.63
#61	4.62	4.55	0.26	0.07	5.48	4.24	4.31	4.33	4.42	4.75	5.01	5.13
#62	4.26	4.25	0.21	0.04	5.54	3.76	3.95	4.01	4.11	4.37	4.48	4.60
#63	4.20	4.19	0.11	0.01	4.58	3.91	4.03	4.06	4.12	4.26	4.34	4.39
#64	4.84	4.86	0.24	0.06	5.39	4.29	4.46	4.49	4.61	5.03	5.12	5.16
#65	3.82	3.78	0.21	0.04	5.29	3.54	3.58	3.60	3.65	3.92	4.07	4.21
#66	4.65	4.67	0.30	0.09	6.00	3.88	4.08	4.24	4.49	4.78	5.05	5.18
#67	4.52	4.49	0.36	0.13	5.60	3.81	4.04	4.06	4.17	4.78	5.02	5.11
#68	4.25	4.25	0.06	0.00	4.48	4.03	4.16	4.18	4.21	4.29	4.33	4.34
#69	4.30	4.25	0.24	0.06	5.27	3.95	4.02	4.05	4.14	4.39	4.56	4.89
#70	4.75	4.71	0.27	0.07	5.69	4.46	4.46	4.47	4.50	4.97	5.14	5.24
#71	4.59	4.59	0.08	0.01	5.14	4.17	4.46	4.50	4.55	4.61	4.67	4.70
#72	4.47	4.41	0.26	0.07	5.87	3.79	4.21	4.23	4.30	4.55	4.85	5.01
#73	3.96	3.93	0.11	0.01	4.52	3.70	3.82	3.84	3.88	4.00	4.10	4.16
#74	4.76	4.71	0.31	0.10	5.73	4.20	4.40	4.43	4.50	4.91	5.29	5.41
#75	4.23	4.25	0.12	0.02	4.67	3.78	3.97	4.05	4.17	4.31	4.37	4.41
#76	4.12	4.00	0.37	0.14	5.21	3.67	3.71	3.76	3.86	4.13	4.75	4.84
#77	4.59	4.57	0.20	0.04	6.06	4.28	4.37	4.42	4.49	4.63	4.71	4.80
#78	3.43	3.38	0.26	0.07	5.08	3.06	3.10	3.17	3.24	3.54	3.78	4.01
#79	4.18	4.15	0.14	0.02	4.87	3.63	4.07	4.09	4.12	4.17	4.26	4.52
#80	4.50	4.50	0.27	0.07	5.14	3.78	4.08	4.16	4.26	4.70	4.86	4.94
#81	4.27	4.17	0.21	0.04	5.01	4.03	4.07	4.08	4.11	4.39	4.60	4.68
#82	4.45	4.39	0.15	0.02	5.25	4.24	4.33	4.34	4.36	4.45	4.74	4.77
#83	4.65	4.72	0.30	0.09	5.28	4.10	4.17	4.19	4.32	4.86	5.02	5.10
#84	4.07	4.02	0.16	0.03	4.97	3.90	3.94	3.95	3.98	4.07	4.25	4.40
#85	4.32	4.27	0.19	0.04	4.91	3.71	4.07	4.12	4.18	4.43	4.60	4.69
#86	4.42	4.33	0.21	0.05	5.13	4.11	4.19	4.21	4.26	4.58	4.77	4.82
#87	4.54	4.54	0.09	0.01	4.72	4.23	4.35	4.44	4.48	4.62	4.64	4.65
#88	4.30	4.29	0.11	0.01	4.79	4.06	4.13	4.16	4.22	4.36	4.44	4.47
#89	4.50	4.31	0.34	0.12	5.30	3.99	4.10	4.13	4.19	4.82	4.94	5.00
#90	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Mean	4.33	4.30	0.20	0.05	5.15	3.94	4.08	4.10	4.18	4.45	4.59	4.69
Std. Dev.	0.29	0.30	0.10	0.05	0.43	0.30	0.30	0.32	0.31	0.31	0.33	0.34
5th per.	3.74	3.70	0.08	0.01	4.53	3.32	3.61	3.41	3.53	3.86	4.08	4.14
95th per.	4.76	4.75	0.38	0.14	5.96	4.31	4.46	4.49	4.59	4.94	5.10	5.18

Table C-5. Summary of transport statistics for $\log_{10}$ (water travel time) for paths starting at Q_2.

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#1	4.41	4.33	0.20	0.04	5.10	4.07	4.20	4.22	4.28	4.51	4.69	4.84
#2	4.27	4.28	0.52	0.27	5.53	3.47	3.58	3.63	3.79	4.62	5.07	5.21
#3	4.60	4.53	0.20	0.04	5.40	4.27	4.40	4.42	4.46	4.65	4.92	4.96
#4	4.44	4.43	0.17	0.03	5.06	3.98	4.19	4.25	4.32	4.50	4.70	4.77
#5	4.86	4.82	0.34	0.12	5.88	4.27	4.34	4.44	4.61	5.03	5.42	5.48
#6	4.41	4.36	0.28	0.08	5.17	3.81	4.01	4.04	4.18	4.59	4.79	4.92
#7	4.57	4.46	0.26	0.07	5.36	4.26	4.29	4.31	4.37	4.69	5.05	5.15
#8	4.99	4.93	0.27	0.07	6.25	4.51	4.62	4.67	4.84	5.08	5.50	5.54
#9	4.26	4.18	0.25	0.06	5.43	3.96	3.98	4.00	4.06	4.39	4.61	4.75
#10	4.37	4.33	0.22	0.05	5.19	3.83	3.99	4.04	4.21	4.50	4.64	4.74
#11	4.77	4.70	0.27	0.08	5.61	4.45	4.49	4.51	4.57	4.87	5.15	5.48
#12	4.69	4.68	0.14	0.02	5.19	4.44	4.48	4.50	4.58	4.79	4.87	4.92
#13	4.18	4.18	0.10	0.01	4.51	3.99	4.02	4.04	4.10	4.25	4.31	4.34
#14	4.67	4.65	0.31	0.09	5.95	4.21	4.26	4.30	4.41	4.86	5.04	5.16
#15	4.52	4.50	0.27	0.07	5.41	4.07	4.16	4.23	4.28	4.69	4.89	4.98
#16	4.65	4.58	0.37	0.14	5.75	4.11	4.16	4.22	4.33	4.90	5.12	5.34
#17	4.08	4.00	0.30	0.09	4.90	3.61	3.71	3.74	3.82	4.37	4.47	4.62
#18	4.41	4.37	0.23	0.05	5.27	4.00	4.15	4.20	4.27	4.47	4.58	5.00
#19	4.87	4.81	0.24	0.06	5.58	4.50	4.58	4.61	4.68	5.03	5.24	5.31
#20	4.61	4.65	0.27	0.07	5.18	3.97	4.10	4.19	4.41	4.82	4.92	4.98
#21	3.78	3.58	0.73	0.53	5.51	2.68	2.75	2.95	3.25	4.27	4.87	5.11
#22	4.55	4.55	0.24	0.06	6.09	3.85	4.13	4.22	4.38	4.70	4.84	4.89
#23	3.78	3.77	0.05	0.00	4.02	3.66	3.70	3.72	3.74	3.81	3.85	3.87
#24	4.58	4.54	0.21	0.05	5.67	4.17	4.32	4.36	4.43	4.65	4.90	4.98
#25	4.60	4.57	0.20	0.04	5.15	4.20	4.30	4.34	4.46	4.73	4.87	4.95
#26	5.40	5.42	0.09	0.01	5.58	5.18	5.24	5.26	5.33	5.47	5.51	5.53
#27	5.09	5.18	0.35	0.12	6.10	4.31	4.40	4.47	4.90	5.31	5.41	5.53
#28	4.07	4.02	0.17	0.03	4.90	3.84	3.88	3.90	3.94	4.16	4.29	4.38
#29	4.88	4.74	0.36	0.13	5.97	4.35	4.49	4.51	4.58	5.15	5.45	5.55
#30	4.82	4.81	0.15	0.02	5.60	4.30	4.61	4.65	4.71	4.89	4.98	5.08
#31	4.15	4.10	0.22	0.05	5.30	3.80	3.97	4.00	4.04	4.16	4.25	4.78
#32	4.86	4.86	0.28	0.08	5.86	4.11	4.39	4.51	4.67	5.01	5.19	5.34
#33	3.61	3.51	0.28	0.08	4.87	3.27	3.29	3.31	3.44	3.72	3.99	4.24
#34	4.08	4.02	0.29	0.09	5.30	3.60	3.67	3.77	3.93	4.13	4.35	4.95
#35	4.63	4.59	0.14	0.02	5.26	4.39	4.44	4.45	4.56	4.69	4.81	4.88
#36	4.67	4.66	0.12	0.01	5.05	4.41	4.49	4.53	4.59	4.75	4.83	4.87
#37	4.39	4.34	0.20	0.04	5.53	4.09	4.18	4.22	4.29	4.39	4.58	4.95
#38	4.15	4.03	0.28	0.08	4.95	3.88	3.90	3.91	3.94	4.26	4.64	4.78
#39	4.37	4.10	0.44	0.20	5.33	3.93	3.95	3.97	4.01	4.85	5.00	5.10
#40	5.12	5.15	0.26	0.07	5.85	4.61	4.70	4.77	4.89	5.30	5.40	5.64
#41	4.24	4.21	0.11	0.01	5.02	4.08	4.12	4.13	4.16	4.28	4.40	4.45
#42	4.78	4.68	0.23	0.05	5.90	4.21	4.53	4.57	4.63	4.95	5.04	5.14
#43	4.63	4.57	0.28	0.08	5.58	4.26	4.30	4.32	4.37	4.81	5.04	5.11
#44	4.81	4.72	0.43	0.19	6.02	4.27	4.31	4.33	4.38	5.16	5.42	5.52
#45	4.76	4.76	0.23	0.05	5.30	4.21	4.35	4.43	4.58	4.94	5.04	5.12
#46	4.59	4.52	0.23	0.05	5.22	4.24	4.30	4.34	4.40	4.74	4.95	5.02
#47	3.92	3.84	0.35	0.12	5.23	3.39	3.46	3.54	3.67	4.09	4.38	4.68
#48	4.45	4.40	0.24	0.06	5.63	4.14	4.18	4.21	4.30	4.50	4.68	5.11
#49	4.20	4.21	0.18	0.03	4.64	3.74	3.85	3.92	4.09	4.32	4.40	4.46
#50	4.46	4.47	0.14	0.02	5.14	4.04	4.26	4.29	4.36	4.50	4.59	4.73
#51	4.30	4.30	0.18	0.03	4.91	3.90	4.03	4.07	4.15	4.42	4.51	4.56
#52	4.40	4.50	0.26	0.07	5.29	3.86	4.05	4.09	4.17	4.57	4.62	4.82
#53	4.65	4.60	0.30	0.09	5.87	4.11	4.19	4.24	4.53	4.80	4.92	5.29
#54	4.55	4.51	0.36	0.13	6.00	3.89	4.06	4.12	4.31	4.71	4.87	5.50

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#55	4.16	4.14	0.15	0.02	5.06	3.79	3.97	3.99	4.06	4.22	4.32	4.40
#56	4.69	4.63	0.27	0.07	5.49	4.28	4.38	4.40	4.46	4.86	5.07	5.21
#57	4.24	4.31	0.28	0.08	5.05	3.81	3.85	3.87	3.97	4.40	4.60	4.71
#58	3.94	3.86	0.34	0.11	5.36	3.44	3.53	3.62	3.72	4.01	4.59	4.71
#59	4.46	4.37	0.24	0.06	5.97	4.17	4.23	4.24	4.28	4.60	4.84	4.93
#60	4.60	4.59	0.04	0.00	4.74	4.45	4.55	4.56	4.57	4.61	4.63	4.65
#61	4.49	4.44	0.22	0.05	5.72	4.12	4.27	4.28	4.35	4.57	4.75	4.96
#62	4.48	4.38	0.34	0.11	5.80	3.79	4.04	4.10	4.22	4.71	4.97	5.08
#63	4.20	4.19	0.10	0.01	4.54	3.95	4.05	4.07	4.13	4.27	4.34	4.39
#64	4.91	4.94	0.16	0.02	5.44	4.62	4.69	4.70	4.75	5.02	5.10	5.17
#65	3.72	3.65	0.22	0.05	5.01	3.44	3.48	3.50	3.55	3.81	4.04	4.16
#66	4.62	4.66	0.26	0.07	5.68	3.90	4.18	4.27	4.46	4.74	4.85	5.05
#67	4.78	4.76	0.25	0.06	5.42	4.26	4.40	4.46	4.58	4.95	5.12	5.21
#68	4.26	4.26	0.05	0.00	4.42	4.07	4.18	4.19	4.22	4.30	4.32	4.34
#69	4.41	4.39	0.19	0.04	5.13	3.97	4.14	4.21	4.28	4.49	4.62	4.70
#70	4.56	4.49	0.19	0.03	5.54	4.43	4.44	4.45	4.46	4.55	4.78	5.03
#71	4.61	4.60	0.09	0.01	5.14	4.34	4.49	4.53	4.56	4.64	4.69	4.75
#72	4.75	4.77	0.26	0.07	5.88	4.17	4.31	4.37	4.53	4.94	5.05	5.13
#73	3.92	3.90	0.09	0.01	4.28	3.75	3.79	3.81	3.85	3.96	4.03	4.11
#74	4.72	4.66	0.24	0.06	7.15	4.40	4.45	4.47	4.53	4.85	4.98	5.06
#75	4.27	4.28	0.12	0.01	4.54	3.95	4.03	4.09	4.20	4.35	4.41	4.46
#76	4.34	4.38	0.27	0.08	5.11	3.90	3.99	4.01	4.05	4.57	4.70	4.81
#77	4.80	4.68	0.32	0.11	6.08	4.37	4.44	4.48	4.56	4.93	5.40	5.43
#78	3.54	3.48	0.26	0.07	5.07	3.14	3.23	3.25	3.35	3.67	3.94	4.07
#79	4.15	4.14	0.07	0.01	4.86	3.78	4.07	4.09	4.12	4.16	4.18	4.20
#80	4.50	4.49	0.23	0.05	5.16	3.97	4.16	4.21	4.31	4.64	4.82	4.90
#81	4.18	4.12	0.16	0.03	4.90	4.03	4.05	4.06	4.08	4.19	4.39	4.58
#82	4.49	4.44	0.17	0.03	5.26	4.24	4.34	4.35	4.38	4.51	4.76	4.81
#83	4.62	4.59	0.37	0.13	5.42	4.11	4.16	4.19	4.26	4.96	5.11	5.20
#84	4.06	3.99	0.19	0.04	5.02	3.88	3.91	3.93	3.95	4.06	4.36	4.47
#85	4.52	4.55	0.32	0.10	6.37	3.98	4.10	4.17	4.25	4.66	4.85	4.99
#86	4.53	4.40	0.28	0.08	5.21	4.15	4.22	4.24	4.29	4.85	4.95	5.02
#87	4.55	4.55	0.09	0.01	4.92	4.25	4.40	4.46	4.49	4.62	4.65	4.66
#88	4.85	4.91	0.44	0.20	5.96	4.08	4.20	4.24	4.41	5.15	5.38	5.55
#89	4.58	4.56	0.21	0.04	5.18	4.16	4.26	4.30	4.42	4.72	4.86	4.97
#90	4.76	4.76	0.23	0.05	5.30	4.21	4.35	4.43	4.58	4.94	5.04	5.12
Mean	4.47	4.43	0.24	0.07	5.36	4.05	4.15	4.20	4.29	4.60	4.78	4.92
Std. Dev.	0.34	0.35	0.11	0.07	0.49	0.35	0.35	0.34	0.34	0.36	0.37	0.38
5th per.	3.78	3.71	0.08	0.01	4.53	3.42	3.47	3.52	3.61	3.89	4.04	4.18
95th per.	4.90	4.92	0.40	0.16	6.08	4.48	4.60	4.63	4.73	5.15	5.41	5.52

Results for HRD realization 2

Table C-6. Summary of transport statistics for $\log_{10}$ (F-ratio) for paths starting at Q_1.

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#1	5.81	5.81	0.23	0.05	6.97	5.45	5.50	5.53	5.64	5.91	6.10	6.21
#2	5.65	5.58	0.26	0.07	6.97	5.43	5.46	5.49	5.52	5.63	5.81	6.21
#3	6.10	6.06	0.20	0.04	7.12	5.79	5.88	5.90	5.97	6.17	6.30	6.43
#4	6.02	5.97	0.17	0.03	6.72	5.79	5.82	5.84	5.89	6.10	6.27	6.38
#5	5.62	5.60	0.14	0.02	6.02	5.41	5.43	5.44	5.51	5.71	5.83	5.88
#6	5.78	5.72	0.19	0.04	7.23	5.36	5.62	5.65	5.67	5.83	6.02	6.18
#7	6.13	6.10	0.24	0.06	7.20	5.54	5.74	5.85	5.98	6.25	6.42	6.54
#8	6.78	6.79	0.22	0.05	7.66	5.93	6.34	6.53	6.67	6.89	7.02	7.11
#9	5.96	5.93	0.15	0.02	6.99	5.73	5.78	5.82	5.85	6.03	6.12	6.21
#10	6.98	6.99	0.20	0.04	7.82	6.44	6.58	6.68	6.84	7.11	7.21	7.27
#11	5.75	5.67	0.29	0.08	7.15	5.46	5.49	5.51	5.59	5.76	6.02	6.46
#12	5.90	5.88	0.10	0.01	6.33	5.70	5.76	5.79	5.82	5.95	6.01	6.06
#13	5.86	5.76	0.26	0.07	6.89	5.63	5.64	5.65	5.69	5.92	6.26	6.49
#14	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#15	6.11	6.10	0.19	0.04	6.84	5.68	5.78	5.87	5.98	6.22	6.33	6.42
#16	5.92	5.91	0.10	0.01	6.34	5.71	5.77	5.80	5.84	5.97	6.04	6.10
#17	6.12	6.09	0.21	0.04	7.23	5.72	5.83	5.87	5.96	6.23	6.36	6.44
#18	6.33	6.25	0.28	0.08	7.18	5.88	5.98	6.03	6.12	6.57	6.76	6.82
#19	7.04	7.03	0.15	0.02	7.50	6.67	6.79	6.85	6.92	7.13	7.24	7.29
#20	6.02	6.03	0.21	0.04	6.74	5.55	5.64	5.71	5.90	6.15	6.25	6.36
#21	6.51	6.45	0.26	0.07	7.59	5.95	6.17	6.21	6.28	6.71	6.87	6.96
#22	5.87	5.84	0.13	0.02	6.39	5.57	5.69	5.72	5.78	5.94	6.04	6.10
#23	6.18	6.18	0.16	0.03	7.09	5.80	5.97	5.98	6.02	6.28	6.38	6.42
#24	5.89	5.81	0.36	0.13	7.14	5.44	5.48	5.51	5.59	6.13	6.34	6.61
#25	5.62	5.56	0.22	0.05	6.89	5.30	5.39	5.43	5.50	5.64	5.92	6.11
#26	5.66	5.59	0.28	0.08	7.32	5.35	5.42	5.46	5.51	5.68	5.84	6.21
#27	6.45	6.41	0.35	0.12	7.43	5.87	5.91	5.98	6.17	6.73	6.93	7.04
#28	6.05	6.03	0.16	0.02	6.62	5.76	5.84	5.87	5.92	6.13	6.24	6.37
#29	6.55	6.47	0.27	0.07	7.31	5.95	6.19	6.24	6.32	6.77	6.93	7.01
#30	5.78	5.77	0.10	0.01	6.28	5.54	5.62	5.66	5.71	5.83	5.88	5.96
#31	5.38	5.36	0.50	0.25	7.01	4.63	4.65	4.72	5.03	5.64	5.99	6.41
#32	5.09	5.06	0.11	0.01	5.80	4.97	4.98	4.99	5.01	5.14	5.24	5.30
#33	6.00	5.95	0.23	0.05	7.01	5.64	5.72	5.75	5.82	6.07	6.35	6.43
#34	5.07	5.03	0.17	0.03	5.46	4.73	4.82	4.86	4.93	5.20	5.31	5.35
#35	6.72	6.75	0.25	0.06	7.50	6.01	6.19	6.32	6.59	6.89	7.00	7.06
#36	5.93	5.89	0.13	0.02	6.97	5.72	5.79	5.81	5.84	5.97	6.13	6.17
#37	5.69	5.70	0.12	0.01	6.25	5.39	5.51	5.54	5.59	5.76	5.82	5.85
#38	5.97	5.97	0.08	0.01	6.28	5.72	5.84	5.87	5.92	6.02	6.08	6.13
#39	6.11	6.04	0.22	0.05	7.04	5.83	5.87	5.89	5.94	6.24	6.42	6.55
#40	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#41	5.92	5.86	0.27	0.07	7.13	5.54	5.61	5.64	5.70	6.06	6.33	6.46
#42	6.19	6.15	0.14	0.02	6.99	5.98	6.01	6.03	6.07	6.27	6.38	6.44
#43	6.75	6.79	0.25	0.06	7.65	6.02	6.36	6.37	6.59	6.92	7.04	7.11
#44	5.77	5.78	0.24	0.06	7.11	5.24	5.42	5.48	5.59	5.87	6.02	6.16
#45	5.92	5.91	0.12	0.01	6.31	5.56	5.74	5.77	5.84	6.00	6.08	6.13
#46	6.17	6.12	0.23	0.05	7.17	5.72	5.84	5.90	6.00	6.31	6.48	6.59
#47	5.76	5.75	0.18	0.03	6.42	5.46	5.49	5.52	5.60	5.90	5.97	6.03
#48	6.00	5.96	0.19	0.04	7.37	5.42	5.79	5.83	5.88	6.04	6.20	6.34
#49	6.13	6.10	0.15	0.02	6.97	5.88	5.94	5.96	6.01	6.20	6.30	6.40
#50	5.83	5.87	0.15	0.02	6.35	5.51	5.53	5.59	5.71	5.94	5.97	6.01
#51	5.87	5.86	0.13	0.02	6.43	5.56	5.66	5.69	5.78	5.95	6.02	6.06
#52	6.11	6.08	0.12	0.01	6.75	5.91	5.96	5.98	6.02	6.16	6.27	6.33

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#53	6.12	6.09	0.17	0.03	6.74	5.81	5.89	5.93	6.00	6.20	6.34	6.44
#54	5.82	5.83	0.20	0.04	6.69	5.16	5.44	5.54	5.70	5.94	6.06	6.12
#55	6.46	6.40	0.22	0.05	7.15	6.11	6.20	6.24	6.31	6.52	6.81	6.92
#56	6.04	6.03	0.19	0.04	6.84	5.69	5.76	5.79	5.89	6.15	6.29	6.36
#57	5.78	5.75	0.18	0.03	6.95	5.55	5.59	5.61	5.68	5.83	5.93	6.01
#58	5.96	5.91	0.19	0.04	6.91	5.69	5.73	5.76	5.84	5.99	6.15	6.43
#59	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#60	6.06	6.07	0.18	0.03	6.57	5.42	5.79	5.83	5.93	6.19	6.28	6.35
#61	5.98	5.93	0.24	0.06	7.22	5.52	5.62	5.69	5.79	6.17	6.28	6.36
#62	5.82	5.80	0.16	0.03	6.65	5.36	5.56	5.64	5.73	5.88	5.99	6.06
#63	6.61	6.69	0.29	0.08	7.27	5.84	6.08	6.15	6.35	6.80	6.93	6.99
#64	6.23	6.21	0.13	0.02	7.02	5.99	6.06	6.08	6.13	6.29	6.40	6.45
#65	5.51	5.47	0.19	0.04	6.36	5.17	5.24	5.28	5.37	5.60	5.79	5.87
#66	6.12	6.11	0.17	0.03	6.94	5.81	5.88	5.92	5.99	6.22	6.32	6.42
#67	6.50	6.46	0.32	0.10	7.53	6.05	6.08	6.10	6.21	6.78	6.94	7.04
#68	5.92	5.91	0.18	0.03	6.74	5.56	5.62	5.69	5.80	6.02	6.12	6.18
#69	5.45	5.40	0.25	0.07	7.21	5.25	NaN	5.25	5.30	5.47	5.60	5.63
#70	6.00	5.97	0.12	0.01	6.37	5.79	5.85	5.87	5.91	6.07	6.17	6.21
#71	6.07	6.03	0.25	0.06	7.29	5.65	5.75	5.81	5.91	6.17	6.31	6.52
#72	5.98	5.96	0.29	0.08	7.13	5.53	5.63	5.65	5.76	6.11	6.25	6.62
#73	6.03	6.03	0.17	0.03	6.79	5.49	5.76	5.82	5.91	6.13	6.22	6.29
#74	6.48	6.46	0.31	0.09	7.31	5.89	6.05	6.10	6.20	6.74	6.86	6.94
#75	6.22	6.21	0.21	0.04	6.76	5.84	5.94	5.95	6.01	6.39	6.50	6.55
#76	6.50	6.46	0.28	0.08	7.32	5.83	6.10	6.15	6.26	6.72	6.88	6.97
#77	6.68	6.70	0.25	0.06	7.51	5.70	6.16	6.31	6.55	6.83	6.95	7.05
#78	5.76	5.76	0.11	0.01	6.19	5.38	5.59	5.64	5.69	5.82	5.90	5.94
#79	6.00	5.99	0.11	0.01	6.92	5.80	5.87	5.89	5.93	6.04	6.10	6.14
#80	6.75	6.78	0.24	0.06	7.47	6.09	6.29	6.40	6.61	6.89	7.01	7.10
#81	5.85	5.80	0.17	0.03	6.99	5.62	5.66	5.68	5.74	5.89	6.13	6.18
#82	6.12	6.08	0.23	0.05	6.95	5.65	5.78	5.84	5.94	6.26	6.43	6.58
#83	5.56	5.55	0.06	0.00	6.08	5.47	5.50	5.50	5.52	5.58	5.62	5.67
#84	6.09	6.05	0.18	0.03	7.42	5.76	5.88	5.91	5.96	6.15	6.26	6.36
#85	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#86	6.37	6.26	0.29	0.09	7.37	5.90	6.02	6.05	6.13	6.62	6.78	6.87
#87	5.79	5.77	0.13	0.02	6.29	5.53	5.61	5.62	5.68	5.87	5.96	6.02
#88	6.69	6.72	0.23	0.05	7.35	6.20	6.30	6.35	6.53	6.85	6.98	7.05
#89	5.77	5.76	0.12	0.02	6.62	5.50	5.57	5.60	5.69	5.82	5.93	5.98
#90	6.23	6.23	0.18	0.03	6.80	5.85	5.93	5.98	6.10	6.36	6.45	6.50
Mean	6.05	6.02	0.20	0.05	6.91	5.65	5.86	5.81	5.90	6.15	6.29	6.40
Std. Dev.	0.37	0.38	0.07	0.03	0.45	0.31	0.33	0.35	0.36	0.41	0.41	0.41
5th per.	5.48	5.43	0.10	0.01	6.14	5.17	5.32	5.27	5.33	5.59	5.71	5.76
95th per.	6.73	6.77	0.30	0.09	7.52	6.07	6.29	6.36	6.59	6.89	7.00	7.08

Table C-7. Summary of transport statistics for $\log_{10}$ (F-ratio) for paths starting at Q_2.

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#1	5.61	5.54	0.21	0.04	6.33	5.26	5.38	5.39	5.45	5.75	5.90	6.05
#2	5.67	5.59	0.28	0.08	7.15	5.45	5.48	5.49	5.54	5.64	5.93	6.34
#3	6.10	6.05	0.21	0.04	7.18	5.81	5.89	5.91	5.96	6.16	6.29	6.42
#4	6.02	5.97	0.17	0.03	6.60	5.80	5.83	5.85	5.89	6.12	6.25	6.35
#5	5.63	5.61	0.14	0.02	6.07	5.40	5.41	5.43	5.52	5.71	5.83	5.88
#6	5.81	5.78	0.28	0.08	6.91	5.40	5.46	5.50	5.58	5.89	6.20	6.37
#7	6.14	6.13	0.24	0.06	7.14	5.54	5.70	5.85	6.00	6.27	6.44	6.57
#8	6.77	6.78	0.22	0.05	7.57	5.95	6.33	6.50	6.66	6.90	7.00	7.10
#9	5.96	5.92	0.15	0.02	6.95	5.73	5.77	5.82	5.86	6.02	6.10	6.21
#10	7.01	7.03	0.20	0.04	7.69	6.46	6.64	6.74	6.86	7.14	7.24	7.29
#11	5.73	5.69	0.22	0.05	7.28	5.47	5.51	5.54	5.60	5.76	5.88	6.01
#12	5.91	5.89	0.11	0.01	6.70	5.73	5.77	5.79	5.83	5.96	6.03	6.07
#13	5.80	5.73	0.20	0.04	6.69	5.63	5.63	5.64	5.67	5.81	6.10	6.30
#14	5.84	5.81	0.22	0.05	6.90	5.35	5.53	5.60	5.70	5.94	6.10	6.20
#15	6.08	6.05	0.16	0.03	7.06	5.67	5.85	5.90	5.97	6.17	6.29	6.36
#16	5.92	5.91	0.09	0.01	6.26	5.71	5.78	5.80	5.85	5.97	6.03	6.08
#17	6.12	6.11	0.18	0.03	6.91	5.73	5.82	5.89	5.98	6.24	6.33	6.41
#18	6.33	6.22	0.30	0.09	7.18	5.86	5.97	6.01	6.10	6.53	6.80	6.90
#19	7.05	7.05	0.15	0.02	7.70	6.71	6.81	6.86	6.93	7.14	7.24	7.29
#20	6.03	6.04	0.19	0.04	6.71	5.53	5.67	5.77	5.93	6.14	6.24	6.32
#21	6.55	6.52	0.26	0.07	7.22	6.03	6.18	6.22	6.30	6.76	6.90	6.98
#22	5.87	5.84	0.14	0.02	6.59	5.57	5.68	5.72	5.78	5.92	6.03	6.10
#23	6.15	6.15	0.15	0.02	6.94	5.83	5.96	5.97	6.00	6.26	6.35	6.39
#24	5.87	5.77	0.34	0.12	7.33	5.44	5.49	5.52	5.59	6.10	6.30	6.47
#25	5.63	5.57	0.24	0.06	7.01	5.27	5.38	5.43	5.49	5.63	5.87	6.12
#26	5.69	5.60	0.30	0.09	7.34	5.36	5.44	5.47	5.53	5.70	5.91	6.26
#27	6.47	6.46	0.33	0.11	7.33	5.79	5.97	6.03	6.22	6.69	6.93	7.06
#28	6.04	6.02	0.17	0.03	6.61	5.76	5.81	5.85	5.92	6.12	6.26	6.37
#29	6.52	6.45	0.27	0.08	7.48	5.99	6.14	6.21	6.30	6.73	6.91	6.98
#30	5.78	5.77	0.11	0.01	6.45	5.54	5.60	5.65	5.71	5.83	5.90	5.94
#31	5.07	4.80	0.52	0.27	6.92	4.59	4.59	4.60	4.64	5.39	5.72	6.27
#32	5.09	5.06	0.11	0.01	5.84	4.97	4.98	4.98	5.00	5.15	5.23	5.29
#33	6.01	5.96	0.25	0.06	7.41	5.61	5.71	5.74	5.85	6.08	6.37	6.51
#34	5.00	4.98	0.16	0.03	5.46	4.71	4.78	4.80	4.87	5.09	5.27	5.31
#35	6.74	6.74	0.24	0.06	7.71	5.97	6.25	6.35	6.62	6.89	7.00	7.07
#36	5.94	5.90	0.13	0.02	6.76	5.74	5.79	5.81	5.85	5.98	6.13	6.18
#37	5.71	5.72	0.12	0.02	6.93	5.44	5.52	5.55	5.60	5.77	5.83	5.86
#38	5.97	5.96	0.09	0.01	6.47	5.74	5.83	5.86	5.90	6.01	6.08	6.13
#39	6.13	6.08	0.22	0.05	8.00	5.86	5.88	5.90	5.95	6.28	6.41	6.49
#40	5.71	5.69	0.17	0.03	6.95	5.45	5.50	5.52	5.58	5.78	5.89	5.99
#41	5.97	5.94	0.27	0.07	6.93	5.55	5.62	5.66	5.75	6.11	6.40	6.50
#42	6.20	6.16	0.14	0.02	7.12	5.99	6.02	6.03	6.08	6.29	6.37	6.44
#43	6.75	6.78	0.24	0.06	7.53	6.13	6.36	6.38	6.59	6.91	7.01	7.10
#44	5.80	5.81	0.23	0.05	7.17	5.34	5.45	5.51	5.64	5.87	6.05	6.20
#45	5.91	5.90	0.12	0.02	6.55	5.55	5.71	5.75	5.82	5.98	6.07	6.12
#46	6.16	6.13	0.22	0.05	6.78	5.70	5.84	5.89	6.02	6.31	6.48	6.61
#47	5.77	5.77	0.18	0.03	6.48	5.47	5.51	5.53	5.61	5.92	5.99	6.03
#48	6.02	5.98	0.18	0.03	6.92	5.53	5.79	5.84	5.90	6.08	6.22	6.37
#49	6.13	6.09	0.14	0.02	6.84	5.91	5.95	5.97	6.02	6.21	6.31	6.40
#50	5.82	5.86	0.15	0.02	6.20	5.50	5.53	5.59	5.71	5.93	5.97	5.99
#51	5.86	5.86	0.13	0.02	6.42	5.55	5.66	5.69	5.78	5.94	6.01	6.06
#52	6.12	6.09	0.13	0.02	6.86	5.90	5.98	6.00	6.04	6.17	6.26	6.36
#53	6.15	6.12	0.18	0.03	6.73	5.83	5.91	5.95	6.00	6.26	6.41	6.49
#54	5.88	5.89	0.20	0.04	7.20	5.37	5.50	5.61	5.77	5.99	6.09	6.14

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#55	6.44	6.41	0.19	0.03	7.12	6.11	6.22	6.24	6.31	6.51	6.68	6.87
#56	6.05	6.03	0.19	0.04	6.66	5.72	5.77	5.81	5.90	6.16	6.29	6.39
#57	5.78	5.74	0.18	0.03	7.03	5.57	5.59	5.63	5.68	5.83	5.91	5.99
#58	5.97	5.93	0.20	0.04	6.94	5.64	5.73	5.79	5.85	6.00	6.15	6.46
#59	5.31	5.17	0.39	0.15	6.89	4.91	4.96	5.00	5.06	5.32	5.98	6.24
#60	6.02	6.04	0.19	0.04	6.54	5.45	5.61	5.80	5.90	6.14	6.23	6.28
#61	5.98	5.94	0.25	0.06	6.63	5.46	5.60	5.68	5.79	6.19	6.30	6.40
#62	5.83	5.82	0.16	0.03	6.63	5.37	5.56	5.64	5.75	5.89	6.01	6.09
#63	6.60	6.67	0.29	0.08	7.21	5.84	6.08	6.16	6.35	6.81	6.93	6.99
#64	6.22	6.20	0.14	0.02	7.02	6.00	6.05	6.08	6.13	6.28	6.38	6.48
#65	5.44	5.42	0.18	0.03	6.06	5.11	5.17	5.21	5.30	5.54	5.68	5.77
#66	6.03	6.01	0.19	0.03	7.15	5.70	5.78	5.82	5.90	6.11	6.24	6.35
#67	6.57	6.50	0.33	0.11	7.47	6.07	6.09	6.12	6.29	6.84	6.99	7.10
#68	5.92	5.90	0.19	0.04	7.04	5.54	5.63	5.68	5.80	6.00	6.14	6.23
#69	5.49	5.44	0.27	0.07	6.80	5.25	NaN	5.27	5.32	5.51	5.64	6.24
#70	6.01	5.98	0.12	0.01	6.47	5.73	5.84	5.88	5.92	6.08	6.18	6.22
#71	6.08	6.05	0.23	0.05	7.22	5.67	5.78	5.83	5.93	6.17	6.31	6.47
#72	6.03	6.02	0.30	0.09	7.19	5.56	5.64	5.67	5.78	6.12	6.36	6.73
#73	6.04	6.05	0.16	0.03	7.01	5.52	5.77	5.82	5.94	6.13	6.23	6.29
#74	6.47	6.45	0.30	0.09	7.13	5.91	6.04	6.10	6.20	6.71	6.87	6.94
#75	6.18	6.16	0.20	0.04	6.74	5.87	5.94	5.95	5.98	6.34	6.47	6.52
#76	6.48	6.43	0.27	0.07	7.32	5.85	6.10	6.15	6.25	6.69	6.84	6.94
#77	6.69	6.72	0.28	0.08	7.83	5.50	6.16	6.31	6.56	6.84	7.00	7.07
#78	5.74	5.73	0.12	0.02	6.15	5.36	5.54	5.62	5.67	5.81	5.89	5.95
#79	5.99	5.98	0.11	0.01	6.93	5.81	5.87	5.88	5.92	6.04	6.11	6.15
#80	6.73	6.77	0.27	0.07	7.73	6.08	6.21	6.32	6.57	6.89	7.03	7.12
#81	5.84	5.81	0.15	0.02	6.61	5.62	5.66	5.69	5.74	5.89	6.02	6.17
#82	6.09	6.05	0.23	0.05	6.91	5.66	5.76	5.81	5.91	6.23	6.38	6.48
#83	5.53	5.52	0.05	0.00	5.88	5.35	5.47	5.48	5.49	5.55	5.57	5.59
#84	6.08	6.05	0.17	0.03	7.30	5.77	5.87	5.91	5.97	6.14	6.25	6.34
#85	5.50	5.51	0.12	0.01	6.02	5.25	5.31	5.34	5.40	5.57	5.63	5.67
#86	6.38	6.28	0.29	0.08	7.27	5.81	6.01	6.06	6.14	6.62	6.79	6.88
#87	5.79	5.77	0.13	0.02	6.20	5.57	5.60	5.62	5.69	5.87	5.97	6.04
#88	6.70	6.74	0.24	0.06	7.61	6.18	6.31	6.36	6.49	6.86	7.00	7.07
#89	5.77	5.77	0.14	0.02	6.67	5.53	5.57	5.60	5.69	5.82	5.91	6.01
#90	6.17	6.17	0.19	0.04	7.00	5.76	5.87	5.92	6.01	6.32	6.41	6.46
Mean	6.02	5.99	0.20	0.05	6.91	5.64	5.82	5.79	5.88	6.12	6.27	6.38
Std. Dev.	0.39	0.41	0.07	0.04	0.47	0.32	0.35	0.36	0.39	0.43	0.42	0.42
5th per.	5.38	5.29	0.11	0.01	6.04	5.04	5.07	5.10	5.18	5.45	5.64	5.72
95th per.	6.73	6.76	0.32	0.10	7.69	6.10	6.28	6.35	6.58	6.89	7.00	7.10

Table C-8. Summary of transport statistics for log_{10} (water travel time) for paths starting at Q_1.

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#1	4.57	4.50	0.28	0.08	5.40	3.93	4.19	4.30	4.36	4.72	5.04	5.19
#2	4.31	4.28	0.14	0.02	5.03	4.14	4.17	4.19	4.22	4.34	4.47	4.62
#3	4.46	4.43	0.17	0.03	5.33	4.16	4.22	4.26	4.34	4.57	4.69	4.75
#4	4.39	4.38	0.07	0.01	4.71	4.26	4.30	4.31	4.33	4.43	4.48	4.52
#5	4.36	4.34	0.26	0.07	5.14	3.96	3.99	4.01	4.15	4.53	4.62	4.91
#6	4.87	4.62	0.50	0.25	6.27	4.43	4.45	4.47	4.50	5.28	5.72	5.92
#7	4.41	4.33	0.25	0.06	4.99	3.99	4.15	4.21	4.27	4.39	4.93	4.94
#8	4.55	4.56	0.13	0.02	4.95	4.19	4.30	4.36	4.47	4.62	4.71	4.75
#9	4.30	4.28	0.12	0.01	5.07	4.12	4.18	4.20	4.23	4.33	4.40	4.49
#10	4.80	4.84	0.21	0.04	5.97	4.38	4.46	4.49	4.62	4.95	5.02	5.06
#11	4.26	4.23	0.20	0.04	5.34	3.93	3.97	4.00	4.14	4.36	4.49	4.60
#12	4.34	4.34	0.11	0.01	4.71	4.02	4.16	4.21	4.26	4.42	4.49	4.53
#13	4.29	4.26	0.25	0.06	5.05	3.86	3.91	4.00	4.11	4.41	4.70	4.79
#14	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#15	4.51	4.49	0.36	0.13	5.44	3.69	3.86	4.00	4.28	4.81	4.96	5.07
#16	4.26	4.26	0.14	0.02	4.90	3.91	4.02	4.08	4.17	4.34	4.42	4.47
#17	4.41	4.40	0.13	0.02	5.06	4.13	4.21	4.24	4.31	4.48	4.58	4.64
#18	4.21	4.20	0.16	0.03	4.51	3.86	3.96	3.99	4.07	4.37	4.41	4.44
#19	5.27	5.30	0.09	0.01	5.66	4.95	5.06	5.11	5.24	5.33	5.35	5.38
#20	3.98	3.90	0.25	0.06	4.77	3.49	3.66	3.69	3.78	4.15	4.38	4.43
#21	4.38	4.39	0.12	0.02	4.68	4.08	4.15	4.18	4.32	4.45	4.53	4.60
#22	4.39	4.38	0.11	0.01	5.00	4.11	4.24	4.27	4.32	4.43	4.50	4.57
#23	4.15	4.37	0.66	0.43	5.58	2.87	3.15	3.17	3.61	4.56	4.98	5.15
#24	3.95	3.95	0.18	0.03	4.77	3.26	3.62	3.72	3.86	4.04	4.13	4.22
#25	4.31	4.29	0.15	0.02	5.20	4.00	4.12	4.18	4.24	4.34	4.40	4.70
#26	4.35	4.31	0.22	0.05	5.23	3.91	4.06	4.10	4.19	4.46	4.66	4.79
#27	4.70	4.68	0.17	0.03	5.61	4.24	4.46	4.52	4.59	4.76	4.83	4.94
#28	4.31	4.31	0.13	0.02	4.81	4.01	4.09	4.15	4.25	4.37	4.45	4.53
#29	4.63	4.63	0.12	0.02	5.09	4.11	4.39	4.48	4.55	4.70	4.76	4.80
#30	4.12	4.14	0.16	0.03	4.78	3.67	3.83	3.89	4.02	4.23	4.30	4.35
#31	4.79	4.69	0.32	0.10	5.80	4.36	4.41	4.43	4.50	5.11	5.26	5.30
#32	4.32	4.24	0.33	0.11	5.34	3.71	3.84	3.91	4.10	4.53	4.84	5.03
#33	4.33	4.27	0.28	0.08	5.82	3.87	4.03	4.10	4.19	4.36	4.56	5.03
#34	4.10	4.08	0.28	0.08	5.02	3.44	3.64	3.71	3.94	4.23	4.54	4.63
#35	4.35	4.35	0.16	0.02	5.06	4.00	4.10	4.15	4.22	4.44	4.56	4.59
#36	4.08	4.08	0.14	0.02	5.21	3.59	3.87	3.90	3.99	4.16	4.24	4.29
#37	4.18	4.18	0.08	0.01	4.50	4.03	4.06	4.08	4.12	4.23	4.27	4.31
#38	4.30	4.16	0.23	0.05	4.95	3.91	4.07	4.08	4.10	4.51	4.59	4.71
#39	4.55	4.48	0.21	0.05	5.54	4.33	4.38	4.39	4.43	4.54	4.88	5.10
#40	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#41	4.12	4.11	0.22	0.05	5.40	3.67	3.81	3.89	3.99	4.20	4.30	4.37
#42	4.59	4.68	0.36	0.13	5.62	3.86	4.03	4.09	4.24	4.82	5.04	5.15
#43	4.35	4.35	0.17	0.03	4.82	4.00	4.06	4.12	4.23	4.46	4.57	4.64
#44	4.71	4.68	0.35	0.12	5.55	3.84	4.09	4.20	4.48	5.00	5.10	5.23
#45	4.28	4.23	0.34	0.12	5.79	3.49	3.81	3.86	4.00	4.53	4.70	4.82
#46	4.15	4.14	0.20	0.04	4.81	3.72	3.86	3.91	4.00	4.26	4.35	4.45
#47	4.13	4.12	0.08	0.01	4.76	3.98	4.01	4.03	4.07	4.17	4.23	4.28
#48	4.18	4.11	0.41	0.16	5.62	3.40	3.54	3.73	3.91	4.39	4.73	4.97
#49	4.44	4.42	0.10	0.01	4.88	4.27	4.30	4.32	4.35	4.50	4.57	4.60
#50	4.29	4.19	0.25	0.06	5.28	3.95	3.98	4.01	4.11	4.48	4.57	4.78
#51	4.39	4.39	0.12	0.02	4.83	4.12	4.20	4.23	4.30	4.46	4.55	4.60
#52	4.23	4.20	0.21	0.04	5.76	3.91	3.96	4.03	4.09	4.31	4.46	4.58
#53	5.29	5.32	0.32	0.10	6.20	4.41	4.80	4.87	4.99	5.51	5.72	5.79
#54	4.52	4.47	0.26	0.07	6.13	4.30	4.33	4.36	4.40	4.51	4.60	5.32

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#55	5.11	5.01	0.27	0.07	6.05	4.74	4.81	4.83	4.89	5.31	5.50	5.59
#56	3.99	3.88	0.27	0.07	5.16	3.61	3.74	3.77	3.83	4.05	4.39	4.57
#57	3.49	3.48	0.52	0.27	5.24	2.72	2.75	2.77	3.01	3.78	4.23	4.38
#58	4.54	4.42	0.29	0.08	6.27	4.17	4.30	4.31	4.35	4.62	4.88	5.16
#59	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#60	4.53	4.49	0.30	0.09	5.28	3.46	4.10	4.16	4.27	4.80	4.94	5.00
#61	4.36	4.36	0.18	0.03	5.17	3.97	4.08	4.12	4.22	4.48	4.58	4.66
#62	4.34	4.33	0.14	0.02	5.39	3.98	4.16	4.19	4.25	4.40	4.46	4.50
#63	4.29	4.28	0.17	0.03	4.84	3.89	4.02	4.07	4.15	4.40	4.52	4.56
#64	4.58	4.57	0.12	0.01	5.24	4.32	4.42	4.44	4.50	4.65	4.73	4.78
#65	4.18	3.96	0.41	0.17	5.77	3.77	3.79	3.81	3.85	4.56	4.81	4.92
#66	4.55	4.52	0.17	0.03	5.75	4.24	4.36	4.39	4.45	4.60	4.67	4.74
#67	4.56	4.55	0.08	0.01	4.90	4.38	4.44	4.46	4.50	4.61	4.66	4.69
#68	3.93	3.91	0.17	0.03	4.82	3.52	3.69	3.73	3.81	4.04	4.17	4.22
#69	4.25	4.14	0.26	0.07	4.97	3.98	4.00	4.02	4.06	4.49	4.68	4.77
#70	4.48	4.42	0.25	0.06	5.45	4.07	4.17	4.22	4.29	4.57	4.86	4.97
#71	4.17	4.16	0.20	0.04	4.94	3.64	3.84	3.91	4.02	4.29	4.42	4.49
#72	4.29	4.27	0.17	0.03	4.84	3.94	4.01	4.06	4.17	4.39	4.50	4.58
#73	4.40	4.41	0.10	0.01	4.69	4.14	4.24	4.26	4.33	4.47	4.53	4.58
#74	4.40	4.37	0.18	0.03	5.19	4.12	4.20	4.22	4.27	4.47	4.59	4.75
#75	4.22	4.23	0.10	0.01	5.05	3.90	4.07	4.11	4.16	4.27	4.31	4.34
#76	4.19	4.16	0.18	0.03	4.92	3.83	3.94	3.97	4.05	4.30	4.41	4.47
#77	4.29	4.28	0.12	0.02	5.30	3.82	4.08	4.16	4.22	4.35	4.43	4.47
#78	4.33	4.23	0.21	0.04	5.03	3.94	4.12	4.13	4.15	4.48	4.65	4.71
#79	4.53	4.51	0.16	0.02	5.79	4.15	4.38	4.40	4.45	4.57	4.63	4.68
#80	4.66	4.67	0.12	0.01	4.93	4.34	4.43	4.49	4.60	4.73	4.80	4.84
#81	4.14	4.13	0.17	0.03	5.31	3.79	3.90	3.94	4.02	4.23	4.35	4.43
#82	3.94	3.94	0.18	0.03	4.50	3.24	3.63	3.71	3.82	4.07	4.16	4.22
#83	4.49	4.46	0.26	0.07	5.24	4.05	4.17	4.18	4.22	4.71	4.84	4.93
#84	4.54	4.49	0.19	0.04	5.18	4.21	4.31	4.34	4.39	4.66	4.85	4.91
#85	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
#86	4.38	4.37	0.10	0.01	4.84	4.10	4.25	4.27	4.30	4.43	4.52	4.56
#87	4.39	4.25	0.29	0.08	5.10	3.99	4.10	4.13	4.17	4.68	4.85	4.94
#88	4.59	4.59	0.14	0.02	4.99	4.36	4.37	4.39	4.48	4.68	4.78	4.82
#89	4.35	4.33	0.21	0.04	5.20	3.97	4.06	4.11	4.20	4.44	4.65	4.73
#90	4.11	4.14	0.37	0.14	5.19	2.59	3.36	3.63	4.02	4.25	4.44	4.67
Mean	4.37	4.34	0.21	0.06	5.21	3.94	4.08	4.13	4.22	4.50	4.64	4.75
Std. Dev.	0.27	0.27	0.11	0.06	0.41	0.38	0.33	0.32	0.29	0.29	0.31	0.33
5th per.	3.96	3.92	0.09	0.01	4.69	3.25	3.58	3.70	3.82	4.06	4.23	4.28
95th per.	4.79	4.69	0.39	0.15	6.01	4.38	4.45	4.49	4.60	5.05	5.18	5.31

Table C-9. Summary of transport statistics for log_{10} (water travel time) for paths starting at Q_2.

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#1	4.46	4.39	0.34	0.12	5.66	3.87	4.02	4.10	4.18	4.64	5.06	5.13
#2	4.73	4.77	0.25	0.06	5.25	4.30	4.33	4.36	4.49	4.91	5.01	5.08
#3	4.82	4.74	0.27	0.07	5.80	4.48	4.52	4.55	4.59	4.96	5.33	5.38
#4	4.40	4.38	0.07	0.00	4.77	4.27	4.31	4.32	4.35	4.43	4.49	4.52
#5	4.32	4.26	0.27	0.07	5.23	3.93	3.94	3.97	4.16	4.38	4.81	4.86
#6	5.41	5.41	0.17	0.03	6.06	4.97	5.14	5.20	5.30	5.51	5.61	5.69
#7	4.57	4.53	0.29	0.08	5.40	4.04	4.18	4.24	4.33	4.81	5.00	5.06
#8	4.89	4.84	0.23	0.05	5.66	4.43	4.56	4.64	4.70	5.02	5.24	5.32
#9	4.51	4.52	0.22	0.05	5.15	4.18	4.21	4.24	4.30	4.64	4.79	4.90
#10	5.24	5.23	0.24	0.06	5.76	4.76	4.83	4.90	5.07	5.44	5.56	5.65
#11	4.47	4.36	0.35	0.13	5.76	4.00	4.05	4.09	4.23	4.56	5.06	5.28
#12	4.75	4.67	0.25	0.06	5.46	4.39	4.44	4.47	4.54	4.94	5.15	5.24
#13	4.35	4.30	0.24	0.06	5.17	4.00	4.02	4.06	4.21	4.43	4.77	4.83
#14	4.04	4.04	0.18	0.03	5.26	3.70	3.76	3.81	3.95	4.12	4.20	4.25
#15	4.68	4.73	0.28	0.08	5.34	4.02	4.24	4.31	4.40	4.86	5.03	5.10
#16	4.48	4.42	0.29	0.08	5.62	4.03	4.16	4.21	4.31	4.50	4.92	5.20
#17	4.55	4.53	0.23	0.06	5.56	4.18	4.26	4.30	4.37	4.63	4.77	5.17
#18	4.47	4.46	0.24	0.06	5.22	4.07	4.14	4.17	4.26	4.64	4.79	4.87
#19	5.28	5.31	0.10	0.01	5.52	4.99	5.07	5.11	5.24	5.34	5.37	5.40
#20	3.90	3.83	0.24	0.06	4.51	3.42	3.59	3.64	3.73	4.09	4.28	4.36
#21	4.54	4.50	0.18	0.03	5.23	4.13	4.27	4.32	4.42	4.66	4.78	4.89
#22	4.64	4.69	0.21	0.04	5.26	4.16	4.34	4.36	4.44	4.75	4.90	4.99
#23	4.39	4.56	0.69	0.47	5.96	3.16	NaN	3.18	3.78	4.92	5.10	5.13
#24	3.99	4.01	0.17	0.03	4.45	3.12	3.68	3.79	3.93	4.06	4.15	4.21
#25	4.77	4.76	0.25	0.06	5.58	4.25	4.40	4.44	4.57	4.91	5.10	5.19
#26	4.68	4.72	0.29	0.08	5.47	4.05	4.21	4.28	4.40	4.90	5.02	5.10
#27	4.93	4.91	0.20	0.04	5.63	4.46	4.63	4.71	4.81	4.99	5.17	5.34
#28	4.32	4.31	0.14	0.02	5.20	4.03	4.11	4.16	4.25	4.38	4.47	4.56
#29	4.64	4.64	0.12	0.01	5.08	4.15	4.43	4.48	4.56	4.71	4.77	4.81
#30	4.62	4.61	0.29	0.09	5.35	4.04	4.16	4.22	4.35	4.83	4.99	5.08
#31	4.51	4.48	0.20	0.04	5.77	4.18	4.26	4.29	4.36	4.59	4.72	4.82
#32	4.46	4.36	0.30	0.09	5.50	4.16	4.17	4.18	4.20	4.55	5.02	5.07
#33	4.81	4.79	0.28	0.08	6.31	4.29	4.41	4.45	4.59	4.98	5.15	5.27
#34	3.94	3.89	0.35	0.12	4.87	3.35	3.45	3.50	3.67	4.09	4.52	4.56
#35	4.55	4.54	0.15	0.02	5.03	4.24	4.31	4.35	4.45	4.64	4.76	4.81
#36	4.57	4.55	0.24	0.06	5.19	4.04	4.21	4.27	4.35	4.72	4.88	5.01
#37	4.46	4.43	0.25	0.06	5.44	4.10	4.17	4.19	4.24	4.62	4.82	4.86
#38	4.20	4.11	0.20	0.04	5.15	3.89	4.02	4.04	4.07	4.25	4.46	4.63
#39	4.62	4.50	0.27	0.07	5.52	4.38	4.41	4.42	4.45	4.61	5.13	5.25
#40	4.54	4.48	0.24	0.06	5.42	4.00	4.24	4.29	4.37	4.62	4.97	5.04
#41	4.57	4.59	0.31	0.10	5.53	3.90	4.12	4.19	4.29	4.75	4.97	5.14
#42	4.90	4.92	0.40	0.16	5.88	3.83	4.11	4.26	4.69	5.19	5.37	5.50
#43	4.66	4.64	0.36	0.13	5.60	3.98	4.11	4.22	4.53	4.71	5.22	5.55
#44	4.71	4.69	0.24	0.06	5.42	4.03	4.39	4.44	4.55	4.78	5.13	5.16
#45	4.22	4.16	0.29	0.08	5.90	3.60	3.79	3.87	4.01	4.41	4.60	4.72
#46	4.41	4.45	0.32	0.10	5.17	3.80	3.93	3.99	4.12	4.66	4.81	4.92
#47	4.46	4.42	0.31	0.09	5.23	4.07	4.10	4.12	4.17	4.69	4.90	4.96
#48	4.30	4.21	0.47	0.22	6.18	3.17	3.63	3.75	3.96	4.56	4.91	5.09
#49	4.76	4.71	0.27	0.07	5.34	4.29	4.37	4.41	4.53	4.99	5.14	5.20
#50	4.20	4.13	0.22	0.05	5.05	3.93	3.95	3.96	4.08	4.23	4.52	4.58
#51	4.79	4.78	0.18	0.03	5.39	4.46	4.54	4.56	4.63	4.90	5.04	5.12
#52	4.66	4.57	0.25	0.06	6.43	4.35	4.45	4.47	4.51	4.69	5.11	5.22
#53	5.06	5.07	0.53	0.28	6.36	4.08	4.28	4.36	4.60	5.49	5.80	5.88
#54	5.20	5.23	0.37	0.14	6.11	4.39	4.49	4.54	5.03	5.46	5.61	5.75

Location	Mean	Median	Std-Dev	Var	Max	Min	5% Perc	10% Perc	25% Perc	75% Perc	90% Perc	95% Perc
#55	5.30	5.31	0.27	0.07	6.13	4.74	4.87	4.92	5.10	5.48	5.64	5.76
#56	3.91	3.85	0.21	0.04	5.09	3.51	3.70	3.73	3.79	3.94	4.15	4.38
#57	3.62	3.59	0.47	0.23	5.16	2.73	2.86	3.00	3.28	3.88	4.25	4.43
#58	4.85	4.83	0.25	0.06	5.83	4.41	4.47	4.53	4.66	4.98	5.17	5.29
#59	4.20	4.17	0.26	0.07	5.01	3.68	3.81	3.88	4.00	4.38	4.57	4.63
#60	4.47	4.41	0.24	0.06	5.12	3.86	4.07	4.19	4.29	4.64	4.79	4.88
#61	4.36	4.36	0.17	0.03	6.04	4.01	4.10	4.15	4.24	4.45	4.55	4.62
#62	4.71	4.68	0.27	0.07	5.78	4.16	4.32	4.38	4.52	4.88	5.06	5.18
#63	4.43	4.44	0.16	0.03	4.77	3.93	4.11	4.19	4.32	4.55	4.62	4.67
#64	4.71	4.64	0.24	0.06	5.57	4.34	4.43	4.47	4.54	4.84	5.12	5.21
#65	3.83	3.83	0.07	0.01	4.27	3.70	3.73	3.74	3.78	3.88	3.92	3.95
#66	5.05	4.99	0.28	0.08	5.83	4.33	4.69	4.72	4.82	5.29	5.44	5.49
#67	4.63	4.57	0.20	0.04	5.48	4.43	4.46	4.49	4.53	4.66	4.81	5.08
#68	3.89	3.87	0.16	0.03	4.43	3.49	3.63	3.69	3.77	3.98	4.15	4.20
#69	4.50	4.39	0.36	0.13	5.52	4.05	4.08	4.10	4.17	4.78	4.95	5.10
#70	4.59	4.52	0.30	0.09	5.47	4.00	4.20	4.24	4.37	4.79	5.03	5.12
#71	4.50	4.46	0.35	0.12	5.63	3.91	4.03	4.09	4.22	4.64	5.09	5.15
#72	4.52	4.43	0.28	0.08	5.63	4.10	4.18	4.22	4.30	4.66	4.96	5.05
#73	4.78	4.71	0.30	0.09	5.75	4.24	4.38	4.43	4.59	4.92	5.20	5.33
#74	4.48	4.45	0.20	0.04	5.26	4.14	4.22	4.25	4.33	4.58	4.74	4.81
#75	4.21	4.21	0.08	0.01	4.59	3.95	4.08	4.11	4.16	4.25	4.29	4.32
#76	4.17	4.14	0.18	0.03	5.15	3.79	3.92	3.96	4.02	4.27	4.41	4.48
#77	4.30	4.29	0.12	0.01	5.08	3.92	4.13	4.18	4.23	4.35	4.42	4.48
#78	4.24	4.17	0.17	0.03	5.25	4.02	4.09	4.11	4.13	4.33	4.50	4.57
#79	4.70	4.58	0.33	0.11	5.88	4.29	4.35	4.38	4.49	4.79	5.27	5.34
#80	4.68	4.68	0.11	0.01	5.28	4.36	4.48	4.55	4.61	4.74	4.80	4.85
#81	4.38	4.36	0.29	0.08	5.42	3.88	3.97	4.03	4.15	4.59	4.75	4.85
#82	3.92	3.89	0.28	0.08	4.96	3.34	3.50	3.60	3.75	4.03	4.20	4.65
#83	4.43	4.44	0.25	0.06	5.10	4.11	4.13	4.13	4.16	4.61	4.75	4.84
#84	4.65	4.60	0.24	0.06	5.29	4.26	4.33	4.36	4.43	4.87	4.97	5.04
#85	4.05	4.05	0.26	0.07	5.24	3.54	3.66	3.74	3.85	4.14	4.36	4.46
#86	4.39	4.38	0.10	0.01	4.88	4.08	4.25	4.27	4.32	4.45	4.52	4.56
#87	4.31	4.22	0.26	0.07	5.18	4.00	4.07	4.10	4.15	4.32	4.77	4.90
#88	4.61	4.60	0.14	0.02	4.99	4.36	4.39	4.41	4.50	4.71	4.80	4.83
#89	4.51	4.49	0.24	0.06	5.19	4.01	4.14	4.19	4.33	4.68	4.82	4.90
#90	4.20	4.17	0.45	0.20	6.15	2.63	3.44	3.59	4.03	4.38	4.83	4.93
Mean	4.52	4.49	0.25	0.07	5.41	4.03	4.17	4.21	4.33	4.65	4.87	4.97
Std. Dev.	0.34	0.35	0.10	0.06	0.43	0.40	0.35	0.36	0.34	0.36	0.37	0.38
5th per.	3.91	3.86	0.10	0.01	4.55	3.17	3.55	3.59	3.76	4.01	4.17	4.28
95th per.	5.13	5.15	0.42	0.18	6.14	4.47	4.66	4.72	4.93	5.39	5.50	5.60

Appendix D

Files with co-ordinates for Forsmark features

Table D-1. Files with co-ordinates for tunnels, deposition holes, ramp and shafts in layout D2 for Forsmark (Forsmark D2 – Sammanställning av PPs leveranser till SR-Site (2).pdf from TRAC.).

File	SKB dok ID	Description	Date (latest version)
DA_13.XLS	1170578	Deposition holes, AREA A	2008-05-23
DB_13.XLS	1170580	Deposition holes, AREA B	2008-05-23
DC_13.XLS	1170582	Deposition holes, AREA C	2008-05-23
DD_13.XLS	1170584	Deposition holes, AREA D	2008-05-23
DA_END_13.XLS	1170579	Deposition tunnels, AREA A	2008-05-23
DB_END_13.XLS	1170581	Deposition tunnels, AREA B	2008-05-23
DC_END_13.XLS	1170583	Deposition tunnels, AREA C	2008-05-23
DD_END_13.XLS	1170585	Deposition tunnels, AREA D	2008-05-23
Other tunnels, shafts and ramp			
DABCD.XLS	1169615	Main and transport tunnels	2008-04-29
SA.XLS	1169646	Ventilation shaft from central area	2008-04-29
SB.XLS	1169647	Elevator shaft from central area	2008-04-29
SC.XLS	1169648	Skip shaft from central area	2008-04-29
SD.XLS	1169622	Ventilation shaft from deposition area	2008-04-29
RB.XLS	1169645	A access ramp	2008-04-29
C.XLS	1169643	Central area	2008-04-29

The files are stored at the TRAC data base, http://svn.skb.se/trac/SR-SiteDataStorage/browser/SERCO/Pathlines/090827_fs_Q123_2000_pline_merged_ptb.zip