P-12-21

SKB Task Force GWFTS – Task 7 Descriptions for hydrogeological modelling of Olkiluoto, Finland

Compilation of all task descriptions assessed within the Task 7 of the SKB Task Force on modelling of groundwater flow and transport of solutes

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Keywords: Olkluoto, Finland, Äspö Task Force, Task description, Modelling.

Abstract

This report compiles the task descriptions that have been assessed within the Task 7 exercise in the SKB Task Force on Modelling of Groundwater Flow and Transport of Solutes. The specific task descriptions are given in seven appendices. Task 7 is conducted with a set of different modelling tools all assessing regions of the Olkiluoto island in Finland.

Sammanfattning

Denna rapport sammanställer de modelleringsbeskrivningar som har använts för simuleringar inom Task 7 inom ramen för SKB Task Force on Modelling of Groundwater Flow and Transport of Solutes. Modelleringsbeskrivningarna återges i sju appendix. Task 7 har fokuserat på modelleringar av olika regioner av Olkiluoto i Finland med olika modelleringsverktyg.

Contents

1 Introduction

The SKB Task Force on Modelling of Groundwater Flow and Transport of Solutes is intended to be a forum for the organisations supporting projects at and related to the Äspö Hard Rock Laboratory (HRL). The Task Force considers conceptual and numerical modelling of groundwater flow and solute transport in fractured rock. In particular, the Task Force proposes, reviews, evaluates and contributes to modelling work relevant to the Äspö HRL.

Each organisation supporting the Äspö HRL is invited to form or appoint a *Modelling Team* that performs modelling of experiments selected by and/or suggested to the Task Force. The modelling efforts of such teams outside the Äspö HRL are supported by their respective "mother organisations". Each team may choose whether to participate in the different modelling tasks.

The Task Force meets regularly; during Task 7 there have normally been two meetings each year. Task 7 started in the spring 2005 and the final modeling team presentations were given during January 2012.

The work of the modelling groups is coordinated using task descriptions developed by the Task Force Secretariat. The descriptions define the objective and scope of models to be developed within the task, together with the data to be used and required outputs. This report presents the task descriptions developed within Task 7. The modelling work itself is documented in individual reports from each modelling group together with an evaluation report provided by the Task Reviewer. A list of the task description documents and the relevant Appendices is given in Table 1-1.

This report is provided as an underlying reference to other Tasks and reports.

Table 1-1. Task definition documents and appendices.

Appendix	Task definition documents
Appendix 1	Original Task 7 Description
Appendix 2	Definition of initial Task 7 generic modelling exercise
Appendix 3	Revised Task 7 Description
Appendix 4	Task 7a Description
Appendix 5	Updated Task 7a Description
Appendix 6	Task 7b Description
Appendix 7	Task 7c Description

2 Task 7

Task 7 is unique in that it was the first task that focused on a site other than the Äspö HRL. Task 7 was instead based on site characterization data from the Finnish candidate spent fuel repository site located at Olkiluoto Island.

The site is planned to dispose of spent fuel from TVO's (Teollisuuden Voima Oy) and Fortum's power reactors in a KBS-3 type repository to be constructed at a depth between 400 and 600 m in the crystalline bedrock at the Olkiluoto site.

Olkiluoto is an island of about 10 km^2 area, separated from the mainland by a narrow strait, on the coast of the Baltic Sea. The repository for spent fuel will be constructed in the central part of the island. Olkiluoto Island has a continental climate with some local marine influence. In the spring, temperature is significantly lower on the island than inland. Correspondingly, the warm sea moderates temperature differences between day and night in the autumn, so that frosts are rare. The winter is usually temperate.

The Olikluoto site investigations will culminate in the construction of the ONKALO underground rock characterization facility. The investigations in the ONKALO are an essential support for the application of the construction license for the repository. The application for the construction license is to be submitted to the authorities by the end of 2012.

2.1 Evolution of the Task 7 Description

The original task description developed in April 2005 is presented in **Appendix 1**. The first task description focused on issues concerning open boreholes and how to model such features in a groundwater system subjected to a long-term pumping test. Task 7 was initiated with a generic exercise, in which the different modeling teams were asked to illustrate and verify their ability to simulate flow into, out of, and along open boreholes. The definition of this generic exercise is presented in **Appendix 2.**

From these early studies Task 7 developed considerably from what had been originally intended. An updated task description is presented in **Appendix 3**. In the revised specification it is stated that: "Task 7 aims at providing a bridge between the site characterisation (SC) and performance assessment (PA) approaches to pumping tests and measurement from borehole flow logging. Open boreholes are during certain periods of the investigations a feature at many sites and Task 7 aims to develop an understanding of the effects of open boreholes on the groundwater system and the use of data from such boreholes in site characterisation and performance assessment."

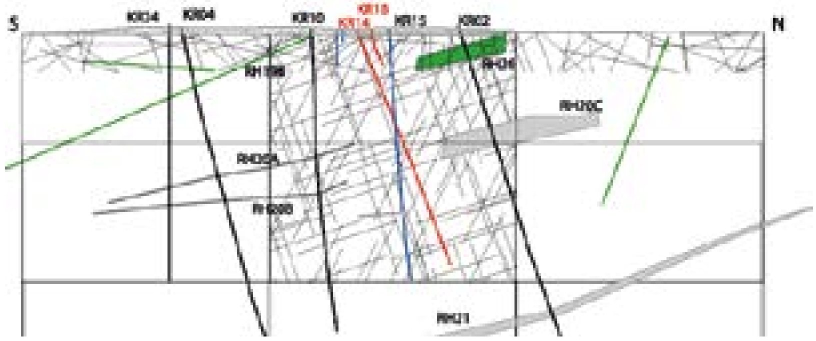
The task has been supported with an extensive body of observation data recorded before, during and after the different hydraulic tests, accompanied by detailed and voluminous characterization data. Clearly, utilization of this large data set was, in itself, challenging.

However within Task 7, modelling of the KR24 pumping test is only the first element of a larger study which includes: modelling of smaller scale pump tests in KR14 and KR18 and consideration of the fracture system at the canister scale.

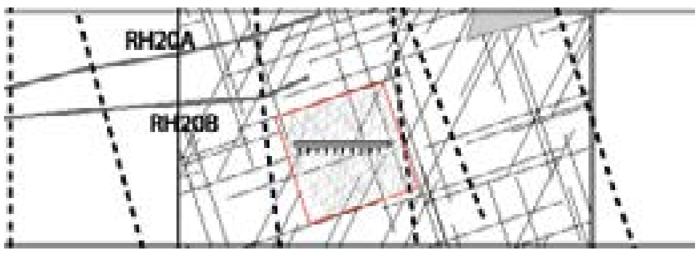
The strategy of Task 7 was to proceed from the largest scale (site scale with focus on fracture zones) to smaller scales (rock block) (see Figure 1-1). Task 7 finishes with measurements at the scale of the engineered barrier in a low permeability rock block. At each scale, specific goals were defined within the context of the overall Task 7 goal, and modelling tasks were defined to support those goals. In the end the final integrated model was only partially completed as part of Task 7c.

Task 7a
Pump Test KR24
Focus on major fracture zones and structural framework

Task 7b
Pump tests KR18, KR14
Focus on background rock



Task 7c
Focus on canister scale
Small scale hydraulic testing and geological mapping



Possible final task
Integration across scales

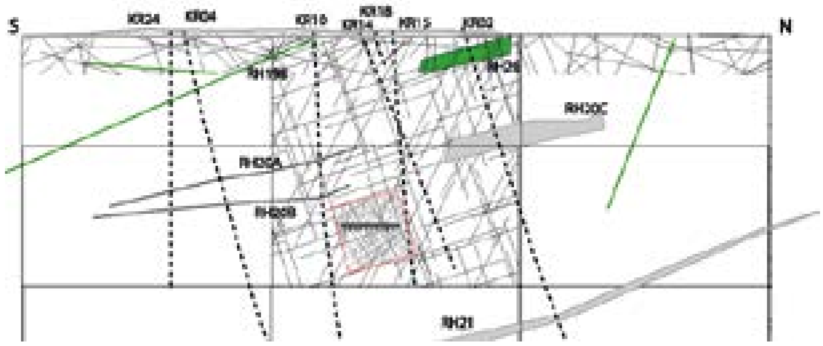


Figure 2-1. Schematics of the different Task 7 sub-tasks and their anticipated scale and focus.

2.2 Task 7a

Task 7a aimed at understanding the large scale structures and effects. It considered a region of approximately 10 km^2 surrounding borehole KR24 at the Olkiluoto site. KR24 was the pilot borehole for the planned ventilation shaft for Onkalo and was used for a long-term pumping test prior to shaft excavation. The test setup included pumping from two borehole sections. The lower part of KR24 was partially isolated by a by-pass packer (throttle valve) so that the deeper sections of the borehole experienced a smaller drawdown than the upper section during the pumping. The idea of this set-up was to achieve as high a drawdown as possible to get detectable pressure or flow responses around KR24 (especially for the groundwater table) – due to the high yield below 80 m it was calculated that it is not possible to get high drawdown in a open borehole

The definitions for Task 7a and its associated sub-tasks are presented in **Appendix 4** and **Appendix 5.**

The objectives of Task 7a were specified through a set of goals:

1) to understand the major features of the groundwater system,
2) to understand the consequences of the tests and measurement systems used, e.g. the open boreholes,
3) to understand how to model open boreholes within site characterisation studies and for the provision of parameters for PA,
4) to understand how PFL measurements could reduce uncertainty in models as compared to models calibrated with only head measurements,
5) to increase understanding of compartmentalisation and connectivity at the Olkiluoto site and more generally in fractured crystalline rock, and
6) to evaluate how uncertainty in PA can be reduced based on the analysis of the Olkiluoto dataset.

For further details concerning the objectives see the relevant appendices.

2.3 Task 7b

Task 7b aimed at understanding the block scale in regards of flow and pressure responses to hydrotesting. Task 7b considered a sub-volume of the Task 7a region in part bounded by major fracture zones and other natural boundaries. The KR14-18 cross-hole interference tests were organized in several stages. Firstly the boreholes were investigated with a difference flow method (the PFL) in open boreholes. Thereafter hydraulic tests were conducted with multi-packer systems, where various intervals were isolated from the rest of the boreholes with inflatable packers. The description of Task 7b and its associated sub-tasks are presented in **Appendix 6**.

The objectives of Task 7b were specified through a set of goals:

1) to understand how major features could be used as boundary conditions,
2) to understand the minor features of the groundwater system, (background rock)
3) to understand the consequences of the tests and measurement systems used, e.g. the open boreholes,
4) to understand how to model open boreholes within site characterisation studies and for the provision of parameters for PA,
5) to understand how PFL measurements could reduce uncertainty in models as compared to models calibrated with only head measurements,
6) to increase understanding of compartmentalisation and connectivity at the block scale, and
7) to evaluate how uncertainty in PA can be reduced based on the analysis of the Olkiluoto dataset.

For further details concerning the objectives see the relevant appendices.

2.4 Task 7c

Task 7C aimed at understanding the near-field scale in regards of flow and pressure responses in low permeability fractured rock. Task 7C considered small sub-volumes surrounding three Onkalo shafts at the Olkiluoto site in Finland. The definition of Task 7c and its associated sub-tasks are presented in **Appendix 7**.

The objectives of Task 7C were to use PFL to characterise and analyse procedures to quantitatively describe low transmissive fractures; and to demonstrate procedures of characterisation of flow in fractures of transmissivity less than $1 \cdot 10^{-9} m^2/s$. These objectives were specified through a set of goals:

1) to advance the understanding of PA relevant single fracture micro-structural models,
2) to use PFL to characterise in-plane fracture heterogeneities,
3) to improve the ability to predict inflow to suitable and un-suitable canister hole,
4) to assess if data from pilot boreholes has any predictive power with regard to prediction of flow to canister holes.

For further details see the relevant appendices.

3 This report

In this report all appendices contain the material exactly as provided to the modellers.

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Appendix 1

Task 7 – Modelling the KR24 long-term pumping test at Olkiluoto

Henry Ahokas and Lasse Koskinen, April 18, 2005

A1.1 Summary

Hydraulic responses during construction of a deep repository are of great interest because they may provide information for characterization of hydraulic properties of the bedrock and for estimation of possible hydraulic disturbances caused by the construction. Task 7 will focus on the underground facility ONKALO at the Olkiluoto site in Finland, and is aimed at simulating the hydraulic responses detected during a long-term pumping test carried out in borehole KR24 in the spring of 2004. During the test traditional pressure responses in 15 packed-off and in 50 open boreholes as well as flow responses in 9 deep and in three shallow boreholes were detected. Detailed documentation of test results will be published in spring 2005 (Vaittinen and Ahokas 2005, Rouhiainen and Pöllänen 2005). An overview of the test is presented in Appendix 1.1.

Task 7 will focus on large-scale (100 m – 1 km) characterization of properties of hydraulically conductive zones and other bedrock properties around the planned ventilation tunnel (i.e. the location of borehole KR24) of ONKALO.

A1.2 Framework

Spent fuel repository plan

Spent fuel from the Finnish nuclear power reactors is planned to be disposed of in a KBS-3 type repository to be constructed at a depth between 400 and 600 m in the crystalline bedrock at the Olkiluoto site. According to current plans, the operation of the facility would commence after 2020.

Olkiluoto

Olkiluoto is an island of the size of about 10 km^2, separated from the mainland by a narrow strait, on the coast of the Baltic Sea. The repository for spent fuel will be constructed in the central part of the island (Figure A1-1). Olkiluoto Island has a continental climate with some local marine influence. In the spring, temperature is significantly lower on the island than inland. Correspondingly, the warm sea equalises the temperature differences between day and night in the fall, so that frosts are rare. The winter is usually temperate. The mean temperature at Olkiluoto was in the period of 1992 to 2001 5.8°C. The snow thickness is usually less than 20 cm and water equivalent of snow is below 40 mm. The amount of snow varies during winter with temperature fluctuating around 0°C. For a short review on the geology of the site, see Appendix 1.1.

Site Investigations

The suitability of Olkiluoto to accommodate a spent fuel repository has been investigated over fifteen years by means of ground and air-based methods and from shallow and deep (300–1,000 m) boreholes. The current (March 2005) number of deep boreholes is 33. The accumulated body of site data is very extensive.

ONKALO

The site investigations will culminate in the construction of the ONKALO underground rock characterization facility. This construction work started in July 2004 and is expected to complete in 2010. The investigations in the ONKALO are an essential support for the application of the construction license for the repository. The application of the construction license is to be submitted to the authorities by the end of 2012.

Figure A1-1. Olkiluoto Island and the location of the ONKALO (thick oval). The repository for spent nuclear fuel will be constructed in the north west of the ONKALO.

The investigations in ONKALO will aim at further characterization of bedrock properties and to find the most suitable locations for the first deposition tunnels and holes for spent fuel canisters (Posiva 2003b). Tests and demonstrations of repository technologies will also be carried out in ONKALO. The underground parts of ONKALO consist of a system of exploratory tunnels accessed by a tunnel and a ventilation shaft. The ventilation shaft is to be located in the place of borehole KR24. The main characterization level will be located at a depth of about 400 m and the lower characterization level at a depth of about 500 m. Demonstrations and tests of repository technologies will mainly be carried out on the main level. The total underground volume of ONKALO will be approximately 330,000 m^3 with the combined length of tunnels and shaft of about 8,500 m. The construction and installations will be completed by 2010. Investigations will be started already during the construction phase.

Borehole KR24 pumping test

In preparations for the ONKALO excavations, a long-term pumping test was carried out in a 550 m deep, vertical borehole KR24 from 25 March to 2 June 2004 in order to produce detailed information about the effects and hydraulic connections on the scale of 0.1–1 km. It is expected that tackling the pumping test with various conceptual models, building on their model specific assumptions, and making use of their model specific strengths, as well, will lead to an improved understanding of the hydrogeological characteristic of crystalline fractured rock. Furthermore this will enhance the capabilities for resolving groundwater flow and transport issues in connection to the ONKALO thereafter.

Task 7

The proposed Äspö task force assignment, Task 7, is to be supported with an extensive body of observation data recorded before, during and after the pumping test, accompanied by detailed and voluminous characterization data set accumulated to date. Clearly, utilization of this data set is challenging itself.

Äspö vs. Olkiluoto

It is very beneficial to this study to recall a similar field test that was carried out at the Äspö island (Gustafson and Ström 1995). This test, called the LPT2 pumping and tracer test, consisted in a pumping phase that began in September 1990 and ended with a 1-month recovery phase in January 1991. The modeling activities for the LPT2 experiment were divided into the analysis of the hydrogeologic response – Task 1 – and analysis of the tracer test – Task 2. While the LPT2 experiment has some differences compared to the borehole KR24 pumping test, these tests actually are similar to the extent that many of the ideas of the LPT2 test may be re-utilized in connection to the borehole KR24 pumping test. In particular:

"The first modeling task was above all a learning exercise for the modeling groups entering the Task Force and for the task force organization as such."

Gustafson and Ström (1995).

In this very similar spirit, the borehole KR24 pumping test is presented to offer the first opportunity to foreign organizations to get acquainted with the site characterization data of Olkiluoto. As in the case of the LPT2 experiment, the borehole KR24 pumping test may be considered from the modeling point of view, the Olkiluoto data collection point of view, and the site characterization point of view.

Furthermore, at Äspö, eleven different groups have modeled Task 1 using different conceptual and numerical methodologies for simulating flow and transport in fractured rocks. A wide range of approaches was used, from rather straightforward using assumptions of one-dimensional flowpaths to advanced discrete fracture network modeling using site fracture data.

While from the viewpoint of modeling approaches a similar breadth of modeling approaches is strongly advocated, the two pumping experiments at Äspö and Olkiluoto have differences. Firstly, Olkiluoto is a site to truly accommodate a repository whereas Äspö is a genuine research and development site. From the point of view of hydrogeologic characterization, this has implications concerning the allowable impact of *in-situ* research activities that cannot be detrimental to long term safety.

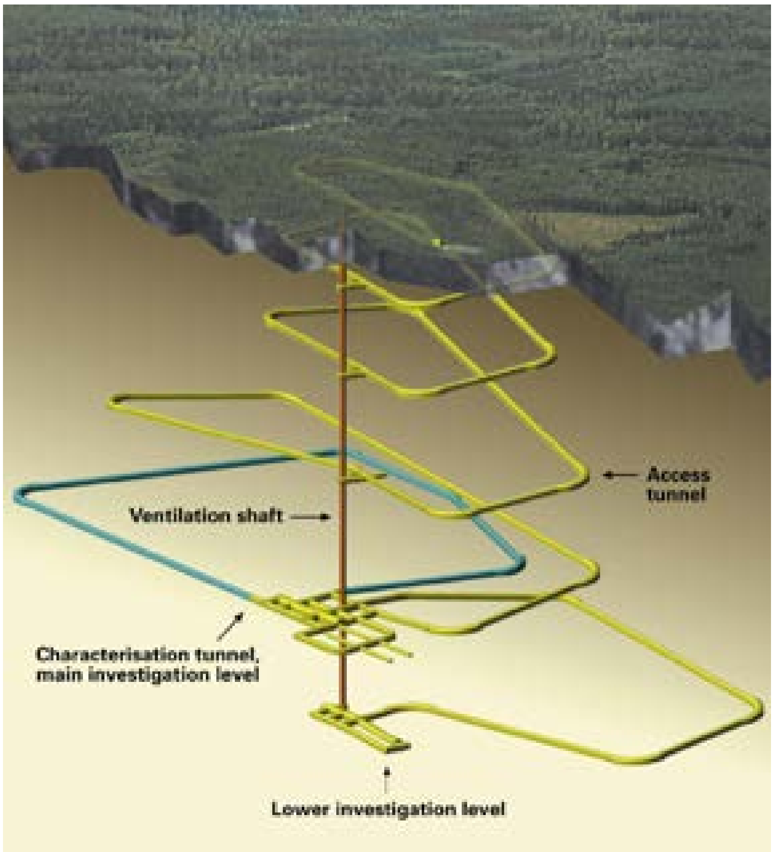


Figure A1-2. *The ONKALO rock characterization facility. The construction of ONKALO started in July 2004 and is planned to last until about 2010. Borehole KR24 is located in the place of the ventilation shaft of the figure.*

Secondly, since the days of the LPT2 experiment our understanding of important factors has developed significantly. In particular, it is seen as imperative to minimize the geochemical disturbance at the repository depth. The geochemical disturbance in the form of upconing of deep highly saline groundwater or intrusion of marine waters ought to be prevented. Thirdly, many of the observation boreholes in the borehole KR24 pumping test were open. While these open boreholes have to be considered in the model as additional hydrogeologic features. The reason why some of the boreholes were open is that in these Posiva Flow Log (later DIFF-tool and (difference) flow logging method, see Öhberg and Rouhiainen 2000) measurements of flow were performed. The DIFF-tool is able to detect even minute groundwater flows (flow from the bedrock to the borehole or from the borehole to the bedrock) and minute changes in these. This is the fourth difference between the LPT2 and borehole KR24 experiments as no such device was used at Äspö at the time of the experiment.

Bedrock model

The current bedrock model (due to be updated by the end of this year) is a detailed data base that depicts over one hundred fracture zones[1] and sparsely fractured rock between them. As is typical for crystalline, hard fractured bedrock, the hydrogeologic conductivity field is highly heterogeneous exhibiting a range of variance over several orders of magnitude.

A1.3 Objectives

A1.3.1 Objectives of the borehole KR24 pumping test

The construction of the underground facilities – ONKALO and spent fuel disposal tunnels – at Olkiluoto will affect besides the water table and hydraulic head in the vicinity of the access tunnel and shafts also the groundwater circulation at depth in general. To predict the effects and to characterize hydraulic connections on the scale of 100 m to 1 km, a long-term pumping test was carried out in deep borehole KR24.

A1.3.2 Objectives of Task 7

While at first Task 7 is about modeling of the borehole KR24 pumping test it lies within a wider setting of with site investigation data in general and ultimately site characterization. Thereby even this rather "simple" problem bears the full complexity of the site-specific characterization of crystalline fractured hard rock.

Task 7A – Development of numerical means and methods

The deliverables of this task are descriptions of the numerical means to tackle fractured crystalline rock, pumping borehole and open boreholes in numerical grids (i.e. finite difference or finite elements model meshes).

Each group of modellers is to use its own numerical means and method and each means has its own issues related to applicability of it. For example, in the case of difference method, the representation of fracture zones may deviate a lot from that in the methods based on the finite element method. While the usual approach is the so called implicit fracture zone method (where finite elements or numeric elementary blocks are all three dimensional) the FEM also facilitates adoption of a lower dimensional representation of the fracture zones (a la VTT's FEFTRA). Also, the representation of a pumping borehole clearly requires special considerations – in particular in the form of spatial resolution close to the sink. Furthermore, as the DIFF-tool operates in an open borehole, the numerical models have to be able to incorporate them as other hydrogeologic features of very high ability to conduct water.

[1] For the bedrock model update in 2005, the fracture zones are called deformation zones – among which "fracture zones" constitute just one category. For an "early communication" about very recent geological data compilation, see Posiva 2005.

The objectives of Task 7A are to:

- Determine proper means of incorporating open boreholes in the hydrogeologic models – and estimate their significance to the observed and calculated response fields.

  In a numerical model based on the finite element method, an open borehole may be represented with one-dimensional finite elements having a high conductance (e.g. $2m^3/s...4m^3/s$)
- Implementation of the calculation of results corresponding to flow logging measurements in numerical models.
- Conditioning of the model with borehole-specific data.

  There is available a large body of data on fracture intersections facilitating, e.g. determination of the orientations and positions of intersecting fractures, and their local transmissivities.
- Implement the pumping in the numerical models with suitably determined boundary conditions.

  It is presumed at in most numerical models the pumping will be incorporated by setting the applied drawdown or pumping rate to the node(s). However, in the case of linear finite element and a large size of them the actual realized pumping boundary condition should be confirmed separately.
- Assess the need for free surface/unsaturated flow modeling.

  The pumping response observations clearly imply changes in the water table's elevation in the vicinity of the pumping borehole. This may have a noteworthy influence on the pumping response in general. In a mathematical model the free surface/unsaturated flow would formally be represented with nonlinear equations.

Task 7B – Data collection and use of the site data

The deliverables of the subtask are the descriptions of which data are to be used and how. How much data are needed, what are the requirements for the coverage of the data. For example, the DFN modelling over a large area (that is about $1km^2$) may require specific data at the boreholes from which there are flow logging measurements whereas the modellers that utilize equivalent porous medium model may get along with considerably less. Are all necessary data available, and if not can it collected and delivered for the modellers in time? Also, as the amount of data in Posiva's TUTKA and POTTI data bases is huge, there clearly is need for devising tools to extract and process the data for easiest incorporation in the numerical simulations.

This task is also related to deeper site characterization issues. Because the amount of data is so large it is customary to make use of it only partly, but on the other hand, it is a crucial review issue to justify that not all data are used. Furthermore, a related nontrivial issue is address the question that when there are enough site data.

The objectives of Task 7B are to:

- Obtain appropriate tools and means to make use of the site data to the largest extent possible as seen necessary – and assess the implication of not using all data that would have been possible.
- Provide suggestions for further data collection and data processing for modeling. E.g. what kind of *new* borehole data would improve site understanding.
- Address the question how the location of the observation boreholes might affect the successfulness of a modeling effort.
- Explore possible biases in the hydrogeologic response data, and their significance to task results.
- Data flow quality management.

  What are the proper practices to ensure that correct, checked, and valid data is made use in the modeling?

Task 7C – Borehole KR24 pumping test simulations including the calibration of flow models

The deliverables from this subtask are the calculated quantities that correspond to the measured ones – drawdown and flow measurements. These results are to be supplied in a tabulated form and/or as graph as a function of time together with performance measures. These results should be provided both prior to any calibration measures and for the final calibrated flow models.

The objectives of Task 7C are to

- Produce calculated results corresponding to the measurements during the borehole KR24 pumping test before any calibration measures.
- Perform any calibration deemed necessary for the fullest consistency with the reality. Assessment of the degree of heterogeneity (in fracture zone and fracture planes) and its impact on the calculated observables. It may be a customary presumption that for pressure responses, the internal heterogeneity is not very important but the bulk transmissivity/conductivity it gives rise to is more important but the flow logging measurements might be clearly more sensitive to local conditions.
- Produce calculated results corresponding to the measurements during the borehole KR24 pumping test after the calibration.
- Report the results prior to and after the calibration.
- Identify the reasons for possible discrepancies between measured and calculated results before and after the calibration.
- Analyze differences between field methods (flow loggings vs. pressure observations) to detect responses caused by pumping.

Task 7D – Site characterization

The deliverables of this subtask are the reports or memos on the essential characteristics of the deep groundwater circulation at the site.

Site characterization is a concept that is not confined to explaining observed responses in a field test but, using this as a minimum requirement, also characterizes the groundwater flow in terms of, e.g. flow rates (and distribution thereof), flow velocities, flow directions, recharge and discharge areas, and flow paths together with identification of the most essential features and characteristics for the deep groundwater circulation at the site. A fundamental means of gaining this information is sensitivity and uncertainty analyses.

The objectives of Task 7D are to:

- Calculate the parameters that represent the deep groundwater circulation at the site.
- Identify areas of discharge and recharge and flow paths connecting them.
- Assess the ill-posedness of the problem and its consequence to possibilities of finding the unique characterization/interpretation result.

  A related question is the ability to make *true* predictions based on the model. How much the analysis of borehole KR24 pumping test did contribute to the hydrogeologic characterization of the site?
- Modeling approach dependent characterizations, for example in a DFN model it should be possible to apply a correlation between the transmissivity and size of a fracture (which seems to have evolved to a customary conjecture in SKB modeling reports).

Can this type of data be based on geological or hydrogeological data and observations?

- Assess the consistency of models (on different scales).

DFN models presumably are applicable on much finer scale than a model that assumes average bulk properties on scale of hundreds of meters. On the other hand, while these bulk properties are based on a rather simple estimation (but produced together with full recognition of the wide variance of individual borehole measurements associated with each interpreted fracture zone intersection) it is very reasoned to get knowledge of the consistency of the bulk properties a DFN model *would* correspond to and those of the simple evaluations. In connection to this, it would be valuable to learn from any indication of hydrogeologic anisotropy (which those simple bulk estimations would never unveil).

A1.4 Organisation

1. A project manager will be responsible for steering of the project, co-ordination of project participants, organisation of working group meetings, management of project web pages, etc. The project manager will also be responsible for development of the project data base, structural framework, assumptions, benchmark cases, etc. The project manager may be assisted by consultants to perform these tasks.
2. Official communication (data deliveries, result deliveries etc.) between the project manager and modelling teams will go through the Task Force secretariat.
3. Hierarchical structure: Task Force (as a project steering committee) → Project Manager → Project Technical Teams → Technical Reviewers

A1.5 Time schedule

- Final Task Definition presented at TF#20 in May 2005.
- Proposal for Task Description of Task 7A presented at TF#20.
- Final Task Description Task 7A in August 2005.
- Preliminary Task 7A results at TF#21.
- Final Task 7A and preliminary Task 7B results at TF#22.
- Final Task 7B and preliminary 7C results at TF#23.
- Final Task 7C results at TF#24.
- Review completed at TF#25.

A1.6 Detailed suggestions

- A wide range of conceptualizations regarding the bedrock (and processes?) should be used together with varying degree of simplifications.
- A wide range of tools should be used.
- Practical calibration means should be presented/reviewed.
- The influence of the open boreholes should be evaluated. What is the best/right way to incorporate them in the modeling. What are the related numerical issues?
- Provide scoping calculations with simple rules of thumb or equations – compare to simple evaluations (type curves).
- The best practices for the role of numerical flow modeling in site characterization should be defined.
  - Definition of objectives, i.e. what constitutes 'site characterization'.
  - Identification of processes involved in the characterization.
  - Identification of necessary and sufficient site data – will anything ever be enough.
  - Description of field methodologies of gaining the 'sufficient' site data.
  - Best practices of calibration.
  - Added value of conditioning.
  - Description of practices of carrying out sensitivity and uncertainty analyses.
  - Fracture mappings in boreholes – both borehole images and core logs and investigation trenches.
  - Historical flow logging records (seasonal effects, transients caused by measurements itself etc.).
- Discuss the ill-posedness of the problem – to which extent the outcome obtained can be reckoned unique. It only is known there is just one "realization" of the true hydrogeological system.
- The need for transient modeling should be discussed.
- Importance of near-surface phenomena should be estimated (surface water reservoirs, infiltration of precipitated water, unsaturated flow, water table subsidence).
- Lessons learned with respect to how much the KR24 pumping test helps in advance estimation of the hydrogeologic impact of the vertical shaft.

A1.7 Performance measures/output

A performance measure aims at facilitating an efficient comparison between measured and modeled/predicted responses – the drawdown and change in the water exchange rate. Given the huge amount of observed response data it simply is not possible to achieve a sensible overview with visual inspection. A practical starting point is the one adopted by Gustafson and Ström (1995). They proposed a few straightforward performance or evaluation measures of which we exemplify the non-weighted difference

$$dh = \frac{\sum_{i=1}^{n}\left(h_i^m - h_i^c\right)}{n}, \text{ and } \operatorname{abs}(dh) = \frac{\sum_{i=1}^{n}\left|h_i^m - h_i^c\right|}{n},$$ and a similar expression for prediction accuracy:

$$Dh = \frac{\sqrt{\sum_{i=1}^{n}\left(h_i^m - h_i^c - dh\right)^2}}{n-1}$$

Clearly an accompanied and nontrivial question concerns weighting. What should be the basis of weighting (e.g. distance from the pumping borehole) and how to make it sensitized to really reflect the significance of essential responses. Also it remains to be discussed how the flow logging measurements should be incorporated in the performance measures. Most likely it will be advisable to define a separate performance for them – but based on expressions similar to those above.

It is noted that these would only concern the performance measures to be used for intergroup comparison of the modeling outcomes. Any modeling group is invited to apply any other performance measure in their own efforts of calibration.

Appendix 1.1

Brief overview of the site, long-term pumping test in KR24 and data (delivery)

Site description

The Olkiluoto area was first studied geologically in the early 1970's in connection with the site investigations for the nuclear power plant. Investigations continued in the 1980's for the ILW/LLW repository. This work, which was completed in 1989, was in the first place targeted to the western-most part of the 5–6 km long island, which is separated from the mainland by a narrow channel in the east.

The characterisation of the whole island was started in 1987 when the programme for preliminary site characterisation was launched. Since then twelve deep boreholes have been drilled at the central part of the island. This is the part that has been studied most intensively as a potential location for the deep repository. In addition to deep drillings a great number of shallower borehole investigations have been carried out.

Together with the borehole investigations extensive surface surveys, both geological and geophysical, have aimed at exploring the structure of the bedrock, as well as determining the properties of the lithological units of the fractured hard rock. In parallel with the basic geological research hydro-geological and hydrogeochemical studies have been carried out in boreholes to help model and understand the evolution of the groundwater system of the island.

The geology of Olkiluoto is characterised by composite gneisses, in which there are veins of tonalite and granite. The rock mass has an average fracturing of 1–3 fractures/m (Anttila et al. 1999). The rock mass has fractured zones of different magnitudes and orientation. The dominating rock types and the significant fracture zones of the main interest area for the deep repository are presented in Figure A1-1-1.

The studies on the rock mechanical properties of the Olkiluoto gneisses show quite normal behaviour as regards to rock stress. The strength values of the mica-bearing gneiss are to some extent low (approximately 100 MPa). Based on the rock classification analysis carried out the deep repository can be excavated in suitable rock mass volumes by normal methods at the depth interval between 400 and 700 metres.

The measured hydraulic conductivities seem to be log-normally distributed in most cases and this assumption has been used in applying different kinds of statistics and differences for heavily trun-cated data. The main conclusions are:

- Hydraulic properties of the uppermost 100–150 m of the bedrock are distinct from those at greater depth, i.e. hydraulically conductive fractures are more frequent and several very high values exist in this near-surface zone.
- The decrease of hydraulic conductivity with depth seems to be prominent especially in the host rock at shallow depths.
- High conductivities are mostly found in R-structures but several high values also exist in the host rock.
- Subhorizontal fracture zones are hydraulically the most conductive and locally, there are very good hydraulic connections between boreholes along these zones as shown by borehole pumping tests.
- It is noteworthy that even some fractures and fracture zones below a depth of 500 m may have hydraulic conductivities between 10^{-5} and 10^{-7} m/s.

More detailed information on the geological, geohydrological and geochemical characteristics of the Olkiluoto site can be found in the summary report of the site selection research programme (McEwen and Äikäs 2000) and Baseline Conditions (Posiva 2003a).

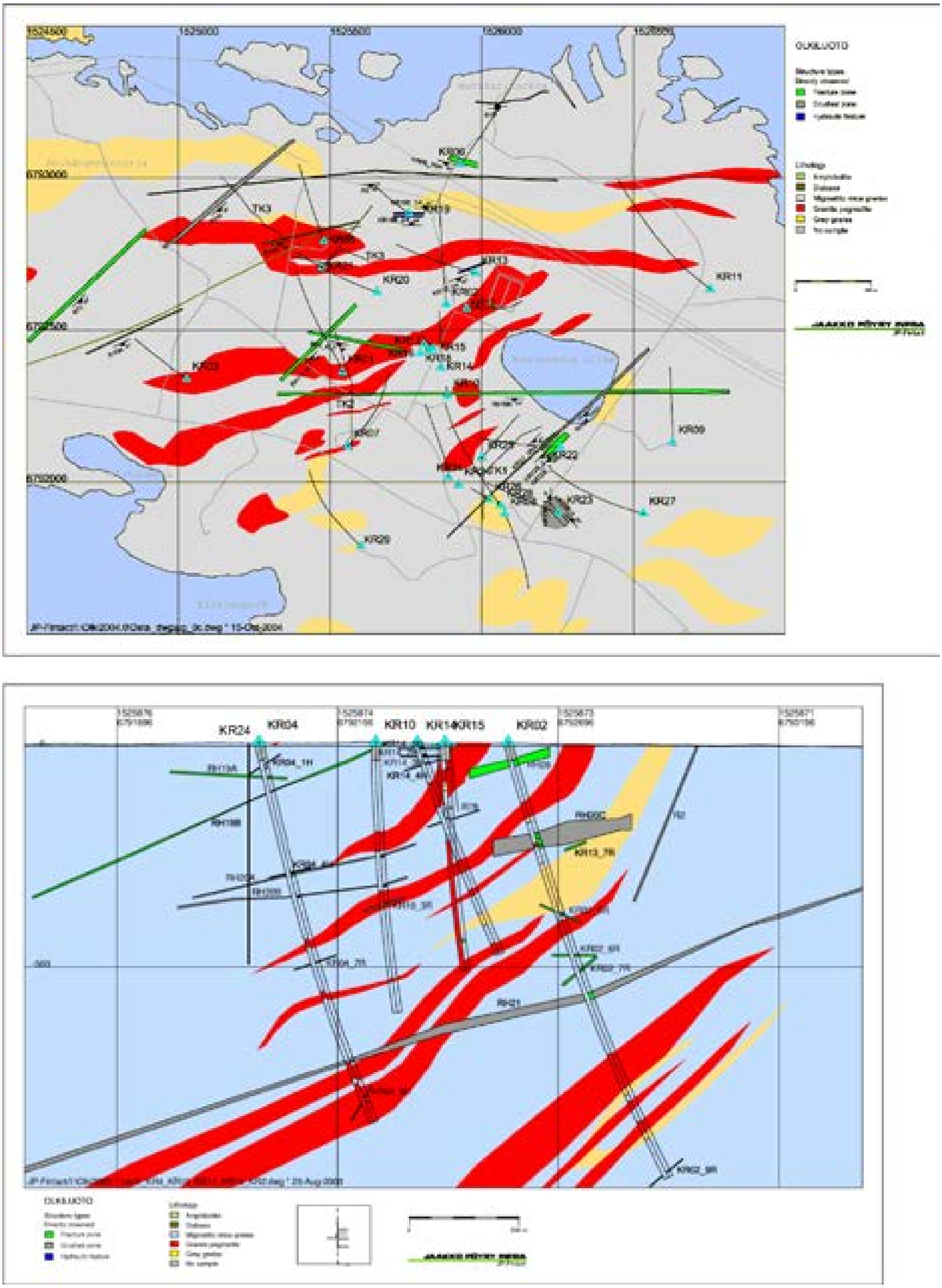


***Figure A1-1-1.** The rock types and fractured zones of the main interest area for deep repository at Olkiluoto (Vaittinen et al. 2003).*

Long-term pumping test in KR24

Long-term pumping test was carried out in deep borehole KR24 during 25.3. – 2.6.2004. To achieve maximum drawdown in the upper part of pumped borehole KR24, one meter long packer with bypass tube was installed at the borehole depth of 80.60 m. The average pumping rate was 18 l/min of which roughly 10 l/min originates below the packer. The pressure responses were recorded in open shallow and deep boreholes, in multilevel piezometers, and in packed-off shallow and deep boreholes during the pumping test. Altogether, 139 pressure observation sections in 68 boreholes were included to the pumping test. Flow responses were measured by flow logging in 12 open boreholes around borehole KR24.

A schematic visualisation on the long-term pumping test is shown in Figure A1-1-2.

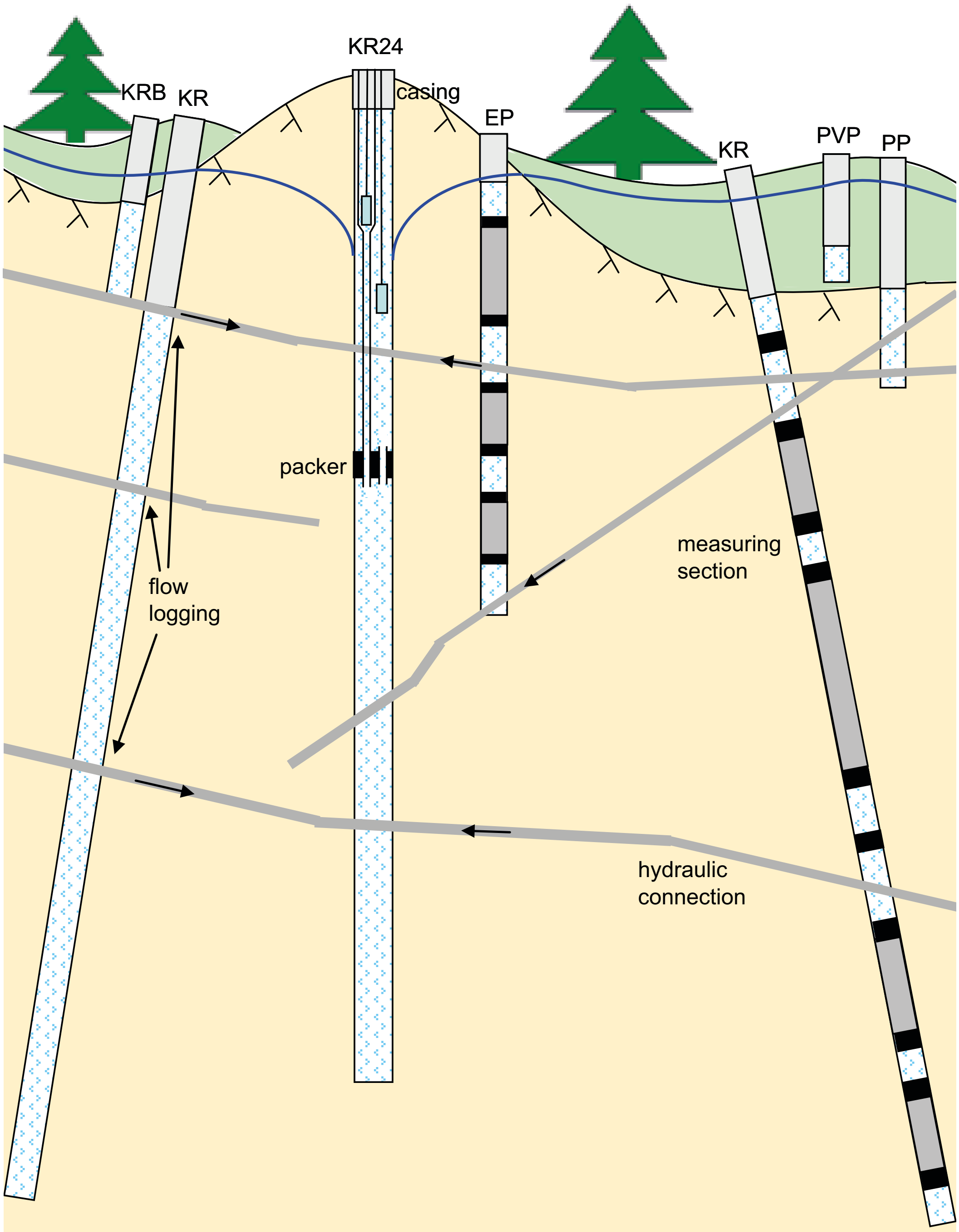


Figure A1-1-2. *A schematic visualisation of the long-term pumping test. Measuring sections in figure are packed-off sections in boreholes.*

A detailed presentation of the observation boreholes locating close to pumped borehole KR24 is in Figure A1-1-3.

Borehole KR24 is drilled on the outcrop and it is cased down to 20.13 m. Thus, the pumping had an effect on the groundwater level through the bedrock, and so the obtained results describe hydraulic connections in the bedrock.

Pressure observations

In pumped borehole KR24, drawdown was appr. 18 m above the packer and 1 m below the packer. In the observation boreholes the strongest drawdown, 5.8 m occurred in the bedrock surface only 30 m from borehole KR24. Otherwise, drawdown was less than –1.16 m. Drawdown was not observed in any of the groundwater observation tubes in the overburden.

An example on pressure observations in packed-off boreholes EP2 and EP3 and in open borehole EP8 are presented in Figure A1-1-4. Summary of observations is shown in Chapter Data (delivery) of this Appendix.

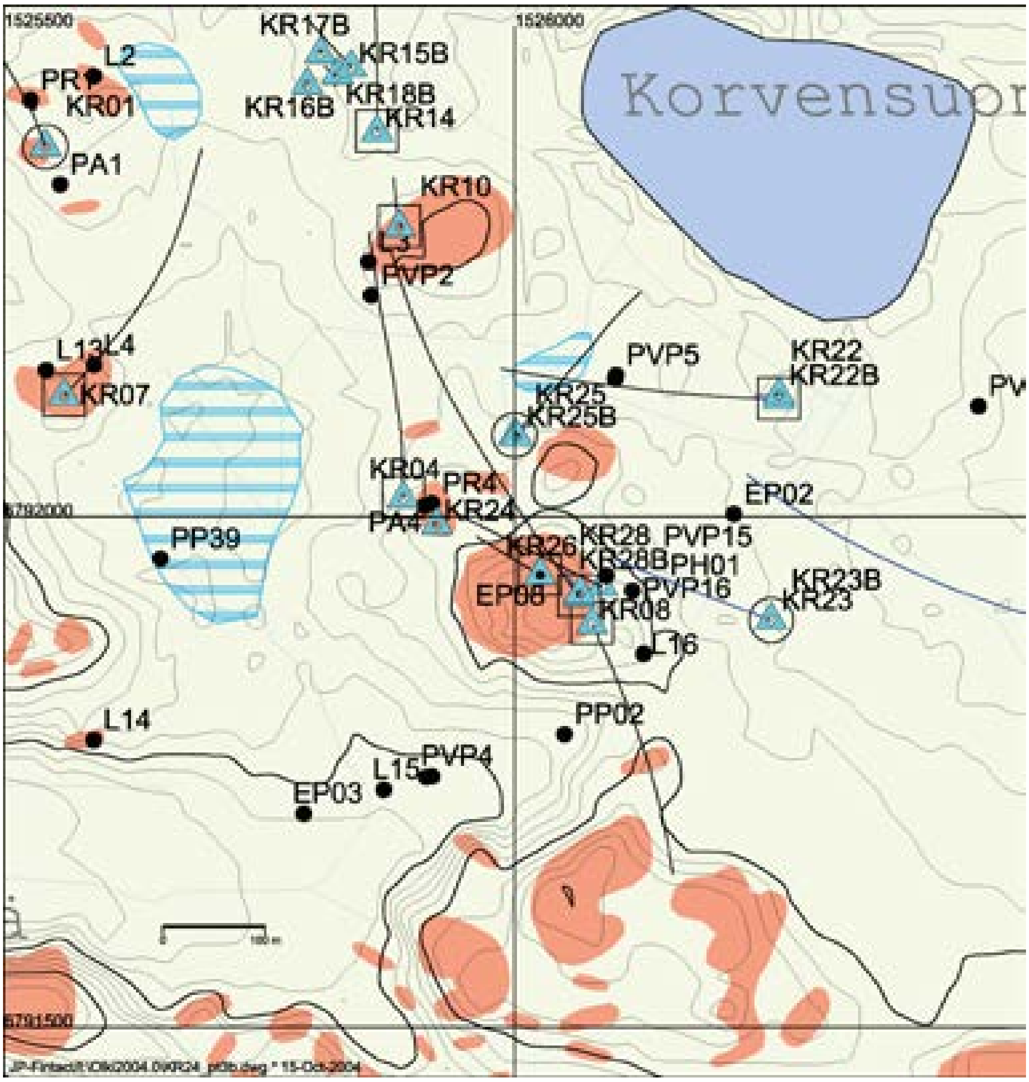
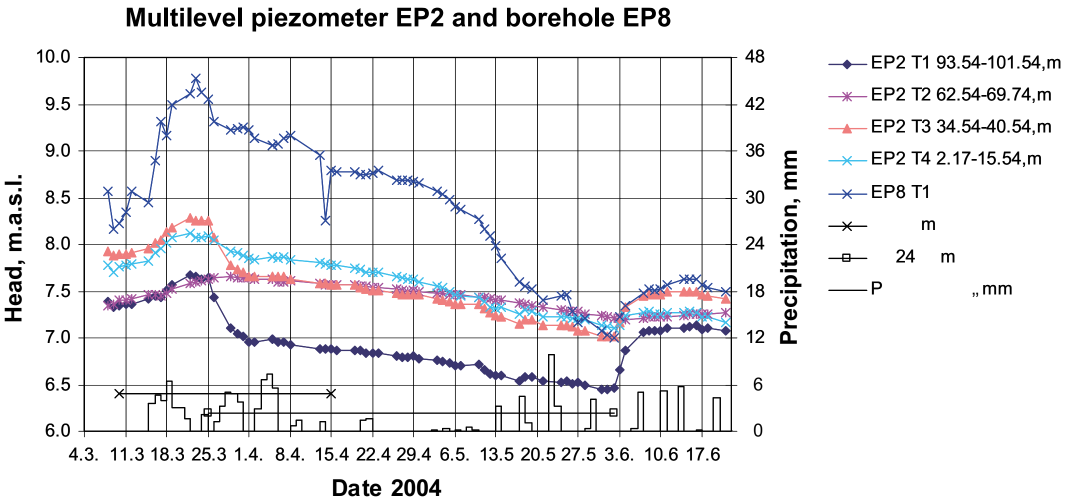


Figure A1-1-3. *Detailed presentation of the location of the boreholes close to pumped borehole KR24 and the altitude contours (1 m) of the topography. As a background information outcrops (red-brown) and wet areas (dashed blue) are presented. Flow loggings were performed in boreholes labelled with open square. Boreholes equipped with open circle are packed-off deep boreholes. In addition, boreholes EP2 and EP3 are packed-off boreholes. Pressure observations in several boreholes outside the area in figure were also performed.*



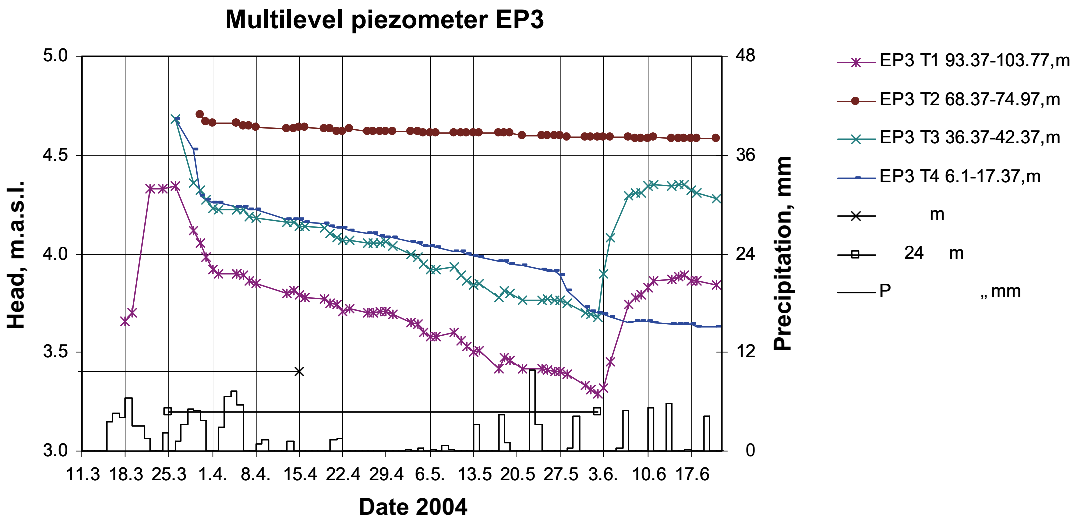


Figure A1-1-4. *Pressure responses in packed-off boreholes EP2, EP3 and in open borehole EP8.*

Flow responses

During the pumping test, the boreholes were measured using 2 m section and 0.25 m depth increments. Flow rates into the borehole or out from it were recorded. Fresh water head along the borehole was also recorded using a high resolution absolute pressure sensor. (The absolute pressure sensor was installed 2003 and it was available in all measurements after that). Single point resistance was also measured with 0.01 m point intervals during the flow loggings. EC and temperature were measured as supplementary methods for indication of saline water.

An example on flow logging results is presented here from borehole KR22. Before the pumping test in the year 2002, borehole KR22 was measured when it was pumped (with drawdowns of 2.5 m and 6.5 m). Section length of 0.5 m was used during the larger drawdown of 6.5 m.

Borehole KR22 was measured just before the pumping test when all the boreholes were at rest (not pumped). All the flow curves together with single point resistance curves are presented in Figures A1-1-5a and A1-1-5b.

The interpretation is based on flow rates in individual fractures. After drawing the flow curves, the first step in data analysis is to map all the active fractures. The depths of these fractures are marked with lines based on single-hole flow measurements when the borehole was pumped. These fractures are in two categories, certain (long line) and uncertain (short line). A fracture is judged to be uncertain if

- flow rate is < 30 ml/h with the largest drawdown,
- noise level in flow is larger than about 20% of the measured flow rate during the largest drawdown, or
- form of a flow anomaly is unclear during the largest drawdown

The flow rates of the mapped fractures are presented with triangles on the flow plots.

For instance, the fracture at 112 m in KR22 has positive flow (into the borehole) during each logging. Flow rate was 38,300 ml/h when the borehole was not pumped and 238,000 ml/h when borehole (KR22) was pumped with 2.5 m drawdown. During the pumping tested (when borehole KR24 was pumped), the flow rate was between 83,000 and 93,000 ml/h.

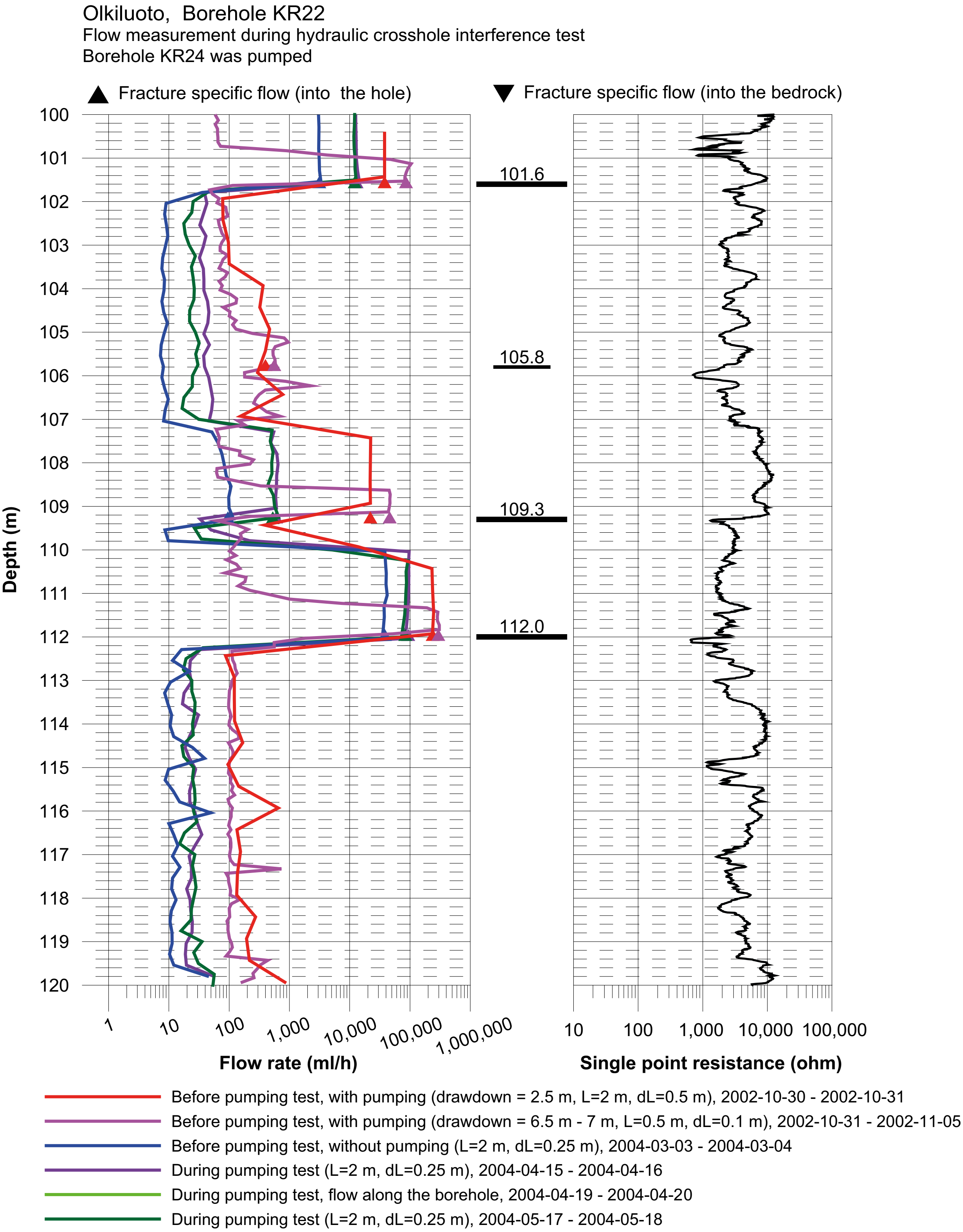


Figure A1-1-5a. *Flow logging results from borehole KR22 depth interval 100–120 m.*

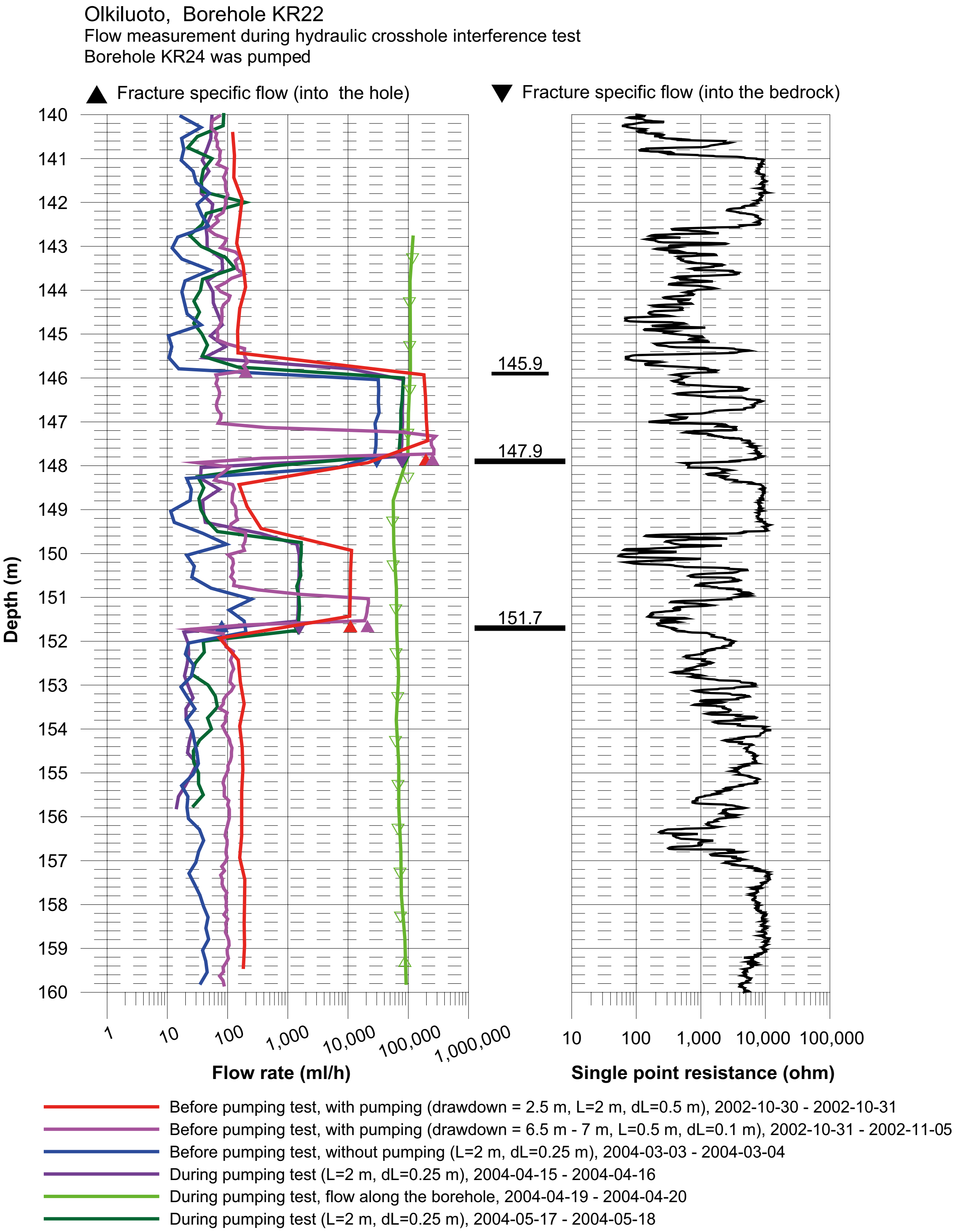


Figure A1-1-5b. *Flow logging results from borehole KR22 depth interval 140–160 m*

Another example is the fracture at 147.9 m. The corresponding flow rates are now –29,900 ml/h (no borehole was pumped), 195,800 ml/h (borehole KR22 was pumped with 2.5 m drawdown) and between –78,600 and –81,700 ml/h (borehole KR24 was pumped).

Conclusion of the examples above could be that in the first case there is no interconnected flow between the boreholes or it is very small while in the other case the interconnection is clear.

Similar results from borehole KR4 are presented in Figures A1-1-6a and A1-1-6b. Summary of measured flows in borehole KR4 is presented in Table A1-1-1.

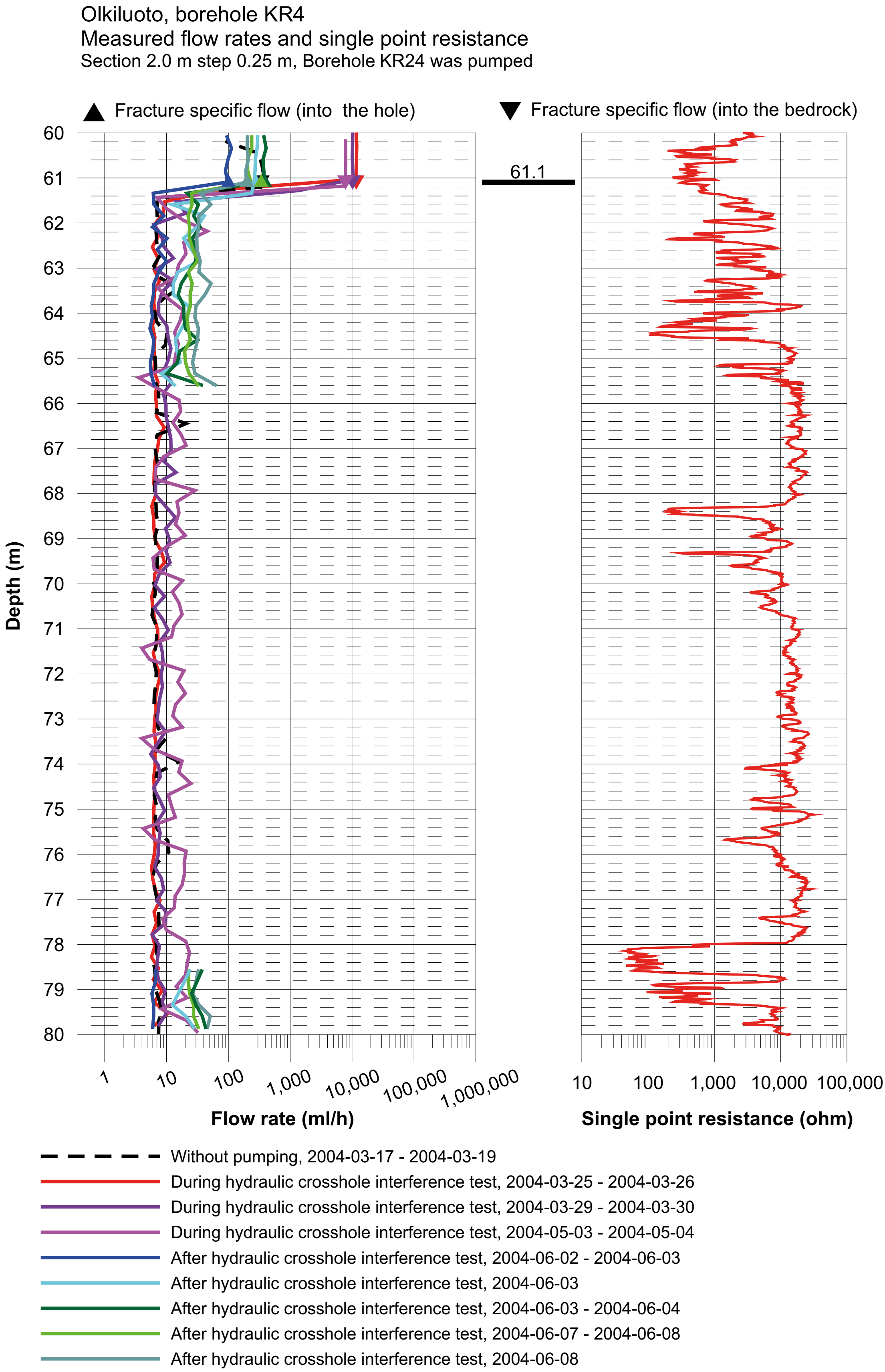


***Figure A1-1-6a.** Flow logging results from borehole KR4 depth interval 60–80 m*

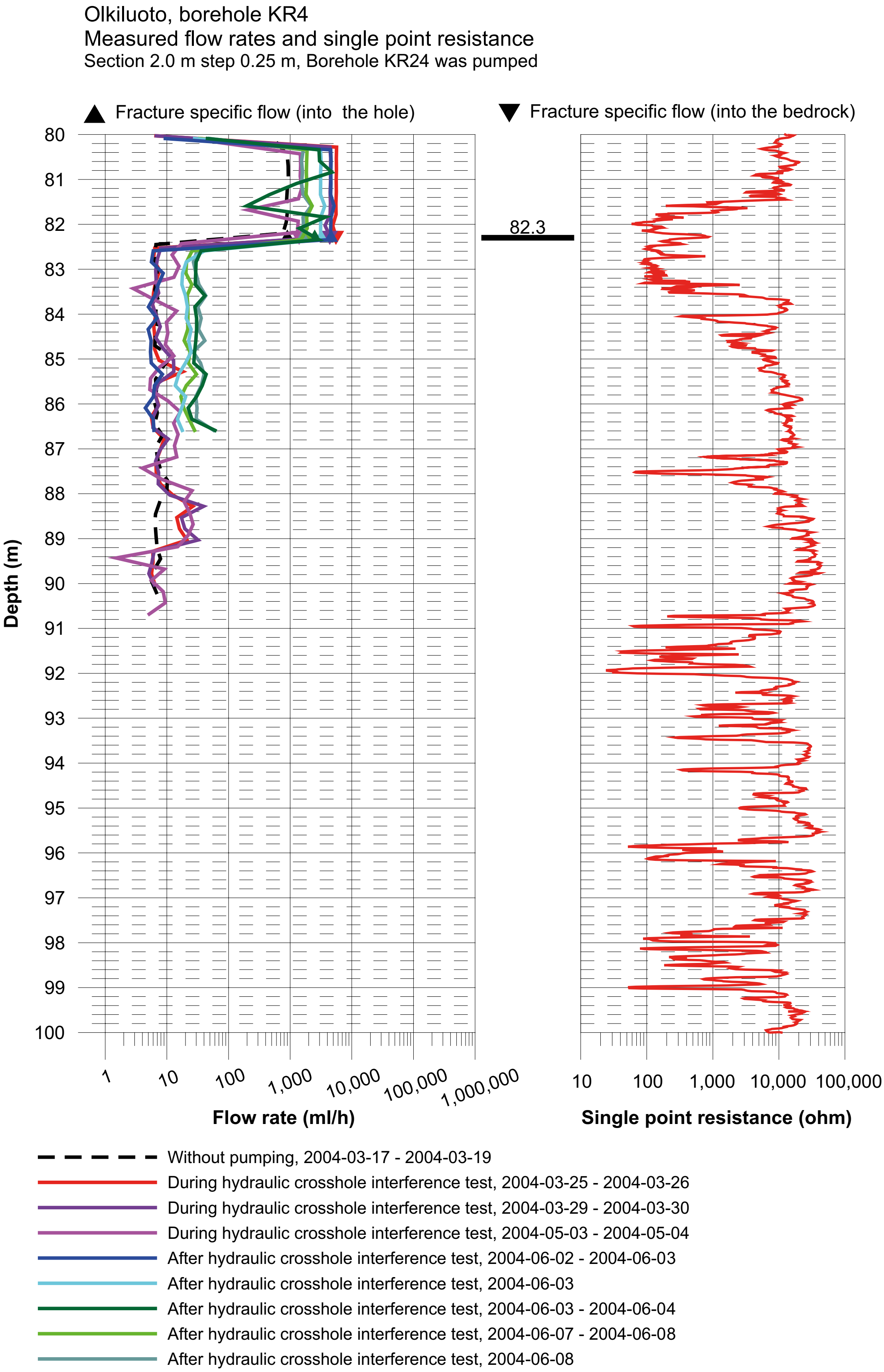


Figure A1-1-6b. *Flow logging results from borehole KR4 depth interval 80–100 m.*

Table A1-1-1. Summary of flow loggings in KR4.

Description of columns:

Depth of fracture (m) from ground level = Depth from reference depth to the fracture (m)
FWH 1 (m.a.s.l.) = Fresh water head in the borehole without pumping (meter above sea level)
Flow1(ml/h) = Flow from the fracture to the borehole without pumping, 2004-03-17 – 2004-03-18
Q1 LLP = Practical lower limit of measurable flow1 (ml/h)
FWH 2 (m.a.s.l.) = Fresh water head in the borehole (meter above sea level)
Flow2(ml/h) = Flow during hydraulic crosshole interference test (borehole KR24 was pumped), 2004-03-25 – 2004-03-26
Q2 LLP = Practical lower limit of measurable flow2 (ml/h)
FWH 3 (m.a.s.l.) = Fresh water head in the borehole with pumping (meter above sea level)
Flow3(ml/h) = Flow during hydraulic crosshole interference test (borehole KR24 was pumped), 2004-03-29 – 2004-03-30
Q3 LLP = Practical lower limit of measurable flow3 (ml/h)
FWH 4 (m.a.s.l.) = Fresh water head in the borehole without pumping (meter above sea level)
Flow4(ml/h) = Flow during hydraulic crosshole interference test (borehole KR24 was pumped), 2004-05-03 – 2004-05-04
Q4 LLP = Practical lower limit of measurable flow4 (ml/h)
FWH 5 (m.a.s.l.) = Fresh water head in the borehole with pumping (meter above sea level)
Flow5(ml/h) = Flow after hydraulic crosshole interference test, 2004-06-02 – 2004-06-03
Q5 LLP = Practical lower limit of measurable flow5 (ml/h)
FWH 6 (m.a.s.l.) = Fresh water head in the borehole with pumping (meter above sea level)
Flow6(ml/h) = Flow after hydraulic crosshole interference test), 2004-06-03
Q6 LLP = Practical lower limit of measurable flow6 (ml/h)
FWH 7 (m.a.s.l.) = Fresh water head in the borehole without pumping (meter above sea level)
Flow7(ml/h) = Flow after hydraulic crosshole interference test, 2004-06-03 – 2004-06-04
Q7 LLP = Practical lower limit of measurable flow7 (ml/h)
FWH 8 (m.a.s.l.) = Fresh water head in the borehole with pumping (meter above sea level)
Flow8(ml/h) = Flow after hydraulic crosshole interference test, 2004-06-07 – 2004-06-08
Q8 LLP = Practical lower limit of measurable flow8 (ml/h)
FWH 9 (m.a.s.l.) = Fresh water head in the borehole with pumping (meter above sea level)
Flow9(ml/h) = Flow after hydraulic crosshole interference test, 2004-06-08
Q9 LLP = Practical lower limit of measurable flow9 (ml/h)

* = Uncertain.

Depth (m)	FWH 1 (m)	Flow1 (ml/h)	Q1 LLP	FWH 2 (m)	Flow2 (ml/h)	Q2 LLP	FWH 3 (m)	Flow3 (ml/h)	Q3 LLP	FWH 4 (m)	Flow4 (ml/h)	Q4 LLP	FWH 5 (m)	Flow5 (ml/h)	Q5 LLP	FWH 6 (m)	Flow6 (ml/h)	Q6 LLP	FWH 7 (m)	Flow7 (ml/h)	Q7 LLP	FWH 8 (m)	Flow8 (ml/h)	Q8 LLP	FWH 9 (m)	Flow9 (ml/h)	Q9 LLP
61.1	6.35	–340	30	6.03	–11,680	30	5.67	–10,160	30	5.24	–7,800	30	5.32	100	30	5.51	280	30	5.67	390	30	5.88	340	50	5.96	200	50
82.3	6.38	900	30	6.08	–5,520	30	5.61	–4,400	30	5.29	–1,400	30	5.43	4,600	30	5.58	3,180	30	5.67	2,500	30	6.01	1,850	50	5.92	1,600	50
116*	6.51	0	30	6.24	0	30	5.77	0	30	5.39	0	30	5.4	0	30	5.61	0	30	5.73	0	30	6.01	0	50	5.96	0	50
116.8	6.49	14,000	30	6.27	4,070	30	5.73	7,000	30	5.41	6,600	30	5.43	7,000	30	5.63	6,000	30	5.76	3,500	30	6.01	2,000	50	5.97	1,000	50
141.6	6.61	910	30	6.39	–270	30	5.93	–380	30	5.59	–490	30	5.6	–1,020	30	5.79	–1,300	30	5.99	–1,350	30	6.17	–1,150	50	6.26	–1,240	50
301.2	7.23	–75	30	7.09	0	30	6.55	0	30	6.31	0	30	6.07	–40	30	6.36	–50	30	6.52	0	30	6.72	–55	50	6.69	0	50
307.6	7.24	–1,320	30	7.17	750	30	6.64	0	30	6.34	580	30	6.07	–960	30	6.38	–920	30	6.56	–620	30	6.74	–1,050	50	6.73	–1,020	50
308.2	7.26	–380	30	7.2	250	30	6.62	0	30	6.34	170	30	6.07	–240	30	6.38	–270	30	6.56	–150	30	6.73	–260	50	6.73	–275	50
314.1	7.3	–17,170	30	7.25	9,670	30	6.72	–3,300	30	6.41	6,500	30	6.11	–9,700	30	6.4	–9,800	30	6.59	–3,030	30	6.78	–6,190	50	6.79	–6,080	50
364.6*	7.73	0	30	7.57	0	30	7.12	0	30	6.8	0	30	6.46	0	400	6.82	220	400	6.87	200	400	7.18	250	400	7.17	–280	400
366.7	7.65	420	30	7.67	5,200	30	7.03	2,280	30	6.82	550	30	6.42	–2,140	400	6.78	960	400	6.83	–2,300	400	7.24	1,420	400	7.15	–1,300	400
370.5*	7.65	20	30	7.62	32	30	7.16	0	30	6.85	0	30	6.42	0	400	6.76	0	400	6.86	0	400	7.16	0	400	7.28	0	400
510.8*	8.99	–57	30	8.95	0	30	8.52	0	30	8.28	0	30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Detected flow connections, based on qualitative evaluation, are concentrated in only few fractures and summary of connections in all measured boreholes is presented in Table A1-1-2.

Table A1-1-2. Summary of detected flow connections based on preliminary qualitative analysis.

Borehole	Depth (m)	Comments
KR4	61.1	
KR4	82.3	
KR7	285–288	
KR8	548.5	
KR10	175.4	weak indication
KR14	–	no clear connections
KR22	112.0	
KR22	151.7	
KR22B	33.6	
KR22B	37.5	
KR22B	39.2	
KR26	51.6	
KR26	93.3	
KR27	257.8	weak indication
KR27	261.8	weak indication
KR27B	–	no clear connections
KR28	134.6	weak indication
KR28	176.5	weak indication
KR28	444.1	weak indication
KR28B	37.9	weak indication

Data (delivery)

As described in previous chapters data concerning the long-term pumping results are available in figures and tables (Excel or text-sheets). Summary of pressure and flow measurements is shown in Tables A1-1-3 and A1-1-4.

Table A1-1-3. Summary of pressure and flow measurements in connection of long-term pumping test in borehole KR24.

Observation point	Pressure (head) observation interval	Notice	Amount of flow loggings (see also Table 11-4)	Notice
Pumping borehole KR24	15 min	In addition, few manual checkings		
Eight packed-off deep boreholes	hour			
Nine deep and three shallow open boreholes	day		once before pumping [1)] twice during pumping once or more after pumping [2)]	[1)] old natural flow results exist for some boreholes [2)] not in all boreholes
Appr. 50 shallow boreholes, multi-level piezometers and observation tubes	day			
Eight shallow boreholes, multi-level piezometers and observation tubes far away from pumping borehole KR24	Week			

Table A1-1-4. Summary of activities in flow loggings before, during and after pumping of borehole KR24.

Started	Finished	Borehole	Activity
8.9.2003	10.9.2003	KR14	Flow logging before pumping
1.10.2003	2.10.2003	KR7	Flow logging before pumping
8.2.2004	12.2.2004	KR27	Flow logging before pumping
25.2.2004	26.2.2004	KR26	Flow logging before pumping
26.2.2004	2.3.2004	KR28	Flow logging before pumping
3.3.2004	4.3.2004	KR22	Flow logging before pumping
8.3.2004	10.3.2004	KR8	Flow logging before pumping
17.3.2004	19.3.2004	KR4	Flow logging before pumping
25.3.2004 *10:17*	26.3.2004 *9:15*	KR4	Flow logging during pumping.
29.3.2004 *13:35*	30.3.2004 *13:25*	KR4	Flow logging during pumping.
30.3.2004 *17:35*	1.4.2004 *8:10*	KR26	Flow logging during pumping.
1.4.2004 *13:33*	1.4.2004 *16:32*	KR28B	Flow logging during pumping.
5.4.2004 *13:26*	6.4.2004 *12:51*	KR28	Flow logging during pumping.
6.4.2004 *16:38*	8.4.2004 *5:05*	KR10	Flow logging during pumping.
13.4.2004 *14:47*	14.4.2004 *15:58*	KR14	Flow logging during pumping.
15.4.2004 *9:36*	20.4.2004 *12:05*	KR22	Flow logging during pumping.
20.4.2004 *15:47*	20.4.2004 *18:06*	KR22B	Flow logging during pumping.
21.4.2004 *15:46*	23.4.2004 *10:56*	KR27	Flow logging during pumping.
26.4.2004 *14:54*	26.4.2004 *18:18*	KR27B	Flow logging during pumping.
27.4.2004 *14:46*	29.4.2004 *5:51*	KR8	Flow logging during pumping.
29.4.2004 *12:28*	30.4.2004 *12:17*	KR7	Flow logging during pumping.
3.5.2004 *16:24*	4.5.2004 *17:36*	KR4	Flow logging during pumping.
5.5.2004 *14:04*	5.5.2004 *22:43*	KR26	Flow logging during pumping.
6.5.2004 *10:27*	6.5.2004 *13:41*	KR28B	Flow logging during pumping.
6.5.2004 *15:42*	10.5.2004 *18:25*	KR28	Flow logging during pumping.
11.5.2004 *10:11*	12.5.2004 *6:25*	KR10	Flow logging during pumping.
12.5.2004 *12:34*	13.5.2004 *14:54*	KR14	Flow logging during pumping.
13.5.2004 *17:55*	13.5.2004 *20:52*	KR22B	Flow logging during pumping.
17.5.2004 *13:13*	18.5.2004 *8:47*	KR22	Flow logging during pumping.
18.5.2004 *13:33*	27.5.2004 *8:59*	KR27	Flow logging during pumping.
27.5.2004 *10:30*	27.5.2004 *13:26*	KR27B	Flow logging during pumping.
27.5.2004 *16:36*	1.6.2004 *0:06*	KR8	Flow logging during pumping.
1.6.2004 *10:50*	2.6.2004 *8:29*	KR7	Flow logging during pumping.
2.6.2004 *15:10*	3.6.2004 *1:44*	KR4	Flow logging after pumping.
3.6.2004 *8:22*	3.6.2004 *17:35*	KR4	Flow logging after pumping.
3.6.2004 *19:15*	4.6.2004 *5:45*	KR4	Flow logging after pumping.
7.6.2004 *18:57*	8.6.2004 *8:25*	KR4	Flow logging after pumping.
8.6.2004 *10:38*	8.6.2004 *22:11*	KR4	Flow logging after pumping.
9.6.2004 *14:24*	9.6.2004 *17:08*	KR27B	Flow logging after pumping.
10.6.2004 *7:30*	10.6.2004 *10:38*	KR27B	Flow logging after pumping.
10.6.2004 *15:14*	10.6.2004 *18:57*	KR22B	Flow logging after pumping.
11.6.2004 *11:07*	14.6.2004 *14:45*	KR28B	Flow logging after pumping.
14.6.2004 *16:44*	15.6.2004 *23:21*	KR28	Flow logging after pumping.
16.6.2004 *10:09*	16.6.2004 *22:03*	KR26	Flow logging after pumping.
17.6.2004 *12:52*	22.6.2004 *2:47*	KR8	Flow logging after pumping.
22.6.2004 *14:05*	23.6.2004 *16:02*	KR8	Flow logging after pumping.

In addition to these results a great amount of site descriptive information and other measurement results are available. In the list below some main data including short comments will be delivered for participants of Task 7. Latest summaries of all investigations are presented in reports Anttila et al. (1999) and Posiva (2003a, 2005).

During the site characterisation programme, Posiva has used the TUTKA data management system to archive field investigation data. The database is a Microsoft Access based meta-database containing information on and reference to the actual data, which are stored separately. Organising the data in this way enables storing of very different types of data and sets practically no limits on the amount of data. Most of the data is stored in ASCII-files, although some images and binary files are also accepted. In addition to the key information and a short description of the data, the TUTKA-database contains the abstracts of the POSIVA- and Working Report-series. (Hellä and Lallo 2004).

New database (POTTI) is in preparation (will be in use in 2005).

Main information concerning Task 7 is listed below:

- **Lithological model of the Olkiluoto island**
  - Complicated bodies of different rock types (see Figure A1-1-1) – available in Surpac and AutoCAD forms.
  - Reported in Vaittinen et al. (2003).
  - Will be updated in 2005.
- **(Hydro)structures (mainly main fracture zones) of the site**
  - Borehole specific sections determined (Vaittinen et al. 2003).
  - Extension and orientation determined – available in Surpac and AutoCAD forms or as text files with x, y, z coordinates.
  - Modified for flow modelling purposes (Andersson et al. 2007) – available as above.
  - Reported in great details in Vaittinen et al. (2003) which is based on data for boreholes KR1–KR23 – today (March 2005) 33 deep drilled boreholes in the island.
  - The effect of new results (boreholes KR24–KR33) on hydro-structures near ONKALO should be analysed – preliminary modification for extension and orientation one of the main structure RH19 has been done in winter 2004/2005 – not reported.
- **Hydraulic properties of the bedrock and the overburden**
  - Results of single hole tests by HTU-tool (double packer tests in selected boreholes and selected sections), DIFF-tool (difference flow logging method, systematic in all boreholes) and Slug-tool (limited amount of one meter T-values in shallow depths in the bedrock and overburden (Refs – great amount of individual working reports – not listed here).
  - Fracture specific transmissivities and fresh water heads determined – data available in Excel or text files, summary of results will be published in spring 2005 (Ahokas et al. 2013).
  - Old interference tests results (Ylinen and Väätäinen 1993, Niva 1996, Jääskeläinen 1998) available as Excel or text files.
  - Values used in various flow models (Löfman 1996, 1999, 2000) available in Excel files.
- **Topography of ground and bedrock surface available in x, y, z coordinates**
- **Equipotentials of mean groundwater level available in x, y, z coordinates**
- **Borehole data (deviation, casing, fractures etc.) available in tables and x,y,z coordinates**

Appendix 2

Task 7 – Test Cases for September 2005

Henry Ahokas and Patrik Vidstrand, July 8, 2005

Introduction

The data presented and additional discussions held at the TF20 meeting at Äspö along with discussions in workgroup sessions during this spring/summer have led to a decision to initiate the Task 7 with a couple of simplified cases.

The modeling of the long-term pumping test in KR24, at Olkiluoto, will therefore be launched gradually, and in this first phase the work with the simplified cases is supposed to create a good platform for further progress within the task.

Below three cases are presented; in order to make the workshop a valuable session it is recommended that the modelling groups (MG) have taken on at least one of these cases before the next meeting in September 2005 in Stockholm. The basic idea of these scoping calculations is to create a common forum, to have preliminary modelling results, and to highlight essential questions and problems before the finalisation of the Task 7 definition.

Scope and objectives

The scope of this first phase is to determine means to incorporate and simulate the responses of open boreholes during a pumping test. Moreover the work gives an opportunity for the MGs to get acquainted with the measured results presented and delivered in TF20 (also available on the SKB web site).

The main objectives of this first phase are:

- To determine means of incorporating open boreholes in numerical groundwater flow models. The influence of the open boreholes should be possible to evaluate in order to discuss issues like: Good and bad methodologies to incorporate open boreholes and which are the related numerical issues?
- To implement results corresponding to flow logging measurements in numerical models.
- To address the need for transient modeling.
- To get acquainted with the available data set and to determine the need of data.

Based on these simplified exercises and understanding of real data each group should be able to address their need and use of data in the final modelling. At the coming workshop we need to address questions like: How much data are needed? What are the requirements for the coverage of data? Are all necessary data available, and if not can it be collected and delivered for the modelers? Which data should to be used for calibration and/or verification?

Short description of the long-term pumping experiment

The groundwater was pumped at constant rate out of borehole KR24. A packer with a bypass tube was placed at approximately 80 metres depth. The pumping of the borehole was performed above the packer with a pumping rate of approximately 18 l/min. It is estimated that 1–4 l/min comes from the three zones described below.

Case descriptions

Modelling set-up descriptions follow on adjacent pages.

Case A is a simplified conceptualisation of three known major hydraulic zones deep (at depth of 100 m and below) in the bedrock. The given transmissivity values and heads are based on single-hole tests.

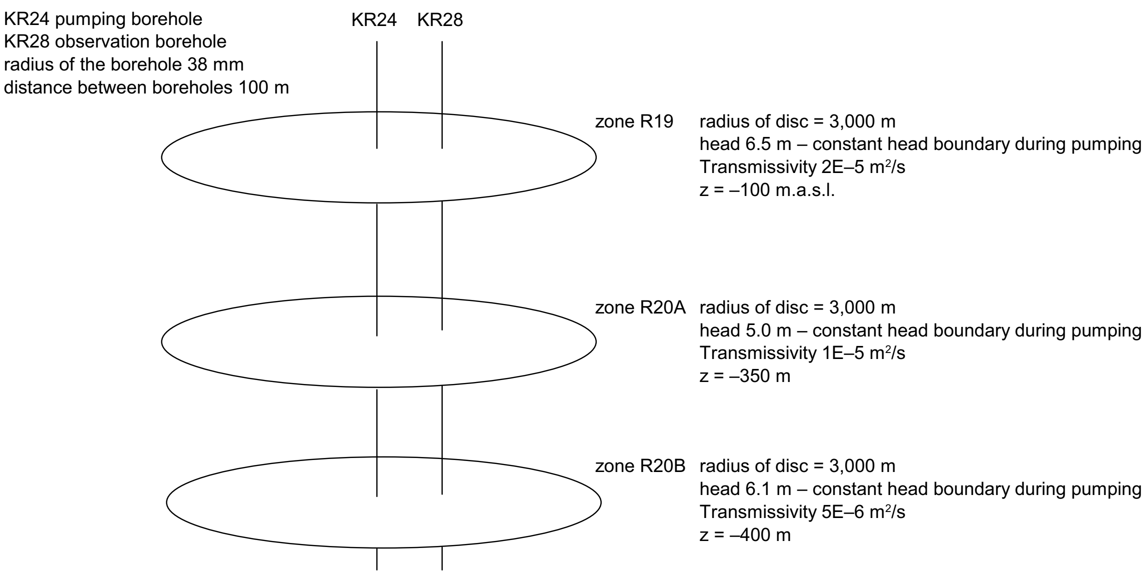
Case B is a “inversion” type exercise where the idea is to produce possible geometries and hydraulic properties however partly governed by the geometries and properties given in Case A i.e. three sub-horizontal zones with transmissivites and heads shown as initial values in Case A.

Case C test the sensitivity of flow and heads due to variations in transmissivity values, boundary conditions, and the extension and geometry of zones (however almost similar geometries as in Case A). The general effect of different transmissivity values on flow changes while pumping was presented at TF20 and a copy of this slide is shown at the end of this document.

One reason for the use of a large radius of influence in Case A is the observed large drawdown in borehole KR28, which may be due different flow geometries than the assumed cylinder symmetric (radial). The value of given head of the lowest zone R20B is uncertain but is higher than the head in the open borehole causing flow from zone into the borehole at least in borehole KR28. It is thus recommended to vary either transmissivity values or heads to get such a result where flow is from zone R20B into borehole.

The main objective of Case C is to test how sensitive measured results are to different initial conditions and estimations. This exercise may also give some ideas how important is to take into account time dependent phenomena in the analysis.

Case A – Steady state simulation of flow and head based on given geometry and boundary conditions



To be simulated:

Case A1

- Flow rate and direction (from zone into borehole or from borehole into zone) during "natural" stage i.e. without pumping in KR24 and KR28.
- Head (water level) in open boreholes KR24 and KR28.

Case A2

- Flow rate and direction (from zone into borehole or from borehole into zone) during pumping of borehole KR24 with constant drawdown of 1.1 m.
- Head (water level) in open borehole KR28.

The pumping borehole KR24 is assumed to be in the centre of all three zones.

The Modelling Groups are free to set necessary boundary conditions except for the predefined within the zones.

Case B – "Inversion modelling exercise" – real data from KR24 and KR28 – solve for the flow rates from zones into borehole KR24, transmissivities, storativity, and boundary conditions for major zones

Assume the same geometry as in Case A.

Data:

Table A2-1. Borehole coordinates (easting, northing, elevation, borehole length) – more detailed in web-site, Delivery 4.

KR24: top:	1,525,923.96	6,791,992.14	9.74		0.0
bottom	1,525,921.14	6,791,993.88	–541.31	551.10	
KR28: top:	1,526,063.00	6,791,921.40	14.40		0.0
bottom	1,525,879.41	6,792,257.85	–516.34	656.42	

Table A2-2. Water level (m.a.s.l.) in open boreholes before pumping (25.3.2005), at the end of pumping (1.6.2005), after recovery of pumping (10.6.2005) and drawdown (based on the difference between the end of pumping and end of recovery).

Borehole/time (date)	25.3.2005	1.6.2005	10.6.2005	Drawdown, m
KR24	5.5	3.5	4.6	1.1
KR28	5.9	4.7	5.5	0.8

Note: the difference between water levels before and after pumping is assumed to be caused by the natural (seasonal) decrease of gw-surface on the island and might be omitted in the simulation e.g. using the measured head at the end of pumping (10.6.2005) for heads before pumping

Table A2-3. Flow (ml/h) before pumping, during pumping and after pumping in KR28 at following depths.

Date – depth >>	155 m	159 m	390 m	444 m
Before pumping – 1.3.2004	69,800	23,500	–65,100	150
During pumping – 5.4.2004	37,200	13,800	–43,600	–370
During pumping – 8.5.2004	39,000	12,000	–64,300	–440
After pumping – 15.6.2004	66,000	20,700	–77,300	160

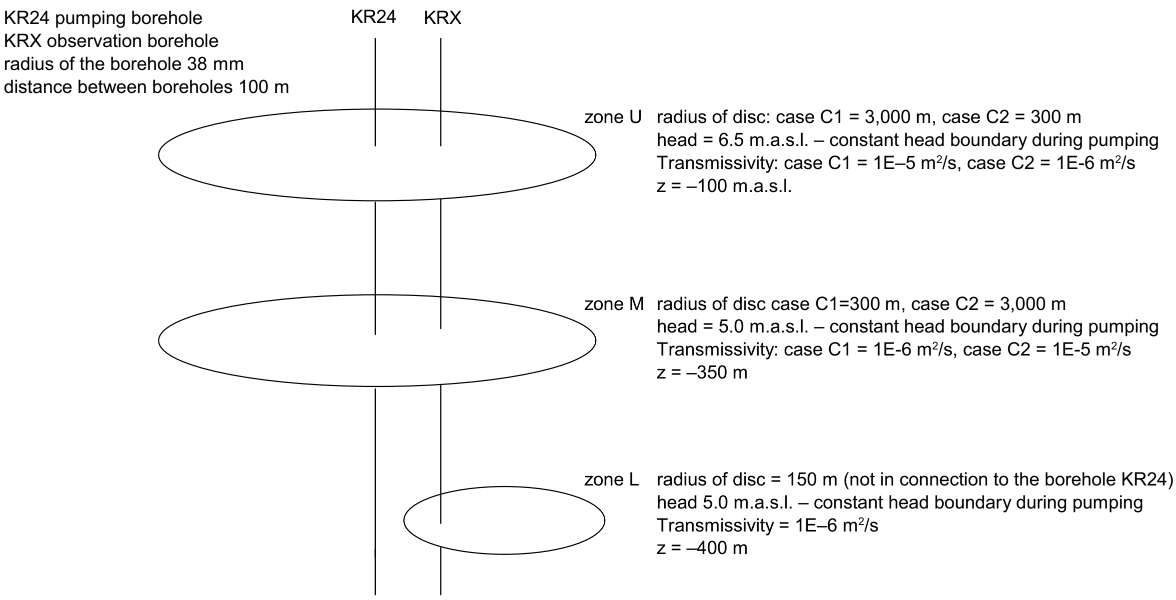
Positive flow: flow from zone into borehole.
Negative flow: flow from borehole into zone.
Depths 155 and 159 m belong to zone R19, 390 m to zone R20A and 444 m to zone R20B (if the geometry of case A is assumed).

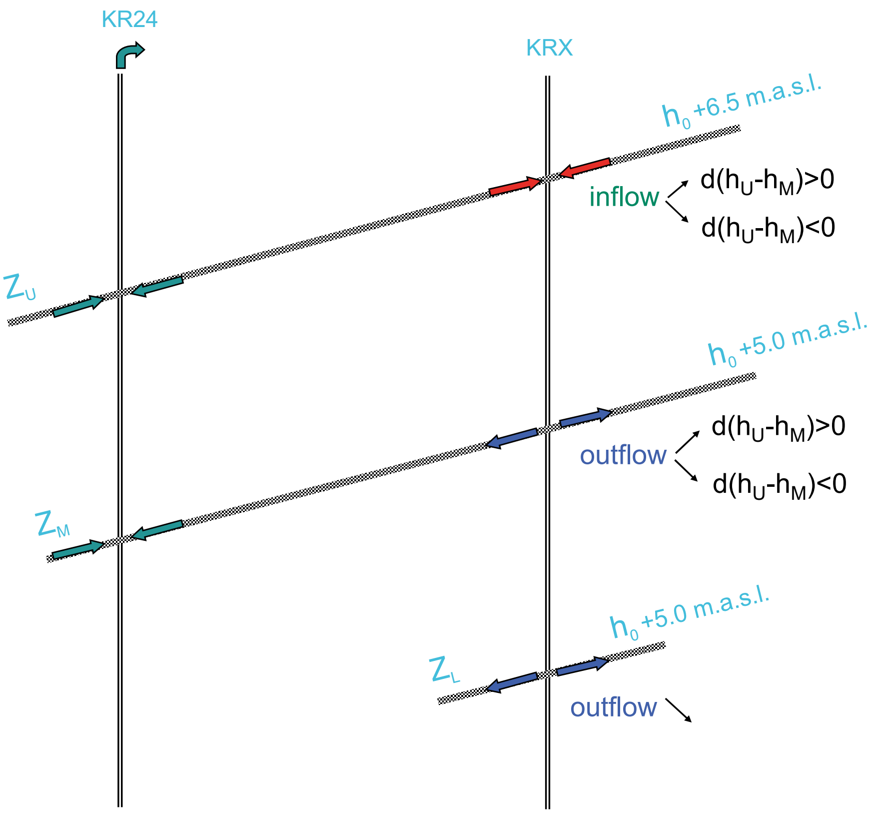
The Modelling Groups are free to set necessary boundary conditions except for the predefined within the zones.

Cases C1 and C2 – Simulation of flow and head – testing of the effect of different transmissivities and radius of influence on flow changes caused by pumping – see the schematic illustration below (modified from presentation in TF20)

The pumping borehole KR24 is assumed to be in the centre of zones U and M.

The Modelling Groups are free to set necessary boundary conditions except for the predefined within the zones.





Appendix 3

Task 7 – Reduction of Performance Assessment uncertainty through modelling of hydraulic tests at Olkiluoto, Finland

Modelling the KR24 and the KR14-18 tests

Henry Ahokas, Lasse Koskinen and Patrik Vidstrand, December, 2006, *Revised June, 2007*

Introduction

Task 7 has developed considerably from what was described in April 2005 and hence we need a revised overall Task 7 description.

This document intends to describe the overall scope and objectives of Task 7 as it is presently envisaged. This document is not a stand alone document, but together with specific sub-task descriptions within the project, this document gives the essential information on Task 7 issues.

Individual sub-tasks will be defined with specific descriptions of the scope, objectives, and performance measures.

Geographical settings

Spent fuel from the Finnish nuclear power reactors is planned to be disposed of in a KBS-3 type repository to be constructed at a depth between 400 and 600 m in the crystalline bedrock at the Olkiluoto site.

Olkiluoto is an island of the size of about 10 km^2, separated from the mainland by a narrow strait, on the coast of the Baltic Sea. The repository for spent fuel will be constructed in the central part of the island (Figure A3-1). Olkiluoto Island has a continental climate with some local marine influence. In the spring, temperature is significantly lower on the island than inland. Correspondingly, the warm sea equalises the temperature differences between day and night in the fall, so that frosts are rare. The winter is usually temperate. The mean temperature at Olkiluoto in the period of 1992 to 2001 was 5.8°C. The snow thickness is usually less than 20 cm and water equivalent of snow is below 40 mm. The amount of snow varies during winter with temperature fluctuating around 0°C.

Figure A3-1. *Olkiluoto Island and the location of the ONKALO (thick oval). The repository for spent nuclear fuel will be constructed in the north west of the ONKALO.*

The site investigations will culminate in the construction of the ONKALO underground rock characterization facility. This construction work started in July 2004 and is expected to complete in 2010. The investigations in the ONKALO are an essential support for the application of the construction license for the repository. The application of the construction license is to be submitted to the authorities by the end of 2012.

The investigations in ONKALO will aim at further characterization of bedrock properties and to find the most suitable locations for the first deposition tunnels and holes for spent fuel canisters (Posiva 2003b). Tests and demonstrations of repository technologies will also be carried out in ONKALO. The underground parts of ONKALO consist of a system of exploratory tunnels accessed by a tunnel and a ventilation shaft. The ventilation shaft is to be located in the place of borehole KR24. The main characterization level will be located at a depth of about 400 m and the lower characterization level at a depth of about 500 m. Demonstrations and tests of repository technologies will mainly be carried out on the main level. The total underground volume of ONKALO will be approximately 330,000 m^3 with the combined length of tunnels and shaft of about 8,500 m.

According to current plans, the operation of the facility would commence after 2020.

Borehole KR24 pumping test

The construction of the underground facilities at Olkiluoto will affect the water table, hydraulic head in the vicinity of the access tunnel and shafts, and also the groundwater circulation at depth in general. To predict the effects and to characterize hydraulic connections on the scale of 100 m to 1 km, a long-term pumping test was carried out in the 550 m deep, vertical borehole KR24 from 25 March to 2 June 2004.

It is expected that tackling the pumping test with various conceptual models, building on their model specific assumptions, and making use of their model specific strengths, will lead to an improved understanding of the hydrogeological characteristic of crystalline fractured rock, and especially of the major fracture zones within the bedrock. Furthermore this will enhance the capabilities for resolving groundwater flow and transport issues in connection to the ONKALO thereafter.

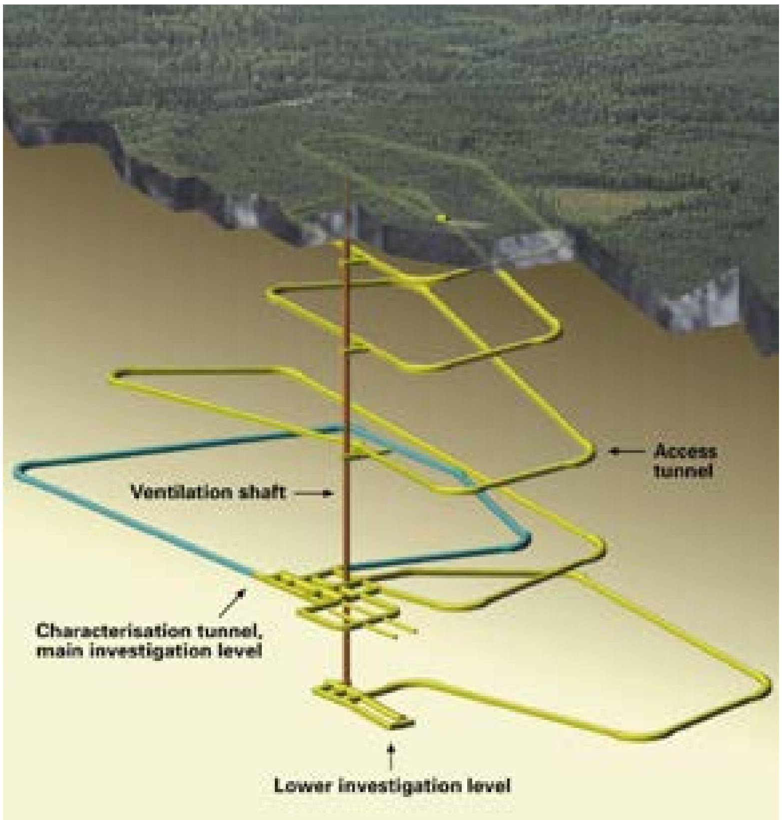


Figure A3-2. *The ONKALO rock characterization facility. The construction of ONKALO started in July 2004 and is planned to last until about 2010.*

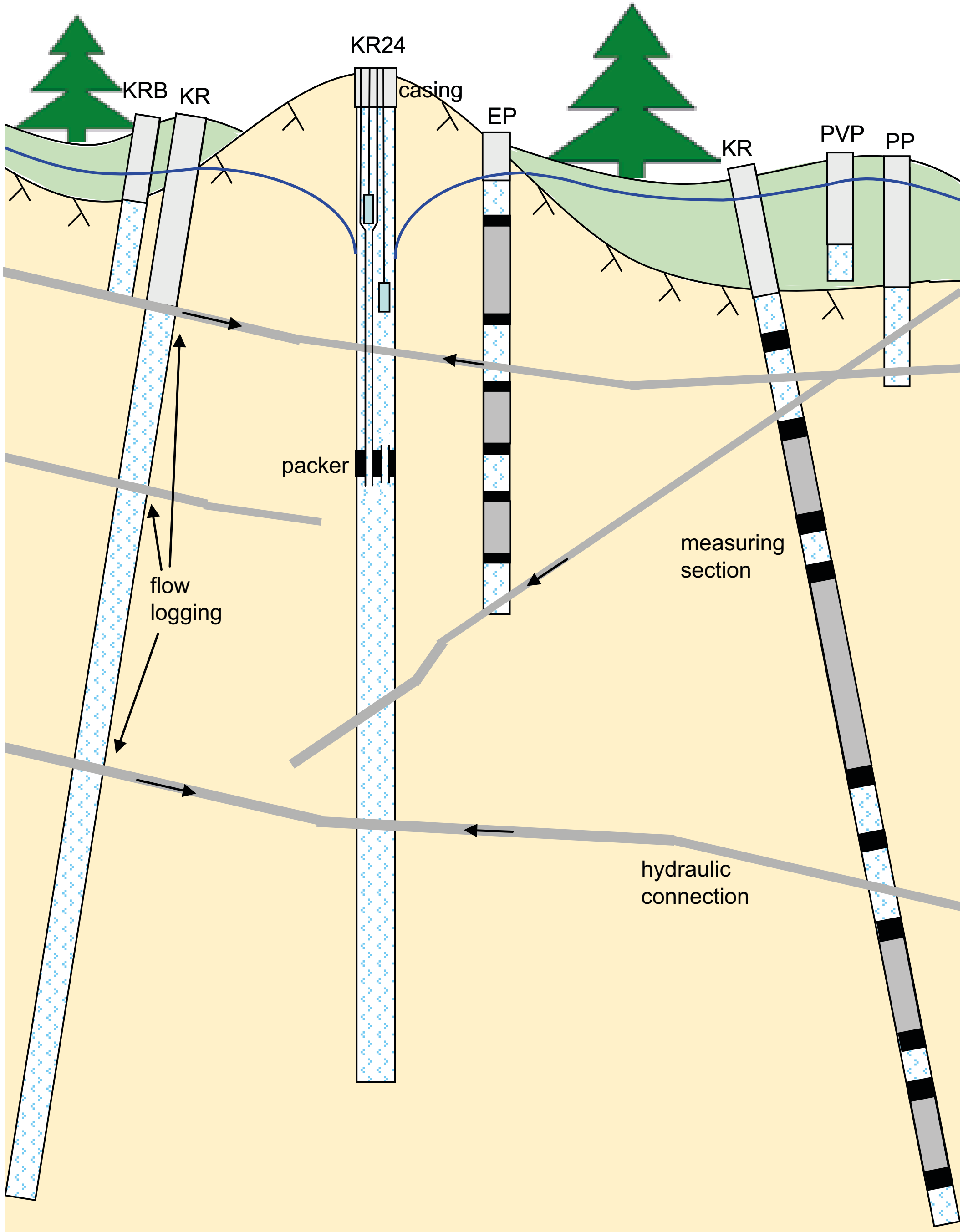


Figure A3-3. *A schematic visualisation of the KR24 long-term pumping test. Measuring sections in figure are packed-off sections in boreholes.*

Borehole KR14-18 cross-hole test

Hydraulic cross-hole interference tests in the scale of 10–100 m were carried out in boreholes KR14–KR18 (including shallow B-boreholes) at Olkiluoto during autumn 2004. These tests were conducted in order to produce detailed information on the effects within the bedrock in-between major fracture zones.

It is hoped that the experience from modelling the KR24 test will be useful in the development of models for the KR14–KR18 tests and that modelling of the fracture zones and background rock at the two scales will be useful in developing understanding of groundwater flow and transport in fractured crystalline rock.

Particular areas of interest may be:

- Use of PFL data in "lower hydraulic conductivity" environment between major zones.
- Local scale hydraulic disturbance due to open boreholes.
- Consistency of treatment of background rock at the two scales.
- Contribution to transport resistance of geosphere from background rock.
- Hydraulic significance and description of fracture zones at block scale (boundary conditions, importance of heterogeneity).
- Influence of near surface conditions.

Objectives

Task 7 aims at providing a bridge between the site characterisation (SC) and performance assessment (PA) approaches to pumping tests and measurement from borehole flow logging. Open boreholes are nowadays a feature at many sites and Task 7 aims to develop an understanding of the effects of open boreholes on the groundwater system and the use of data from such boreholes in site characterisation and performance assessment.

The task is supported with an extensive body of observation data recorded before, during and after the different hydraulic tests, accompanied by detailed and voluminous characterization data set accumulated to date. Clearly, utilization of this data set is challenging itself.

It is very beneficial to this study to recall a similar field test that was carried out at the Äspö Island (Gustafson and Ström 1995). This test, called the LPT2 pumping and tracer test, consisted in a pumping phase that began in September 1990 and ended with a 1-month recovery phase in January 1991. The modelling activities for the LPT2 experiment were divided into the analysis of the hydrogeological response and analysis of the tracer test. While the LPT2 experiment has some differences compared to the borehole KR24 pumping test, these tests actually are similar to the extent that many of the ideas of the LPT2 test may be re-utilised in connection to the borehole KR24 pumping test.

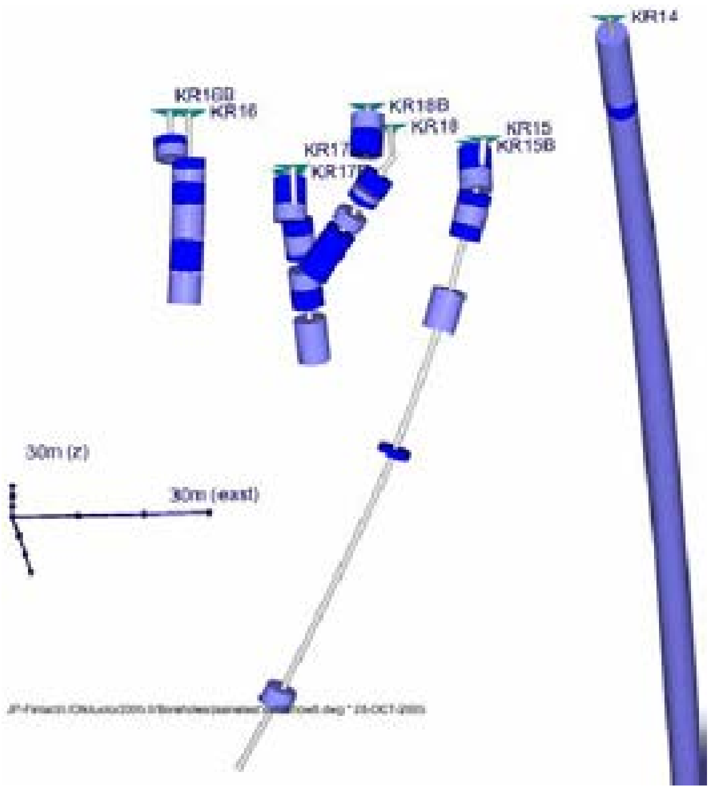


Figure A3-4. *Monitored sections in the boreholes considered in the KR14–KR18 tests. Sections are distinguished with varying colour. The horizontal scale is six times the vertical scale.*

In this very similar spirit, the borehole KR24 pumping test is presented to offer the first opportunity to foreign organizations to get acquainted with the site characterization data of Olkiluoto. As in the case of the LPT2 experiment, the borehole KR24 pumping test may be considered from the modelling point of view, the Olkiluoto data collection point of view, and the site characterization point of view.

However within Task 7, modelling of the KR24 pumping test is only the first element of a larger study which includes: modelling of smaller scale pump tests in KR14 and KR18 and consideration of the fracture system at the canister scale.

Task 7 Strategy

The strategy of Task 7 is to proceed from the largest scale (site scale with focus on fracture zones) to smaller scales (rock block) (see Figure A3-5). Task 7 may finish with exercises at the scale of the engineered barrier. At each scale, specific goals will be defined within the context of the overall Task 7 goal, and modelling tasks will be defined to support those goals.

Task 7a aims at understanding the large scale structures and effects. Task 7a will consider an approximately 10 km^2 region surrounding borehole KR24 at the Olkiluoto site in Finland. KR24 was used for a long-term pumping test. The test setup included pumping from two borehole sections. The lower part of KR24 was partially isolated by a by-pass packer (throttle valve) so that the deeper sections of the borehole experienced a smaller drawdown than the upper section during the pumping.

The objectives of task 7a are specified through a set of goals.

1) To understand the major features of the groundwater system.
2) To understand the consequences of the tests and measurement systems used, e.g. the open boreholes.
3) To understand how to model open boreholes within site characterisation studies and for the provision of parameters for PA.
4) To understand how PFL measurements could reduce uncertainty in models as compared to models calibrated with only head measurements.
5) To increase understanding of compartmentalisation and connectivity at the Olkiluoto site and more generally in fractured crystalline rock.
6) To evaluate how uncertainty in PA can be reduced based on the analysis of the Olkiluoto dataset.

Task 7b aims at understanding the block scale in regards of flow and responses. Task 7b will consider a sub-volume of Task 7a in part bounded by major fracture zones and other natural boundaries. The KR14-18 cross-hole interference test was organized in several stages. Firstly the boreholes were investigated with a difference flow method (the PFL) in open boreholes. There after hydraulic tests were conducted within a multi-packed off system where various sections were isolated from the rest of the boreholes with inflatable packers.

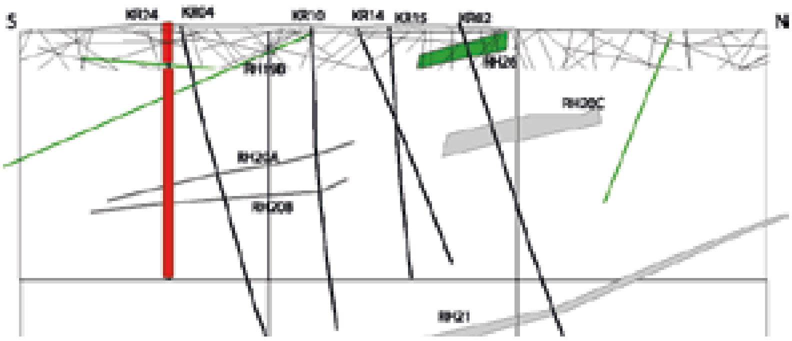
The objectives of the task are specified through a set of goals.

1) To understand how major features could be used as boundary conditions.
2) To understand the minor features of the groundwater system, (background rock).
3) To understand the consequences of the tests and measurement systems used, e.g. the open boreholes.
4) To understand how to model open boreholes within site characterisation studies and for the provision of parameters for PA.
5) To understand how PFL measurements could reduce uncertainty in models as compared to models calibrated with only head measurements.
6) To increase understanding of compartmentalisation and connectivity at the block scale.
7) To evaluate how uncertainty in PA can be reduced based on the analysis of the Olkiluoto dataset.

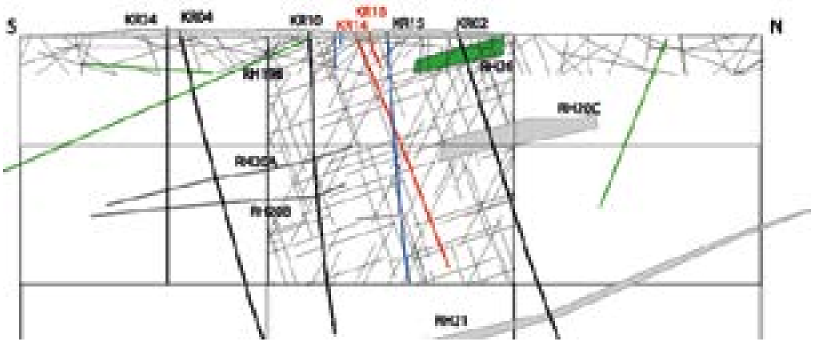
A Task 7c may be included and if so it will aim at understanding the small (canister) scale. One option is to include integration with the Engineered Barrier System (EBS). Herewith issues regarding the buffer and canister scale such as the integration of mechanical, thermal and hydrogeological descriptions of the buffer and the nearfield geosphere could be considered.

Possibly the final temptation will be a simulation integrating all scales from the canister to the entire site.

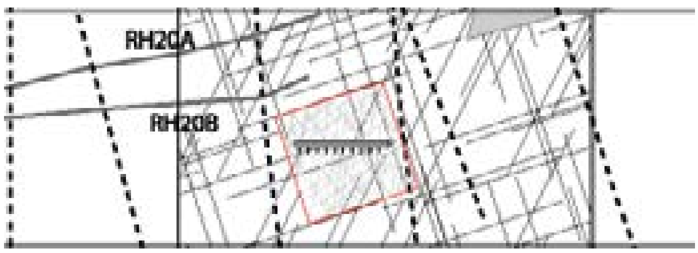
Task 7a
Pump Test KR24
Focus on major fracture zones and structural framework



Task 7b
Pump tests KR18, KR14
Focus on background rock



Task 7c
Focus on canister scale
Small scale hydraulic testing and geological mapping



Possible final task
Integration across scales

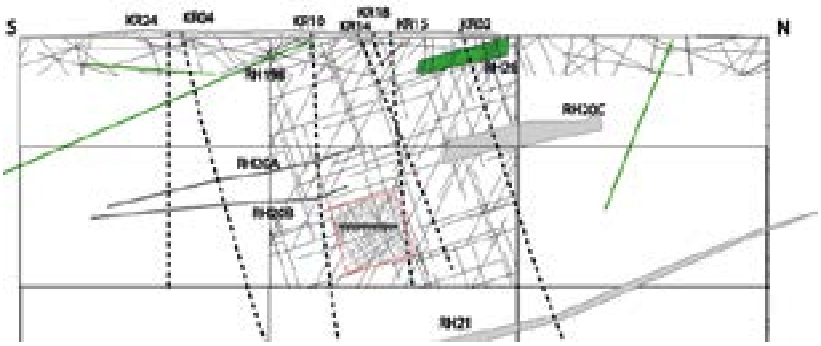


Figure A3-5. *Schematics of the different Task 7 sub-tasks and their anticipated scale and focus.*

Organisation and time schedule

The organisation of the Task 7 follows the structure implemented since the early stages of the Task Force. Task management, procedure, evaluation, and reporting follow the Task Force Charter representing the overall framework for managing the Task Force.

The time schedule of Task 7 is contained within the schedule of Task Force on Modelling of Groundwater Flow and Transport of Solutes.

Autumn 2007	Distribution of scope, objectives, and performance measures for Task 7b
October 1, 2007	All groups to submit PM, Questionnaires, and Technical Notes on Task 7a1 and Task 7a2.
Task Force meeting #23	All groups to submit preliminary results of Task 7a3, Task 7a4 and Task 7a5 for performance measures
April 2008	All groups to submit reports of Task 7a3, Task 7a4, and Task 7a5
Spring/summer 2008	Preliminary workshop on task 7b
Task Force meeting #24	All groups to submit preliminary results of Task 7b for performance measures
	Reporting of full results for Task 7a
Task Force meeting #25	Completed review of Task 7a
	Reporting of full results for Task 7b
Task Force meeting #26	Completed review of Task 7b

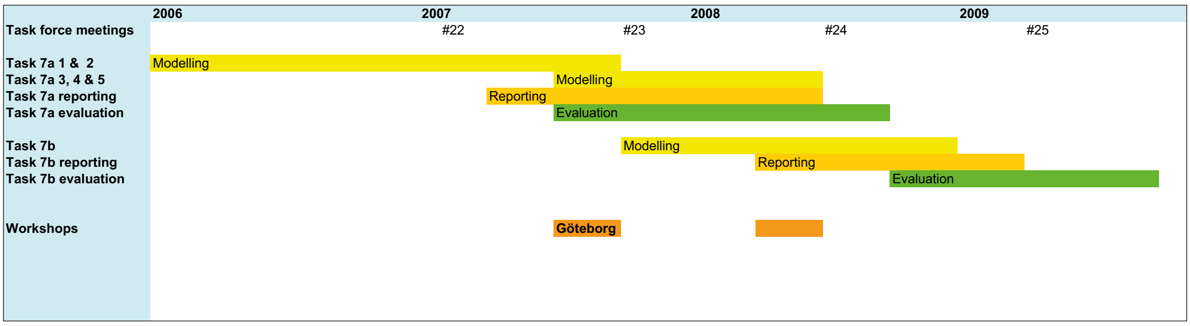
Performance Measures/Output

The performance measures typically relate to measured head, flow or computed transport properties and are documented in the sub-task definitions.

Data distributions and discussion forum

All distribution of data will be available through the web at the task force homepage: www.skb.se/templates/SKBPage_2636.aspx .

At the homepage a discussion forum is supposed to function for placing and answering questions arisen. Essential information on new updates etc is always distributed through e-mail from the secretariat.



Appendix 4

Task description for Task 7A

Specifications for Task 7A1 and Task 7A2

Reduction of Performance Assessment uncertainty through site scale modelling of long-term pumping in KR24 at Olkiluoto, Finland 2006-11-01

Patrik Vidstrand (ed.), William Lanyon and Henry Ahokas

A4.1 Introduction

Task 7 aims at providing a bridge between the site characterisation (SC) and performance assessment (PA) approaches to long-term pumping tests and measurement from borehole flow logging. Open boreholes are nowadays a feature at many sites and Task 7 aims to develop an understanding of the effects of open boreholes on the groundwater system and the use of data from such boreholes in site characterisation and performance assessment.

The strategy of Task 7 is to proceed from the largest scale (site scale with focus on fracture zones) to smaller scales (rock block).Task 7 may finish with exercises at the scale of the engineered barrier. At each scale, specific goals will be defined within the context of the overall Task 7 goal, and modelling tasks will be defined to support those goals.

Task 7A will consider an approximately 10 km^2 region surrounding borehole KR24 at the Olkiluoto site in Finland. KR24 was used for a long-term pumping test. The test setup included pumping from two borehole sections. The lower part of KR24 was partially isolated by a by-pass packer (throttle valve) so that the deeper sections of the borehole experienced a smaller drawdown than the upper section during the pumping.

Task 7A will provide an opportunity for the different modelling groups to become acquainted with the Olkiluoto site in Finland, just as Task 1 (LPT2 Pumping test) provided an introduction to the Äspö site. In addition Task 7A provides an opportunity to illustrate the developments and lessons learnt since Task 1.

This document contains only the essential new information. The data distributed along with Task description version 2.2b together with the new topography file sent out after the workshop in Rauma (11–12th September, 2006) remain valid. A revision of the Task description version 2.2b is currently under way in order to get a good working structure with this document. The future version of the Task description version 2.2b will contain the framework for the conceptual model and the reference data set, and the new document will be referred to as Task 7A reference data set.

Following discussions at the workshop in Rauma (11–12th September, 2006) the framework for Task 7 has been revised and a more detailed structure for Task 7A has been developed. This structure is set out in the next section.

A4.2 Scope

The aim and scope of Task 7A is to simulate the performance of the groundwater system and its response to long term pumping in the presence of open and sealed-off boreholes, by building numerical groundwater flow models of Olkiluoto and testing their robustness. An important aspect of the data from the site is the use of the Posiva Flow Log to measure flow into/out of the boreholes during "undisturbed" and pumped conditions. A special focus on the major hydraulic conductors will yield a good starting point for the next Task 7B which focuses on the block scale system.

Task 7A is divided into five main parts.

(7A1) Hydrostructural model implementation:

Here, each modelling group will implement the same hydrostructural model and reference dataset to model the KR24 pumping tests. The exercise is a forward modelling study with calibration and sensitivity studies to identify the value of the long term pump test and PFL data.

The results will be defined as: (a) forward modelling results, considering only the reference data provided, (b) inverse or calibrated models adjusted to better match the results of the KR24 pump test and PFL data, (c) discussion points considering the differences between the models described in (a) and (b) to identify the "value" of the pumping test and PFL data.

The results will be presented in a report, common for Task 7A1 and Task 7A2.

(7A2) Pathway Simulation within fracture zones:

Here, each modelling group will, within the model developed in Task 7A1, quantify uncertainty on the advective travel time from reference points in borehole KR24 through the fracture zones to a discharge point (or model boundary). Task 7A2 will be conducted under assumed PA relevant boundary conditions.

The results will be given as the 95% bounds, median and mean values for the calculated travel time, together with justification of the bounds and discussion of key uncertainties associated with the calculations.

The results will be presented in a report, common for Task 7A1 and Task 7A2.

(7A3) Ideas for calculation of PA relevant parameters from open borehole information:

Here, each modelling group will consider how the PFL and open hole long-term pumping experiments database of Task 7 might be used to derive transport parameters of "Q/W" ,flow wetted surface (FWS), Beta, Tau, "transport aperture", and "transport width"

The results will be defined through discussion points considering possible changes within the reference dataset and basic conceptual model, to better match the observed hydraulic interference results.

The results will be presented in a report, common for Task 7A3, Task 7A4 and Task 7A5.

(7A4) Quantification of compartmentalisation from open borehole information:

Here, each modelling group will, based on the models developed in Task 7A1, consider how the PFL and long-term pumping test database of Task 7 might be used to provide a quantitative description of the degree of compartmentalisation and connectivity between different locations within the Task 7A rock volume.

The results will be presented in a report, common for Task 7A3, Task 7A4 and Task 7A5.

(7A5) Quantification of transport resistance distributions along pathways:

Here, each modelling group will, based on the work of Task 7A1–7A4 (synthesis of Connectivity, Compartmentalisation, and Q/W distributions from PFL) , quantify uncertainty on the advective travel time from a reference point in borehole KR24 through the fracture zones to a discharge point defined at the surface. Task 7A5 will be conducted under assumed PA relevant boundary conditions.

The results will be given as the the 95% bounds, median and mean values for the calculated travel time, together with justification of the bounds and discussion of key uncertainties associated with the calculations

The results will be presented in a report, common for Task 7A3, Task 7A4 and Task 7A5.

A4.3 Objectives

The objectives of the task are specified through a set of goals.

Goals

The goals of the task are:

1) to understand the major features of the groundwater system,
2) to understand the consequences of the tests and measurement systems used, e.g. the open boreholes,
3) to understand how to model open boreholes within site characterisation studies and for the provision of parameters for PA,
4) to understand how PFL measurements could reduce uncertainty in models as compared to models calibrated with only head measurements,
5) to increase understanding of compartmentalisation and connectivity at the Olkiluoto site and more generally in fractured crystalline rock, and
6) to evaluate how uncertainty in PA can be reduced based on the analysis of the Olkiluoto dataset.

A4.4 Time Schedule

The time schedule for Task 7A is preliminary and contained within the over-all time schedules of Task 7 and the Task Force on Modelling of Groundwater Flow and Transport of Solutes.

- Data distribution for deterministic portions of hydrostructural model, summer 2006.
- Distribution of scope and objectives for Task 7A, together with additional data and model specifications early November 2006.
    - Flow split information in KR24.
    - Kinematic porosity for the deterministic portions of the hydrostructural model.
    - Iinitial conditions, boundary conditions, and performance measures for Task 7A1 and Task 7A2.
- Distribution of over-all scope and objectives for Task 7, early December 2006.
- Distribution of additional initial conditions, boundary conditions, and performance measures for Task 7A3, Task 7A4 and Task 7A5, early December 2006.
- All groups to submit preliminary results of Task 7A1 and Task 7A2 for performance measures for Task Force meeting, January 7 2007.
- Task Force meeting #22, Oskarshamn, January 16–18, 2007.
- All groups to submit reports of Task 7A1 and Task 7A2 at August 2007.
- All groups to submit preliminary results of Task 7A3, Task 7A4 and Task 7A5 for performance measures for Task Force meeting #23, early September 2007.
- All groups to submit reports of Task 7A3, Task 7A4, and Task 7A5 at April 2008.
- Reporting of full results for Task 7A for Task Force meeting #24.

A4.5 The KR24 Boundary condition

The pumping setup used for the test is shown in Figure A4-1.

The total outflow and the head in the upper and lower sections of the borehole were measured. Flow from the lower section passes though a 1m by-pass pipe of 4mm diameter, driven by the head difference between the two borehole sections.

The flow through the bypass has been estimated using a pipe-flow calculation assuming a smooth-walled pipe. The total flow and the contributions from the upper and lower sections (as inferred from the pipe-flow calculation) are shown in Figure A4-2.

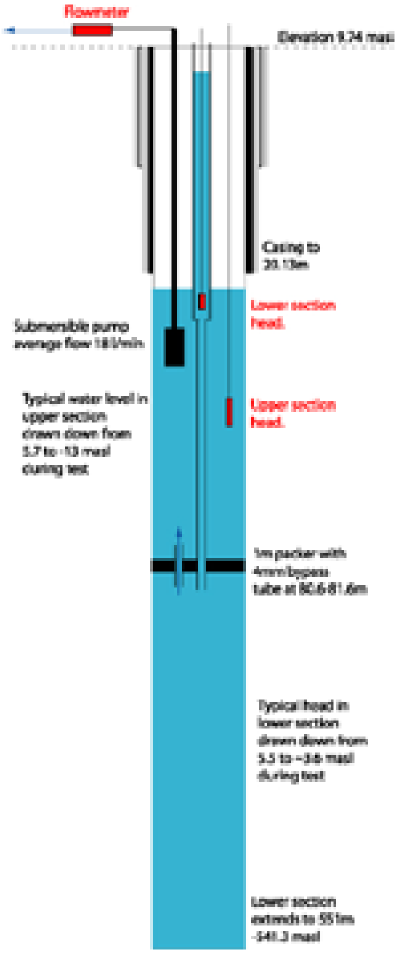


Figure A4-1. *Pumping setup for KR24 (measurement points shown in red).*

Mean values have been estimated as:

- Q_{total}: total flow 18 l/min
- Q_{upper}: flow from rock in upper section 12.5 l/min
- Q_{lower}: flow from the lower section through bypass 5.5 l/min

An estimate of the steady state flow to the lower section assuming a 1.2m drawdown is 5.18 l/min (see Table A4-1) which is in reasonable agreement with the pipe flow estimate at the end of pumping of 5.3 l/min (see Figure A4-2).

There is relatively limited early time (first 24 hrs) flow data and we would expect that the flow from the lower section varies as the drawdown in the two borehole sections evolves. However after the first 24 hours the head difference and flow measurements are relatively constant as shown in Figure A4-2.

In order that the test simulations represent, as well as possible, the real condition at the site during the test, the following options for the KR24 borehole boundary condition are suggested. The options are given in decreasing order of "realism" and are illustrated in Figure A4-3.

Option 1: Withdrawal from the upper section at a total constant rate outflow from the two sections of KR24 of 18 l/min. This option requires that the flow through the by-pass packer is simulated within the models.

Option 2: A constant rate outflow of 12.5 l/min from the upper section and constant rate outflow of 5.5 l/min from the lower section of KR24.

Option 3: A constant rate outflow of 5.5 l/min from the lower section of the borehole only. This option assumes that the responses to the lower section extraction are unaffected by the extraction from the upper section.

The alternative boundary conditions have been provided for the situation where either

a) simulation of the by-pass flow is not practical, or

b) simulation of the two simultaneous extractions are not practical due to limitations in the numerical models or in the available effort.

Table A4-1. Q distribution along borehole (KR24).

Depth of flow (m)	T (m^2/s)	Q (l/min)	Sum of Q	Release point (Task 7A2)
Upper				
23.8	8.16E–06	7.201		
44.2	4.41E–07	0.389		
44.8	7.33E–07	0.647		
47.2	2.99E–06	2.639		
58.1	5.24E–07	0.462		
76.2	1.10E–06	0.971	12.31	
Lower				
94.2	1.89E–05	1.112		
115.5	3.89E–05	2.289		R.p. 1
178.6	1.92E–07	0.011		
188.5	7.19E–08	0.004		
294.8	9.16E–08	0.005		
304.3	1.50E–05	0.882		R.p. 2
305.2	2.30E–08	0.001		
309.4	7.23E–08	0.004		
317.3	3.36E–07	0.020		
331.6	1.04E–05	0.612		R.p. 3
397.1	4.00E–06	0.235		
422.4	1.58E–08	0.001	5.18	

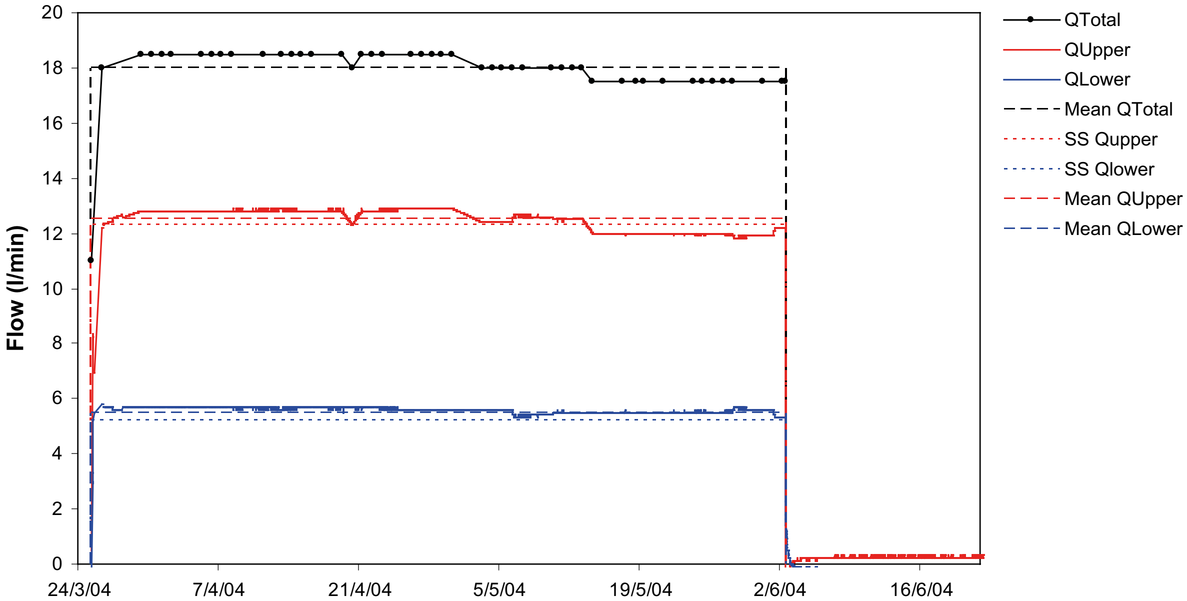
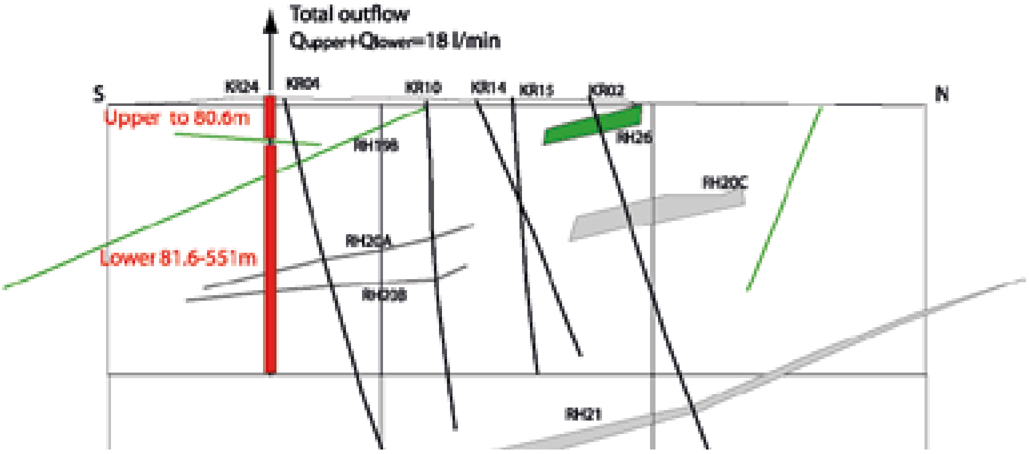
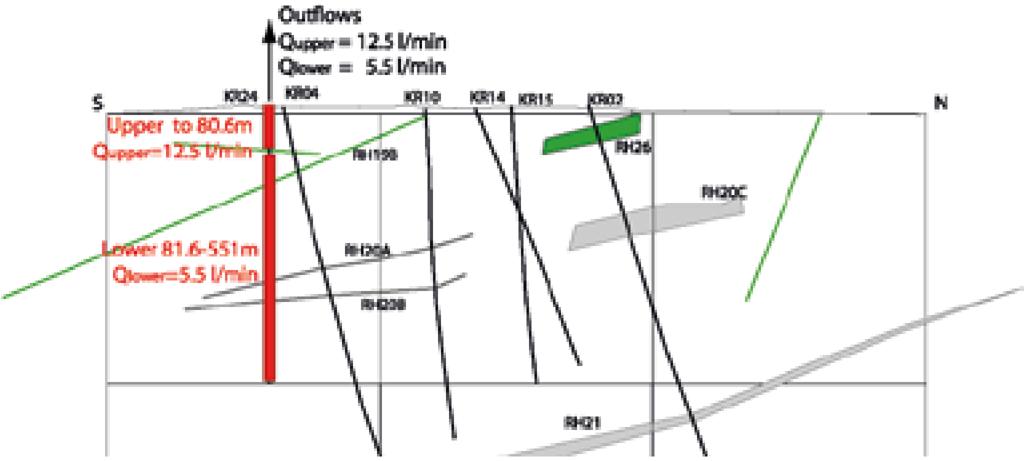


Figure A4-2. *Measured total flow, with estimated contribution from upper (Q_{upper}) and lower (Q_{lower}) sections, steady state flow estimates and approximate mean values.*

Option 1: (Preferred) Boundary condition for Task 7A Pump Test Simulations



Option 2: Alternative boundary condition using two constant rate extractions (where simulation of flow through bypass not practical).



Option 3: Alternative boundary condition using extraction from lower test section (where simulation of simultaneous extraction from both test sections not practical).

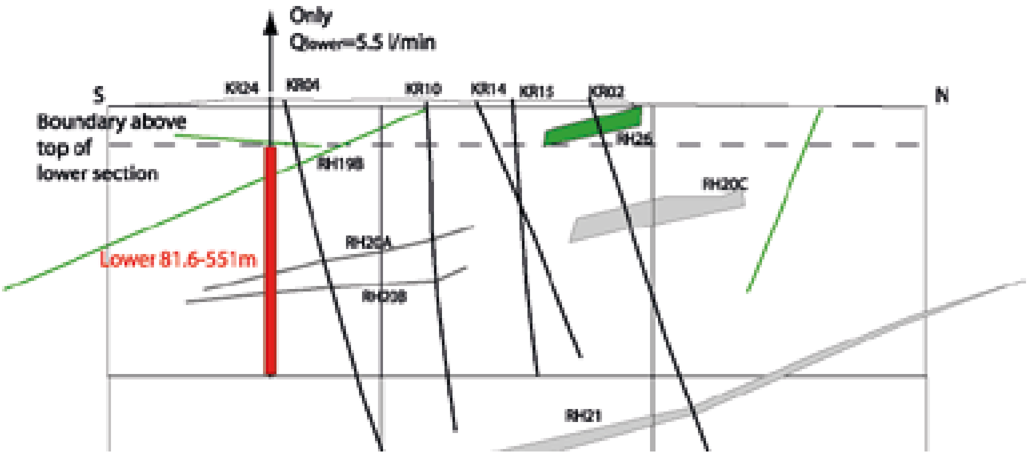


Figure A4-3. *Options for KR24 borehole boundary conditions.*

A4.6 The top boundary condition and the surface layer

The annual precipitation at Olkiluoto island is approximately 550 mm of which 60–70% evaporates by evapotranspiration. The potential recharge at the site is approximately 100–150 mm/a and the most likely deep groundwater recharge to bedrock during natural conditions is approximately 5–20 mm/a, for this study assume 5 mm/a.

Data relevant to treatment of upper boundary:

Data	File
Ground surface topography.	Topography.txt
Equipotentials for the groundwater table.	GW-table-long-term-mean.txt
Groundwater table before the pumping and after recovery periods (two weeks after the stop of pumping) at shallow observation points.	Observations of gw.table.xls
Coordinates of observation points.	Borehole-xyz-data.zip

The modelling teams are free to specify recharge and hydraulic properties at the surface as required by their model. One possibility for modelling teams would be to include a permeable surface layer within their models such that the initial groundwater table could be created through groundwater recharge on the surface layer similar to that presented in Figure A4-4. However other approaches may be adopted according to the needs and available facilities of each model.

The near-surface rock from 0–80m (upper section of KR24) is not well characterised as the focus of the Olkiluoto site characterisation is on the deeper groundwater flow system. However in order to simulate the KR24 pumping test as it was performed, we need to consider this upper layer of rock.

Two possible options are suggested:

- "Generic" or regular mesh DFN model for near surface rock.
- Effective continuum representation of near surface rock.

The two options are illustrated in Figure A4-5.

The inflow data for KR24 suggests six major flows between 20 and 80m (the borehole is cased down to 20m). The estimated transmissivity varies between 4E–7 and 8E–6 m^2/s with a $\log_{10}$ mean of –5.9 and $\log_{10}$ standard deviation of 0.49 (see Table A4-1). An effective conductivity of approximately 2E–7 m/s can be calculated from the total transmissivity and interval length.

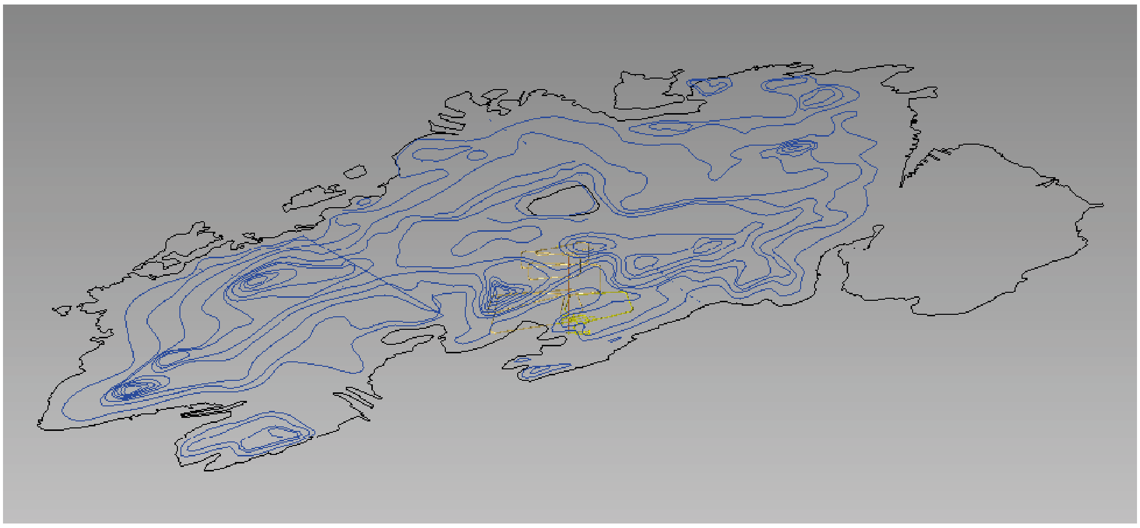


Figure A4-4. *Equipotentials of gw-table (1 m interval, long-term mean).*

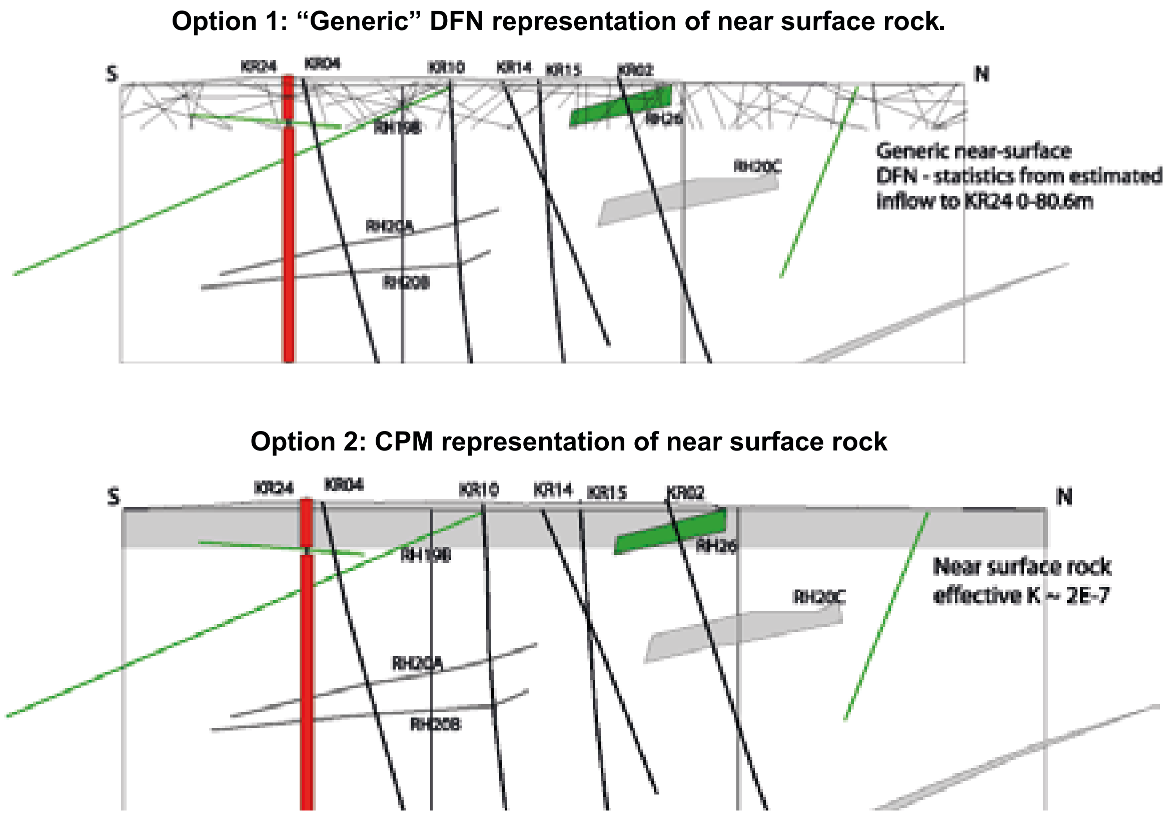


Figure A4-5. Options for representation of near surface rock in KR24 pump test simulation models.

A4.7 Hydrogeological properties

Simplified hydrogeological properties for the main fracture zones are given in Table A4-2.

Table A4-2. Reference values; hydrogeological zone properties.

Fracture zone Name	Transmissivity (log10) Geometric mean (m^2/s)	Standard deviation Log(T)	Transport Aperture (by Doe's law)*(m)	Geological width (mean/range) (m)
HZ001	–7.9	2.1	5.61E–05	5/1–20
HZ002	–6.0	0.6	5.00E–04	5/1–10
HZ003	–6.2	1.3	3.97E–04	5/1–10
HZ004	–6.8	0.7	1.99E–04	25/10–40
HZ19A	–5.8	1.6	6.29E–04	5/1–15
HZ008 **)	–5.0 **	–	1.58E–03	2/1–5
HZ19B	–5.7	1.8	7.06E–04	5/1–15
HZ19C	–5.5	1.3	8.89E–04	4/1–10
HZ20A	–5.1	0.7	1.41E–03	5/1–15
HZ20AE	–6.0	1.2	5.00E–04	5/1–10
HZ20B	–5.2	0.4	1.26E–03	4/1–15
HZ20B_ALT	–5.5	0.9	8.89E–04	8/1–20
HZ21	–7.8	1.8	6.29E–05	11/3–25
HZ21B	–6.1	0.9	4.46E–04	7/1–10
BFZ099	–7.8	1.8	6.29E–05	8/1–25

* Kinematic porosity by dividing transport aperture with mean geological width.
** Optional zone – this zone does not intersect KR-boreholes but is delivered to modellers due to the consistency between other flow simulations to be carried out in Posiva's projects.

Reference values should be used by each group in the "forward modelling" simulation for each group.

The reference value of kinematic porosity for the surface layer is assumed to be $5.0 \cdot 10^{-03}$. If generic fractures are specified the transport aperture could be specified through Doe's law:

$$e_T = 0.5 \cdot \sqrt{T}$$

Modelling groups are expected to vary these properties during calibration and sensitivity simulations in Task 7A1 to Task 7A4.

A4.8 Simulations

Both forward and inverse models are planned. However, if the modellers feel that the results of the forward models are good enough to proceed there is no requirement to run inverse models (although even in this case covariance/uncertainty estimates may be of value).

Name	Task	Description	Forward/Inverse	Boreholes
SS01	7A1	Steady state flow conditions without pumping	Forward	No boreholes
SS02a	7A1	Steady state flow conditions with open boreholes	Forward	Boreholes are open and free to cross-flow.
SS02b	7A1	Steady state flow conditions with open boreholes	Calibrated/Inverse	Boreholes are open and free to cross-flow.
SS03	7A1	Steady states flow with extraction from KR24	Forward	KR24 only
SS04a	7A1	Steady states flow with extraction from KR24	Forward	KR24 + monitoring boreholes
SS04b	7A1	Steady states flow with extraction from KR24	Calibrated/Inverse	KR24 + monitoring boreholes
TR01	7A1	Transient simulation of KR24 test	Forward	KR24 only
TR02a	7A1	Transient simulation of KR24 test	Forward	KR24 + monitoring boreholes
TR02b	7A1	Transient simulation of KR24 test	Calibrated/Inverse	KR24 + monitoring boreholes
PA01	7A2	Transport pathway simulation from KR24 to discharge under PA relevant boundary conditions*.		No boreholes (particles start from position along KR24)

* For the Task 7A2 the boundary conditions specified will be defined through the natural groundwater system from Task 7A1, without the presence of any open boreholes (simulation SS01).

Suggested sensitivity studies

Sensitivity studies are requested from each group but have not been explicitly specified. The topics to be addressed by sensitivity studies are:

a) implementation of heterogeneity in zones and at zone intersections (compartments),

b) implementation of open boreholes,

c) interpretations of Posiva flow log results for flow and transport parameters.

It is envisaged that the performance measures defined above should also be used to investigate and evaluate the results of sensitivity studies.

A4.9 Performance measures, presentation format and points for discussion

Performance measures for head and flow should be provided as time histories where possible, but for comparison purposes the measures will be evaluated at two specific times as listed below.

At the time for submitting preliminary results for Task 7A1 and Task 7A2, an excel file will be distributed and the modellers are asked to fill in the relevant tables according to the performance measures requested (see Table A4-3 – Table A4-7).

Table A4-3. Task 7A1-KR24 Performance measures.

Name	Description	Units	Time
H_{upper}	Head in upper section of KR24	m.a.s.l.	Time history
H_{lower}	Head in lower section of KR24	m.a.s.l.	Time history
H_{upper}–H_{lower}	Differential head between upper and lower sections	m.a.s.l.	Time history
Q_{upper}	Inflow from rock to upper borehole section	l/min	Time history
Q_{lower}	Inflow from rock to lower borehole section	l/min	Time history
Q_{dist}(md)	Distribution of inflow along borehole (KR24, 0–551m)	l/min	Snapshot (see Table A4-7)

Table A4-4. Task7A1-Monitoring interval performance measures.

Name	Description	Units	Time
$H_{monitor}$	Freshwater head in monitoring sections*	m.a.s.l.	Time history
$S_{monitor}$	Drawdown in monitoring sections*	m.a.s.l.	Time history
Q_{dist}(md)	Distribution of inflow along monitoring boreholes** (negative implies flow from borehole to rock)	l/min	Snapshot (see Table A4-7)

* See Table A4-5 for monitoring sections.
** See Table A4-6 for monitoring boreholes.

Table A4-5. Monitoring sections for head and drawdown.

Borehole	Section/Zone
KR04	40–901 m
KR08	20–600 m
KR09	65–75 m, HZ19B
KR09	140–150 m, HZ19A
KR09	565–575 m, HZ20B_ALT
KR12	40–50 m, HZ19C
KR14	10–40 m, HZ19A
KR14	40–60 m, HZ19C
KR14	70–90 m, HZ002
KR22	90–120 m, HZ19A & HZ19B
KR22	140–150 m, HZ19C
KR22	385–295 m, HZ20A
KR23	150–155 m, HZ19A
KR25	90–100 m, HZ19A & HZ19B
KR25	120–130 m, HZ19C
KR25	345–355 m, HZ20A
KR25	405–410 m, HZ20B_ALT

Table A4-6. Monitoring boreholes for flow distributions.

Zone
KR06
KR14
KR22
KR25

Table A4-7. Times for “snapshots” and evaluation of performance measures.

Time	Elapsed (hrs)	Comment
26/3/200414:00	28.1	Close to start of automatic sampling of head data
2/6/200414:40	1,708.8	Final part of drawdown immediately prior to shut-in (best for any comparison with steady state).

For Task 7A2, each modelling group is expected to quantify uncertainty on the advective travel times and recharge/discharge location from a set of specified reference points (see Table A4-1) in borehole KR24 through the fracture zones to a discharge point defined at the surface, under assumed PA relevant boundary conditions. Each modeller will be asked to define and justify 95% bounds, median and mean values for this travel time, using the hydrostructural model from Task 7A1.

Some of the purposes of Task 7A and the future Task 7B are related to the understanding of the usefulness of the Posiva Flow Log (PFL) and the implications due to the measurement system. Therefore during the reporting of Task 7A1 and Task 7A2 the traditional performance measures are complemented with a discussion on results based on the assumptions and specifications.

Essential points for discussion are:

- Hydraulic action of boreholes
  - What is the system response with the boreholes?
  - What is the system response without the boreholes?
  - Do any of the boreholes affect the system more than other boreholes do?
  - Do certain combinations of boreholes affect more than other combinations?
- Value of PFL data
  - In what ways where the PFL data useful for the building of the model.
  - In what ways where the PFL data useful for the verification of the model.
- Relevance to groundwater flow at block scale
  - Can the larger scale models place limits on the effective conductivity of the background rock?
  - Could the results from Task 7A be used as boundary conditions for Task 7B.
  - Which uncertainties are assumed to be transmitted into Task 7B due the simplified deep background rock mass used in Task 7A.
  - How should these uncertainties be assessed in Task 7B.

Each modelling team should present a table with the properties (geometrical and hydrogeological, with uncertainty range for the modelled fracture zones and bedrock) and with flow and head information used. In this table it should be specified which data were used for model set-up, calibration, and verification.

Appendix 5

Task description for Task 7A, Part 2

Specifications for Task 7A3, Task 7A4, and Task 7A5

Reduction of Performance Assessment uncertainty through site scale modelling of long-term pumping in KR24 at Olkiluoto, Finland 2007-05-15, revised 2007-06-28

Patrik Vidstrand (ed.) and Henry Ahokas

A5.1 Introduction

Task 7 aims at providing a bridge between the site characterisation (SC) and performance assessment (PA) approaches to long-term pumping tests and measurement from borehole flow logging. Open boreholes are nowadays a feature at many sites and Task 7 aims to develop an understanding of the effects of open boreholes on the groundwater system and the use of data from such boreholes in site characterisation and performance assessment.

The strategy of Task 7 is to proceed from the largest scale (site scale with focus on fracture zones) to smaller scales (rock block). Task 7 may finish with exercises at the scale of the engineered barrier. At each scale, specific goals will be defined within the context of the overall Task 7 goal, and modelling tasks will be defined to support those goals.

Task 7A considers an approximately 10 km^2 region surrounding borehole KR24 at the Olkiluoto site in Finland. KR24 was used for a long-term pumping test. The test setup included pumping from two borehole sections. The lower part of KR24 was partially isolated by a by-pass packer (throttle valve) so that the deeper sections of the borehole experienced a smaller drawdown than the upper section during the pumping.

This document contains only the essential new information for more detailed modelling within Task 7A. The data distributed along with Task description version 2.2b, Task description for Task 7A (Part 1), and the Technical Memo remain valid.

A5.2 Scope

The aim and scope of Task 7A is to simulate the performance of the groundwater system and its response to long term pumping in the presence of open and sealed-off boreholes, by building and testing the sensitivity of numerical groundwater flow models of the Olkiluoto site. An important aspect of the data from the site is the use of the Posiva Flow Log to measure flow into/out of the boreholes during "undisturbed" and pumped conditions. A special focus on the major hydraulic conductors will yield a good starting point for the next Task 7B which focuses on the block scale system.

Task 7A is divided into five main parts, 7A1 through 7A5. This document provides the specification for Task 7A3 to Task 7A5.

The purpose of Task 7A3–5 is to provide a maximum benefit from the Task 7A effort. By developing calibrated models of the test, for example by incorporating potential flow barriers ("compartments") observed in the pumping-test results, it is expected that the results will provide explanations both for better understanding of the role open boreholes but more particular in modelling performance assessment issues. It is however, expected that individual modelling groups will not necessarily undertake all the subtasks with the same level of effort (according to their interests and facilities within the different numerical codes).

(7A3) Ideas for calculation of PA relevant parameters from open borehole information:

Here, each modelling group will consider how the PFL and open hole long-term pumping experiments database of Task 7 might be used to derive transport parameters.

- Beta (hydrodynamic control of retention – see Cheng and Cvetkovic 2003)
- Tau (water residence time – see Cheng and Cvetkovic 2003)
- "Q/W"(flow rate per fracture width)
- Flow wetted surface (FWS)
- Transport aperture
- Transport width
- Q (water flow m^3/s) through designated volumes (e.g. around a repository) or structures (e.g. flow through a fracture zone or a single fracture), or
- v (flow velocity m/s) within fractures (relevant to buffer erosion)

To the extent possible, the derivation of PA relevant measures from PFL measurements should be compared to the derivation using traditional packer testing.

The results will be defined through discussion points and example calculations based on the results of Task 7A1 and 7A2. It will also be useful if different modelling groups based on experiences and codes could identify the importance of and specify the need for additional information (e.g. micro-structural model) required for transport calculations.

The results will be presented in a report, common for Task 7A3, Task 7A4 and Task 7A5.

(7A4) Calibration for possible compartmentalisation or natural trends from open borehole information:

Here, each modelling group will, based on the models developed in Task 7A1 and conceptual improvements based on Task 7A3, consider how the PFL and long-term pumping test database of Task 7 might be used to quantify the degree of compartmentalisation and connectivity between different locations within the Task 7A rock volume. Also the surface hydrology may need to be included and the issues of conceptualisation of the interface between surface layers and the deep bedrock.

The results will be defined through calibrated models of the pump test and discussion points considering possible changes within the reference dataset and basic conceptual model, to better match the observed hydraulic interference results. The usefulness of PFL data will be tested by performing calibrations using head data alone and head data plus PFL data. The influence of open boreholes on the test and on the groundwater flow system will also be addressed by further simulations.

The results will be presented in a report, common for Task 7A3, Task 7A4 and Task 7A5.

(7A5) Quantification of transport resistance distributions along pathways:

Here, each modelling group will, based on the work of Task 7A1–7A4 (synthesis of Connectivity, Compartmentalisation, and Q/W distributions from PFL), quantify uncertainty on the advective travel time from a reference point in borehole KR24 through the fracture zones to a discharge point defined at the surface. Task 7A5 will be conducted under assumed PA relevant boundary conditions.

The results will be used to define and justify 95% bounds, median and mean values for the advective travel time.

The results will be presented in a report, common for Task 7A3, Task 7A4 and Task 7A5.

A5.3 Objectives

The objectives of the task are specified through a set of goals. Which are the same as distributed earlier in Task description for Task 7A (Part 1).

Goals

1) to understand the major features of the groundwater system,
2) to understand the consequences of the tests and measurement systems used, e.g. the open boreholes,
3) to understand how to model open boreholes within site characterisation studies and for the provision of parameters for PA,
4) to understand how PFL measurements could reduce uncertainty in models as compared to models calibrated with only head measurements,
5) to increase understanding of compartmentalisation and connectivity at the Olkiluoto site and more generally in fractured crystalline rock, and
6) to evaluate how uncertainty in PA can be reduced based on the analysis of the Olkiluoto dataset.

A5.4 Time schedule

The time schedule for Task 7 is preliminary and contained within the over-all time schedules of Task 7 and the Task Force on Modelling of Groundwater Flow and Transport of Solutes. The Time schedule here presented is the same as in the Technical Memo after Task Force meeting #22.

Task Force meeting #23	All groups to submit preliminary results of Task 7a3, Task 7a4 and Task 7a5 for performance measures
April 2008	All groups to submit reports of Task 7a3, Task 7a4, and Task 7a5
Task Force meeting #24	Reporting of full results for Task 7a
Task Force meeting #25	Completed review of Task 7a

A5.5 The KR24 Boundary condition

The KR24 Boundary condition is the same as specified in Task description for Task 7A (Part 1).

However, the earlier document specified three options. The first option is optimal. However that specification is complicated due to the turbulent nature of the flow in the pipe. It is not considered worthwhile to create numerical means for solving this issue hence herein only the second option is recommended.

Option 2. A constant rate outflow of 12.5 l/min from the upper section and constant rate outflow of 5.5 l/min from the lower section of KR24.

The measured total flow and the estimated pipe-flow inferred contributions from the upper and lower are shown in Figure A4-2. The modellers should keep in mind that the distribution of flow can be different than shown in Figure A1-1-2 and the effect of this uncertainty may be an additional sensitivity study.

The pumping setup used for the test is shown in Figure A4-1.

A5.6 The top boundary condition and the surface layer

The annual precipitation at Olkiluoto island is approximately 550 mm of which 60–70% evaporates by evapotranspiration. The potential recharge at the site is approximately 100–150 mm/a.

Data relevant to treatment of upper boundary:

Data	File
Ground surface topography	Topography.txt
Equipotentials for the groundwater table	GW-table-long-term-mean.txt
Groundwater table before the pumping and after recovery periods (two weeks after the stop of pumping) at shallow observation points	observations of gw.table.xls
Digital model of wetlands, streams at Olkilouto	wet.dwg
Coordinates of observation points	borehole-xyz-data.zip

The modelling teams are free to specify recharge and hydraulic properties at the surface as required by their model.

However, the treatment of the surface layer and its interaction with the deep bedrock is for Task 7A4 subject to adjustment in order to create a model set-up that better fit the site specific information.

As discussed during Task Force meeting #22 the surface hydrology may need to be included in some form.

Additional data on the natural trends of the groundwater table at Olkiluoto is distributed in addition to this document.

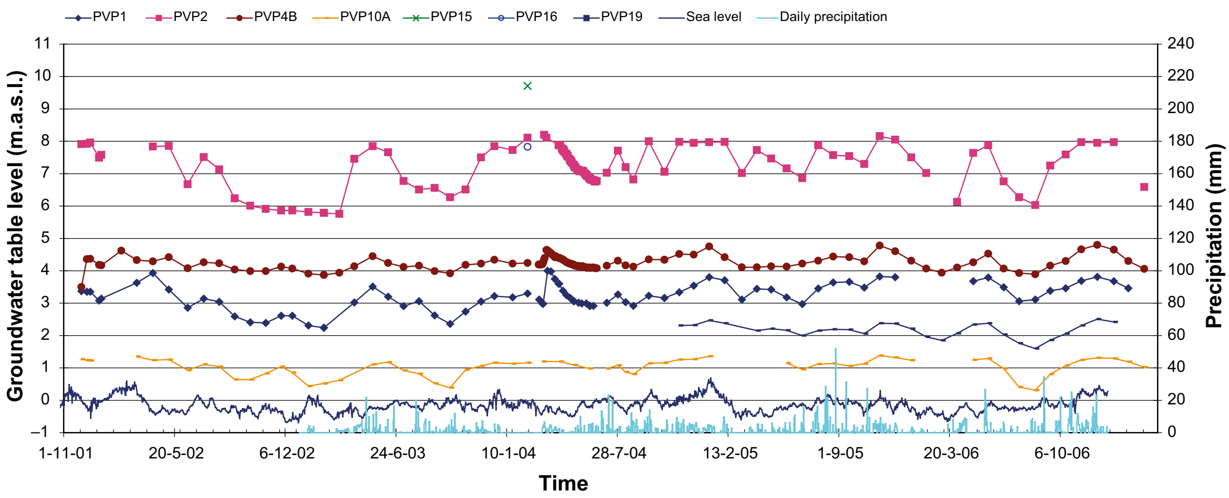


Figure A5-1. Examples of groundwater table data for the soil cover, sea level, and precipitation for Olkiluoto.

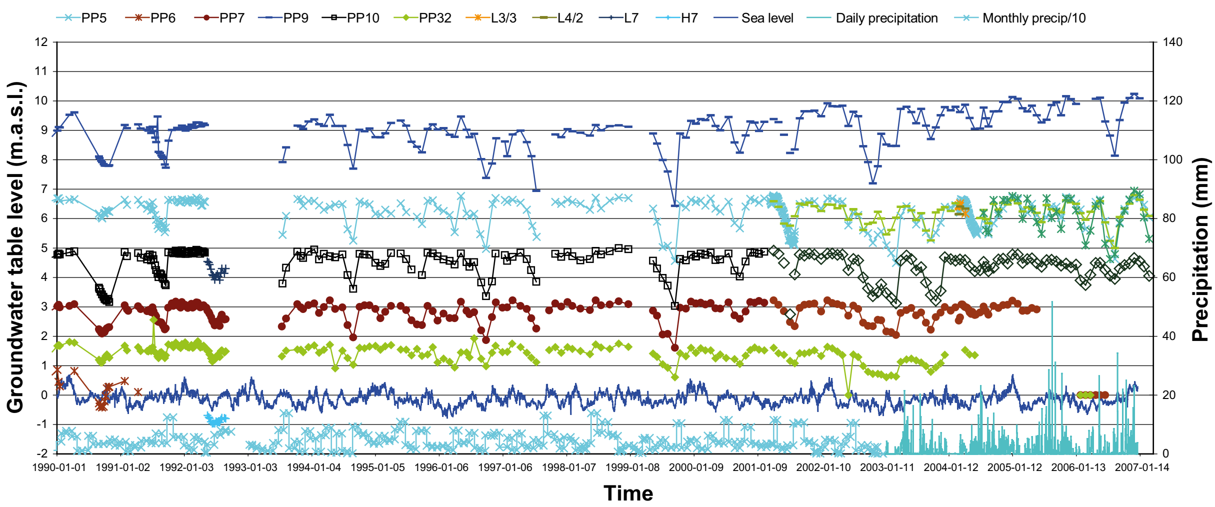


Figure A5-2. Examples of groundwater table data for the surficial bedrock, sea level, and precipitation for Olkiluoto

A5.7 Simulations

Inverse modelling is anticipated for TS10. All other simulations are forward models.

Inverse modelling or calibration modelling should address at least one "large" calibration issue (e.g. fracture zone size, in-fracture heterogeneity, surface connectivity, fracture zone crossings). Modelling groups are free to choose calibration issues. The choice made should be listed and explained during reporting.

Important for the Tasks overall issue is that calibration not only addresses heads but also PFL (flow) information. It is further anticipated that in order to address compartmentalisation and connectivity issues the calibration targets should not only be KR24 but also cross-hole information.

Table A5-1. Simulations to be carried out for Task 7a4 and 7a5.

Name	Task	Description	Boreholes	Purpose
TS10a	7A4	Pumping in KR24 – calibration to head measurement only	Boreholes are open and free to cross-flow.	Calibration of models
TS10b	7A4	Pumping in KR24 –calibration to PFL and head measurements	Boreholes are open and free to cross-flow.	Calibration of models
SS11	7A4	No pumping	Boreholes are open and free to cross-flow.	Influence of open boreholes on groundwater flow system
TS12	7A4	Pumping in KR24	Only KR24	Influence of open boreholes on pump test response
SS13	7A4*	"Natural conditions"	No boreholes	Influence of open boreholes on groundwater flow system – comparison with SS11
PA10	7A5*	"PA conditions"	No boreholes	PA calculations

* The boundary conditions specified is defined below.

In the table above the notations "natural conditions" and "PA conditions" are used. The intensions of these notations are to model a groundwater system without disturbances of any kind. Neither borehole nor pumping is apparent within the system. "Natural conditions" is how we believe the system worked before we interfered with boreholes etc. The "PA conditions" is the system that we hope will re-appear in the future; hopefully this system will be similar to the "natural conditions".

Suggested sensitivity studies

In order to strengthen the results from the simulations sensitivity studies are requested from each group but have not been explicitly specified. The topics to be addressed by sensitivity studies are:

d) implementation of heterogeneity in zones and at zone intersections (compartments),

e) implementation of open boreholes,

f) interpretations of Posiva flow log results for flow and transport parameters.

It is envisaged that the performance measures defined below should also be used to investigate and evaluate the results of sensitivity studies.

Where formal inverse modelling methods have been applied sensitivity/uncertainty outputs (e.g. covariances) should be presented and discussed.

A5.8 Performance measures, Presentation format and points for discussion

A5.8.1 Discussion points for Task 7A3

The performance of Task 7A3 will in part be based on code comparisons as there are no measurements direct measurements of transport properties from the KR24 test. Strictly defined performance measures (as given for other subtasks) have not been given due to the exploratory nature of the subtask. However to allow comparison between the teams, it is essential that, during reporting, all modelling teams address issues concerning at least the points specified below.

For Task 7A3 essential points for discussion are:

- What characteristics in PFL data are important.
- What can PFL data tell about fracture characteristics t.
- What can PFL data tell about heterogeneity within and between fractures.
- What parameters do we need for PA transport calculations in fractured rock.
- What additional benefits are there in acquiring PFL data for PA.
- How were the PA measures estimated?
- How was transport aperture and transport width assessed?

However, it is also expected that each modelling team will calculate relevant PA measures:

- Beta (hydrodynamic control of retention – see Cheng et al. 2003).
- Tau (water residence time – see Cheng and Cvetkovic 2003).
- "Q/W"(flow rate per fracture width).
- Flow wetted surface (FWS).

The calculations should be done for two main situations:

- Monitoring sections to KR24 for flow and pressure conditions relevant for the pumping-test.
- Monitoring sections to release locations (surface/sea) under relevant PA conditions.

Monitoring sections are those of Table A1-1-3 that represent packed-off sections.

Finally all modelling teams should present simulation results on:

- Q (water flow m^3/s) through structure HZ19A.

The basis for all above is to extract the Q_c (cross fracture flow) and e_t (transport aperture) with a method free to establish. Discussion on the workshop in Gothenburg (June 2007) is a good basis for ideas on a method.

A5.8.2 Performance measures for 7A4 and 7A5

The performance measures are the same as for Task 7A1 and Task 7A2. Performance measures for head and flow should be provided as time histories where possible, but for comparison purposes the measures will be evaluated at two specific times as listed below.

At the time for submitting preliminary results for Task 7A4 and Task 7A5 an Excel file will be distributed and the modellers are asked to fill in relevant tables according to the performance measures asked for. Each of these Excel spreadsheets should be filled out for each of the simulations listed in Table A5-1 above.

Table A5-2. Task7A4-KR24 Performance measures.

Name	Description	Units	Time
H_{upper}	Head in upper section of KR24	m.a.s.l.	Time history
H_{lower}	Head in lower section of KR24	m.a.s.l.	Time history
H_{upper}–H_{lower}	Differential head between upper and lower sections	m.a.s.l.	Time history
Q_{upper}	Inflow from rock to upper borehole section	l/min	
Q_{lower}	Inflow from rock to lower borehole section	l/min	
Q_{dist} (md)	Distribution of inflow along borehole (KR24, 0–551m)	l/min	Snapshot (see Table A4-7)

Table A5-3:Task7A4-Monitoring interval performance measures.

Name	Description	Units	Time
$H_{monitor}$	Freshwater head in monitoring sections*	m.a.s.l.	Time history
$S_{monitor}$	Drawdown in monitoring sections*	m.a.s.l.	Time history
Q_{dist}(md)	Distribution of inflow along monitoring boreholes** (negative implies flow from borehole to rock)	l/min	Snapshot (see Table A4-7)

* See Table A5-4 for monitoring sections.
** See Table A5-5 for monitoring boreholes.

Table A5-4. Monitoring sections for head and drawdown.

Borehole	Section/Zone	Comment
KR04	40–901 m	
KR08	20–600 m	
KR09	65–75 m, HZ19B	
KR09	140–150 m, HZ19A	
KR09	565–575 m, HZ20B_ALT	
KR12	40–50 m, HZ19C	
KR14	10–40 m, HZ19A	
KR14	40–60 m, HZ19C	
KR14	70–90 m, HZ002	
KR22	90–120 m, HZ19A & HZ19B	
KR22	140–150 m, HZ19C	
KR22	385–295 m, HZ20A	
KR23	150–155 m, HZ19A	
KR25	90–100 m, HZ19A & HZ19B	
KR25	120–130 m, HZ19C	
KR25	345–355 m, HZ20A	
KR25	405–410 m, HZ20B_ALT	

Table A5-5. Monitoring boreholes for flow distributions.

Zone	Comment
KR06	
KR14	
KR22	
KR25	

Table A5-6. Times for "snapshots" and evaluation of performance measures.

Time	Elapsed (hrs)	Comment
26/3/200414:00	28.1	Close to start of automatic sampling of head data
2/6/200414:40	1,708.8	Final part of drawdown immediately prior to shut-in (best for any comparison with steady state).

For Task 7A5, each modelling group is expected to quantify uncertainty on the advective travel times and recharge/discharge location from a set of specified reference points (same as for Task 7A2) in borehole KR24 through the fracture zones to a discharge point defined at the surface, under assumed PA relevant boundary conditions. Each modeller will be asked to define and justify 95% bounds, median and mean values for this travel time, using the hydrostructural model from Task 7A4.

A5.8.3 Traceability and use of data

Each modelling team should present a table with the properties (geometrical and hydrogeological, with uncertainty range for the modelled fracture zones and bedrock) and with flow and head information used. In this table it should be specified which data was used for model set-up, calibration, and verification.

Appendix 6

Task description for Task 7B

Specifications for Task 7B1, Task 7B2, amd Task 7B3

Reduction of Performance Assessment uncertainty through block scale modelling of interference tests in KR14-18 at Olkiluoto,Finland 2007-09-21, revised 2008-10-06

Technical Committee of Task 7: Henry Ahokas, Bill Dershowitz, David Holton, Antti Poteri and Patrik Vidstrand (ed.)

A6.1 Introduction

Task 7 aims to provide a bridge between the information derived from site characterisation (SC) and performance assessment (PA). Task 7 has a particular focus: how information from the new flow-logging tools (so-called POSIVA Flow Log) can be used to maximum benefit, to reduce key uncertainties for the PA.

Open boreholes are a feature at many sites (either as part of how a testing program is performed, or the potential future consequences of unsealed boreholes). Task 7 aims to develop an understanding of the effects of open boreholes on the groundwater system and the use of data from such boreholes to inform the site characterisation and performance assessment.

The overall strategy of Task 7 is to progress from the large scale (Olkiluoto site-scale with focus on fracture zones) to a small sub-volume or rock block-scale, i.e. between the significant flowing features. Task 7 may finish focusing on an even smaller scale, that of the engineered barrier. At each scale, specific goals will be defined within the context of the overall Task 7 goal, and modelling tasks will be defined to support those goals.

Task 7A considered a region of approximately 10 km^2 in the vicinity of borehole KR24 at the Olkiluoto site in Finland. KR24 was used for a long-term pumping test.

Task 7B considers a smaller volume of an approximately 500 by 500 m^2 region surrounding a group of boreholes KR14-18 at the Olkiluoto site in Finland. The fundamental objectives of the task are:

- to quantify the reduction of uncertainty in the properties of the fracture network,
- and to assess the Posiva Flow-logging (PFL) data when analysing the rock (rock mass).

Task 7B will be based on a small sub-volume of the Olkiluoto site-scale Task 7A (see Figure A1-1-1). Posiva Flow Log (PFL) and double-packer (HTU-tool) data of the groundwater system will be used in order to create a statistical description of conductive fractures along the boreholes.

The intention is to develop a block scale model where major fracture zones may be used as the boundary conditions for the modelling domain.

The PFL and double packer (HTU-tool) data will be used to analyse the background fracture networks. Major fracture zones and results from Task 7A may be used as boundary conditions. It is anticipated that this approach will highlight the uncertainties concerning the importance of background fractures in terms of identification of the flow distribution within the bedrock and help identify other issues such as compartmentalisation.

This document contains the essential information for more detailed modelling within Task 7B, short descriptions of data will accompany the data delivery. The data and descriptions distributed along with Task 7A remain valid with the exception of the deterministic hydro-structural model. The updated model of 2008 is used instead of the 2006 model used in Task 7A. Differences between the two models are minor in the large-scale (as can be seen in Figure A1-1-1 where the zones are illustrated) but significant in a detailed scale.

Scope

The aim and scope of Task 7B is to simulate the performance of the groundwater system and its response to different interference pumping in the presence of open and sealed-off boreholes, by building and testing the sensitivity of numerical groundwater flow models of the KR14-18 region of the Olkiluoto site. An important aspect of the data from the site is the use of the Posiva Flow Log to measure flow into/out of the boreholes during "undisturbed" and pumped conditions and the possibility to compare this kind of "flow response" data to "pressure response" data (see e.g. Figure A1-1-2) in the same boreholes. Task 7B is divided into three main parts, 7B1 through 7B3.

A6.2 Task 7B1

Task 7B1 is a "conceptual" task; the task is intended to address conceptual issues concerning:

- **Model boundary conditions**: Derive and justify boundary conditions for a simulation over a block scale volume plausibly bounded by structure HZ19A or the surface and structure HZ20A or just cut in the background rock. Describe (and justify) the borehole abstraction boundary condition.
- **Background fracture population**: Develop and describe a methodology for representing the background fractures in the model region (EPM,DFN,CN, or Hybrid model concepts) including structure HZ19C from Task 7A (that is structure HZ19C is part of the background fractures in this sub-task), based on PFL single borehole information, fracture logging, and generic correlations. Major feature HZ19C has generally been treated as homogenous and extensive in Task 7A. Within task 7B it may need to be treated as patchy "minor feature" or be limited in size/connectivity to explain KR14 pump test's "unison" approx. 3.5 m drawdowns (see Figure A6-3).
- **Sequential model development**: Define approaches for the estimation of fracture (or cell) geometries and properties (firstly as forward followed by calibration) from a modelling sequence, e.g.: 1) Models conditioned on single borehole PFL tests, 2) Models conditioned on cross-hole packer tests, and 3) Models conditioned on cross-hole PFL flow logging. Outline the expected methodology to verify the suggested approaches.
- **Compartmentalisation analysis**: Evaluate possible conceptual models and boundary conditions to explain observed phenomena, such as e.g. "unison" hydraulic responses to KR14 pumping (especially in the HZ19C structure), "step function" transient hydraulic responses, and differential flow signatures
- **Flow distribution**: Evaluate possible generic approaches for utilising the flow distributions measured in single hole and multiple borehole tests within models used for simulations of "PA time-scale" and boundary conditions.

Within the conceptual task of 7B1 the modelling groups are specifically asked to establish a methodology to model the transverse measures (cross-flow investigation) that is presently under way at the Olkiluoto site. In a broad sense the test is conducted in a system where all boreholes are open and free to cross-flow. In one of the open boreholes a disturbance (pumping) is forcing the system to respond. Within the un-pumped boreholes, the cross-flow tool successively investigated each of the flowing structures temporarily isolating each feature with small packers.

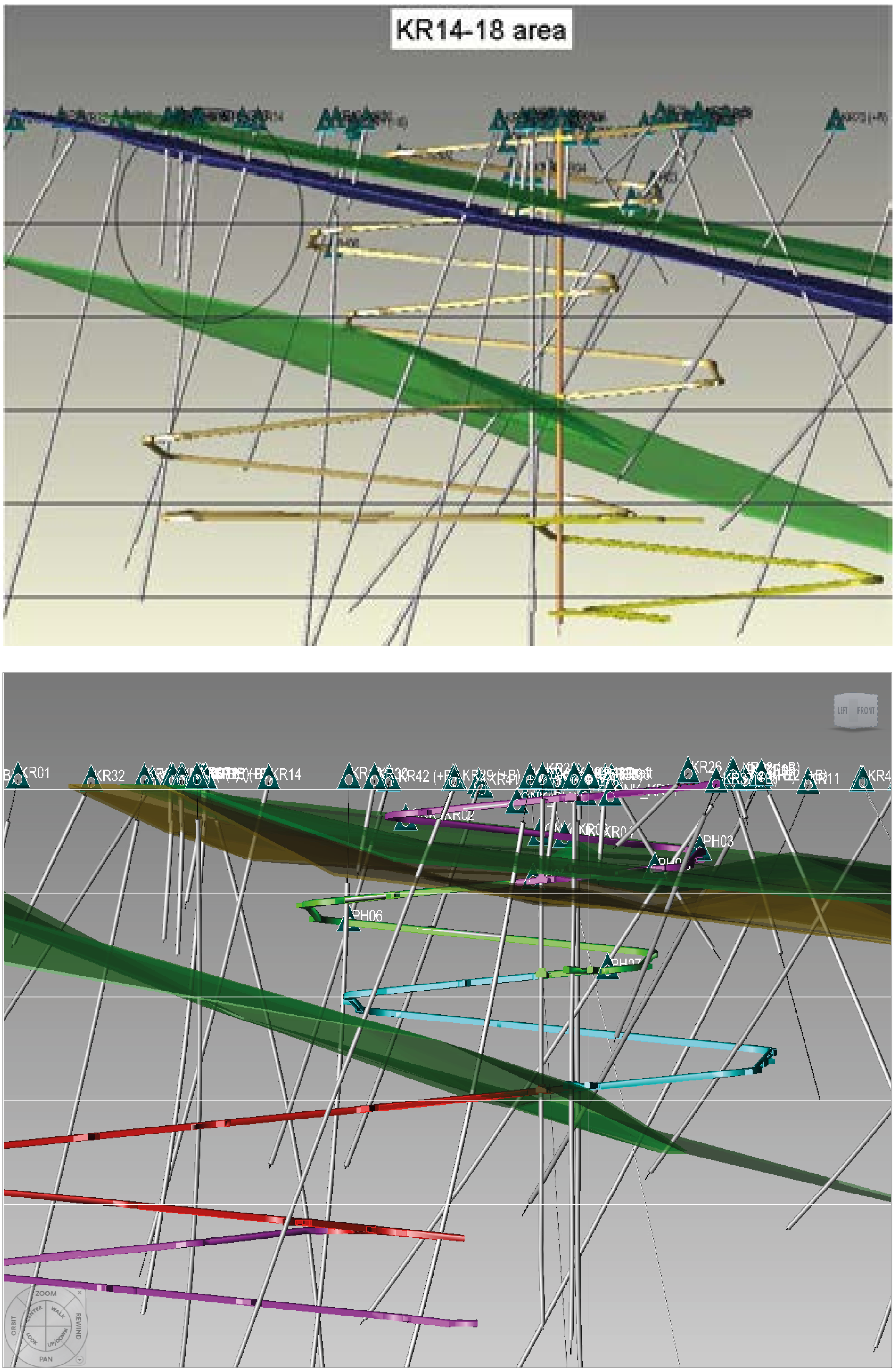


Figure A6-1. *Illustration of the three major fracture zones (model 2006 upper figure, model 2008 lower figure) of significance for the model domain of the KR14-18 interference pumping test. Structure HZ19A (green zone at top) may be used as top boundary; alternatively the ground surface could be used in a similar manner as in Task 7A. In the lower figure brown zone is HZ19C and the lower green is HZ20A. Depth lines are shown for every 100 m.*

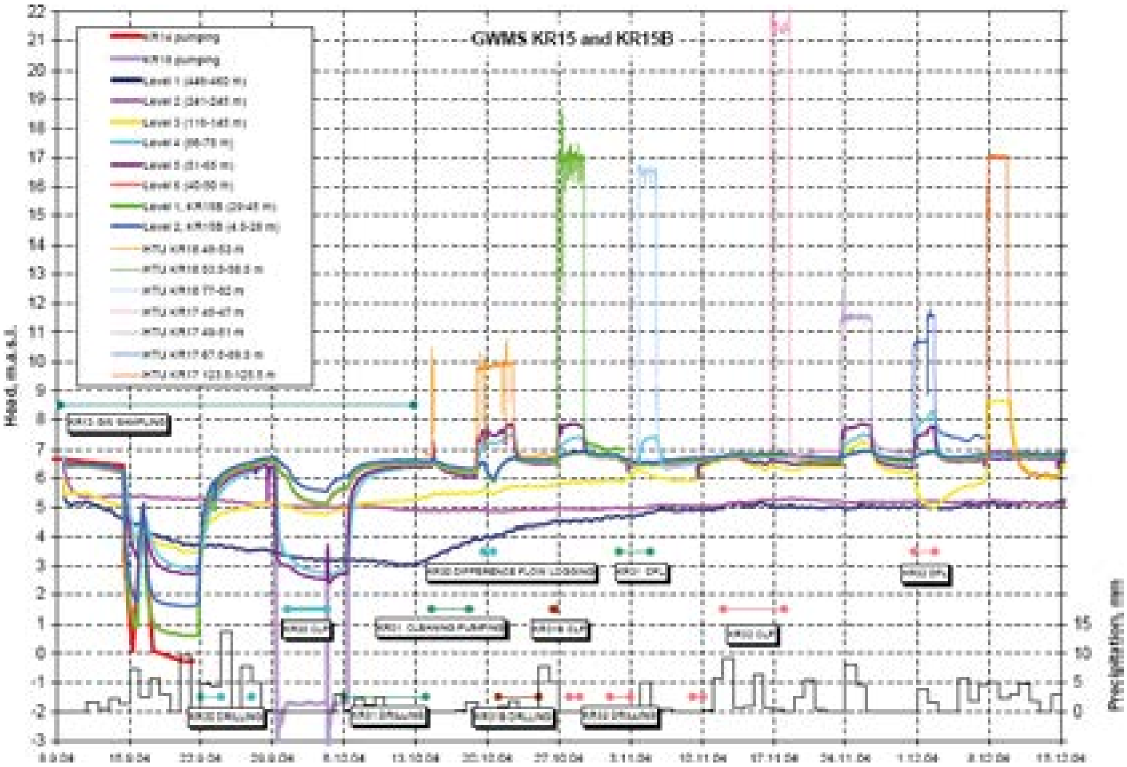


Figure A6-2. Illustration of results of the KR14-18 pressure interference tests.

A6.3 Task 7B2

Task 7B2 will consist of a series of modelling exercises, based on the concepts derived through the work of Task 7B1. The modelling contains elements of forward modelling based on the original conceptual model, calibration modelling with focus on conceptual (hydro-structural) development, "blind" predictions of flow and pressure responses due to pumping in KR15, and prediction of transverse flow distribution in KR15 due to extraction in KR14.

- **Forward modelling:** Utilize the Task 7B hydro-structural model and background fracture representation (EPM, DFN, CN, or Hybrid model concepts) developed within 7B1 to simulate (dH and Q) due to the KR14, KR18, and KR15 pumping tests in a "forward" sense (i.e. directly utilizing derived parameters and geometries). It is important to address only the original conceptual model and parameterisation during the forward modelling and not to "jiggle" the parameters in order to get a better match. The forward modelling of KR15 is "predictive" and is intended as a test of the proposed simulation scheme.
- **Model calibration/inversion** to decrease the difference between measured and simulated heads and flows. Preference is to adjustments and improvements to the conceptual model and background fracture representations that can be justified from uncertainties in the hydro-structural model rather than arbitrary skin and parameter tweaks. Whatever the calibration method justification for the approach should be provided.
- **Prediction of cross-fracture flow:** Posiva is currently measuring cross-fracture flows in response to KR14-18 pumping, in open holes, using the new "Transverse Flow Meter". The modelling groups will utilise the models developed from the interference pumping tests of dH and Q to make these predictions. Each prediction should be specified as cross-flow (ml/hr) with ± 95% bounds. Modellers should specify what they mean by 95% bounds.
- **Extrapolation to PA boundary conditions and particle tracking:** Carry out simulations and/or analyses to predict flow (β) distributions along transport pathways from a specified point in the heart of the model region. "PA boundary conditions" to be based on the large scale non-pumped situation. Provide justification and limitations of the assumptions made.

Each modelling team should present a number of performance measures. The modelling teams should within the reporting also address differences between the modelled results and the measured results. The performance measures that are asked for are flows and heads at a series of locations in different boreholes.

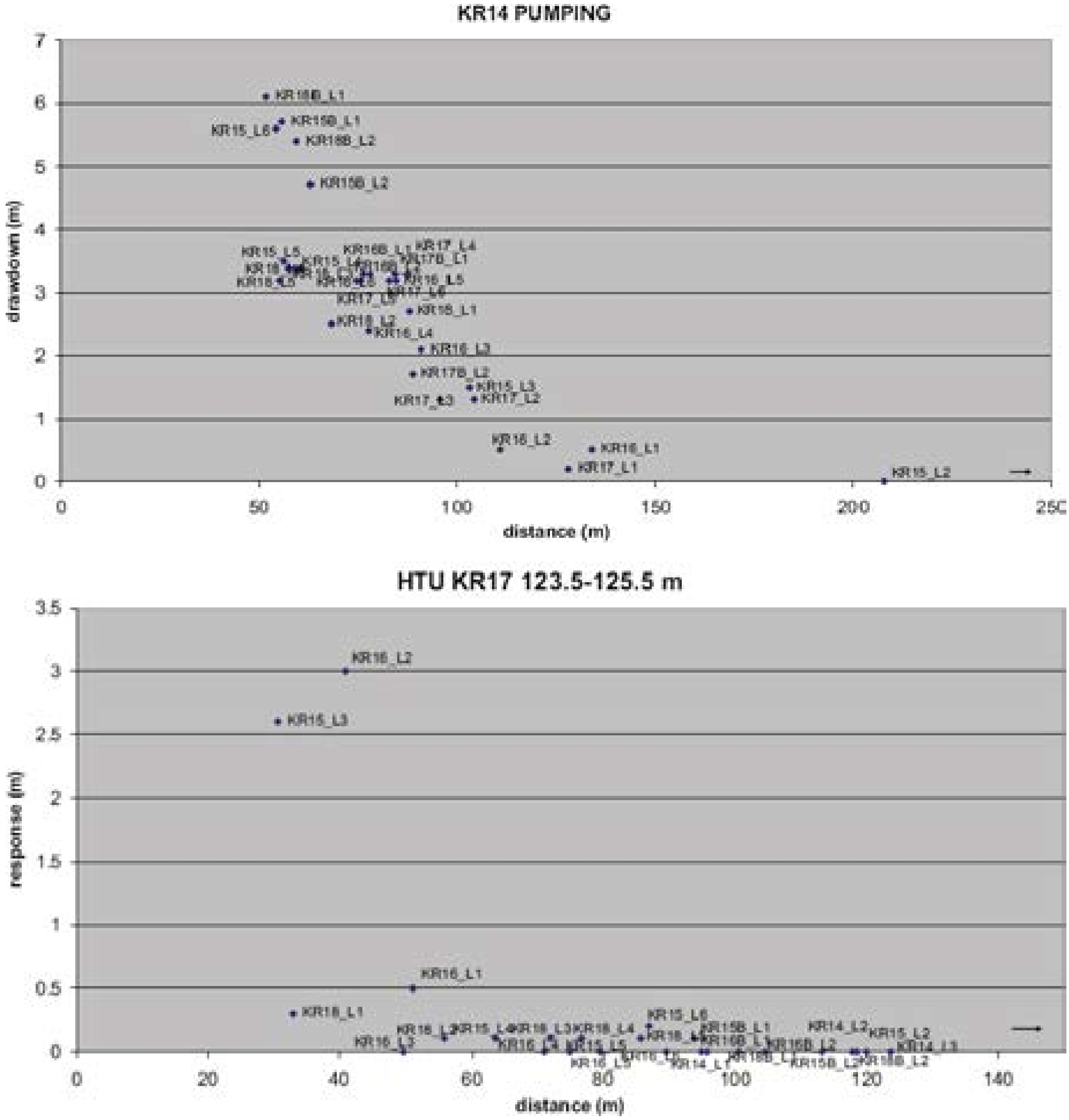


Figure A6-3. Illustration of results of the KR14-18 interference tests.

A6.4 Task 7B3

Task 7B3 will consist of a Bayesian update to 7B1 and 7B2 based on lessons learned and collaboration within the Task Force, possibly performed during work-shops. Essential questions that need to be addressed are:

- What are the likely consequences of using the boundary conditions – e.g. are they conservative in terms of Beta, flow distribution etc.?
- What did we learn about the modelling of background fractures with our chosen approach?
- Does this dataset provide evidence for compartmentalisation, and if so what, if anything, is the implication for PA?
- What is missing from site characterisation that is necessary to properly define PA conditions (for example, how velocities on pathways vary under natural gradients, how different porosities act along these pathways, channel geometries, fracture intersections, mixing/branching, dilution, matrix-channel interaction surface areas)?
- How has (or whether) uncertainty been reduced?

A6.5 Uncertainty

As Task 7 aims at reducing uncertainty in performance assessment of a potential site and herein the reduction should be based on information gathered in the Finnish site investigation programme at Olkilouto. Within the Finnish programme, so far, no tracer experiments have been conducted. Instead, a major task has been to describe the flow distribution along open boreholes in natural (un-pumped) and disturbed (pumped) systems. Lately the task is also complemented with information concerning transverse flow in fractures that has temporarily been isolated in the otherwise open borehole system.

In the present context, the terms performance assessment and safety assessment are given the same meaning, even though different organisations may use the terms slightly differently.

A performance assessment typically includes an uncertainty analysis containing two key elements. These are:

1. The possibility of technical defects (e.g. holes in canisters, open pathways through the clay barrier, etc).
2. The possibility of unknown fast flow paths through the geosphere.

Of these two issues, the first one is not considered within Task 7.

A6.5.1 Definition of reduction of uncertainty within Task 7

Task 7 aims at reducing the uncertainty associated with performance assessment relevant parameters using hydrogeological modelling and interpretation. The data set for Task 7 includes detailed flow distributions in/out of boreholes and the flow connections between different boreholes along with the newly developed transverse (cross-flow) measurements over isolated borehole sections.

In Task 7A large-scale structures were typically represented with uniform transmissivity and background fractures were ignored. In Task 7B the background fractures are the primary issue to be studied, including conceptual models for connectivity and in-fracture heterogeneity, as well as large-scale connectivity.

An a priori assessment of transmissivity and connectivity is likely to include a large range of possible solutions. The aim of the exercise is therefore to constrain the variability in transmissivity and connectivity by use of the flow data and thus to study the propagation of this variability into performance measures identified by the Task Force and considered as relevant parameters for performance assessment,. These exercises would, we believe, contribute to a "reduction of uncertainty" in performance assessment results.

A6.6 Objectives

Task 7B aims at understanding the block scale in regards of flow and responses. Task 7B will consider a sub-volume of Task 7A in part bounded by major fracture zones and the ground surface boundary. The KR14-18 cross-hole interference test was organized in several stages. Firstly the boreholes were investigated with a difference flow method (the PFL) in open boreholes. There after hydraulic tests were conducted using multi-packer systems where borehole sections were isolated with inflatable packers.

The objective of task 7B is:

- to evaluate how uncertainty in PA can be reduced based on the analysis of the Olkiluoto dataset.

This objective is specified through a set of goals.

1) to understand how major features could be used as boundary conditions,
2) to understand the minor features of the groundwater system, (background rock),
3) to understand the consequences of the tests and measurement systems used, e.g. the open boreholes,
4) to understand how to model open boreholes within site characterisation studies and for the provision of parameters for PA,
5) to understand how PFL measurements could reduce uncertainty in models as compared to models calibrated with only head measurements, and
6) to increase understanding of compartmentalisation and connectivity at the block scale.

An additional out-come of Task 7A and Task 7B may be an established consensus on the term and usage of compartmentalisation.

A6.7 Time schedule

The time schedule for Task 7B is preliminary and contained within the overall time schedules of Task 7 and the Task Force on Modelling of Groundwater Flow and Transport of Solutes.

January 2009	Workshop on Task 7B. Preliminary results on Task 7B2 and reporting on Task 7B1 as a technical note.
Task force meeting #25	All groups to submit results of Task 7B2 for performance measures
Autumn 2009	Reporting of task 7B3 results
Task force meeting #26	Completed review of Task 7B

A6.8 The conceptual model

The conceptual model is the outcome of task 7B1 and may be different for all modelling groups.

Each modelling group may specify their model of geometry, structures, background fractures, in-fracture heterogeneity, etc.

Data relevant for construction of a conceptual model:

Data	File
Data of single-borehole PFL tests of KR14–KR18* and KR15B–KR18B* as fracture specific transmissivity values with fracture orientation and geological parameters.	OL-KR14-18 All Fractures.zip (include nine files: KR##_Fractures.xls)
Transmissive fractures found by PFL but corresponding fracture in core not identified	Fractures without geoparameters.xls
Data of single-borehole HTU (double packer) tests of KR14–KR18 and KR15B–KR18B	HTUdata KR14-18.xls
Geometry of the HZ-model 2008	HZ-08_faces_rev_20080312.txt, HZ-08_20080409.dwg, HZ-08_20080409local.dwf
Ground surface topography	Topography.txt (as in Task 7a)

* Deep boreholes are called either KR15A or KR15 etc. and shallow (45 m) B-holes KR15B etc.

A6.9 Boundary conditions

A6.9.1 The KR14-18 Boundary condition

Hydraulic cross-hole interference flow and pressure response and flow response tests in the scale of 10–100 m were carried out in boreholes KR14–KR18 (including shallow B-boreholes) at Olkiluoto during winter 2001–2002 and autumn 2004, correspondingly. These tests were conducted in order to produce detailed information on the effects within the bedrock in-between major fracture zones.

Data relevant to treatment of KR14-18 boundary conditions:

Data	File
PFL measurements of KR15–18, KR15B–KR18B, while pumping in KR14 (including data without pumping).	FDOL15A14AF1-final.xls etc.
PFL measurements of KR14,16–18, KR15B–KR18B, while pumping in KR18 (including data without pumping).	FDOL15A18AF1-final.xls etc
Packed-off measurement at KR15–18, KR15B–KR18B, while pumping in KR14 and KR18.	OLKR15 pressure observations.xls etc
Packed-off measurements of KR14–17, KR15B–KR18B, while overpressures by HTU in KR17 and KR18.	OLKR15 pressure observations.xls etc
Packer locations in KR14–KR18 and KR15B–KR18B.	Packer intervals of KR14-18.xls
Pumping rates and drawdowns during PFL measurements.	summary of head and pumping.xls

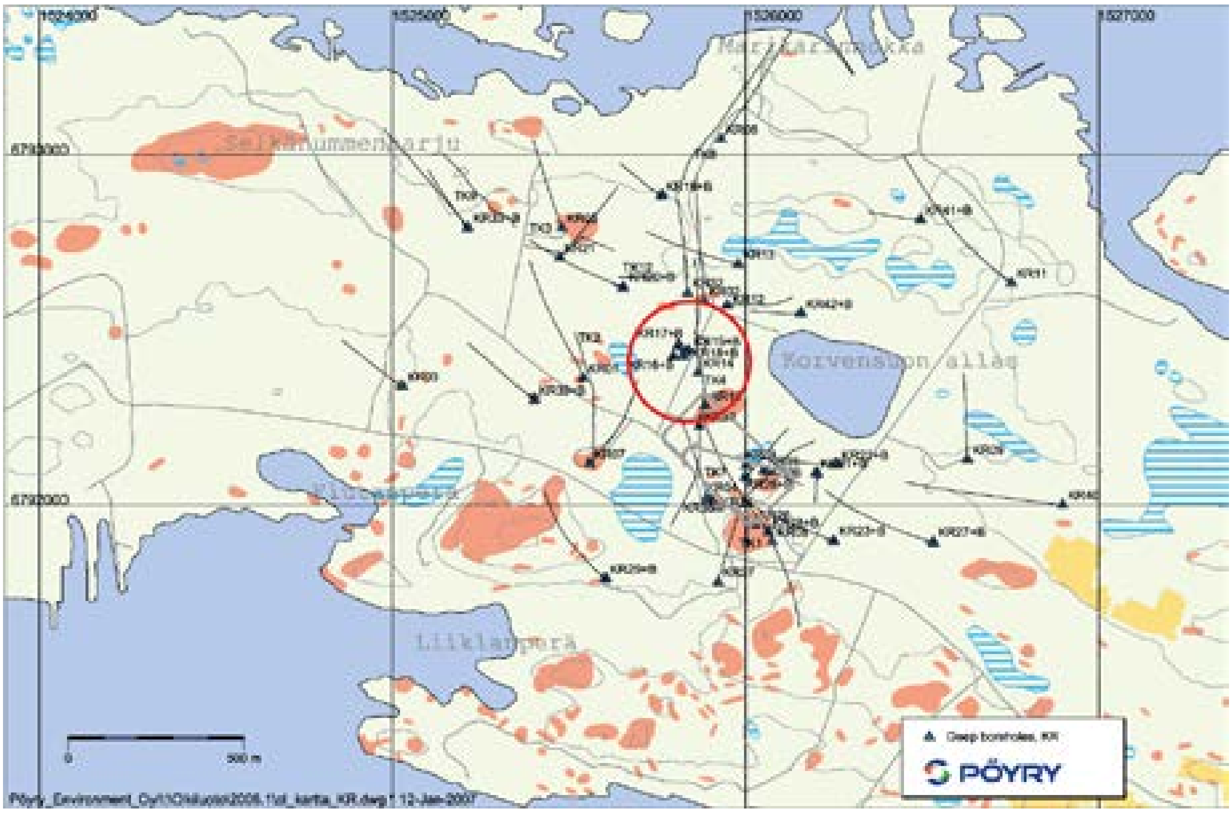


Figure A6-4. Illustration of the KR14-18 region at the Olkiluoto site.

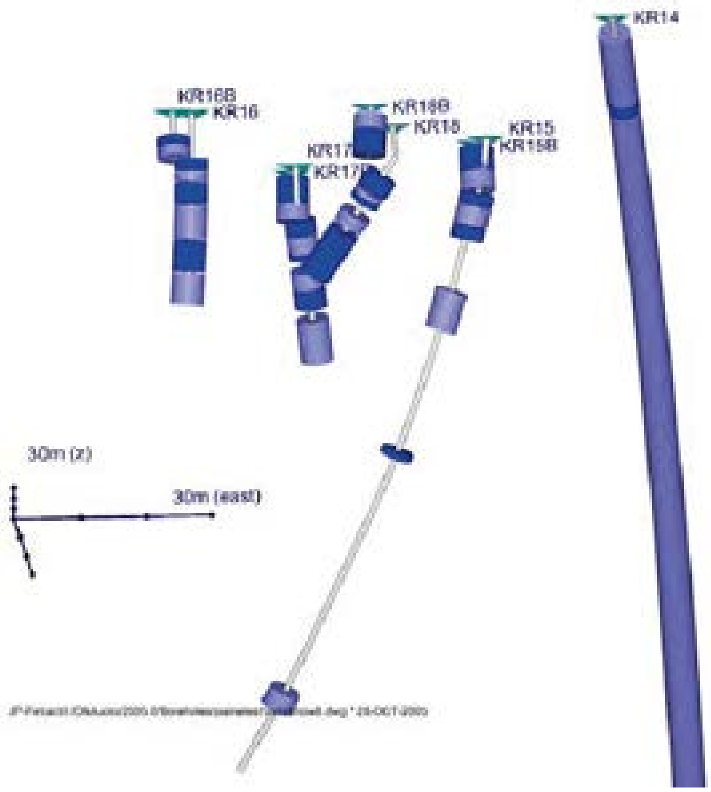


Figure A6-5. Monitored sections in the boreholes considered in the KR14–KR18 tests. Sections are distinguished with varying colour. The horizontal scale is six times the vertical scale.

A summary of actions of sink/source character during the flow response tests in 2002 and pressure response tests in 2004 is given below:

Flow response tests in 2002 (copy of Table 5-1 of WR 2003-30 and terms modified):

Started	Finished	Borehole	Activity
4.1.2002 *09:10*	18.1.2002 0*8:43*	KR15	Pumping water from the open borehole.
9.1.2002 *11:10*	14.1.2002 *11:15*	KR15	Single hole PFL
14.1.2002 *14:45*	14.1.2002 *18:30*	KR15B	Flow responese PFL
14.1.2002 *19:45*	15.1.2002 *5:30*	KR18	Flow responese PFL
15.1.2002 *10:15*	15.1.2002 *14:15*	KR18B	Flow responese PFL
15.1.2002 *15:15*	15.1.2002 *19:45*	KR17B	Flow responese PFL
15.1.2002 *20:45*	16.1.2002 *11:30*	KR17	Flow responese PFL
16.1.2002 *12:45*	17.1.2002 *13:00*	KR14	Flow responese PFL
17.1.2002 *14:30*	17.1.2002 *18:30*	KR16B	Flow responese PFL
17.1.2002 *18:45*	18.1.2002 *7:00*	KR16	Flow responese PFL
21.1.2002 *16:40*	1.2.2002 0*8:00*	KR16	Pumping water from the open borehole.
22.1.2002 *15:00*	24.1.2002 *21:10*	KR16	Single hole PFL
25.1.2002 *9:00*	25.1.2002 *12:00*	KR16B	Flow responese PFL
14.1.2002 *19:45*	15.1.2002 *5:30*	KR18B	Flow responese PFL
15.1.2002 *10:15*	15.1.2002 *14:15*	KR18	Flow responese PFL
15.1.2002 *15:15*	15.1.2002 *19:45*	KR15B	Flow responese PFL
15.1.2002 *20:45*	16.1.2002 *11:30*	KR15	Flow responese PFL
16.1.2002 *12:45*	17.1.2002 *13:00*	KR14	Flow responese PFL
17.1.2002 *14:30*	17.1.2002 *18:30*	KR17B	Flow responese PFL
17.1.2002 *18:45*	18.1.2002 *7:00*	KR17	Flow responese PFL
4.2.2002 *14:25*	19.2.2002 0*8:30*	KR17	Pumping water from the open borehole.
5.2.2002 *13:20*	7.2.2002 *10:20*	KR17	Single hole PFL
7.2.2002 12:45	7.2.2002 *16:15*	KR17B	Flow responese PFL
11.2.2002 *8:20*	11.2.2002 *11:30*	KR15B	Flow responese PFL
11.2.2002 *12:30*	11.2.2002 23*:40*	KR15	Flow responese PFL
12.2.2002 *10:00*	12.2.2002 *13:00*	KR16B	Flow responese PFL
12.2.2002 *13:20*	13.2.2002 8*:30*	KR16	Flow responese PFL
13.2.2002 *9:50*	15.2.2002 *10:20*	KR14	Flow responese PFL
18.2.2002 *10:40*	18.2.2002 13*:45*	KR18B	Flow responese PFL
18.2.2002 *14:40*	18.2.2002 21*:50*	KR18	Flow responese PFL
25.2.2002 *10:30*	7.3.2002 *11:50*	KR18	Pumping water from the open borehole.
26.2.2002 *13:10*	28.2.2002 09*:50*	KR18	Single hole PFL
28.2.2002 *10:45*	28.2.2002 14*:00*	KR18B	Flow responese PFL
28.2.2002 *15:00*	4.3.2002 15*:45*	KR15	Flow responese PFL
4.3.2002 *16:20*	4.3.2002 21*:20*	KR15B	Flow responese PFL
5.3.2002 *8:20*	5.3.2002 12*:20*	KR17B	Flow responese PFL
5.3.2002 *13:00*	5.3.2002 21*:15*	KR17	Flow responese PFL
5.3.2002 *22:45*	6.3.2002 16*:35*	KR14	Flow responese PFL
6.3.2002 *17:50*	7.3.2002 0*5:00*	KR16	Flow responese PFL
7.3.2002 *8:30*	7.3.2002 11*:45*	KR16B	Flow responese PFL
12.3.2002 *08:15*	21.3.2002 *11:15*	KR14	Pumping water from the open borehole.
18.3.2002 *11:15*	18.3.2002 *14:45*	KR16B	Flow responese PFL
18.3.2002 *15:00*	19.3.2002 *1:35*	KR16	Flow responese PFL
19.3.2002 *11:15*	19.3.2002 *14:10*	KR17B	Flow responese PFL
19.3.2002 *14:45*	20.3.2002 *0:10*	KR17	Flow responese PFL
20.3.2002 *10:10*	20.3.2002 *12:35*	KR18B	Flow responese PFL
20.3.2002 *12:50*	20.3.2002 *18:40*	KR18	Flow responese PFL
20.3.2002 *19:20*	21.3.2002 *7:45*	KR15	Flow responese PFL
21.3.2002 *08:30*	21.3.2002 *11:15*	KR15B	Flow responese PFL

Pressure response tests in 2004 (summary from Tables 1–5 of WR 2006-01):

Phase 1:

Pumping of open borehole KR14 between 14.9. – 21.9. 2004 (Q = c. 25 l/min). Monitoring in packed-off sections as stated below.

Phase 2:

Pumping of open borehole KR18 between 29.9. – 6.10. 2004 (Q = c. 5–7 l/min). Monitoring in packed-off sections as stated below.

Phase 3:

HTU overpressures (injection of water) in KR18 for depth sections of:

Section	Overpressure	Data
48–53 m	18.10.–22.10.2004	13.10.–26.10.2004
53.5–58.5 m	26.10.–30.10.2004	26.10.–2.11.2004
77–82 m	3.11.–5.11.2004	3.11.–9.11.2004

Monitoring in packed-off sections as stated below.

Phase 4:

HTU overpressures (injection of water) in KR18 for depth sections of:

Section	Overpressure	Data
45–47 m	16.11.–18.11.2004	16.11.–23.11.2004
49–51 m	23.11.–26.11.2004	23.11.–30.11.2004
67.5–69.5 m	30.11.–2.12.2004	30.11.–7.12.2004
123.5–125.5 m	7.12–9.12.2004	7.12.–14.12.2004

Monitoring in packed-off sections as stated in the table below (and in file Packer intervals of KR14-18-rev1.xls).

All pumping and overpressures of phase1 to 4 are shown in data file: Pumpings and overpressures (pressure tests in 2004).zip

Packed-off intervals and observations during pressure response tests in 2004 (note: some observations have been continued after tests as a part of long-term monitoring).

Drillhole	Note	Code of obs. Interval (GWMS)	Sec. up	Sec. down	Observations
KR14	casing 0–9.52 m	L3	9.52	46	13.10–14.12. 2004
KR14		L2	47.5	52.5	
KR14		L1	53.5	514.1	
KR14		L3	9.52	46.5	28.9.–11.10. 2004
		L2	47.5	52.5	
		L1	53.5	514.1	
KR15	casing 0–39.98 m	L6	40	50	8.9.–31.12. 2004
KR15		L5	51	65	
KR15		L4	66	75	
KR15		L3	116	145	
KR15		L2	241	245	
KR15		L1	446	460	
KR15B	casing 0–4.48 m	L2	4.5	28.7	8.9.–31.12. 2004
KR15B		L1	29.7	45	
KR16	casing 0–40.23 m	L6	40	52	10.9.–14.12. 2004
KR16		L5	53	62	
KR16		L4	63	82	
KR16		L3	83	112	
KR16		L2	113	142	
KR16		L1	143	170.2	
KR16B		L3	4.5	25	10.9.–14.12. 2004
KR16B	casing 0–4.48 m	L2	26	35	
KR16B		L1	36	45	
KR17	casing 0–39.92 m	L6	40	51	9.9.–9.11. 2004
KR17		L5	52	66	
KR17		L4	67	71	
KR17		L3	82	96	
KR17		L2	97	111	
KR17		L1	122	157.13	
KR17B	casing 0–4.1 m	L2	4.1	30.3	9.9.–22.11. 2004
KR17B		L1	31.3	45	
KR18	casing 0–39.81 m	L5	40	53	10.9.–27.9. 2004 + 11.11.–31.12. 2004
KR18		L4	54	58	
KR18		L3	59	63	
KR18		L2	74	83	
KR18		L1	89	125.49	
KR18B	casing 0–6.51 m	L2	6.51	22.7	10.9.–31.12. 2004
KR18B		L1	23.7	45	

A6.10 The top boundary condition and the surface layer

The top boundary condition specification may be defined through the use of structure HZ19A or the ground surface. Justifications for the choice of the top boundary conditions shall be presented by each modelling group.

The annual precipitation at Olkiluoto island is approximately 550 mm of which 60–70% evaporates by evapotranspiration. The potential recharge at the site is approximately 100–150 mm/a.

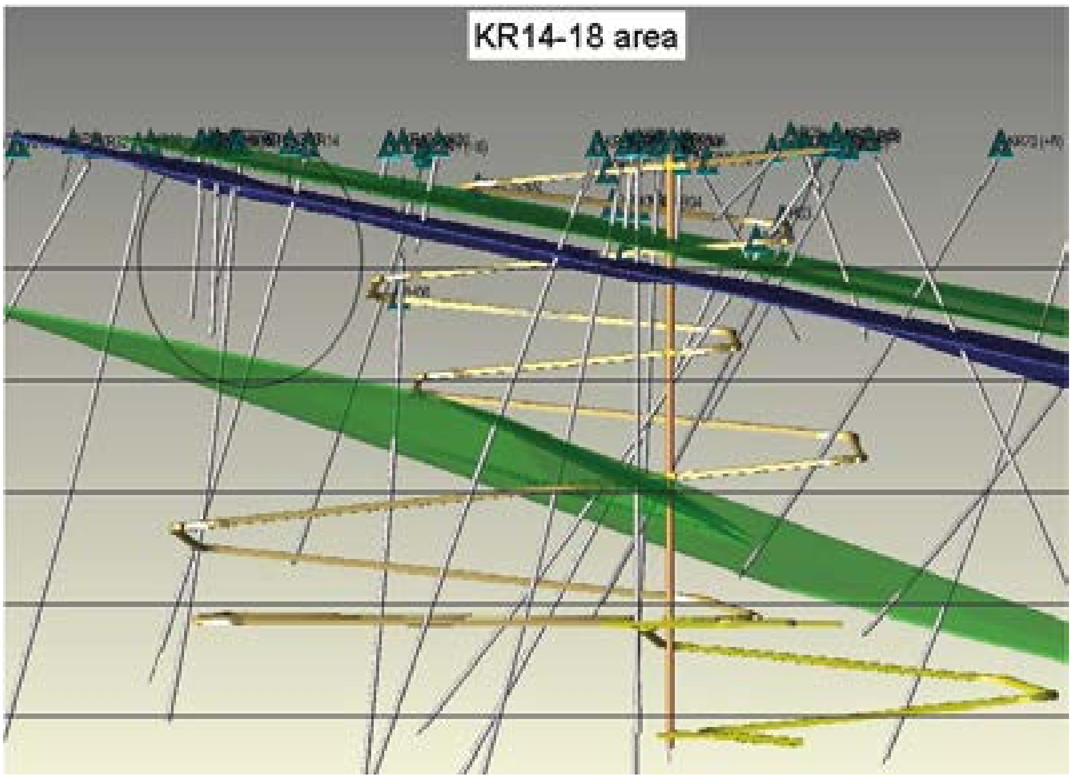


Figure A6-6. Illustration of the three major fracture zones of significance for the model domain of the KR14-18 interference pumping test. Structure HZ19A (zone at top) may be used as the top boundary; alternatively the ground surface may be used in a similar manner as in Task 7A. (Same as upper figure of Figure A6-1.)

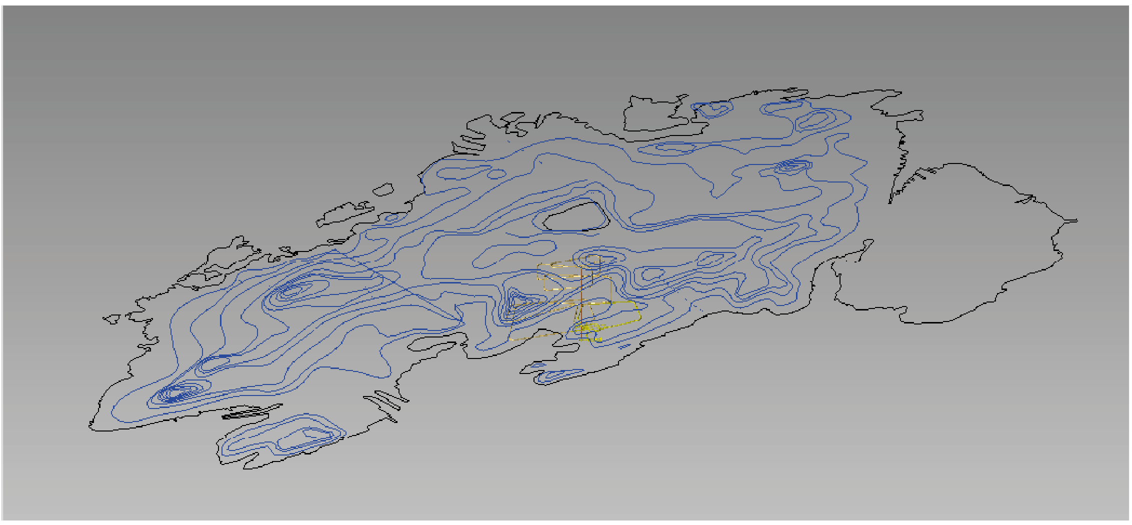


Figure A6-7. Equipotentials of gw-table (1 m interval, long-term mean).

Data relevant to treatment of top boundary conditions if the ground surface is used are the same as during task 7A:

Data	File
Ground surface topography	*Topography.txt (as in Task 7a)*
Equipotentials for the groundwater table	*GW-table-long-term-mean.txt (as in Task 7a)*
Groundwater table in shallow bedrock and oveburden (long-term observation data around 2002 and 2004 tests)	*observations of gw.table (overburden).xls* *observations of gw-table (bedrock).xls*
Digital model of wetlands, streams at Olkilouto	*wet.dwg (as in Task 7a)*
Coordinates of observation points	borehole-xyz-data.zip (as in Task 7a)

The modelling teams are free to specify recharge and hydraulic properties at the surface as required by their model.

A6.11 Simulations

Table A6-1. Simulations to be carried out for Task 7B2. Calibration targets are found in the data files described under the KR14-18 boundary condition section above and are summarised in a version of the Performance Measure spreadsheets provided to the modelling groups.

Name	Description	Boreholes	Purpose
SS20a	"Natural conditions"	No boreholes	Forward
SS21	"Natural conditions"	Boreholes are open and free to cross-flow	Calibration
SS22	"Natural conditions"	Boreholes are packed-off	Calibration
SS20b	"Natural conditions"	No boreholes	Based on calibrated models after SS21 & SS22
PA20c	"PA conditions"**	No boreholes	Forward
SS23a	Pumping in KR14	Boreholes are open and free to cross-flow	Forward
			(followed by …)
SS23b	Pumping in KR14	Boreholes are open and free to cross-flow	Calibration
SS24a	Pumping in KR14	Boreholes are packed-off	Forward
			(followed by …)
SS24b	Pumping in KR14	Boreholes are packed-off	Calibration
SS25a	Pumping in KR18	Boreholes are open and free to cross-flow	Forward
			(followed by …)
SS25b	Pumping in KR18	Boreholes are open and free to cross-flow	Calibration
SS26a	Pumping in KR18	Boreholes are packed-off	Forward
			(followed by …)
SS26b	Pumping in KR18	Boreholes are packed-off	Calibration
TS27***	Pumping in KR15	Boreholes are open and free to cross-flow	Forward
TS28***	Pumping in KR14	Boreholes are open and free to cross-flow except for one isolated flowing structures in other boreholes*	Forward
PA29	"PA conditions"**	No boreholes	Forward

* Tested flowing structures are to be specified at the planned work-shop for task 7B.
** The boundary conditions specified is defined below.
*** These test could first be done as steady-state and reported in a similar manner as the proposed SS simulations. Transient simulations could be done if times available or if the modelling groups prefer.

In the simulation sequence above it is important to bear in mind the sequence and that the following simulations strive at becoming better overall and not locally. Hence, as example, after simulations of pumping in KR18 the result should fit this KR18 investigation but also still be valid for the KR14 investigation. The modeller should be cautious when assigning single transmissivity values to large flowing features especially when simulations are suggesting potentially radically different values for the same feature. The "predictive" simulation of the KR15 extraction is intended to provide a test of the proposed simulation scheme.

In Table A6-1 the notations "natural conditions" and "PA conditions" are used. The intentions of these notations are to model a groundwater system without disturbances of any kind. Neither borehole nor pumping is apparent within the system. "Natural conditions" is how we believe the system worked before we interfered with boreholes etc. The "PA conditions" is the system that we hope will re-appear in the future; hopefully this system will be similar to the "natural conditions".

Each issue during calibrations should be documented as regard of what changes were made, why the changes were made, and what effects did the changes lead to.

Suggested sensitivity studies

In order to strengthen the results from the simulations sensitivity studies are requested from each group but have not been explicitly specified. The topics to be addressed by sensitivity studies are:

g) implementation of heterogeneity in zones/fractures and at zone/fracture intersections (compartments),

h) implementation of open boreholes,

i) interpretations of Posiva flow log results for flow and transport parameters.

It is envisaged that the performance measures defined below should also be used to investigate and evaluate the results of sensitivity studies.

Where formal inverse modelling methods have been applied sensitivity/uncertainty outputs (e.g. covariances) should be presented and discussed.

A6.12 Performance measures, presentation format and points for discussion

As one important deliverable of the task 7B (as a whole), it is suggested that the workflow is reported as an issue/evaluation table. The suggested table is based on the example for a planning table presented by Derschowitz & Ushida at task force meeting #23. The issue/evaluation table should contain at least the following columns:

- Issue
- Conceptual ideas
- Implementation
- Assumptions required for the implementation
- Implementation uncertainties
- Modelling approach
- Analysis
- Options considered
- Implication for site investigations
- Implication for site understanding
- Implication for PA
- Implication for repository design
- Priority

The issue/evaluation table should be reported along with each subtask, hence being a history of conceptual changes and increased understanding through-out task 7B.

The essential issues are in principal the same as the goals to be addresses as presented in the objectives section. In summary they are:

- Boundary conditions on bounding features
- Geometry and connectivity of fracture network
- Hydraulic interference
- Cross-hole flow

For each issue a range of different sub-issues should be addressed.

The treatment and expectations of the performance measure is distributed in a separate document accompanying the excel files for performance measures and calibration targets. These three documents are prepared by the task evaluator.

A6.13 Reporting for Task 7B1

The aim of reporting Task 7B1 is to:

- Discuss and construct a range of hydrostructural conceptual models not inconsistent with KR14-18 single borehole PFL logging.
- Discuss and construct a range of hydrostructural conceptual models not inconsistent with the KR14 open borehole PFL tests, but also consistent with the single borehole PFL tests.
- Discuss and construct a range of hydrostructural conceptual models not inconsistent with the KR14 packer tests, but still consistent with the single borehole PFL tests as well as the open borehole PFL tests.

In the reporting the range of uncertainty and non-uniqueness for each of the data levels should be evaluated, that is an a-priori distribution for in-put parameters and result parameters should be established.

The table structure below is to provide as a basis for a flexible table format that the different modelling groups should use to describe their conceptual model for flow in the rock within the KR14-18 area. The entries in the table are provided for illustration only.

Structure/Feature	Deterministic zones	Background rock
Description	Site scale major fracture zones	Small scale fractures and matrix between major structures
Location and spatial distribution	As specified in Posiva bedrock model 08	Volume away from Deterministic zones
Hydraulic properties (T or K) and storage	Geometric mean T from observations of zones. S=2T	Uniform isotropic $K=10^{-9}$ m/s
Heterogeneity/microstructure	Lognormal T variation based on observed T distribution	None
Aperture/porosity	Transport aperture = 1mm	0.1%
Orientation	As specified in Posiva bedrock model 08	N/A
Length scale	As specified in Posiva bedrock model 08	N/A
Likely numerical representation/s	Smeared fracture model or custom mesh based on zone geometry	Effective continuum
Significant uncertainties in description	None	Extent of damage zones around major zones Existence of local zones
Prior probability distributions for key parameters	Standard error of mean transmissivity from observations.	$\text{Log}_{10}\text{K–P}_{10}= –8$ $\text{Log}_{10}\text{K–P}_{50}= –9$ $\text{Log}_{10}\text{K–P}_{90}= –10$
Approach to choice of model volume and setting model boundary conditions	500 m × 500 m × 500 m block centred on KR15. Side boundaries constant head, upper boundary from groundwater table.	
Treatment of boreholes and features intersecting boreholes (e.g. conditioning)	Finite element mesh refined around target boreholes, no conditioning of realisations to borehole data	

In addition to this table a short textual description of the model should be provided. The model description should identify hydraulic properties and structures together with any additional processes that are thought significant (e.g. density driven flow if believed/proved important). The text should be accompanied by at least the illustrations listed below (more figures/illustrations are welcome).

- Sketch identifying major structures and features within the KR14-18 investigation volume, either as 3D or as cross-sections (vertical and horizontal).
- Sketch (or sketches) illustrating typical 10m·10m·10m volumes within the model. The number of sketches should correspond to the expected spatial variation within the model for a homogeneous model only a single sketch would be required, however it's believed that multiple sketches will be needed e.g. around a major deterministic zone, away from deterministic zones.
- Additional sketches can be provided for microstructural models if desired.

In order to facilitate a Bayesian update in 7B3 it will be necessary to identify a prior distribution for the key parameters. The format shown in table structure above provides space for modelling groups to document prior distributions.

A6.14 Performance measures for 7B2

The performance measures are in principal the same as those for Task 7A. Performance measures for head and flow for transient simulations should be provided as time histories where possible, but for comparison purposes the measures will be evaluated at two specific times as listed below.

In order to address the main objective of the task, that is to reduce the uncertainty in PA, one needs to have a prior expectation. It is recommended that the results of simulation SS20a is to be used as a basis for evaluation of uncertainty reduction.

At the time for submitting preliminary results for Task 7B2 an Excel file will be distributed and the modellers are asked to fill in relevant tables according to the performance measures asked for. Each of these Excel spreadsheets should be filled out for each of the simulations listed in Table A5-1 above.

Table A6-2. Task7B2 – Performance measures.

Name	Description	Units	Time
H_{bh}	Head in pumping borehole	m.a.s.l.	Time history
S_{bh}	drawdown in pumping borehole	m.a.s.l.	Snapshot (see Table A4-7)
Q_{dist}(md)	Distribution of inflow along boreholes	l/min	Snapshot (see Table A4-7)

Table A6-3. Task7B2 – Monitoring interval performance measures.

Name	Description	Units	Time
$H_{monitor}$	Freshwater head in monitoring sections*	m.a.s.l.	Time history
$S_{monitor}$	Drawdown in monitoring sections*	m.a.s.l.	Time history
Q_{cf}	Cross-flow in borehole*	l/min	Snapshot (see Table A4-7)
Q_{dist}(md)	Distribution of inflow along monitoring boreholes** (negative implies flow from borehole to rock)	l/min	Snapshot (see Table A4-7)

* See Table A6-4 for monitoring sections.
** See Table A6-5 for monitoring boreholes.

Table A6-4. Monitoring sections for head and drawdown. Specified as an interval around known locations of flow.

Borehole	Section
KR14	79–81
KR14	12.5–14.5
KR14	49.5–51.5
KR15	41–43
KR15B	41–43
KR16	79–81
KR16	151.5–153.5
KR16B	31.5–33.5
KR17	66.5–68.5
KR17B	41–43
KR18	56–58
KR18B	31–33

Table A6-5. Monitoring boreholes for flow distributions.

Borehole
KR14
KR15
KR16
KR17
KR18

Table A6-6 Times for "snapshots" and evaluation of performance measures.

Elapsed time (hrs)
24
240

Within the reporting important points for comparison and model evaluation are:

- Comparison of results will depend on how the modellers avoid artefacts associated with the limited model volume and relatively close boundary conditions.
- One measure of understanding of the site is the ability to reproduce the shape of the "distance drawdown" plots for the different pump tests.
- Modellers are charged to detect the open borehole artefacts in the flow response measurements based on understanding from simulations of open boreholes as well as packed-off borehole experiments.
- Consider methods established or suggested in Task 7A3 to extract cross-fracture flow.

A6.15 Performance measures for 7B3

The task suggests that the modelling groups apply a "Bayesian" update phase within 7B3. It is not intended that all the modelling groups apply Bayesian probability models within Task 7B[2]. Instead the idea is that the lessons learned should allow different users to reproduce revised versions of outputs from Task 7B1 and 7B2 for the purposes of evaluation of this process we need to document the state prior to this update.

Task 7B3 is partly based on interaction between different modelling groups as regard of results and methods. Based on exchange of methodologies modelling groups may need to refine the model specifications. Task 7B3 intends to answer questions like:

- What, if any, PA-relevant parameters can be extracted from open boreholes?
- How is connectivity information useful for PA, which generally is carried out based on some kind of stream-tube connection from the waste to the accessible environment?
- What is missing from site characterization that is necessary to properly define PA parameters (for example, how velocities on pathways vary under natural gradients, how different porosities act along these pathways, channel geometries, fracture intersections, mixing/branching, dilution, matrix-channel interaction surface areas)?
- Generalise the procedure from site characterization to PA parameters from this particular Olkiluoto case for wider applications.

also as

- it is anticipated that different modellers will use different simplifications to approximate open boreholes for the PFL tests. The modelling groups must address differences in results plausible due to simplifications adopted.

Hence, in reporting the different modelling groups are asked to discuss and elaborate the points specified above.

A6.16 Traceability and use of data

Each modelling team should present a table with the properties (geometrical and hydrogeological, with uncertainty range for the modelled fracture zones and bedrock) and with flow and head information used. In this table it should be specified which data was used for model set-up, calibration, and verification.

A6.17 Summary of task outputs from modelling groups

In summary the deliverables of task 7B are:

- Report.
- Issue/Evaluation Table.
- Questionnaire.
- Performance Measures 7B1, 7B2, and 7B3.

[2] Even though some Bayesian models have been presented within Task 7A3 e.g. from VTT using the Ensemble Kalman Filter.

Appendix 7

Task description for Task 7C

Specifications for Task 7C

Posiva Flow Logging characterisation and analysis of low permeable fractures and assessment of flow distribution pattern at shaft wall sections at Onkalo, Olkiluoto, Finland 2009-11-27, Revised: 2009-12-08

Technical Committee of Task 7: Henry Ahokas, Niclas Bockgård, Bill Dershowitz, Antti Poteri, David Holton and Patrik Vidstrand (ed.)

A7.1 Introduction

Task 7 aims to provide a bridge between the information derived from site characterisation (SC) and performance assessment (PA). Task 7 has a particular focus: how information from the new flow-logging tools (so-called POSIVA Flow Log) can be used to maximum benefit, to reduce key uncertainties for the PA.

The overall strategy of Task 7 is to progress from the large scale (Olkiluoto site-scale with focus on fracture zones) to the much smaller scale, that of the engineered barrier. At each scale, specific goals will be defined within the context of the overall Task 7 goal, and modelling tasks will be defined to support those goals.

Task 7A considered a region of approximately 10 km^2 in the vicinity of borehole KR24 at the Olkiluoto site in Finland. KR24 was used for a long-term pumping test.

Task 7B considered a localized near-field scale (50 m × 50 m × 50 m) volume within an approximately 500 by 500 m^2 region surrounding a group of boreholes KR14-18 at the Olkiluoto site in Finland. The local volume also includes a ventilation shaft, which provides unique geologic and hydrogeologic characterization access to fracture traces where they intersect the shaft.

Task 7C will focus on three single fractures. The single fractures will be based on single fracture characteristics from the characterisation of three ventilation shafts at the Onkalo of the Olkiluoto site in Finland.

The three fractures were selected because they represent a class of low transmissivity fractures which are important for performance assessment, yet have only limited characterization using conventional hydrogeological test methods. The Task 7C fractures are estimated to have transmissivity values of approximately $1 \cdot 10^{-9}$, $1 \cdot 10^{-10}$, and $1 \cdot 10^{-11}$ m^2/s.

The low transmissive nature of these fractures makes the Task 7C a new and challenging task, as there is no established procedure for characterising the hydrogeological properties of such fractures. Hence all modelling groups will need to address the conceptual models for single fractures that are plausible both as regard of flow and transport modelling.

The three fractures selected for Task 7C represent a good target for study because there is a relatively large database available describing the fractures. Each fracture is characterised with at least 4 but up to 7 boreholes, with a variety of different techniques. All boreholes have an available core and the $1 \cdot 10^{-11}$ m^2/s fracture has been characterized by cross-borehole PFL interference test measurements. For one fracture, borehole TV images are available. In all three shafts a shaft wall mapping along trace lines are available and also a detailed mapping along the peripheral of the shaft on the single fractures.

Posiva Flow Log (PFL) data of the groundwater system will be used in order to create a statistical description of in-fracture heterogeneities applied to the three fractures that are the focus of Task 7C.

The intention is to develop a near-field single fracture scale model incorporating essential micro-structural information in order to assess flow pattern on a section of shaft wall and to assess the transport characteristics by F-factor predictions and also to assess the flow distribution on a large scale within a fracture. The task is not about addressing effects of shaft wall EDZ and unsaturated conditions, nor effects due to the grouting of investigation boreholes. Consequently, the three fractures selected were chosen in the region which is considered least disturbed by grouting and construction.

This document contains the technical description for Task 7C, including a summary of anticipated data deliveries for the task.

Clarification

The three fractures described herein are not intended to be modelled at the same time but rather as three models, one for each fracture. The three fractures are physically located within three different ventilation shafts at the Onkalo, however the exact geometrical position is of no importance for the task in itself.

The delivery of one shaft geometry could be used in the assessment of all three fractures. The need for shaft geometry is related to the calculation of F-factors that should be based on release and capture of particles along the periphery of the shaft as represented in the different models; and also for the optional out-put for the nappy experiment simulations.

As each fracture is viewed as individual features the modelling groups are allowed to address the fracture set-up as a heterogeneous two-dimensional problem or a fully three-dimensional set-up with a fracture network on a relevant scale concerning transmissivity and sizes.

It should further be remembered that at the time of the establishment of this data set the shafts were not excavated. Hence the development of the conceptual model of the individual fractures should not include the shaft. The shaft will only be a modelled feature for the optional simulations of the nappy experiment.

Ongoing field activities at Onkalo will, if feasible for the task, be reported in separate PM:s as they become available. However, at present no further data is expected.

At last it was decided at the Task Force meeting #25 that the results of Task 7C1, that is the conceptual model of fracture heterogeneity should be addressed in the remaining simulation TS28 of Task 7B which aims at predicting one of the transverse flow measures in the KR14-18 volume.

Objectives

Task 7C aims at understanding the near-field scale in regards of flow and responses. Task 7C will consider small sub-volumes surrounding three ventilation shafts of Onkalo at the Olkiluoto site in Finland.

The objectives of Task 7C are:

- To use PFL to characterise and analyse procedures to quantitatively describe low transmissive fractures.
- And to demonstrate procedures of characterisation of flow in fractures of transmissivity less than $1 \cdot 10^{-9} m^2/s$.

These objectives are specified through a set of goals.

1) To advance the understanding of PA relevant single fracture micro-structural models.
2) To use PFL to characterise in-plane fracture heterogeneities.
3) To improve the ability to predict inflow to suitable and un-suitable canister hole.
4) To assess if data from pilot boreholes has any predictive power with regard to prediction of flow to canister holes.

In order to fulfil the goals of Task 7 and Task 7C in particular it is essential for Task 7C to have:

1) a clear data set for each of the three fractures,
2) a clear set of output data of the modelling tasks.

In fulfilling the objectives above Task 7C provides new and innovative results with a clear bridge to the future Task 8.

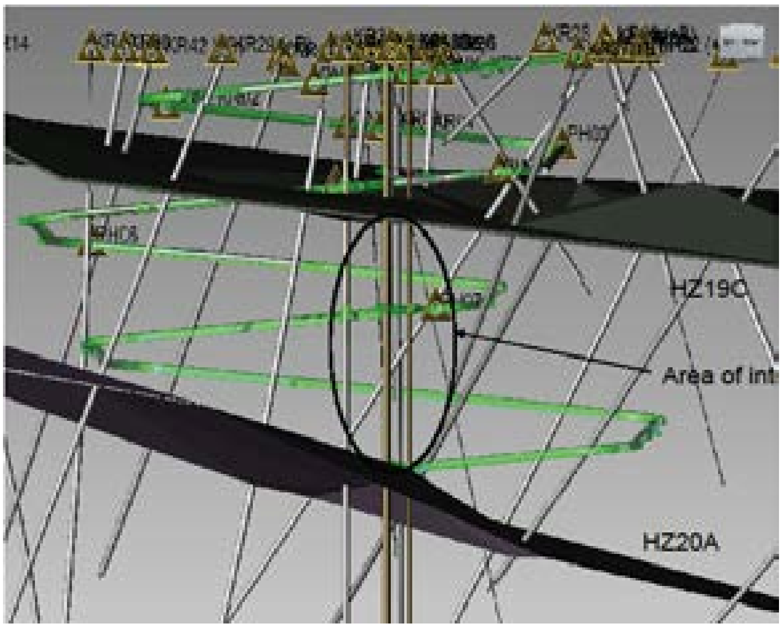


__Figure A7-1.__ Illustration of the setting of the 7C volume.

Scope

Task 7C is divided into four subtasks. It is anticipated that subtasks 7C1 and 7C2 will be undertaken by all participating groups, and perhaps a smaller number of groups will participate in the optional subtasks Task 7C3 and 7C4.

Task 7C1 – Parameterized and justified microstructural model for three fractures

The three fractures identified as the focus of Task 7C1 are characterized by borehole, PFL, and hydraulic testing, and draft/shaft mapping. This data includes information that can be processed in a number of different ways to build a microstructural model for fracture roughness and aperture distributions.

Task 7C1 is intended to provide advances in the characterisation and understanding of flow in of low transmissivity single fractures, with particular emphasis on patterns of aperture, including fracture minerals and infillings, channelling, and fracture intersection effects

In Task 7C1, each group is asked to develop and justify a procedure for parameterising the microstructural model of the three fractures. It is anticipated that this will include the use of generic approaches based on roughness and aperture studies at other sites, as well as access to the database for the Posiva fractures in particular.

Results should be presented as parameterized descriptions, descriptions of assumptions and procedures, and if possible realizations based on the parameterized descriptions with uncertainty bounds.

Within the conceptual task each modelling group should provide a fully parameterised micro-structural model with a clear defensible basis.

Task 7C2 – Simulation of flow patterns in low transmissivity fractures

Task 7C2 is primarily a simulation task for evaluation of the quantitative fracture microstructural descriptions developed in Task 7C1. The task also attempts to assess the implication of these models for safety assessment and reduction of uncertainty.

Using the conceptual models developed in Task 7C1, each group is asked to simulate the following

1. Standard PFL Logs (11).
2. Special PFL Logs (12, with adjacent open holes).
3. F-Factor Calculations.

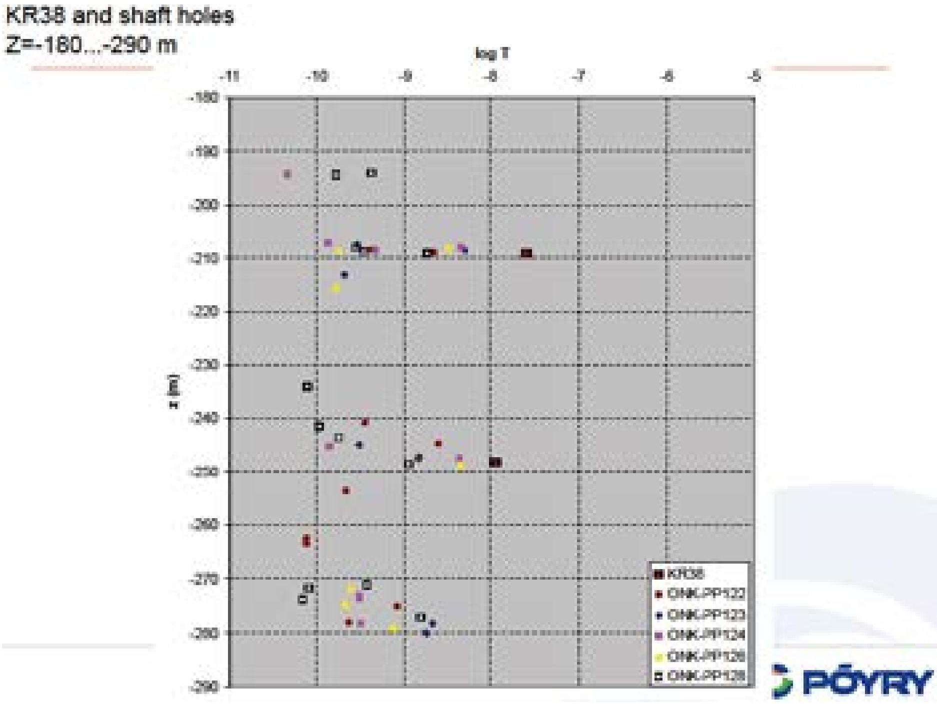


Figure A7-2. Example of PFL results. These results from KR28 and PP122–124, PP126, PP128.

The F-factor should be calculated for each defined single fracture model for a natural gradient of 0.1 in two orthogonal directions (north-south and east-west). Starting and ending point for each location should be at the location of the shaft wall.

Each modelling group should provide performance measure as defined further below.

The data to be used for this set of simulations to support the conceptual work are covered by:

1) 11 single borehole PFL representations,

2) 12 special PFL tests with adjacent open holes ("cross-hole" PFL).

Task 7C3 – Nappy experiment (Optional)

In focusing on single fractures, Task 7C moves to a scale at which the heterogeneity of flow and transport within fracture planes becomes important. This heterogeneity is very difficult to measure in situ, due to effects of stress, mechanical disturbance, boundary conditions, and multiphase flow. Task 7C3 proposes to measure the inflow to the shaft through each of the fractures by placing nappies (disposable diapers) on these fractures where they intersect the shaft wall. This experiment is complicated by these same stress, mechanical disturbance, boundary condition, and multiphase flow effects, but it is hoped that the use of nappies to collect inflow are sufficiently robust to provide a usable measure of the inflow, and the spatial pattern of inflow.

Each group is asked to utilize the microstructural fracture conceptual model of Task 7C1 to predict the inflow on a 10 cm resolution basis along the drift. It is assumed that the modelling groups will make rough approximations to account for disturbing effects, but will still be able to provide a measure of the pattern of inflow, and the mean rate of inflow as measured by the nappies.

Each modelling group should provide performance measure as defined further below.

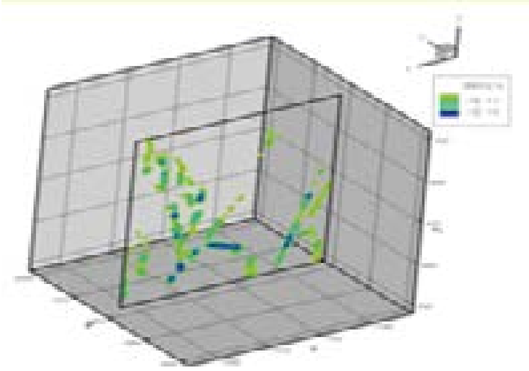


Figure A7-3. *Example of a possible outcome of Task 7C3.*

Task 7C4 Uncertainty of flow in single fractures (Optional, but recommended)

The purpose of Task 7C4 is to quantify the uncertainty which arises for the necessary assumptions, simplifications, and implementation issues found in Tasks 7C1, 2, and 3.

Primarily four areas of uncertainties should be considered:

1) Consequences of parameter uncertainty (aperture, roughness, etc).
2) Consequences of phenomenological uncertainties (physical aperture – transmissivity – hydraulic aperture).
3) Consequences of geological conceptualisation and mathematical implementation (geostatistics).
4) Consequences of boundary conditions (tunnels, other shafts, structures. etc.).

Uncertainty

As Task 7 aims at reducing uncertainty in performance assessment of a potential site and herein the reduction should be based on information gathered in the Finnish site investigation programme at Olkilouto. Within the Finnish programme, so far, no tracer experiments have been conducted. Instead, a major task has been to describe the flow distribution along open boreholes in natural (un-pumped) and disturbed (pumped) systems. Lately the task is also complemented with information concerning transverse flow in fractures that has temporarily been isolated in the otherwise open borehole system.

In the present context, the terms performance assessment and safety assessment are given the same meaning, even though different organisations may use the terms slightly differently.

A performance assessment typically includes an uncertainty analysis containing two key elements. These are:

1. The possibility of technical defects (e.g. holes in canisters, open pathways through the clay barrier, etc).
2. The possibility of unknown fast flow paths through the geosphere.

Of these two issues, the first one is not considered within Task 7.

Definition of reduction of uncertainty within Task 7

Task 7 aims at reducing the uncertainty associated with performance assessment relevant parameters using hydrogeological modelling and interpretation. The reduction is associated with an assessment of PFL measures as regard of no assessment of PFL. The data set for Task 7 includes detailed flow distributions in/out of boreholes and the flow connections between different boreholes along with the newly developed transverse (cross-flow) measurements over isolated borehole sections.

An a priori assessment of transmissivity and connectivity is likely to include a large range of possible solutions. The aim of the exercise is therefore to constrain the variability in transmissivity and connectivity by use of the flow data and thus to study the propagation of this variability into performance measures identified by the Task Force and considered as relevant parameters for performance assessment,. These exercises would, we believe, contribute to a "reduction of uncertainty" in performance assessment results.

Time schedule

The time schedule for Task 7C is preliminary and contained within the overall time schedules of Task 7 and the Task Force on Modelling of Groundwater Flow and Transport of Solutes.

January 2010	Workshop. Presentation of modelling results Task 7C1
April 2010	Modelling results of Task 7C2
Task Force meeting #26, May 2010	Reporting of Task 7C1
October 2010	Reviewing of Task 7C1 and 7C2 Results 7C3 and 7C4
Task Force meeting #27	Completed reporting of Task 7
Spring 2011	Papers

The conceptual model

The conceptual model frame is suggested as a simplified cylinder or box with no-flow top- and bottom boundaries and constant head sides. The dimensions are approximate 40 metres in height and a 30 metres lateral extension (cylinder radius 15 metres or box side 30 metres).

A set of three defined fractures are specified. Fractures are named as FR1-KU1, FR1-KU2 and FR1-KU3 and FR1-KU2 is mapped as Fracture1 in shaft KU2 and was one of the three fractures measured by nappies in shaft KU2. Other fractures mapped and measured by nappies in shaft KU2 were Fracture2 and Fracture3 but these will not be used in this task. However, results can be used as general information and as a background data if needed.

Each modelling group should specify their micro-structural model of fracture properties and in-fracture heterogeneity, etc.

Data relevant for construction of a conceptual model:

Data	File
Fracture trace geometries (Fracture1 is used in this task only)	Fracs.dwg/Fracs.dxf
Fracture and PFL (updated 4-12-2009)	Fracture and PFL data of task 7C_v1.zip
Detailed mapping, photos, water leakage values	Nappy-results and traces in KU2.zip

A7.2 Boundary conditions

The boreholes

The boreholes are established in different phases. The KR boreholes are drilled from ground surface while the PP boreholes are drilled from rock caverns at depth along the main tunnel of Onkalo.

The boreholes are either open or closed; the PP boreholes do under open conditions flow freely into the main tunnel. Closed have the meaning of one packer sealing of the PP borehole at its top so that flow is inhibit towards the main tunnel. Closed does however not mean that different sections along the borehole are isolated.

Data relevant to treatment of boreholes are:

Data	File
Borehole geometry data	Borehole_paths.zip

The shafts

The shafts are raised bored and thereafter maintained at atmospheric pressure conditions.

Data relevant to treatment of shaft boundary are:

Data	File
Shaft wall geometries (section surrounding fractures)	Fracs.dwg/Fracs.dxf

The side boundary condition

The side boundaries or really all natural bedrock is assumed to have a constant pressure. Posiva assume full pressure head at a distance of 15–20 metres away from any tunnel wall. In this exercise Posiva suggests modelling groups to specify a full pressure head relevant for the depth 20 metres into the rock from the shaft walls.

Simulations

Simulations to be carried out for Task 7C1 and 7C2. In the name s stands for single-hole tests and c stands for cross-hole tests in a reference to the notation used by Posiva.

Name	Description	Boreholes	Purpose
s-PP122	Tool for calibration	Borehole PP122 open and PFL measured. Boreholes PP123, PP124, PP126, PP128 closed.	Characterisation of fracture
s-PP123	Tool for calibration	Borehole PP123 open and PFL measured. Boreholes PP122, PP124, PP126, PP128 closed.	Characterisation of fracture
s-PP124	Tool for calibration	Borehole PP124 open and PFL measured. Boreholes PP122, PP123, PP126, PP128 closed.	Characterisation of fracture
s-PP126	Tool for calibration	Borehole PP126 open and PFL measured. Boreholes PP122, PP123, PP124, PP128 closed.	Characterisation of fracture
s-PP128	Tool for calibration	Borehole PP128 open and PFL measured. Boreholes PP122, PP123, PP124, PP126 closed.	Characterisation of fracture
s-PP131	Tool for calibration	Borehole PP131 open and PFL measured. Boreholes PP134, PP137 closed.	Characterisation of fracture
s-PP134	Tool for calibration	Borehole PP134 open and PFL measured. Boreholes PP131, PP137 closed.	Characterisation of fracture
s-PP137	Tool for calibration	Borehole PP137 open and PFL measured. Boreholes PP131, PP134 closed.	Characterisation of fracture
s-PP125	Tool for calibration	Boreholes PP125 open and PFL measured. Boreholes PP127, PP129 closed.	Characterisation of fracture
s-PP127	Tool for calibration	Boreholes PP127 open and PFL measured. Boreholes PP125, PP129 closed.	Characterisation of fracture
s-PP129	Tool for calibration	Borehole PP129 open and PFL measured. Boreholes PP125, PP127 closed.	Characterisation of fracture
c-PP125-1	Tool for calibration	Boreholes PP125 open and PFL measured. Boreholes PP127, PP129 open.	Characterisation of fracture
c-PP125-2	Tool for calibration	Boreholes PP125 open and PFL measured. Boreholes PP127 open, Borehole PP129 closed.	Characterisation of fracture
c-PP125-3	Tool for calibration	Boreholes PP125 open and PFL measured. Boreholes PP127 closed, Borehole PP129 open.	Characterisation of fracture
c-PP127-1	Tool for calibration	Boreholes PP127 open and PFL measured. Boreholes PP125, PP129 open.	Characterisation of fracture
c-PP127-2	Tool for calibration	Boreholes PP127 open and PFL measured. Boreholes PP125 open, PP129 overpressure 2bar.	Characterisation of fracture
c-PP129-1	Tool for calibration	Borehole PP129 open and PFL measured. Boreholes PP125, PP127 open.	Characterisation of fracture
TS-28	Forward/Prediction	KR14-18	
OL-KR38 NS	Forward	No Boreholes	Calculation of F-factor
OL-KR38 EW	Forward	No Boreholes	Calculation of F-factor
OL-KR24 NS	Forward	No Boreholes	Calculation of F-factor
OL-KR24 EW	Forward	No Boreholes	Calculation of F-factor
OL-KR48 NS	Forward	No Boreholes	Calculation of F-factor
OL-KR48 EW	Forward	No Boreholes	Calculation of F-factor

Performance measures, presentation format and points for discussion

As one important deliverable of the Task 7C (as a whole), it is suggested that the workflow is reported as an issue/evaluation table. The suggested table is based on the example for a planning table presented by Dershowitz & Uchida at Task Force meeting #23. The issue/evaluation table should contain at least the following columns:

- Issue.
- Conceptual ideas.
- Implementation.
- Assumptions required for the implementation.
- Implementation uncertainties.
- Modelling approach.
- Analysis.
- Options considered.
- Implication for site investigations.
- Implication for site understanding.
- Implication for PA.
- Implication for repository design.
- Priority.

The issue/evaluation table should be reported along with each simulation, hence being a history of conceptual changes and increased understanding through-out Task 7C.

Reporting for Task 7C

Reporting of Task 7C will be done within the context of the final reporting of Task 7 as a whole.

Performance measures for 7C1

The performance measure for Task 7C1 is a fully parameterized conceptual model and microstructural model for each of the three fractures. The conceptual models should be expressed as value such as aperture and thickness for mobile and immobile zones and their properties, on a grid of the modelling groups' choice, and the specifications for the processes used to generate the spatial field. The modelling groups conceptual models will be compared using both statistical and geostatistical measures.

Description of micro-structural models should including illustrations of the fractures and statistics on apertures, transmissivity values, and other parameters as used by the different modelling groups.

Performance measures for 7C2

Performance measures for Task 7C2 will include pressures, and flow rates for each of the simulated PFL logs, and F-factor calculations. Performance measures for the flow related retention properties are defined following the definitions of the Task 6D. Retention properties along the different flow paths are given by a parameter group that is represented by the F-factor. The F-factor is a parameter group defined by the ratio flow wetted surface to water flux. The F-factor is an integrated quantity that describes flow related retention properties along a flow path. Thus, the value monotonically increases along the flow path.

The estimation of the F-factor depends on the type of model used. In the case of discrete models the F-factor can be estimated as the quotient of the flow channel dimensions (width = W and length = L) and the water flow in the channel, Q. In a simple case with a single channel with constant width it is given by:

$$F = \frac{2\,WL}{Q}$$

If varying flow channel dimensions or variable aperture models are used the quotient should be integrated along the flow path:

$$F = \sum_i \frac{2W_i L_i}{Q_i} = \sum_i \frac{2L_i}{q_i} \ ,$$

where L_i is the path length over the (FEM) element i of the flow model and q_i is the corresponding Darcy velocity, i.e. Q_i/W_i of the element i.

The modelling groups are requested to deliver statistics of the F-factor in years per meter.

Performance measures for 7C3

Each modelling group is asked to predict the flow on each fracture in 10 cm increments, measured clockwise from north, around the periphery of the shaft. It is understood that this prediction will not match measurements to be made by nappies in detail, but it is hoped that the pattern can be matches, at least in a statistical or geostatistical sense.

Performance measures for 7C4

Each modelling group is asked to produce uncertainty bounds for parameters investigated. The parameters should address mean, 75%, and 95% bounds.

Traceability and use of data

Each modelling team should present a table with the properties (geometrical and hydrogeological, with uncertainty range for the modelled fractures and bedrock) and with flow and head information used. In this table it should be specified which data was used for model set-up, calibration, and verification.

Summary of task outputs from modelling groups

In summary the deliverables of task 7C are:

- Report.
- Issue/Evaluation Table.
- Questionnaire.
- Performance Measures.