R-06-57

The Laxemar repository

Modelling changes in the flow, pressure and salinity fields, due to a repository for spent nuclear fuel

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December 2006

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Abstract

Water inflow to an open repository may change the pressure and salinity in a large volume around the repository. The effect can reach the surface and may cause a drawdown of the ground water table and very salt water from below the repository may be transported up to repository level.

A numerical simulation model which simulates these effects is developed and tested. By employing a number of advanced modelling techniques (unstructured grids, free surface algorithm, matrix exchange, etc) it is demonstrated that realistic simulations can be performed. An application to the Laxemar repository is carried out and site specific results are discussed.

The main conclusion of the study is that the inflow to the open repository is of the order 30 l/s if the grouting is very effective (max conductivity 10^{-9} m/s), while this value is doubled if the grouting is less effective (max conductivity 10^{-7} m/s). The area affected by the drawdown is found to be large, up to 10 km^2.

Sammanfattning

Inflöde till ett djupförvar kan ge förändringar i tryck- och saltfältet i en stor volym runt förvaret. Vid markytan kan en sänkning av grundvattenytan bli resultatet. Under förvaret kan en uppåtgående transport, som kan öka salthalten på förvarsnivå, förväntas.

En numerisk modell som beskriver dessa effekter har utvecklats och testats. Genom att utnyttja en rad avancerade tekniker (ostrukturerade beräkningsnät, algoritm för fri grundvattenyta, matrisutbyte, mm) kan realistiska simuleringar erhållas. En tillämpning på ett tänkt förvar i Laxemar visar detta.

Den viktigaste slutsatsen från arbetet är att inflödet till det öppna förvaret kan förväntas vara av storleksordningen 30 l/s om injekteringen är mycket tät (max konduktivitet 10^{-9} m/s) medan inflödet fördubblas för en mindre god tätning (max konduktivitet 10^{-7} m/s). Området som påverkas av grundvattensänkningen på grund av förvaret kan förväntas bli stort (ca 10 km^2).

Contents

1 Introduction

1.1 Background

A repository for spent nuclear fuel will have atmospheric pressure in the tunnels during the excavation and operational phases. In order to reduce the resulting water inflow grouting will be carried out. Unless the inflow is totally eliminated (which is not feasible) a disturbance in the pressure and salinity fields will result.

From several points of view it is of interest to be able to predict these disturbances:

- The ground water table will be lowered due to the tunnel inflow. The water level in lakes and wells is thus affected as well as the flow rate in streams.
- The engineered barriers are known to be affected by the salinity of the surrounding water. It is expected that water from below the tunnel will be transported to the tunnel, carrying water with high salinity (upconing). Also the oxygen saturated water from the ground surface may affect the engineered barriers.
- From a construction point of view it is essential to know the expected inflow to the repository; this in order to perform suitable grouting, design pump systems, etc.

After the closure of the repository a resaturation phase starts. Also this phase and the coupling to the host rock is of interest to simulate. Finally, one needs to consider the possible transport of radionuclides from the repository to ground level. This transport will however not be considered in this report.

Considering all these aspects and the complex geometry of a repository it is realized that the simulation task is far from trivial. A model that resolves the processes around the tunnels (on a metre scale) as linked to regional scales (on the km scale) is needed.

The present report can be considered as the third in a series of reports dealing with repository simulations; the first one reported results for the Simpevarp location /Svensson 2005a/ and the second one considered the Forsmark site /Svensson 2005b/. The site considered in this report is Laxemar, which is located quite close to the Simpevarp area. The numerical model and style of reporting will be similar to the two earlier studies.

1.2 Objectives

The main objectives of the study are:

1. Inflow to the tunnels. In particular the distribution of the inflow (flux and salinity) in space and time is of interest.
2. Upconing of saline water to the repository.
3. Resaturation time after closure.
4. Turnover of water in the upper bedrock and soil.
5. Near-surface drawdown:
   - Extent of influence area and drawdown within it.
   - Effects on wells in rock and overburden.
6. Effects on surface hydrology:
   - Surface water levels.
   - Discharges in water courses.
7. Sensitivity analysis of the hydraulic conductivity of the backfill.

The first five objectives will be in focus in this report. A secondary objective is to demonstrate new methodology, as embodied in the code DarcyTools Version 3.0.

1.3 Scope

In order to meet the objectives a number of advanced modelling techniques are needed. The most important of these are:

- A computational grid that can resolve the geometry of the repository, as embedded in a regional scale model. In this report an unstructured grid will be introduced as a solution to this problem.
- A method to handle a free ground water surface.
- The repository geometry is given in form of high resolution CAD files. These files need to be imported to the code and the computational grid is to be constructed in a way that resolves the geometry.
- The salinity distribution is in focus in the study. The gravitational effects due to the varying salinity as well as the exchange with immobile volumes (including the rock matrix) should be accounted for.
- Grouting will reduce the hydraulic conductivity close to the repository walls. This skin effect needs to be simulated in a realistic manner.
- The resaturation phase calls for a two-phase analysis. In this report a simpler alternative will be tested.
- Deformation zones and fractures need to be accurately represented on the computational grid.

These features are considered to be essential parts of a realistic problem formulation and the modelling task is therefore also a feasibility study.

Some issues that are not considered in this study include: thermal effects and transport of radionuclides from the repository to ground level. It should further be noted that comprehensive calibration and sensitivity studies are outside the scope of the present project.

2 Site description

2.1 General

The Laxemar area is located near the Oskarshamn nuclear power plant, on the east cost of Sweden, see Figure 2-1. In this figure also the Regional Model domain is introduced; the Regional Model covers all catchment areas shown in Figure 2-1, parts of the Baltic Sea and has a depth of 2.1 km.

An outline of the repository is shown in Figure 2-2. The repository is located at a depth of about 500 metres. The layout of the repository is done with respect to major deformation zones in the area.

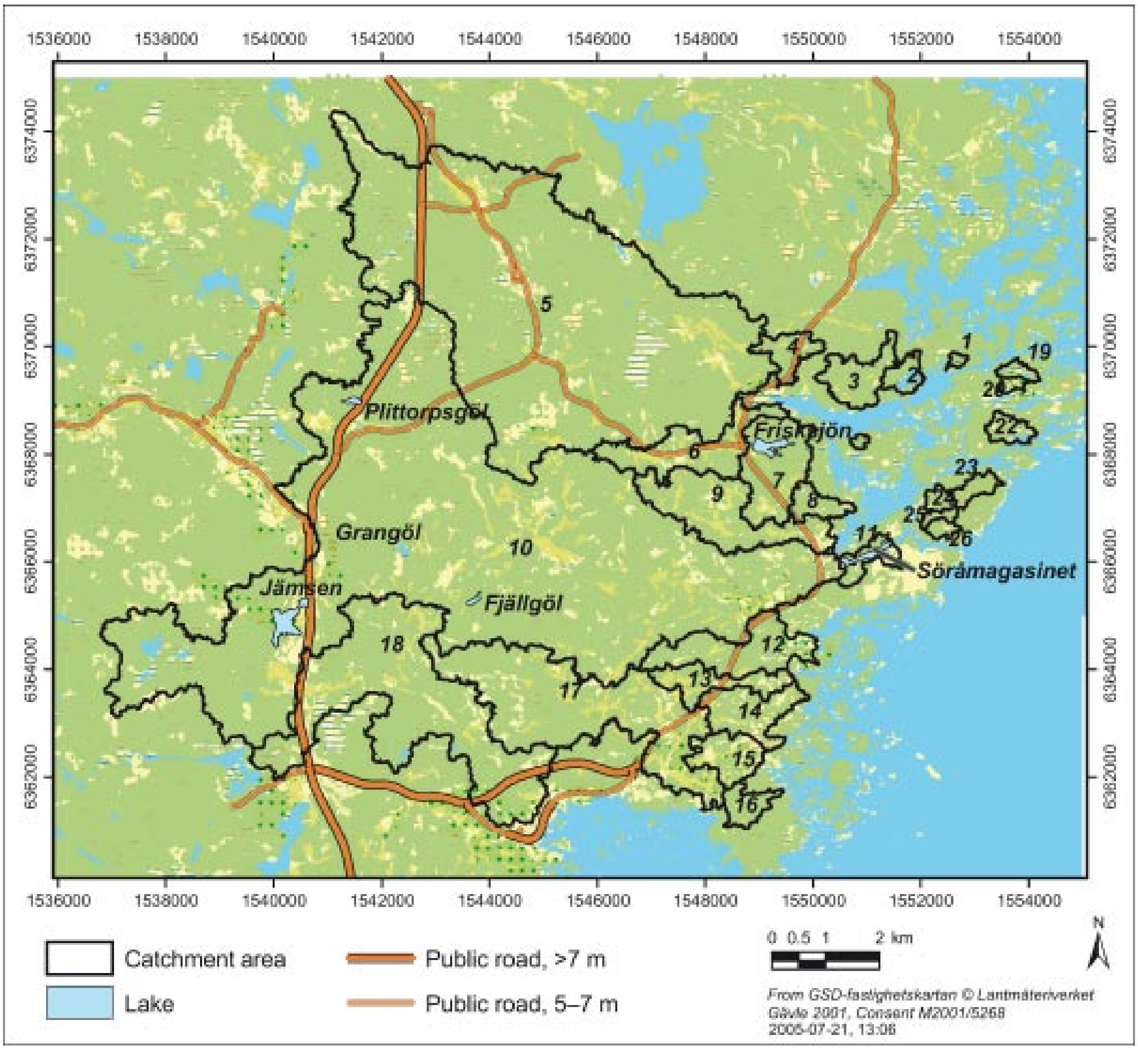


Figure 2-1. *Overview of the Laxemar area and the Laxemar regional model area. The repository is located in catchment areas 6, 7, 8 and 9.*

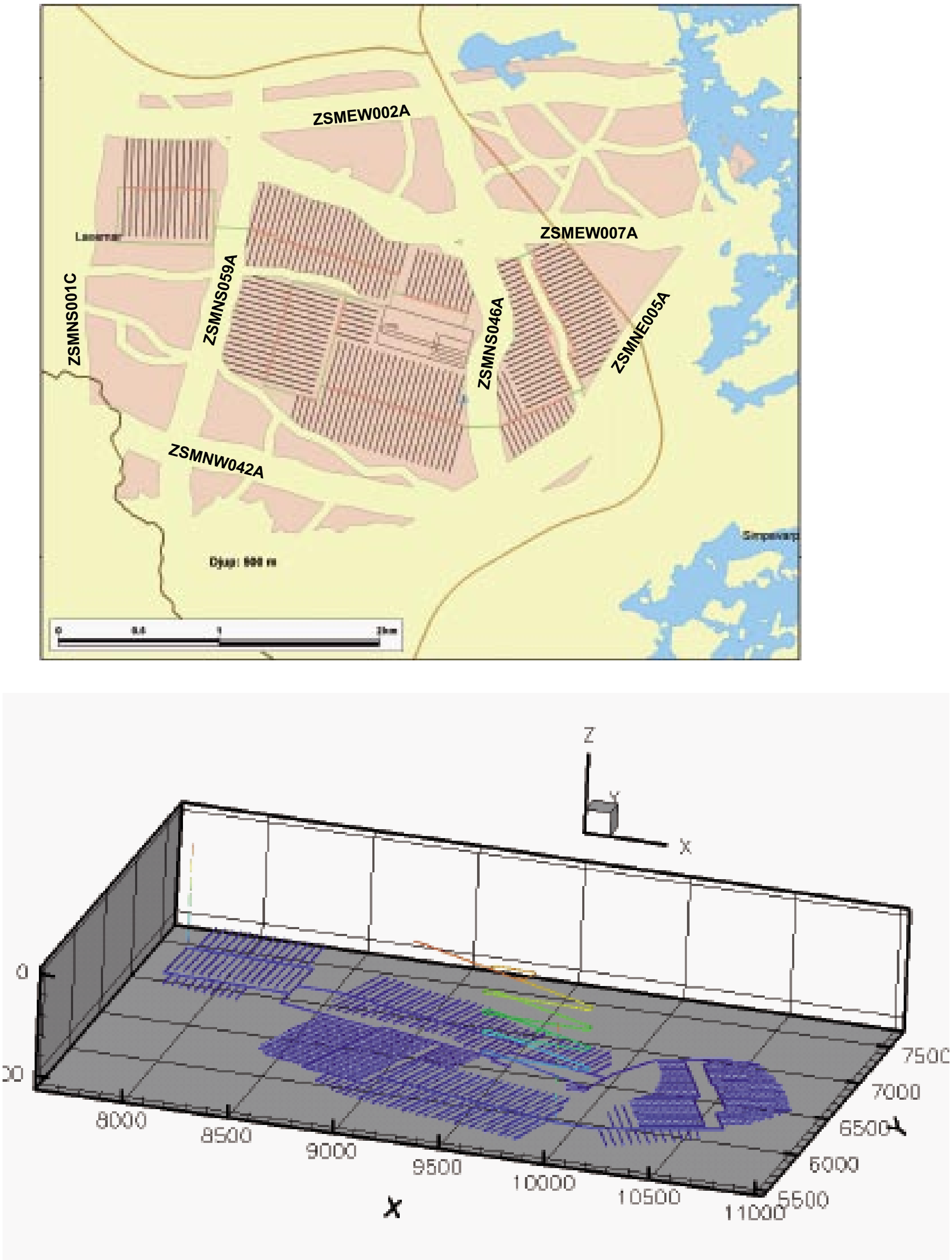


Figure 2-2. Layout of the repository. Position in the horizontal plane (top) and a perspective view. The x and y coordinates in this, and the following figures, refer to the local system in the regional model. The y-direction points to North.

2.2 Site data

The general conditions and data for the model set-up are given in /Hartley et al. 2006/ and /SKB 2006/. Some of the main points are:

- The model domain coordinates are those of the Regional Model.
- The elevation of the top surface of the model was provided by SKB.
- The deterministic fracture network, and the rock volumes in between, should be identical with a base case defined in the Site-descriptive model.
- The tunnel layout is presented in /Jansson et al. 2006/ and is provided by SKB in form of a CAD file (STL-format).
- Initial conditions should be based on the results from the Site-descriptive model.
- Boundary conditions:
  - Prescribed net precipitation (165 mm/year) above sea level, fixed pressure and salinity below.
  - Salinity at bottom boundary fixed to 10%.
  - Hydrostatic conditions on all lateral boundaries.
  - Atmospheric pressure in tunnels.

The fracture network is made up of deterministic deformation zones (lineament) and a stochastic part (DFN). Deformation zones are generally larger than 1 km in length and the DFN thus has to cover scales smaller than 1 km.

An outline of the deformation zones is given by Figure 2-3; some of these zones are also indicated in Figure 2-4. These zones have generally high transmissivity, form a connected network and are hence determining most of the response in the system. Deformation zones are classified as high, medium and low confidence zones. In the present study low confidence zones are excluded.

The DFN is constructed from five fracture sets, having different orientation, intensity and transmissivity /see Table 3-17 in Hartley et al. 2006 for details/. For the regional scale, fractures in the length interval 100 to 1 000 metres are generated. For the region covering the repository a network with length scales from 30 to 100 metres is added. It is noted that the model in the present application adopts the characteristics of hydraulic rock domain A of /Hartley et al. 2006/ for the whole domain. Thus, also the less permeable hydraulic rock domain DEM /Hartley et al. 2006/, where a smaller part of the repository is located, has properties of hydraulic rock domain A in the present application.

According to /Hartley et al. 2006/ a depth trend should be applied to the rock properties. In the present project a depth function that reduces conductivities with an order of magnitude every 400 metres has been employed. The depth function for porosity reduces the magnitude with one order every 800 metres. These trends are believed to be in fair agreement with the suggestions by /Hartley et al. 2006/.

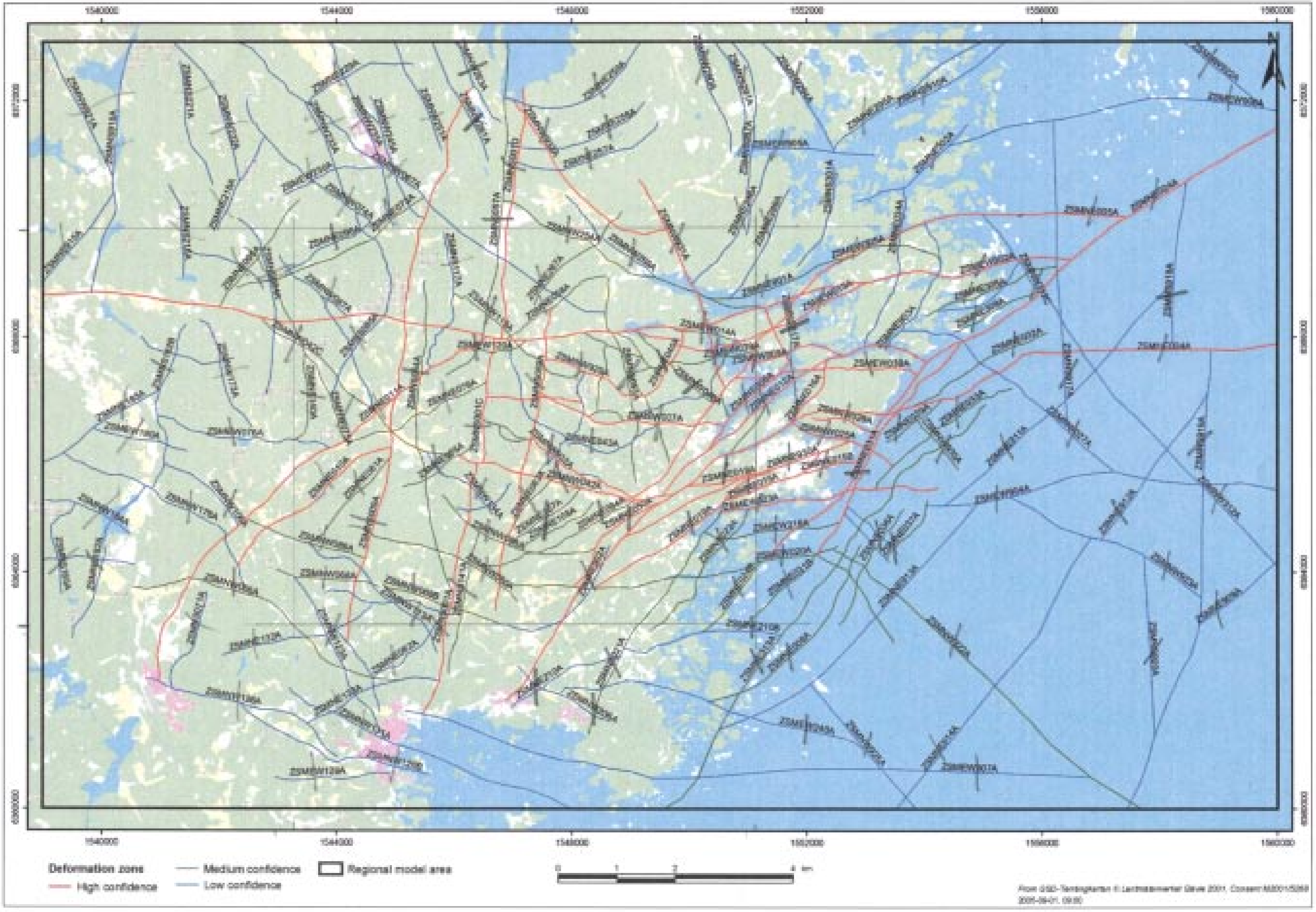


Figure 2-3. Deformation zones within the regional model domain.

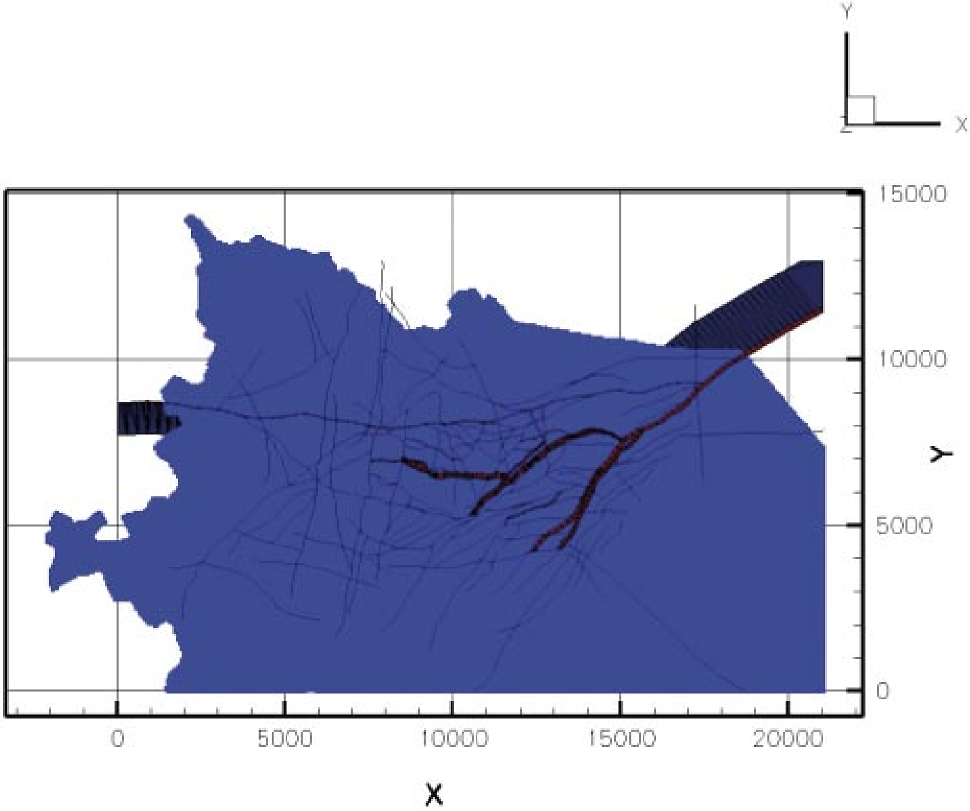


Figure 2-4. *Illustration of Deformation zones in the regional model; the crossings with a plane at 100 m below sea level are shown. Low confidence zones are excluded in this figure.*

3 Mathematical model

For a general description of the basic assumptions and mathematical formulation of DarcyTools, the reader is referred to /Svensson et al. 2006/. In this section some problem specific settings and assumptions will be discussed.

3.1 Properties

As mentioned, the properties should be similar to what was used in the Site-descriptive model and will for this reason not be discussed here. The present set-up, in contrast to the models used in the Site-descriptive modelling, employs a free surface algorithm. As a consequence the near ground properties need to be calibrated, in particular the hydraulic conductivity. Also the drawdown above the repository requires some considerations regarding the conductivity. In Table 3-1 the settings used are summarized. It should be emphasised that this study has not included any "fine trimming" of the surface hydrology part of the model and the values adopted are therefore mainly based on earlier experience and some test simulations. One such "earlier experience" is given by the site model described in /Svensson 1997/, which also applied a free surface condition. The conductivities below a depth of 20 metres are due to the defined base case /Hartley et al. 2006/ in the Site-descriptive model. One important difference, as compared to the Site-descriptive model, concerns the Deformation zones. In the present study the low confidence zones are excluded, while these are included in the Site-descriptive model.

3.2 Equations

The following equations and algorithms are employed.

- Conservation of mass, including the effects of a variable density and specific storativity.
- A transport equation for salinity.
- A transport equation for precipitation water.
- The Darcy equation, including the gravitational term.
- The subgrid model FRAME, based on the multi-rate diffusion model, is used for both salinity and the precipitation tracer.
- The ground water table is tracked with a free surface algorithm that can handle both natural conditions and the drawdown due to the repository.
- A tunnel routine puts atmospheric pressure in all computational cells in contact with the repository. All cell walls of these cells have a specified maximum conductivity.

For a detailed account of equations and algorithms, see /Svensson et al. 2006/.

3.3 Software

DarcyTools V3.0 is used in the study. This is the third major repository project using V3.0. The reason for using this software is that the unstructured grid option (not available in earlier versions) is needed to resolve the geometry of the repository. V3.0 also allows direct import of CAD files in STL format, which is utilized in the present study.

Table 3-1. Properties. As the basic fracture network is imported from the Site-descriptive model, only additional (i.e. min values and near ground properties) properties are given here.

Property	Depth	Values
Porosity (–)	0 → 20 m	$n = 0.05×10^{–depth/20}$ min. value = $10^{–3}$
	20 m →	min. value = $5×10^{–5}$
Conductivity (m/s)	0 → 20 m	$k = 5×10^{–3}×10^{–depht/3}$ min. value = $10^{–6}$ kriver = 2 $k_z = 5×10^{–6}$, constant
	20 m →	min. value = $10^{–10}$
Specific storativity ($m^{–1}$)		min. value = $10^{–7}$ max. value = $10^{–6}$

4 Results

4.1 Fractures, properties and grid

It is perhaps a bit unusual to include properties and grid in the result section. However, as the study is partly a feasibility study and the grid resolution is a major new element of the model, it can be justified. As will be shown, also the representation of properties can be classified as a result in itself.

The grid in the horizontal plane is shown in Figure 4-1. Both the grid making up the upper boundary above sea level ("the land cells") and the grid at 525 m below sea level are shown in the figure. The largest cell size is 120 metres, the surface topography is resolved by a cell size of 60 metres and streams by cells with a dimension of 30 metres. Around the repository a grid size of 30 metres is used. In Figure 4-2 this area is enlarged and one can see the tunnel system. Figure 4-3 gives a further enlargement and one can now discern the smallest cell size used, which is 4 metres. This high resolution is needed to resolve the deposition holes individually. A vertical section through the repository is shown in Figure 4-4. From a depth of 2100 metres a cell size of 120 metres is used; however from 600 m depth and upwards the maximum size is 30 metres. The vertical resolution close to the top boundary is 2 metres. In total about 1.6 million cells are required to specify the problem as outlined.

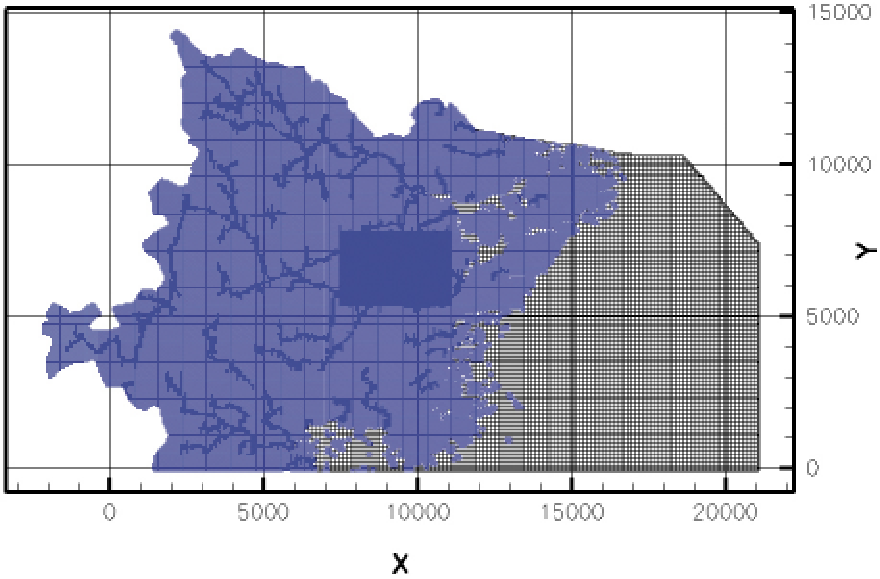


Figure 4-1. *Computational grid. Horizontal plane at ground level and 525 m below sea level. The y-coordinate points in the North direction.*

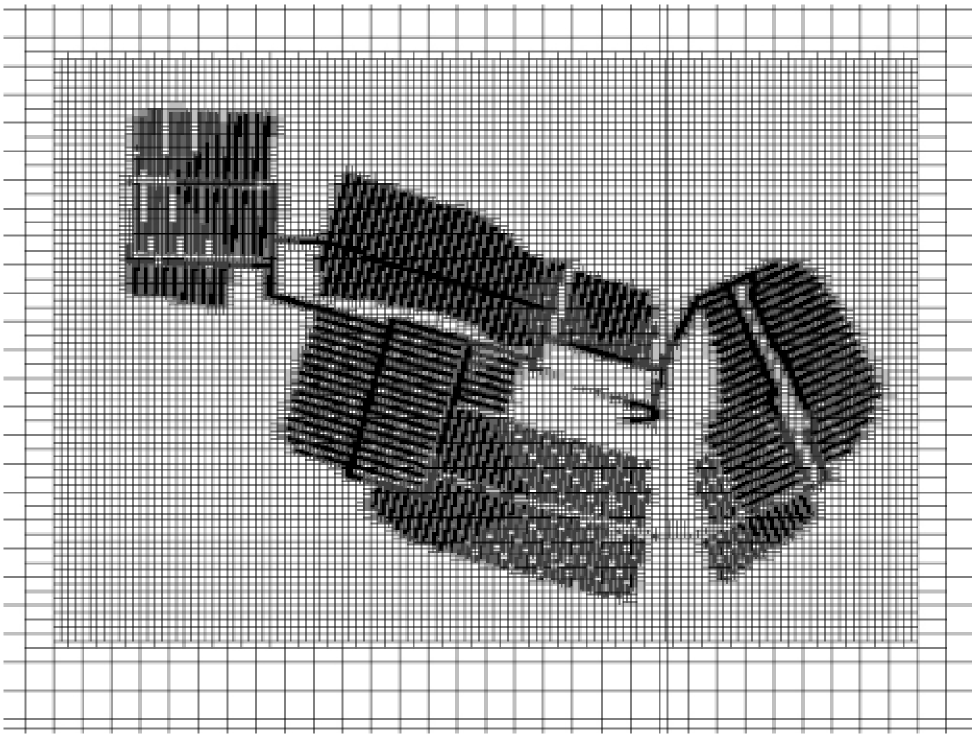


Figure 4-2. *Enlargement of Figure 4-1, with focus on the repository. Depth = 525 metres (metres below sea level).*

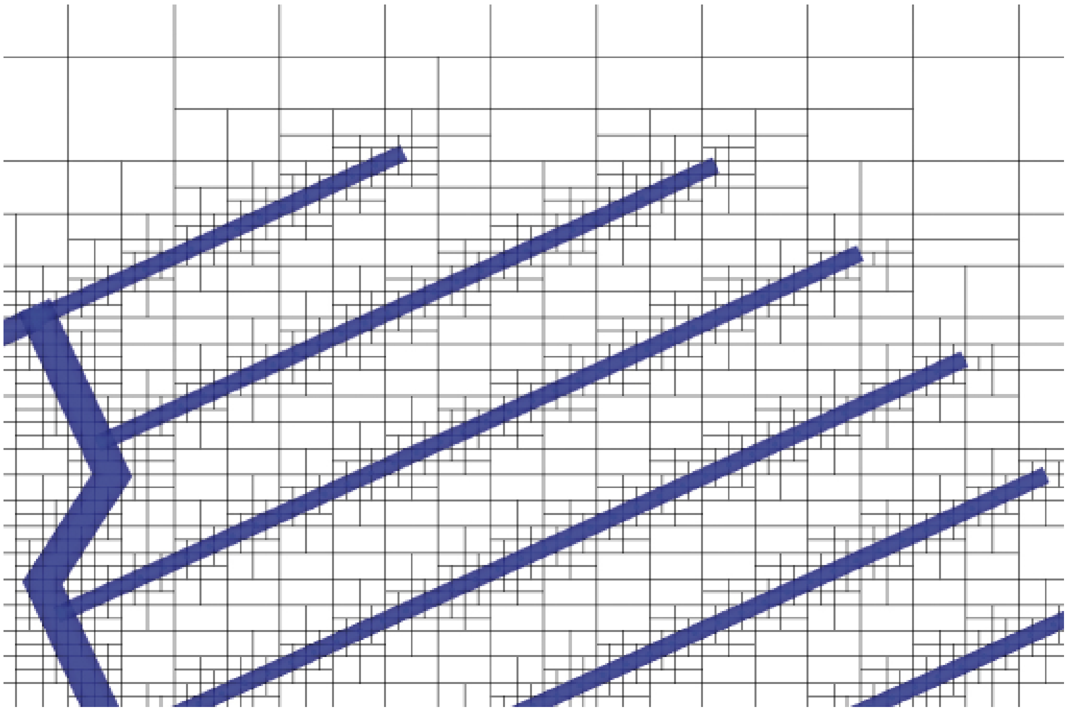


Figure 4-3. *Enlargement showing the North-East part of the repository. Depth = 525 metres (metres below sea level).*

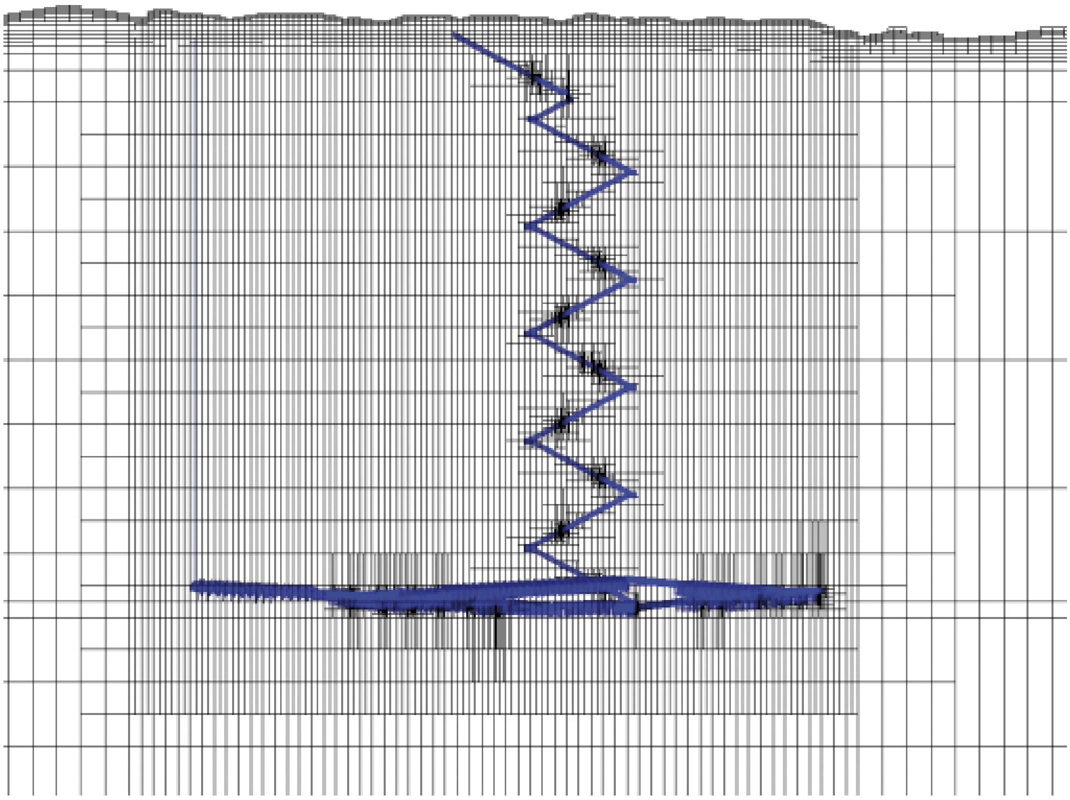


Figure 4-4. *Vertical section (East to West) through the repository area.*

In Figure 4-5, the permeability and porosity fields around the repository are illustrated by two horizontal sections at 525 m below sea level. As can be seen, some zones are crossing the repository. Another illustration of the fracture crossings is given by Figure 4-6. The fractures crossing have a transmissivity of 10^{-5} m^2/s, and it is quite clear already from these illustrations that the inflow to the repository may be significant due to these zones.

4.2 Natural conditions

The natural, or undisturbed, conditions are needed as a reference when the tunnel effects are estimated. Another argument for studying the undisturbed situation is that the surface hydrology part of the model should be calibrated for undisturbed conditions. Due to time constraints this will however not be undertaken in the present study, instead some estimates based on earlier experiences are used.

The saturation level at ground level is shown in Figure 4-7, together with the flow vectors of the streams. A general agreement concerning the location of stream and lakes/wetland is found.

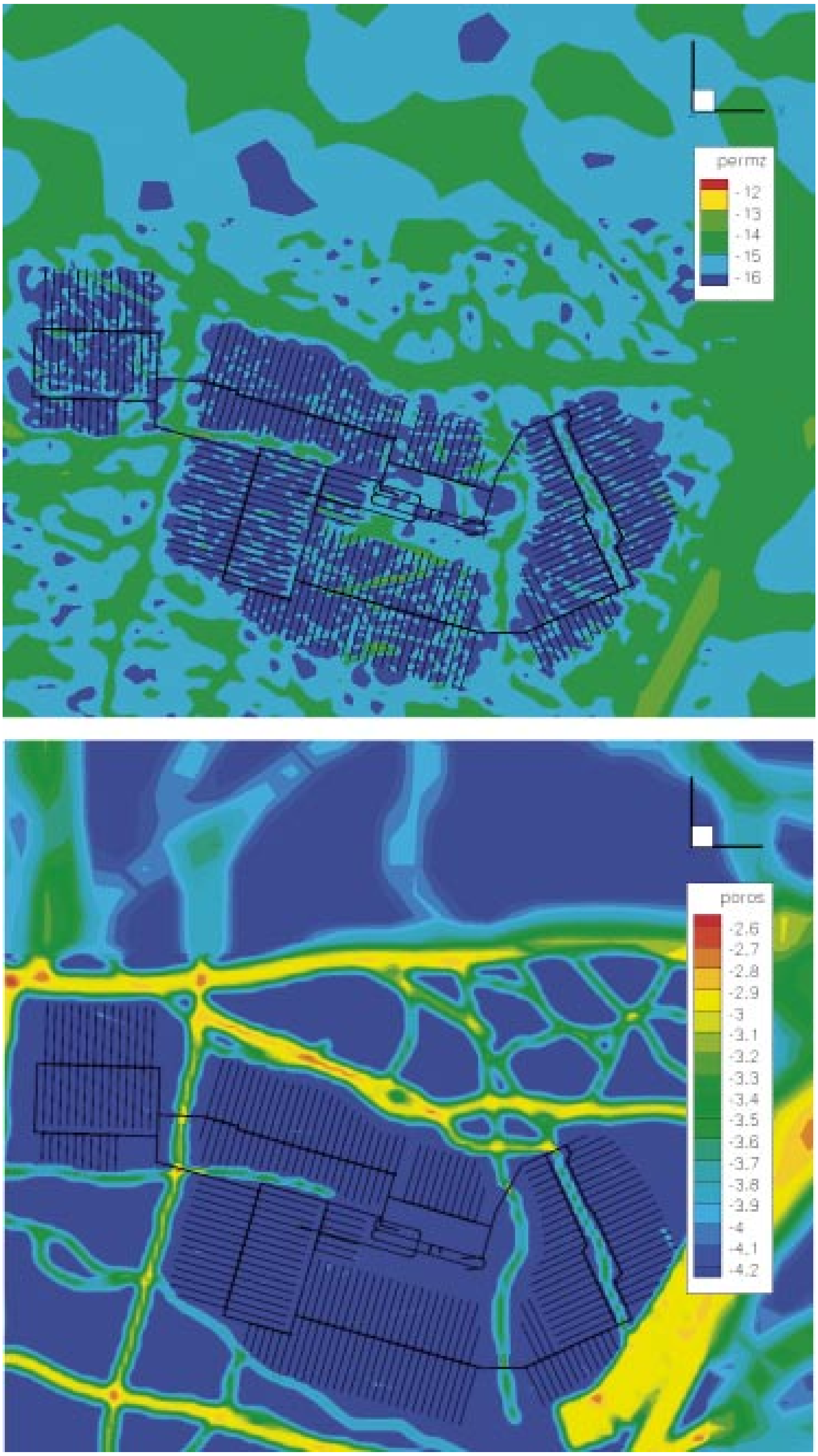


Figure 4-5. *The $\log_{10}$ vertical permeability and $\log_{10}$ porosity in a horizontal (at 525 m below sea level) plane around the repository. An estimate of the corresponding conductivities is obtained by adding +7 to the numbers in the legend. The minimum conductivity is thus around 10^{-9} m/s.*

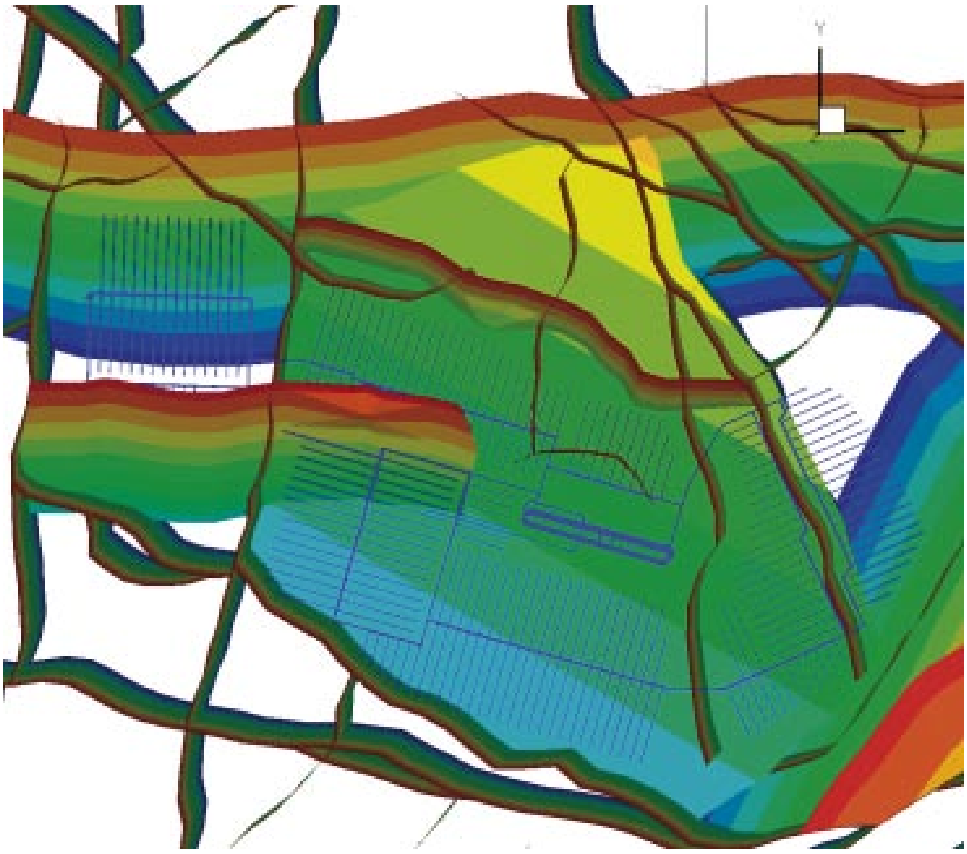


Figure 4-6. Illustration of fracture zones close to, or in contact with, the repository. The zones are coloured with respect to vertical coordinate. The y-coordinate points to North. Fracture zone ZSMEW007A has been removed, in order to see the remaining zones clearer.

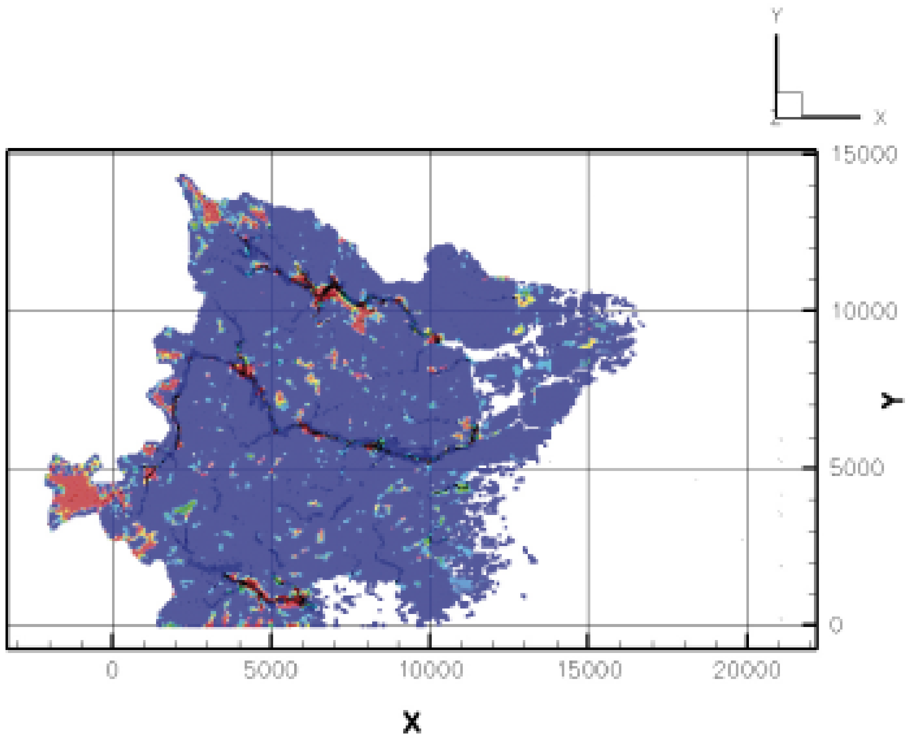


Figure 4-7. The saturation level at ground level. Red colour indicates fully saturated conditions, blue a groundwater table lower than two metres below ground and green colour indicates that the groundwater table is between 0 to 2 metres below ground level. Vectors represent the flow in streams.

The salinity distribution in two vertical sections is shown in Figure 4-8, together with a perspective view. The depth of the fresh water is found to increase towards main land.

Some illustrations of the pressure and vertical Darcyflux can be found in Figures 4-9 and 4-10.

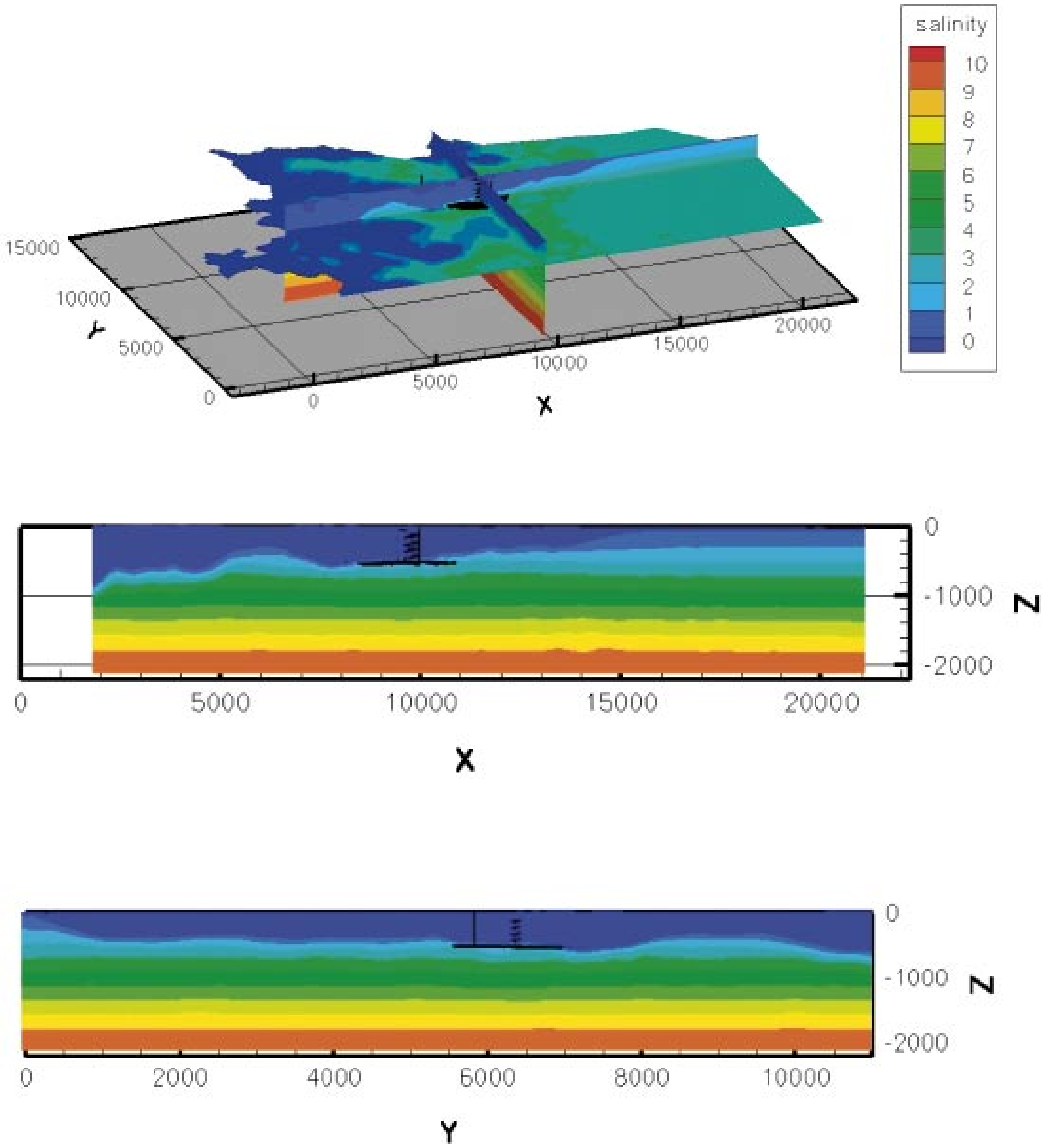


__Figure 4-8.__ Salinity (in %) distribution in a West-East (middle) and South-North (bottom) vertical section through the repository. The top figure is a perspective view looking from South-West.

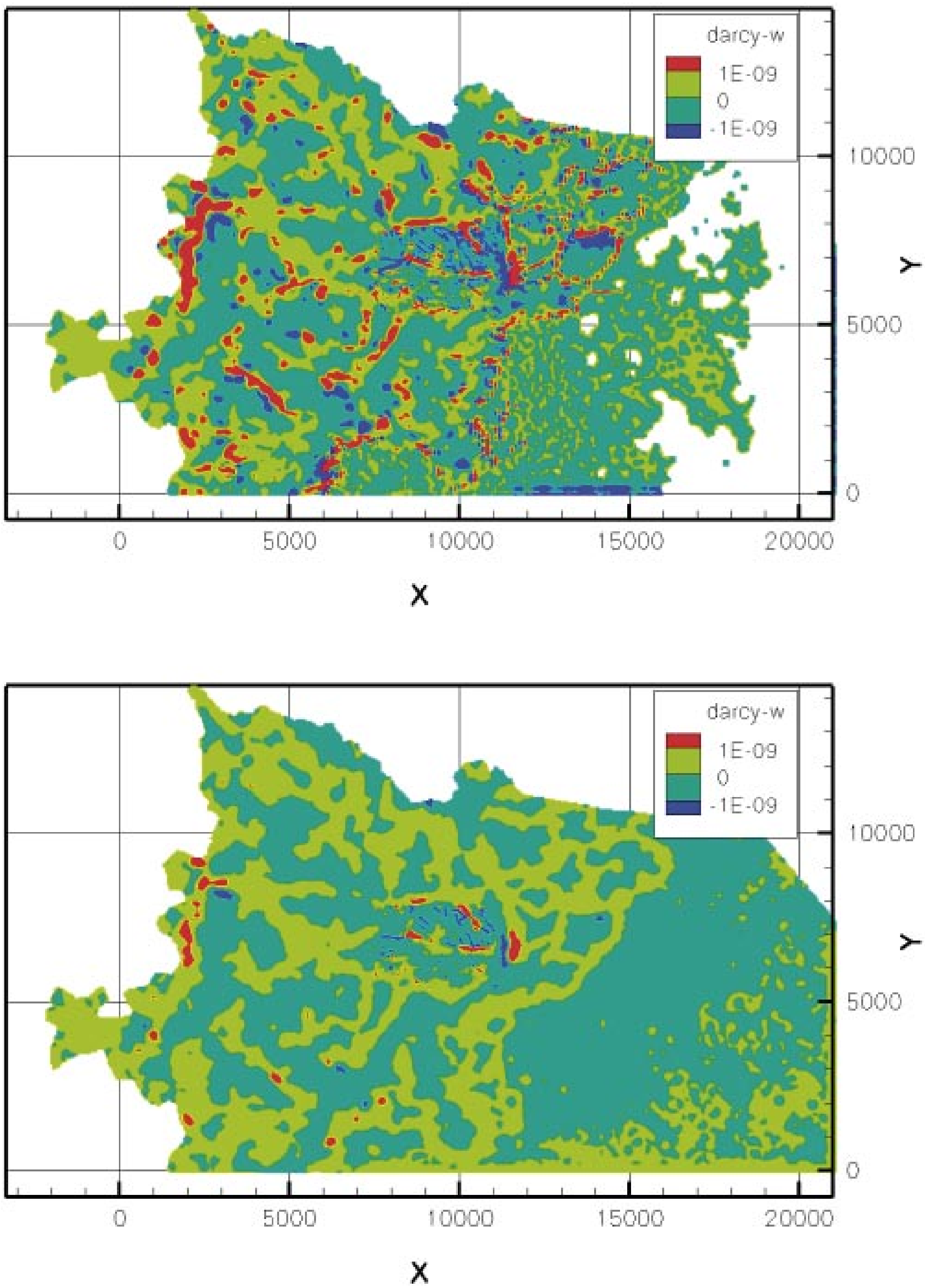


Figure 4-9. *Vertical Darcy velocity distribution at a depth of 10 m below sea level (top) and 70 m below sea level.*

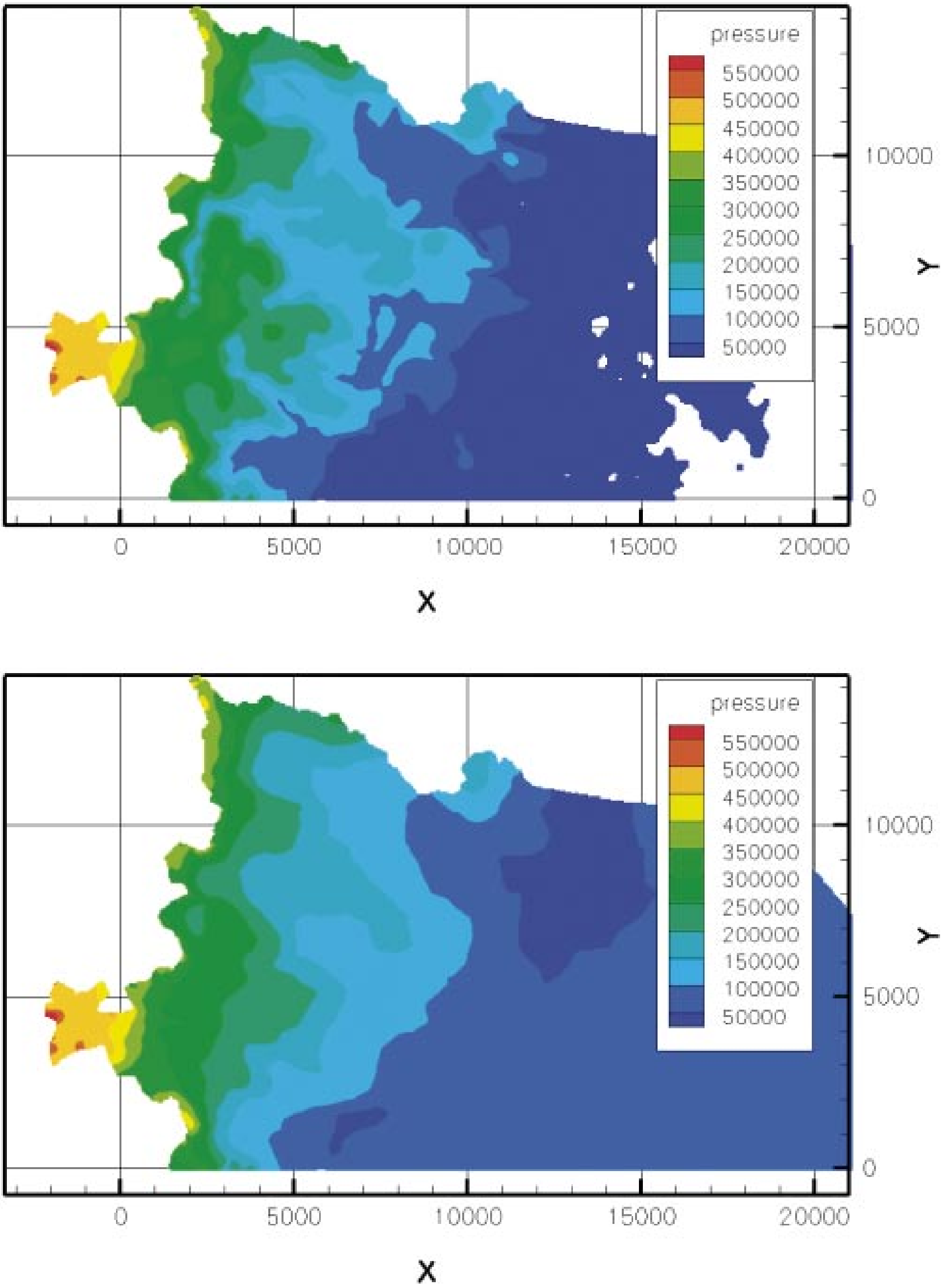


Figure 4-10. *Pressure (excluding the hydrostatic component) (in Pa) distribution 10 m below sea level (top) and at repository depth (525 m below sea level).*

4.3 Open repository

Introduction

The requested results comprise the following:

- A time series of events should be simulated, meaning that different parts of the repository should be closed/open at a particular time. These events will be introduced with reference to Figure 4-11, where the different parts are labelled from A to E. Part A is the ramp and shafts. In the first event, which lasts for seven years, only part A is open. In the second event parts A and B are open for five years. After these twelve years part B is closed and section C is opened and will stay open for 25 years, let us call this period AC. Following this, AD is open for 15 years and finally AE for 15 years. A situation with all parts open, to be called "All open" should also be considered.
- Three different grouting conditions should be evaluated; no grouting, maximum conductivity 10^{-7} m/s and maximum conductivity 10^{-9} m/s in a four metre thick region around the repository.
- The drawdown should be illustrated as the surface area that is lowered 0.3 and 1.0 metre, as compared to virgin conditions.
- Salinity distributions, in particular upconing of salt water from deeper layers, should be reported.
- Precipitation water will be transported downwards due to the open repository. It is of interest to find out if this water will reach repository level.
- Particle tracks from ground level and travel times are also requested.
- Resaturation time should be estimated.

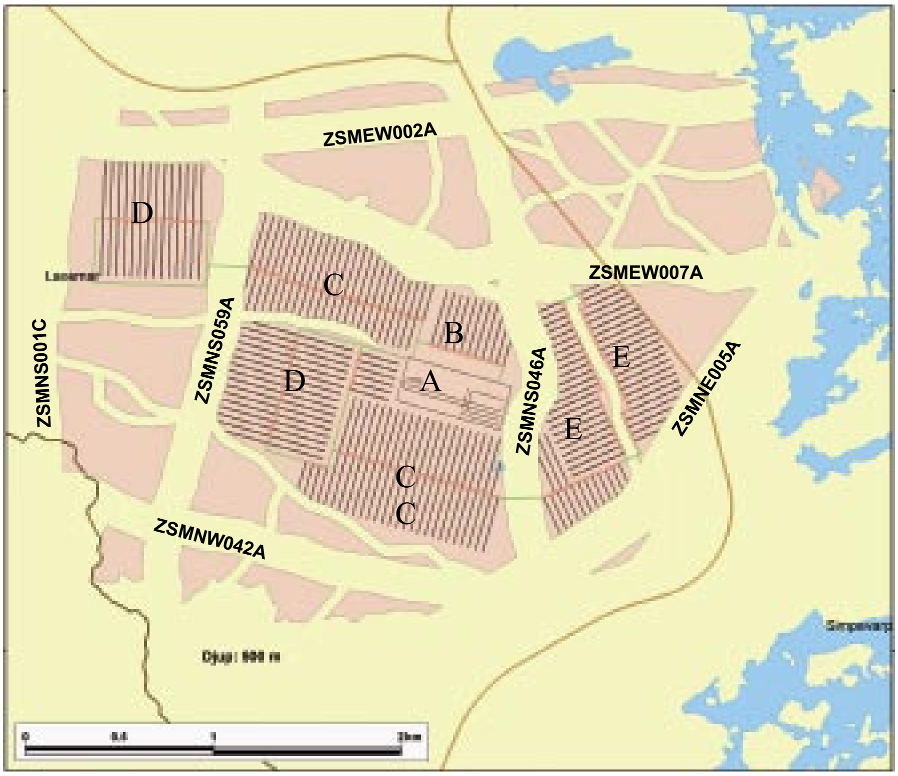


Figure 4-11. *Illustration of different parts of the repository.*

It is not possible (for space if nothing else) to report and illustrate all combinations of the requests listed. There is however another limitation, which deals with the situation considered. It was found that no grouting gives a drawdown that approaches the repository depth (about 525 metres). This can not be handled with the code used and these cases are hence not considered further. Generally speaking, the property conditions specified were sometimes found to require very small time steps in the simulations and that restricted the fulfilment of the requests somewhat.

Inflows

First we will report results for the inflow and the conditions around the repository. In Tables 4-1 and 4-2 the distribution in time for different parts is given for two values on the grouting efficiency. Also the case "All open" is found in the tables.

The pressure around the repository can be studied in Figures 4-12 and 4-13. The first figure illustrates the two cases with all parts open, while the second one shows the distribution for case AE with grouting efficiency 10^{-7} m/s.

Table 4-1. Inflow (in l/s) to different tunnel sections as a function of time. The opening times in year are given in brackets. Max conductivity for tunnel wall cells put to 10^{-9} m/s.

Tunnel section		Open section				
	A (7)	AB (5)	AC (25)	AD (15)	AE (15)	All (5)
A	4.4	4.2	3.7	4.2	4.5	3.2
B		2.2				1.8
C			15.2			12.9
D				9.5		8.2
E					7.2	6.6
Total inflow	4.4	6.4	18.9	13.7	11.7	32.7

Table 4-2. Inflow (in l/s) to different tunnel sections as a function of time. The opening times in year are given in brackets. Max conductivity for tunnel wall cells put to 10^{-7} m/s.

Tunnel section		Open section				
	A (7)	AB (5)	AC (25)	AD (15)	AE (15)	All (5)
A	14.0	13.1	9.6	16.3	18.3	7.8
B		4.1				2.9
C			27.6			21.8
D				15.3		12.2
E					12.7	10.7
Total inflow	14.0	17.2	37.2	31.6	31.0	55.4

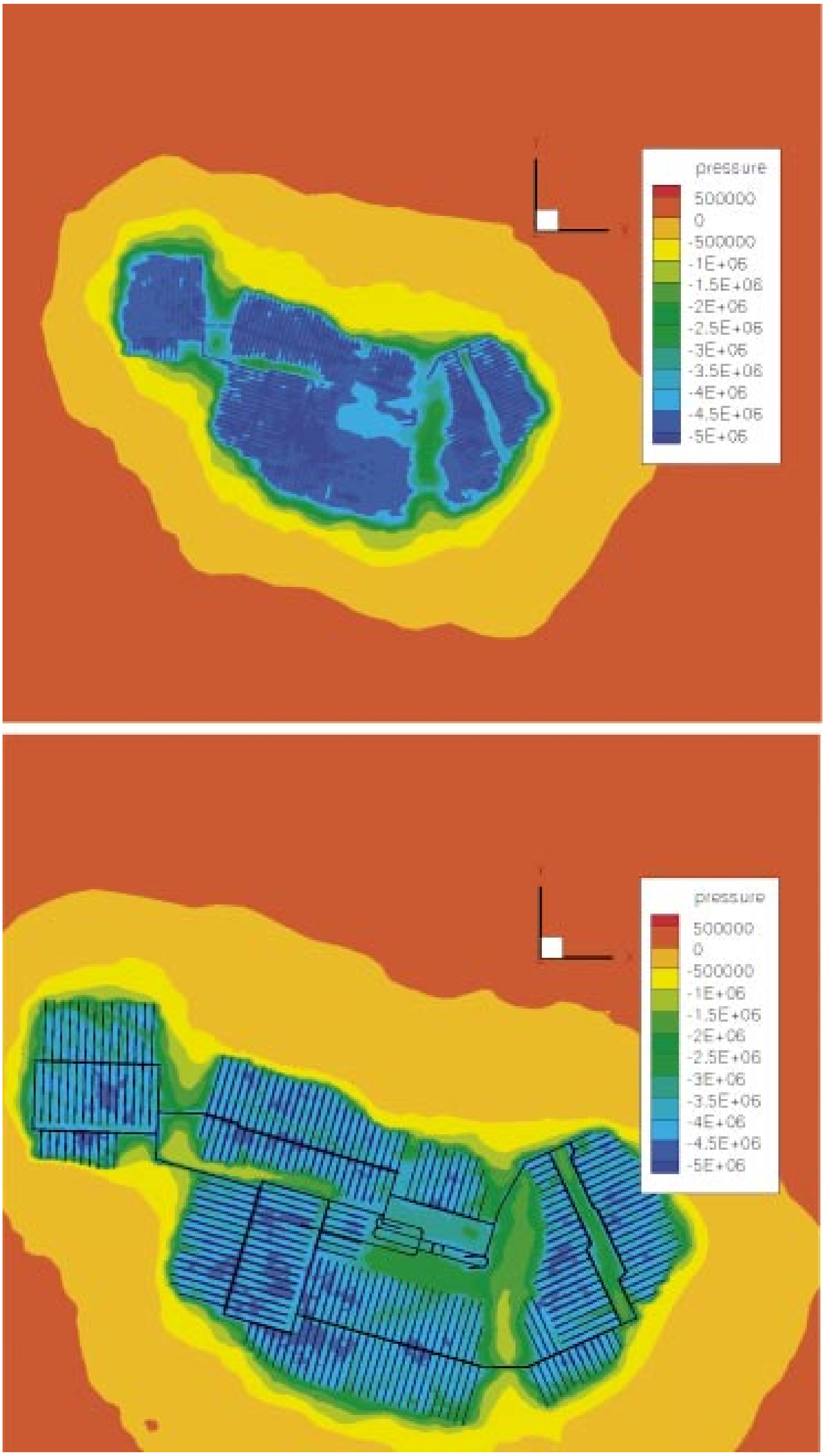


Figure 4-12. *Pressure distribution (excluding the hydrostatic component) at repository depth. Max conductivity 10^{-7} m/s (top) and 10^{-9} m/s, achieved by grouting.*

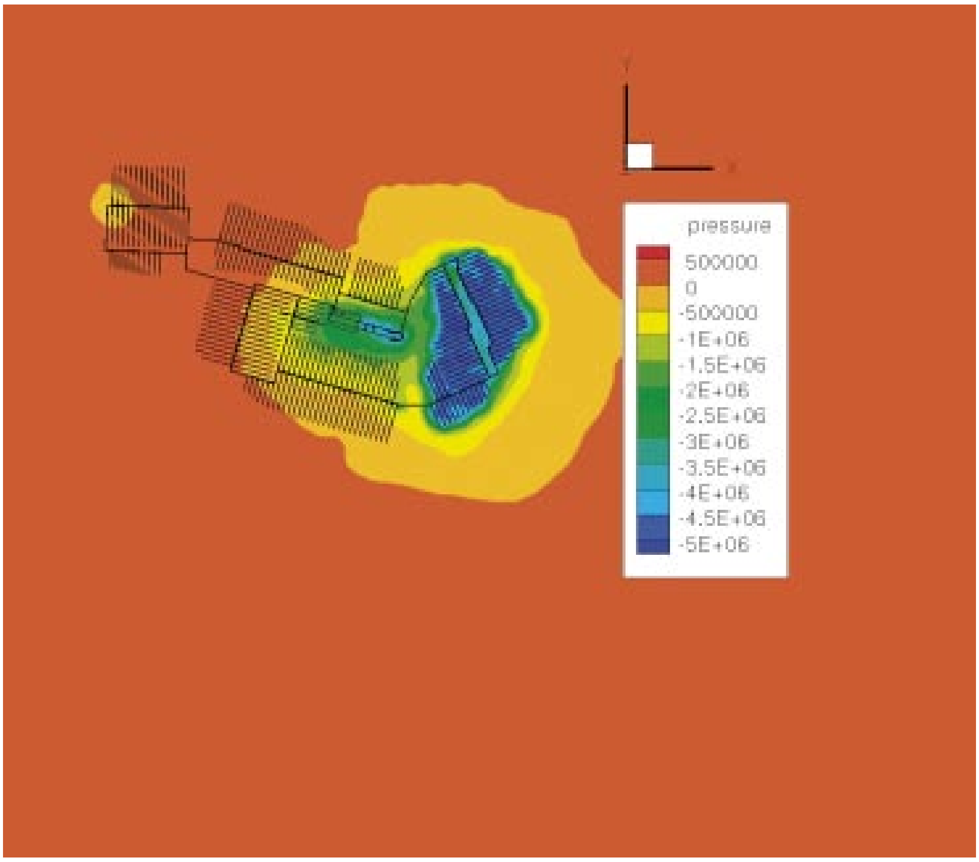


Figure 4-13. *Pressure distribution (excluding the hydrostatic component) at repository depth for case AE and max grouting conductivity 10^{-7} m/s.*

It is clear that the pressure will recover completely when a part is closed and large pressure variations are hence expected during the full sequence of open/closed parts.

Next we look at the flow situation at repository depth, still for the case "All open" and the two grouting efficiencies. In Figure 4-14 the vertical Darcy velocity is shown. One should note that the velocity is negative, i.e. downwards, for most of the plane. It is clear that the deformation zones control most of the flow (see Figures 4-5 and 4-6). This conclusion is supported by Figure 4-15, where the velocity vector at the tunnel walls is plotted. For the grouting efficiency 10^{-7} m/s the velocity scale has been reduced with a factor of three, as compared to the 10^{-9} m/s case.

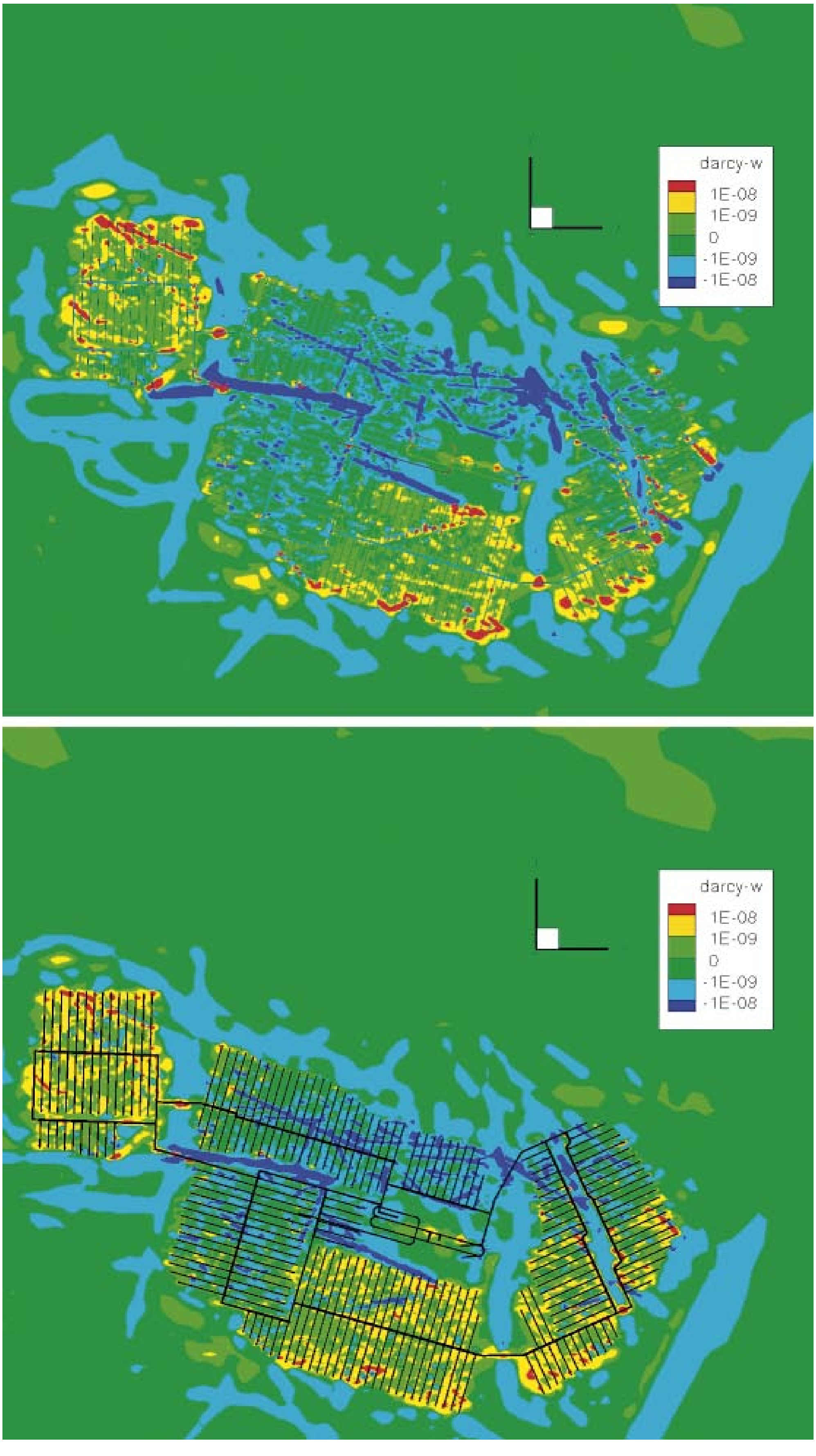


Figure 4-14. Vertical Darcy flux at repository level for case 'All open' and max grouting conductivity 10^{-7} m/s (top) and 10^{-9} m/s.

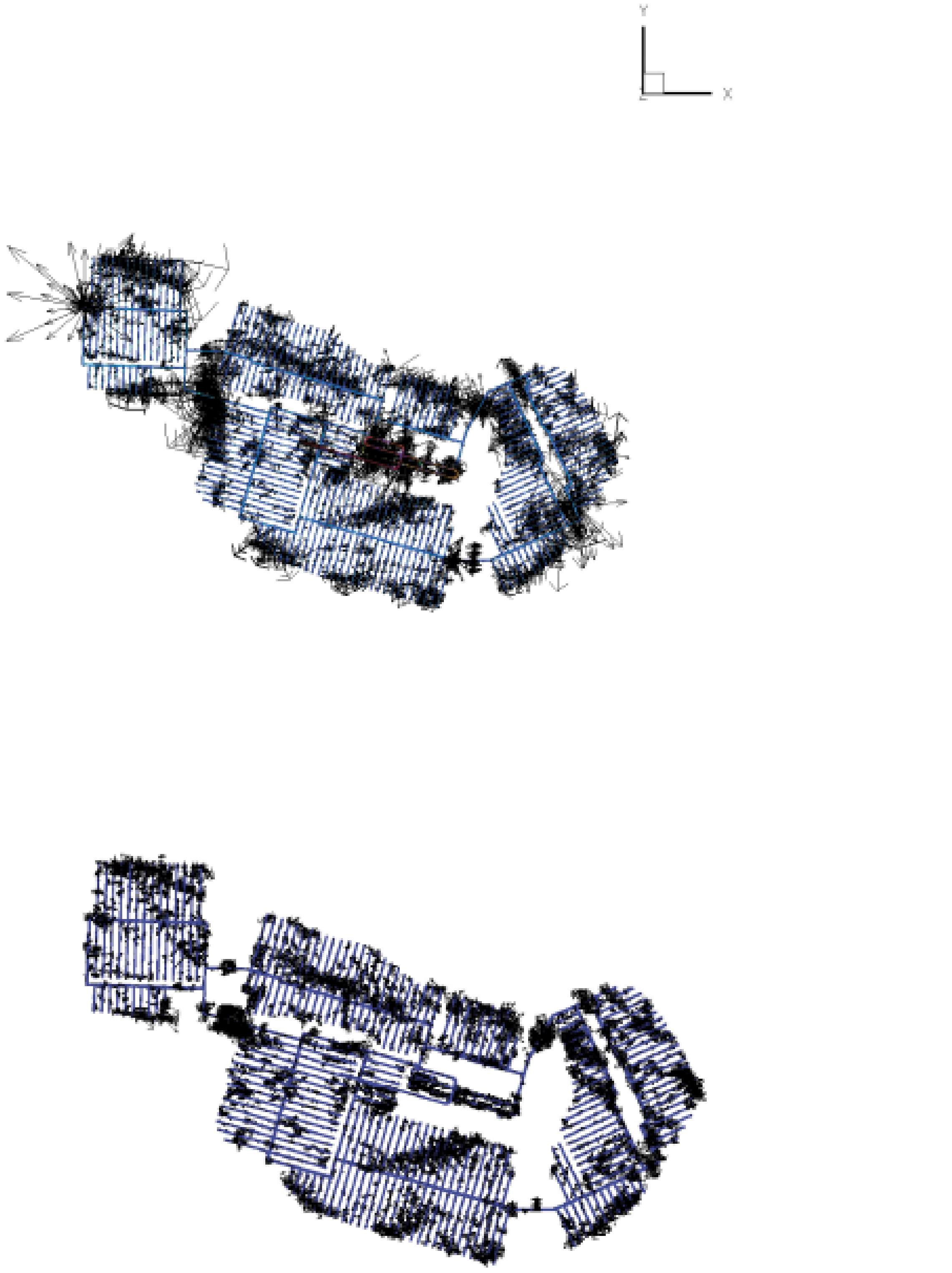
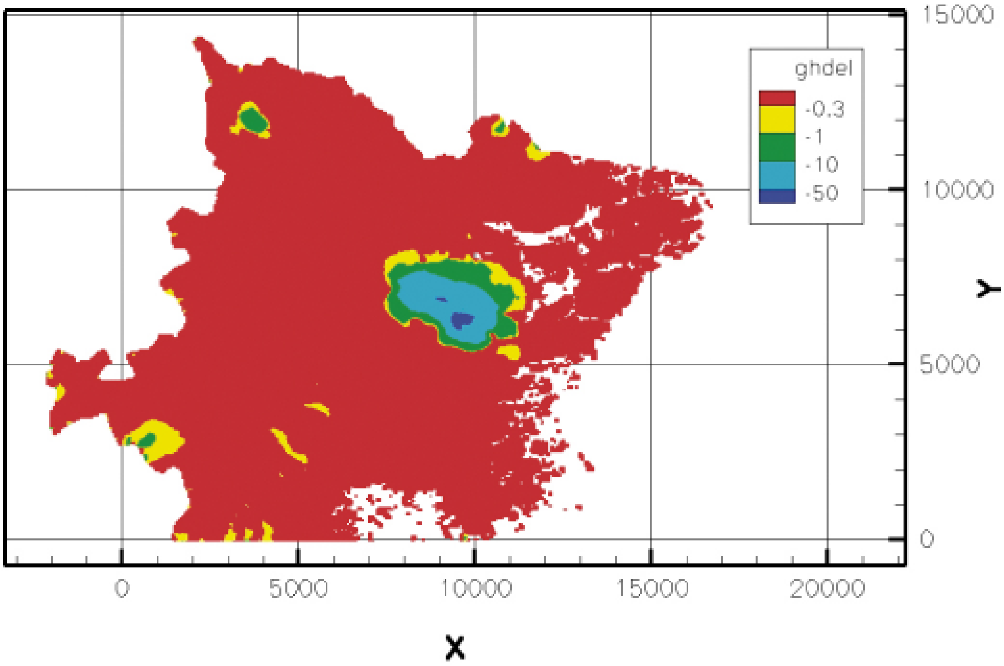


Figure 4-15. *Velocity vectors at tunnel walls for max grouting conductivity 10^{-7} m/s (top) and 10^{-9} m/s. In the top figure the velocity scale is reduced with a factor of three as compared to the bottom one.*

Drawdown

The drawdown picture for the two 'All-cases' is shown in Figure 4-16. As can be seen several km² will get a drawdown exceeding 10 metres.



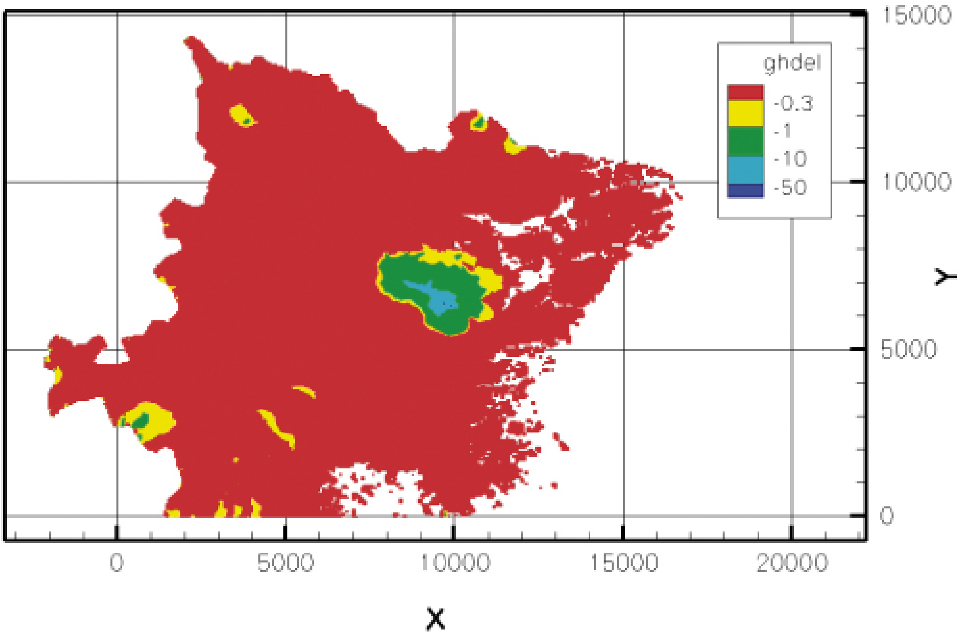


Figure 4-16. *Drawdown at ground level for all parts open. Max grouting conductivity* 10^{-7} *m/s (top) and* 10^{-9} *m/s. Drawdown is calculated with reference to virgin conditions. In the legend ghdel means "groundwater height delta" and it is hence the difference in metres that is shown.*

Salinity

The salinity distributions will be illustrated for case AE, i.e. after the sequences of open/closed parts that lasted for 67 years. The argument for picking this time is that the upconing may need a long time to develop. Results are given in Figures 4-17 to 4-20. The main impressions from these figures are that the upconing is not very pronounced nor is the effect of grouting

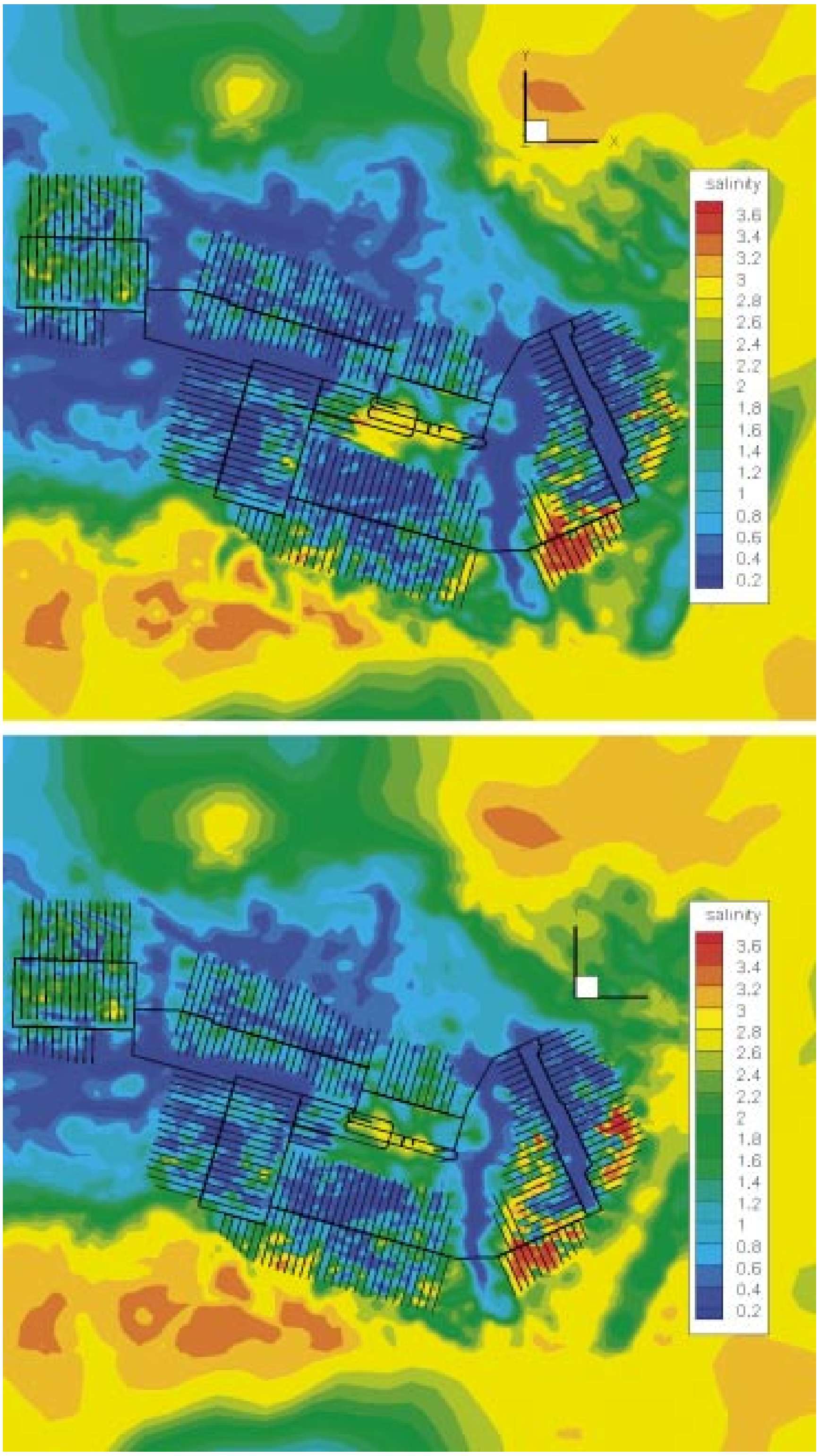


Figure 4-17. *Salinity distribution at repository depth for case AE. Max grouting conductivity 10^{-7} m/s (top) and 10^{-9} m/s.*

efficiency. It is not clear why this is the case; one possible reason is that the repository is located in the fresh water and the response stays above the salinity interface. Another reason could be due to the applied depth trends for conductivity and porosity. One should also note, see Figure 4-20, that a horizontal plane does not tell the whole story. As can be seen in this figure, the salinity can be much higher at the floor of the tunnels, as compared to the roof.

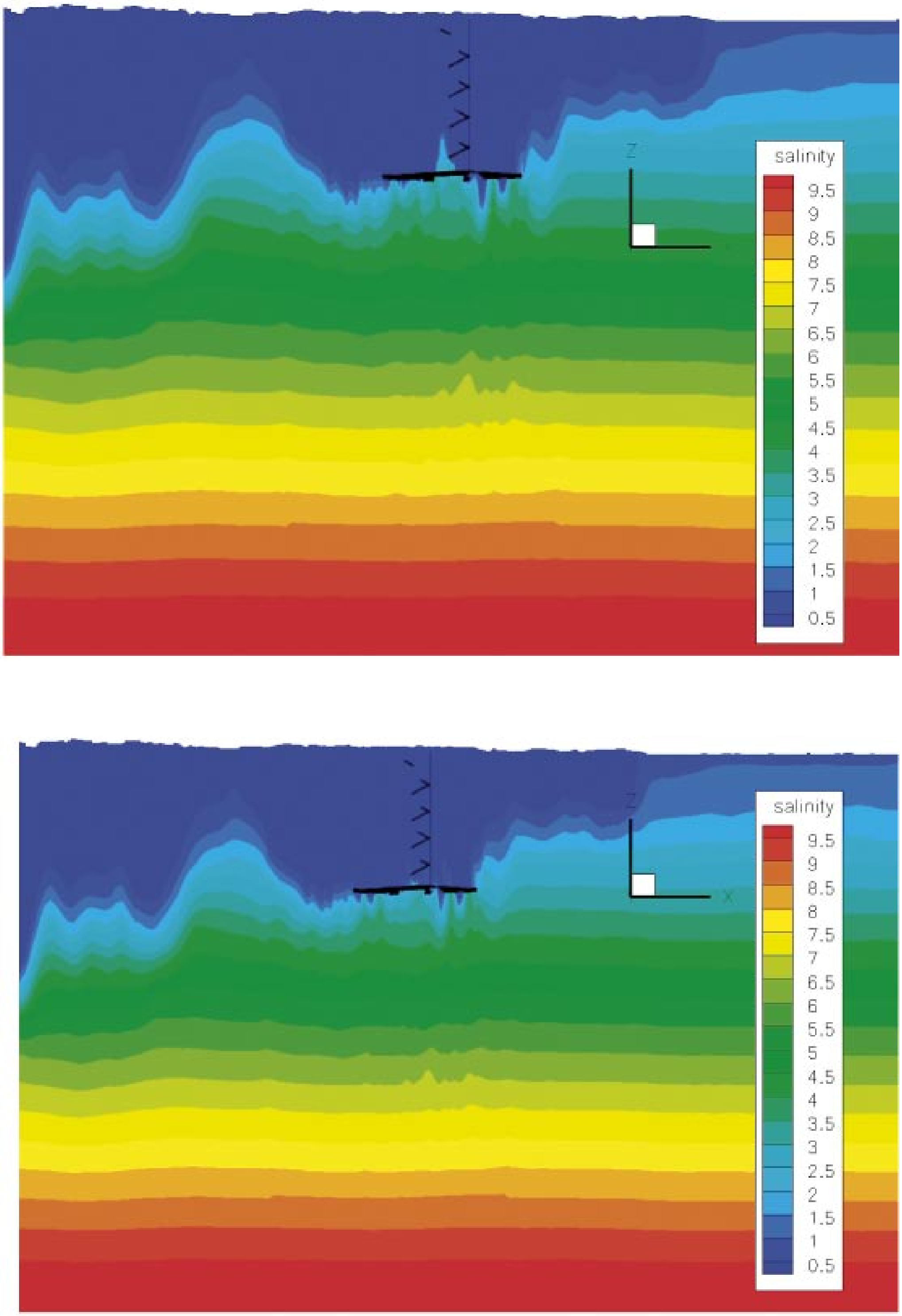


Figure 4-18. *Salinity distribution in a west to east section for case AE. Max grouting conductivity 10^{-7} m/s (top) and 10^{-9} m/s.*

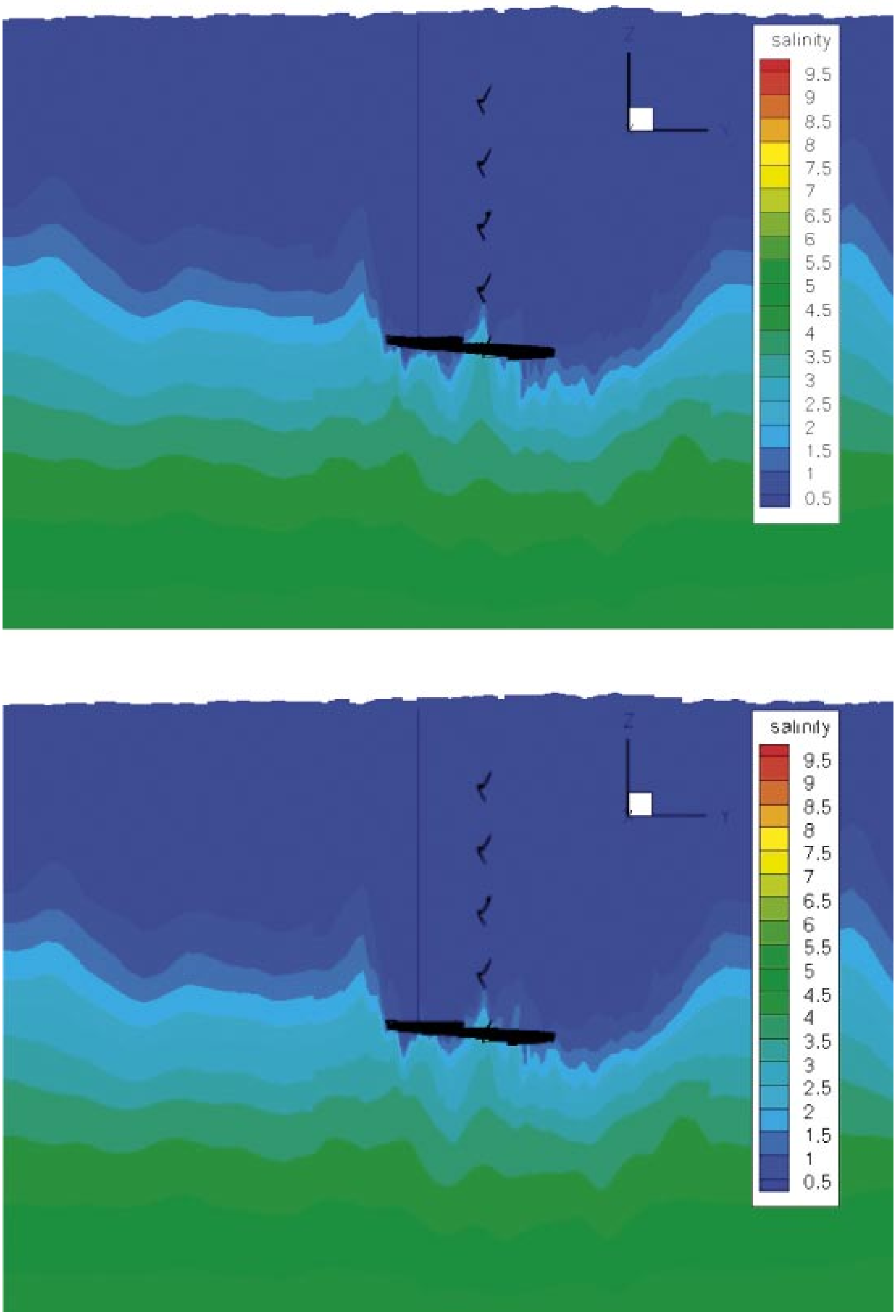


Figure 4-19. *Salinity distribution in a south to north section for case AE. Max grouting conductivity 10^{-7} m/s (top) and 10^{-9} m/s.*

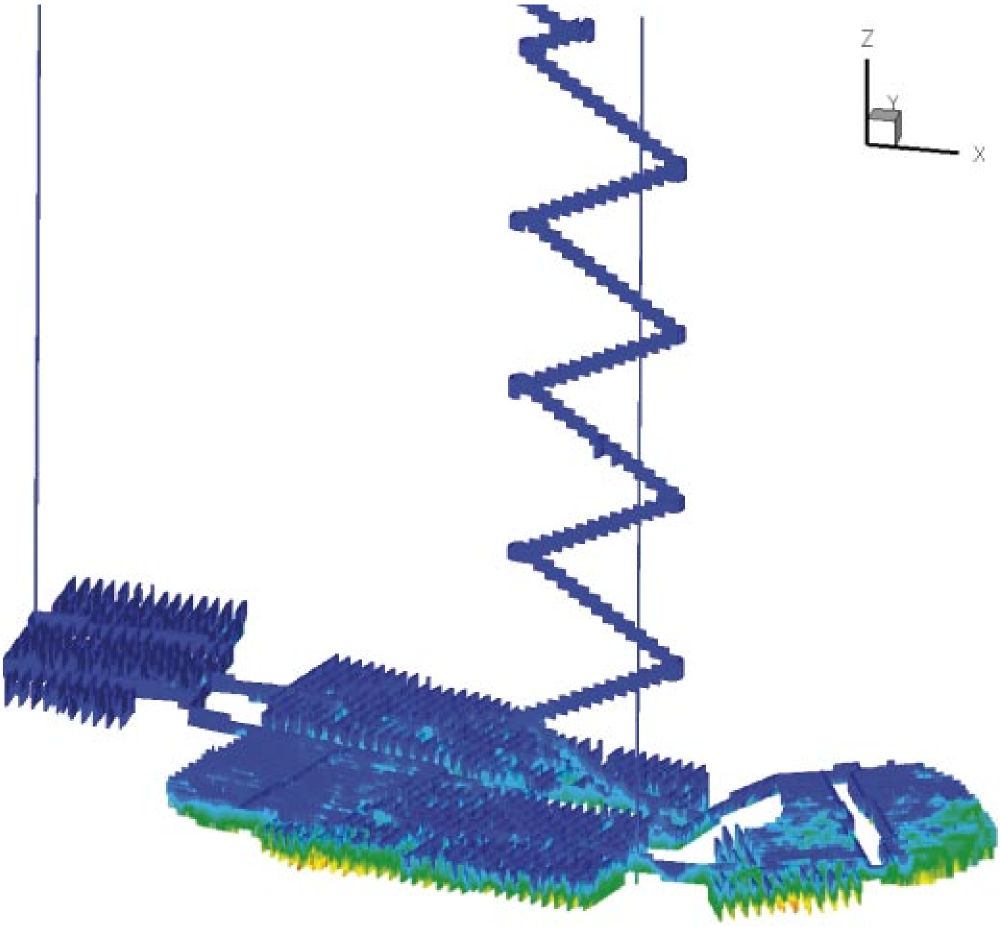


__Figure 4-20.__ Salinity distribution on tunnel walls for case "All Open" and max grouting conductivity 10^{-7} m/s. Note: Salinities range from 0 (blue) to about 3% in this figure.

Precipitation

The distribution of precipitation water after 67 years is shown in Figure 4-21. This figure also shows that the repository depth is dominated by fresh water.

Travel times

Finally the travel times from ground level to repository depth are estimated. As an illustration some trajectories are first shown, see Figure 4-22. One hundred particles were released at 0 m below sea level above part E of the tunnel and tracked to the entrance of the tunnel. Roughly 10% of the particles did not go downwards (probably ended up in the Baltic) about 5% ended in the ramp and the rest in part E. The breakthrough curve, based on 10^5 particles, for the particles ending up in part E can be studied in Figure 4-23. The average transport time is about 12 months.

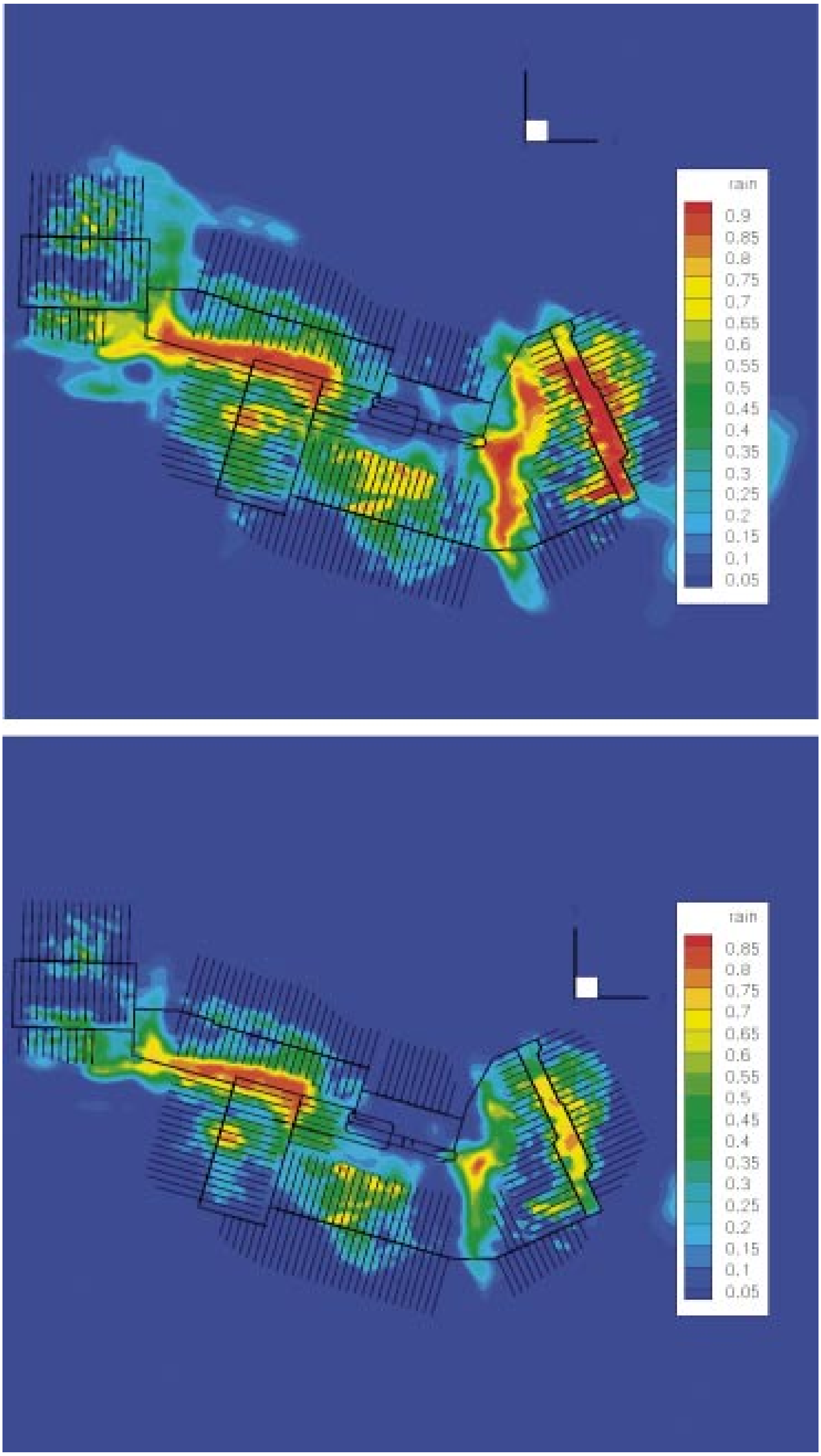


Figure 4-21. *Distribution of precipitation water at repository depth for case AE. Max grouting conductivity 10^{-7} m/s (top) and 10^{-9} m/s.*

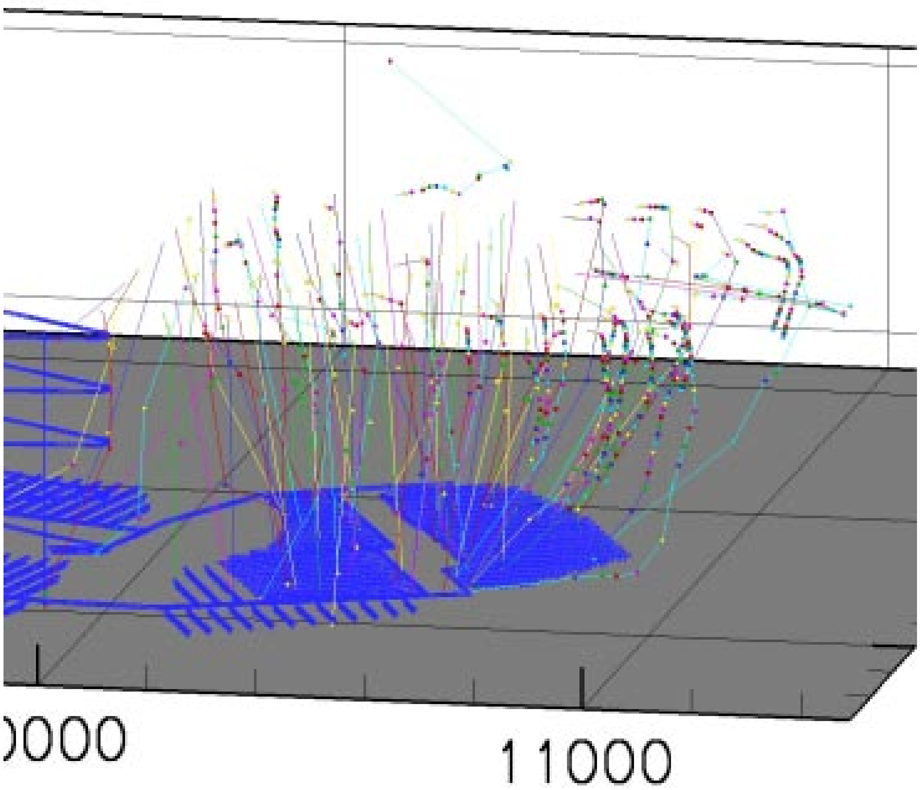


Figure 4-22. *Trajectories from 0 m below sea level to tunnel/ramp. Markers on the trajectories every four months. Case AE with max grouting conductivity 10^{-7} m/s. Tunnel part E shown for orientation; see also Figure 2-2.*

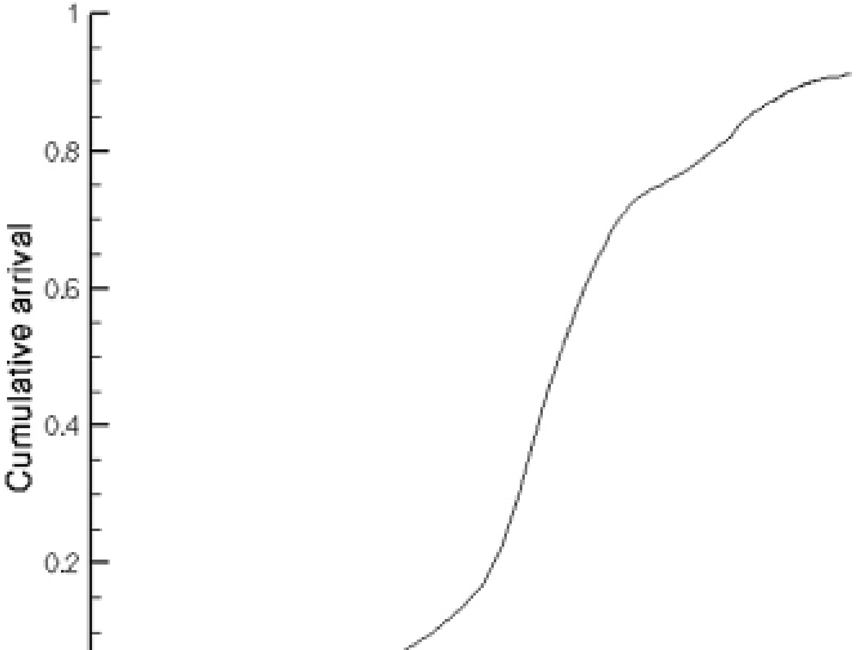


Figure 4-23. *BTC for particles entering tunnel part E. Case AE with max grouting conductivity 10^{-7} m/s.*

4.4 Resaturation phase

One of the objectives of the present work is to estimate the time for resaturation of the backfill. When the backfill is placed in the tunnels, one can expect that the voids are partly filled with water and partly with air. During the saturation process the trapped air thus has to escape somehow (dissolved in the water or rising in form of air bubbles) and the pore space is filled with water. This is a two-phase problem. An illustration of the process is given in Figure 4-24. The transport of water is governed by two processes, a Darcy-flux with a conductivity which is a function of the saturation level and a suction present in the unsaturated part. DarcyTools does not account for two-phase flow and a method that simulates the process by a single-phase approach is therefore sought for. In Figure 4-24 such an approach is illustrated. The storativity term is used to "create" new open volume and a modified conductivity is employed. As we know the total pressure rise (from atmospheric to hydrostatic pressure at repository depth) a suitable storativity coefficient can be chosen. In a two-phase simulation the reduction of the conductivity due to the saturation level may be several orders of magnitude. In the suggested method we expect c_{sat} to be smaller than 1.0, but the reduction should be less dramatic as the suction is neglected and now has to be accounted for by the Darcy flux. The coefficient c_{sat} has to be found from a calibration and can of course not be expected to be general, i.e. it needs to be calibrated for conditions similar to the application in mind.

In the Forsmark Open repository study /Svensson 2005b/ some basic tests of the approach were reported. Here we will continue to evaluate the method by an application to a realistic tunnel geometry. Tunnel part B is used for the test. First the steady state situation with an open tunnel is calculated, then the transient resaturation phase is simulated, see Figure 4-25. The simulation indicates that most of the pressure recovery is achieved in six years. The conductivity of the backfill was put to 10^{-10} m/s in this simulation.

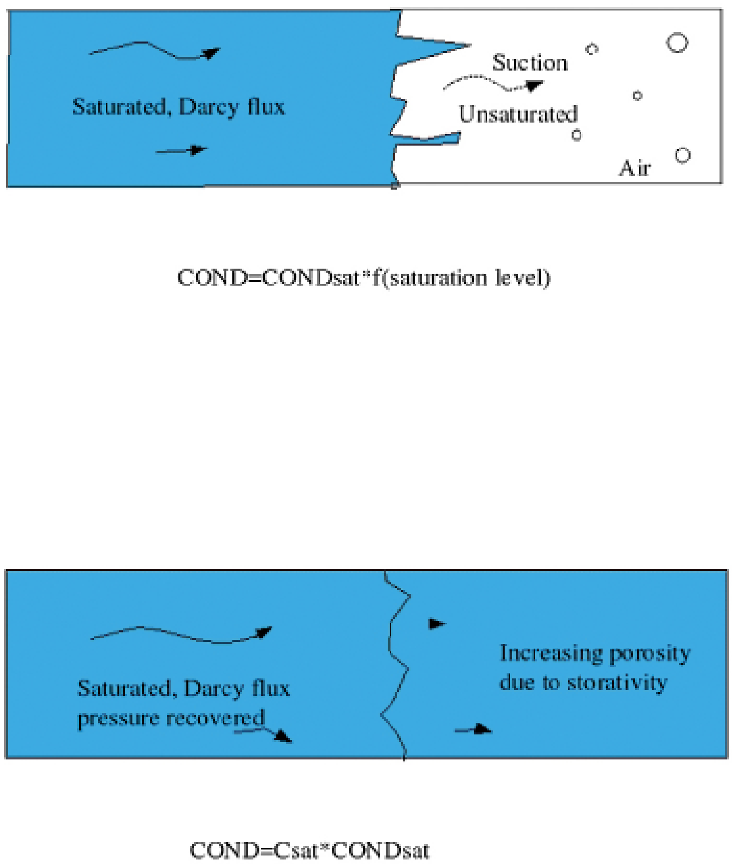
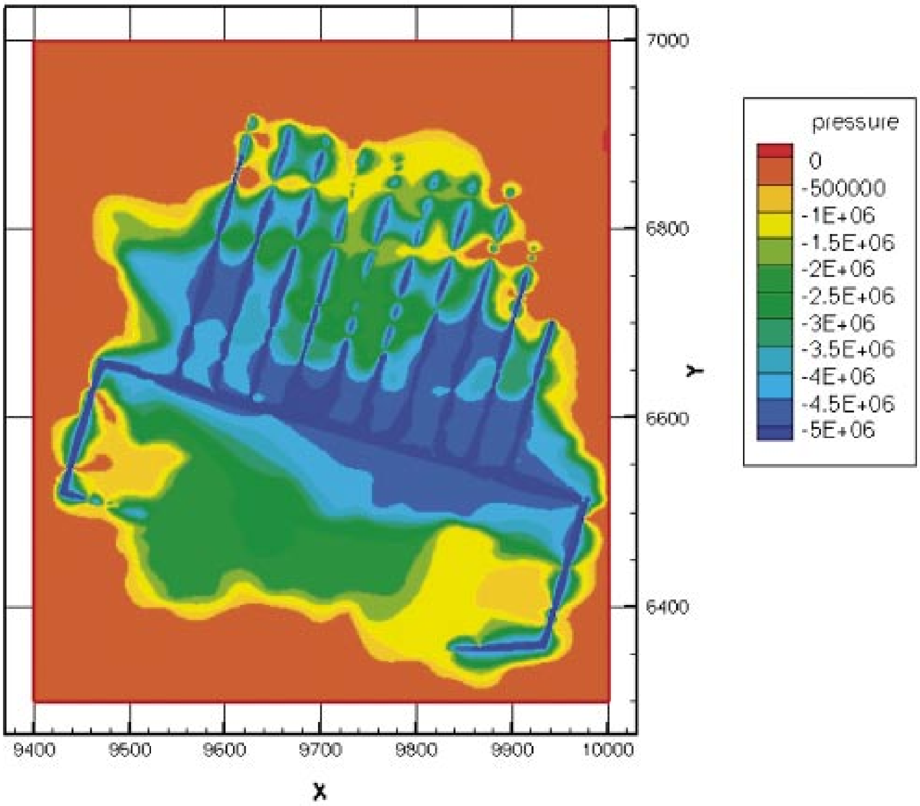


Figure 4-24. *The saturation process. Illustration of physical processes (top) and the approach tested in the present work.*

It should be emphasized that the approach suggested has not yet been properly evaluated and calibrated; the test is hence a feasibility study.



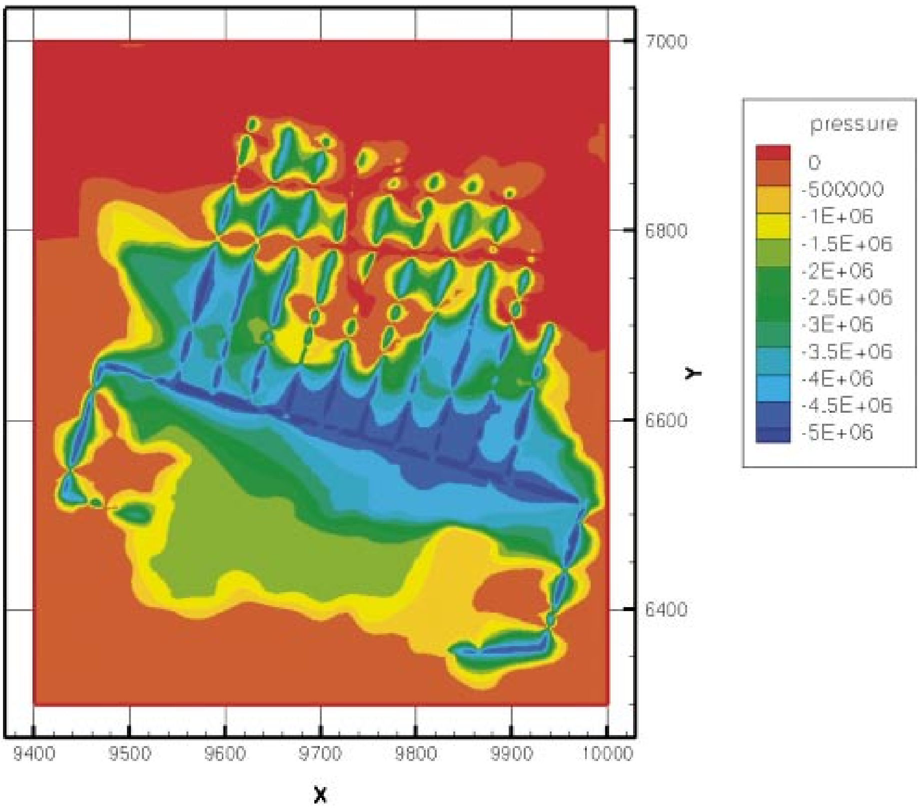


Figure 4-25. *Resaturation of tunnel part B. Steady state initial, i.e. open tunnel, conditions (top) and pressure (excluding the hydrostatic component) distribution after 50 days.*

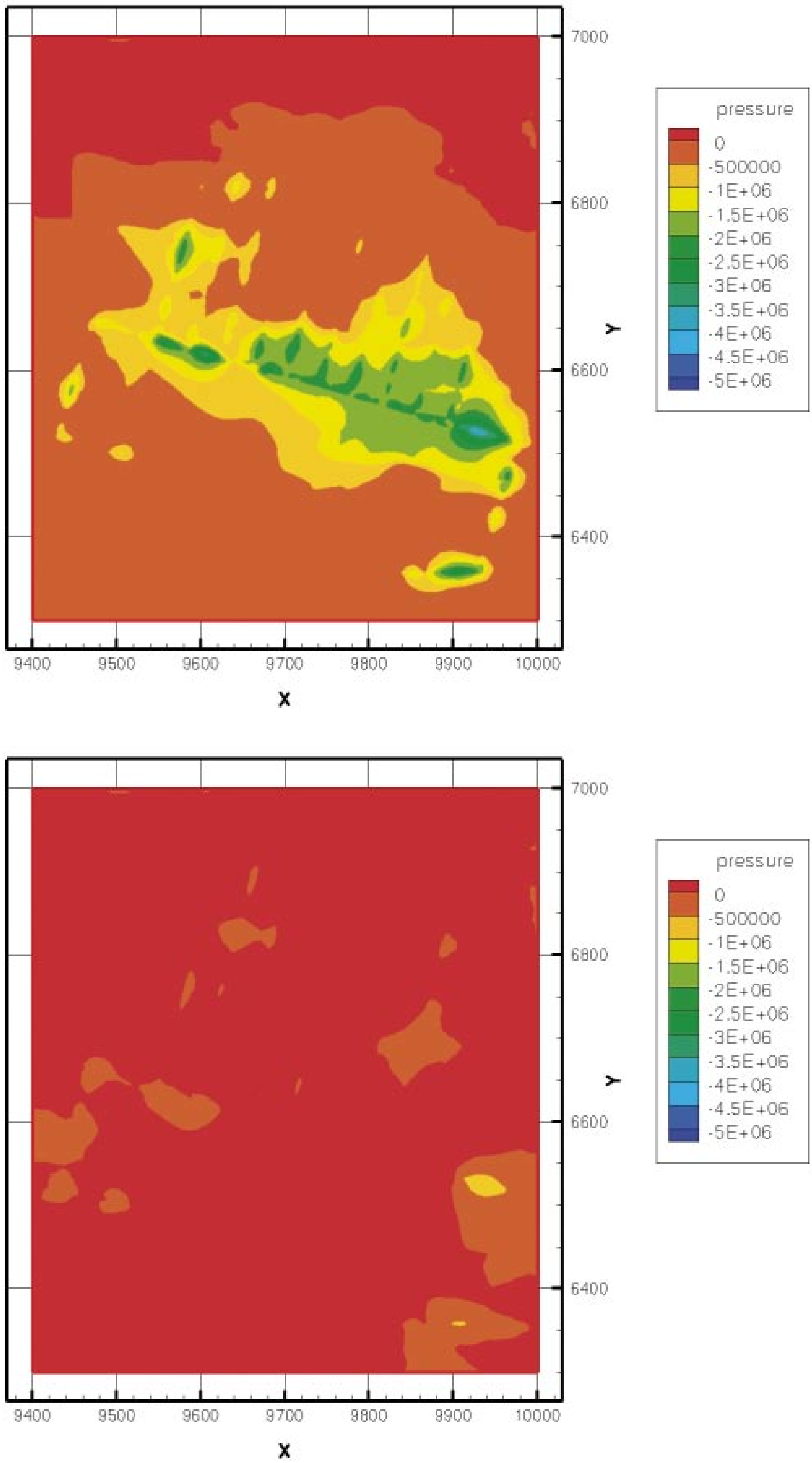


Figure 4-25, cont. *Pressure distribution (excluding the hydrostatic component) after 2 years (top) and 6 years.*

5 Discussion

Simulations of the kind presented in this report are still far from "routine calculations" and should hence be regarded as tentative. The best way to get the simulations on a firm ground is to identify uncertainties and possible further developments/actions and then to carry out these tasks. For the Laxemar Open Repository modelling the following uncertainties and possible improvements have been identified:

Uncertainties

- The fracture network. Both the Deformation zones and the stochastic part (DFN) need to be specified more accurately. This is in a way an obvious statement as it is the network that controls the flow to/from the repository. Nevertheless, the intensity of the DFN seems to be very high.
- The properties of the near ground layer, say top 20 metres, have here been set based on "earlier experience" and some test simulations. It is presently not clear how sensitive the drawdown calculations are to these properties.
- Recharge at ground. A constant value of 165mm/year has been used in this work. Should this value be affected by the drawdown cone? If a larger value should be specified above the depressed ground water table a smaller influence area may result.
- DarcyTools V3.0. The code is still in a β-stage and requires more tests and applications before it can be expected to be "close to bug free".

Possible Improvements

- The main improvement, that should result in increased confidence in the results, is probably related to calibration and sensitivity exercises. Comparisons with surface hydrology data are possible to carry out, while tunnel inflow calibrations are harder to do (comparisons with analytical solutions have been carried out, but these do not test the quality of the fracture network, which is what is needed).
- The surface hydrology part of DarcyTools can be improved in many respects.

6 Conclusions

In the earlier Open Repository projects it was concluded that "the fact that the requested type of calculations can be carried out" is a conclusion worth mentioning. The present study extends the capabilities by considering a sequence of open/closed tunnels and some new experiments on a methodology for the resaturation phase. We can hence conclude that the methodology is progressing in a satisfactory way.

Regarding the results the main conclusions can be summarized as follows:

- The inflow to tunnels and deposition holes will be of order 60 l/s for the lower grouting efficiency (maximum conductivity 10^{-7} m/s) and about 30 l/s for the higher efficiency. Considering the uncertainties of the simulations one should not draw any conclusions from the difference between, for example, the case "All parts open" and the different inflows in the sequence of open/closed parts.
- The drawdown area will be significant. For both the grouting cases an area of about 10km^2 will get a ground water table that is depressed by 0.3 metre or more.
- The upconing of salt water seems to be small for the cases considered.
- Precipitation water will reach repository depth during the open phase of the repository.

7 References

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