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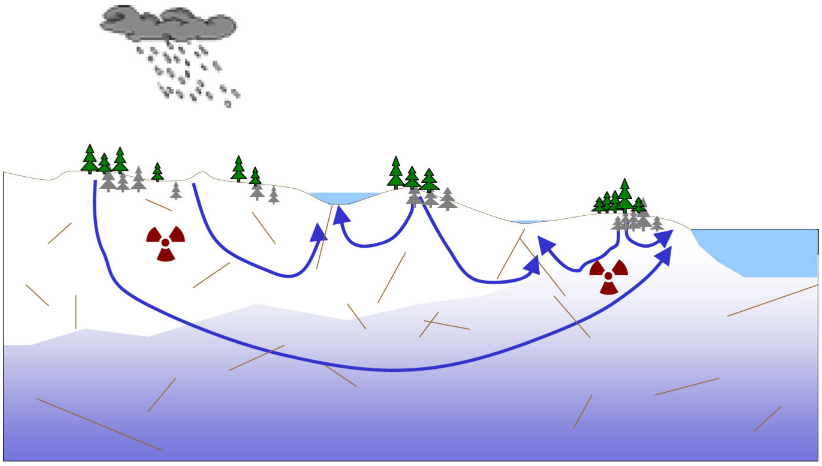
SSI:s granskning av SKB:s storregionala grundvattenmodellering för östra Småland
(SKB Rapport 06-64)

Björn Dverstorp



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TITEL/ TITLE: SSI:s granskning av SKB:s storregionala grundvattenmodellering för östra Småland (SKB Rapport 06-64/ SSI's review of the Swedish Nuclear Fuel and Waste Management Co's (SKB) report on large-scale groundwater flow modelling for eastern Småland in Sweden (SKB Report 06-64).

SAMMANFATTNING: Denna rapport redovisar SSI:s granskning av Svensk Kärnbränslehantering ABs (SKB) fördju-pade analys av storregionala strömningsförhållanden i östra Småland (SKB Rapport 06-64). Som stöd för granskningen har SSI anlitat två externa experter, Anders Wörman vid KTH i Stockholm och Clifford Voss från USGS i USA, vars rapporter redovisas som bilagor.

Granskningen har genomförts inom det samråd som SKB enligt ett regeringsbeslut håller med SSI och Statens kärnkraftinspektion (SKI) om platsundersökningarna för ett kärnbränsleförvar, vilket innebär att synpunkterna i denna granskning ska ses som ett allmänt råd till SKB. SSI:s bedömning är att SKB:s studie är väl genomförd och att den bidrar till en ökad förståelse för olika faktorer av be-tydelse för grundvattnets strömningsmönster. SSI anser dock att utvärderingen av beräkningsre-sultaten är otillräcklig för att kunna dra entydiga slutsatser om betydelsen av storregional grund-vattenströmning som lokaliseringsfaktor för ett slutförvar.

SSI anser därför att SKB bör komplettera sin studie på ett antal punkter och även illustrera vad resultaten innebär för bedöm-ningen av slutförvarets långsiktiga skyddsförmåga. SSI anser även att SKB bör utreda vissa mo-dellosäkerheter som kan ha påverkat beräkningsresultaten. SSI kommer att göra en samlad be-dömning av hur SKB beaktat olika lokaliseringsfaktorer i sitt arbete med att finna en lämplig plats för ett slutförvar i samband med granskningen av SKB:s planerade tillståndsansökan 2009

SUMMARY: This report presents SSI's review of the Swedish Nuclear Fuel and Waste Management Co's (SKB) report (SKB Report 06-64) on large-scale groundwater flow modelling for eastern Små-land in Sweden. SSI review is supported by two external review documents (included as appen-dices) by prof. Anders Wörman (the Royal Institute of Technology in Stockholm) and Dr. Clifford Voss (United States Geological Survey in Reston, USA).

SSI's review is part of a go-vernment decided consultation process on SKB's site investigations aimed at finding a suitable site for a spent nuclear fuel repository. SSI considers that SKB has presented a comprehensive study that contributes to the scientific understanding of how different factors influence the regio-nal groundwater flow pattern. However, in SSI's opinion, SKB's evaluation of the modelling results is not complete enough to support SKB's conclusion that superregional flow conditions can be dismissed as a siting factor. SSI therefore recommends SKB to supplement their study in that respect and also to discuss the implications of identified differences in radionuclide travel times and migration distances on the overall assessment of the repository's long-term protective capability.

SSI also recommends SKB to revisit some of their modelling assumptions to ensure that the model is set up in a way that does not block out large groundwater circulation cells. SSI's recommendations in this review should be regarded as guidance to SKB. SSI will make a formal assessment of how SKB has taken into account different siting factors, in connection with the review of SKB's license application to be submitted in 2009.

Statens strålskyddsinstitut
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Innehållsförteckning

Bilaga 2. Clifford Voss granskning av SKB R-06-64

Technical Review for SSI of: ”Storregional grundvattenmodellering – fördjupad analys av flödesförhållanden i östra Småland. Jämförelse av olika konceptuella beskrivningar” by L.-O. Ericsson, J. Holmén, I. Rhén and N. Blomquist, SKB R-06-64, May 2006.

Clifford I. Voss, U.S. Geological Survey

30 August 2006

This review consists of five parts.

1 - Overview: A great quantity of insightful analysis has been done to evaluate the groundwater flow field in eastern Småland and to evaluate and report factors that control the length of paths from repositories located at 500 m depth. However, the report and model analysis does not address a key point underlying the questions noted by the authorities – whether (inland) sites with good properties of the hydrogeologic barrier exist in the region and whether any of these are better than the (coastal) Laxemar site. The hydrogeologic barrier is more effective in containing potentially released radionuclides from a repository when path length and transport time from the repository site to the termination point of the release path at the surface are greater. The reviewed report shows maps of locations of such sites for various modeled cases, but does not select good inland sites and compare them with Laxemar.

2 - General comments on the report, modeling assumptions and techniques: This list includes a variety of technical comments.

3 - Assumptions that tend to shorten lengths of modeled flow paths: This list mentions important model features that are included in most model cases devised for this study. These features (particularly shallow model bottom and decreasing hydraulic conductivity with depth) tend to cause modeled path lengths to be relatively short in all modeled cases. Evaluation of the impact of these features on the effectiveness of the hydrogeologic barrier was not done fully and independently for each and was most often included in a modeled case that contains other features that also reduce path length. Thus, the results reported come from a conservative analysis of the flow fields in the region, reducing the potential superiority of recharge-area sites (inland) over discharge area sites (e.g. near the coast).

4 - Comparison of sites using 7 modeled cases: Despite the conservativeness of the model analysis, inland sites with good properties in 7 modeled cases were selected by this reviewer and one was compared to Laxemar to demonstrate what the next steps should be. The selected example site is superior to Laxemar overall, in terms of both primary hydrogeologic barrier factors that control radiologic consequences of releases from a repository to the surface environment, path length and travel time.

5 - Conclusions

6 - References

1- Overview

General procedure: I am impressed with both the quality and great quantity of geological and analytical work that was done and reported by the authors, Ericsson, Holmén, Rhén and Blomquist (2006) (herein referred to as EHRB) and I congratulate them on their excellent effort and excellent results. The authors have followed the basic approach to finding sites that have good hydrogeologic barrier properties that I set out in Voss and Provost (2001), in my review (Voss, 2003) of SKB's response report, Follin and Svensson (2003), and in a subsequent series of lectures I presented in Sweden (Voss, 2004a, 2004b, 2005a, 2005b, 2005c).

The approach I suggested builds on the idea that due to implicit and permanent uncertainty in our knowledge of the hydrogeologic structure and parameters of the Swedish bedrock, it would be necessary to create many candidate models of a region and then find sites that have good hydrogeologic barrier properties (mainly long path lengths and travel times for nuclides that may leak from a repository) in all or many of these representations of the region. If a site has good predicted properties in all or many possible conceptual models of the bedrock, then it will most likely have good properties in the true bedrock, which has properties that will never be known with certainty, even after extensive field characterization. This approach should provide the most reliable results possible in the face of our uncertainty in the bedrock structure and properties, and should select places that have good hydrogeologic barrier properties irrespective of which conceptual description of the bedrock is used. To express this another way, this means that, no matter how we believe the hydrogeology of the site to be, it will still have good barrier properties. As mentioned above, EHRB generally followed this approach and they provided maps of sites within their model domain that have good barrier properties.

In this review, the path length and travel time will be referred to as 'primary hydrogeologic barrier factors' that control radiologic consequences of releases from a repository to the surface environment. These are key parts of the "F-parameter", which is the most accepted measure of the hydrogeologic barrier's ability to retard decaying radionuclides before their arrival at the surface environment. This review focuses on the impact of these two parameters on site selection.

Note that EHRB spent much effort evaluating the impact of two other factors besides path length and travel time, the *groundwater flux through the site* and the *direction of flow at the site (upward or downward)*. These latter factors do not have as much influence on the retardation of radionuclides as do path length and/or travel time and may be considered of lesser importance. When finding good sites, it is sufficient to find sites with either long paths or long travel times to increase hydrogeologic barrier function. The authors concluded their work by attempting to identify sites that simultaneously optimize as many as 3 or 4 of these factors, and in doing so, reduced the number of good sites that could be produced by their analysis.

Note also that most conceptual models EHRB selected for analysis tend to reduce the length of flow paths. Most models considered have a shallow bottom and decreasing hydraulic conductivity with depth, making the bottom 'feel' even shallower to the flow system. Whether these two factors are correctly specified in this manner is highly uncertain, but EHRB chose to assume that these would be included in most models. Thus, the flow field analysis should be considered to be highly conservative (i.e. providing highest certainty) for selection of good sites, inasmuch as most models will produce relatively short flow paths compared to other model concepts that could have been used.

A major criticism of the work presented, from the point of view of what I believe the Swedish Authorities expected, concerns the fact that EHRB have not brought their analysis to pertinent conclusions in their report about the relative safety of sites. The ambitious analysis presented remains rather academic, reporting only results of a sensitivity analysis that elucidates the model factors most important in controlling the existence of short and long flow paths in the region. These are reported to be 1- the undulating topography of the water table, and 2- the vertical distribution of permeability. This result is certainly valuable general knowledge, but it is only the first step in the type of analysis that SKB needs to do. What do the current results imply about better and worse repository locations in the region in terms of safety derived from the hydrogeologic barrier – the main question? The authors never mention any rating or comparison of alternative sites in terms of hydrogeologic barrier factors in their actual analysis and conclusions. The authors never mention how the Laxemar site compares with other places within the studied area.

Review of EHRB's conclusions: The authors conclude that inland sites do not generally have longer paths and travel times than do coastal sites. (No one had ever anticipated the opposite, as only particular inland locations in major recharge areas would have the expected good properties.) The authors then conclude that there are particular contiguous regions with good hydrogeologic barrier properties that exist, irrespective of which conceptual model of the bedrock is used as the basis of their model. This reported result is exactly in the spirit of the analysis that I had suggested. The authors end by saying that when more hydrogeologic barrier parameters are optimized simultaneously, fewer good sites can be identified. They focus on the inclusion of the magnitude of groundwater flux through a site as a parameter that, when included in the optimization, greatly reduces the number of sites with good barrier properties. They finally point out that this local groundwater flux through a site depends strongly on local structure and hydraulic parameters, which must be measured by a local field program – and so cannot be evaluated in a regional analysis.

Lack of site comparisons: In not going further with the analysis and discussion, the authors leave the impression in their report that, if all models are considered simultaneously and with equal likelihood, there are no advantageous repository sites in the region when simultaneously optimizing path length, travel time and other factors such as amount of groundwater flux through the site. I would point out that this would imply that Laxemar is as good as any other site in the region, in terms of the hydrogeological barrier function. It is clear from SKB's point of view why this was a politic way to end the discussion of their analysis. However, the authors never compared sites in the model with one another and thus never proved this.

The current and previously-considered candidate repository sites are never shown on the maps presented in the subject report. I drew in approximate locations for Hultsfred and Laxemar sites (Figure 1) and compared these sites with key figures 7-1 through 7-9, of EHRB, which show the 'best locations' for the hydrogeologic parameters of importance, at least among some of the conceptual models preferred by the authors for the comparison. The best locations never occur in the Laxemar site, and some of the best locations are within or just east of the eastern margins of SKB's Hultsfred east candidate site of a few years ago.

Implications for SKB: If other sites were found by EHRB to have better hydrogeologic barrier function than Laxemar, it might be difficult for SKB to present such results without calling into question the optimality of hydrogeologic safety margins of the Laxemar site. Indeed Sweden's Radiation Protection Act (1988:220) and the regulations implemented by the Swedish Radiation Protection Authority (SSI, 1998), require that the principles of best available technique and optimization must be employed when developing repositories for spent nuclear fuel and nuclear waste. These requirements are further developed in SSI's guidance (SSI, 2005) that states that the implementer must be able to motivate all important choices and decisions during the development of a repository, including *siting*, design, construction and operation, in relation to the repository's long-term protective capability. Consequently, the question at hand is whether SKB has sufficiently considered the role of hydrogeologic conditions and their importance for repository safety in their selection of candidate sites for the spent fuel repository. SSI has also asked SKB for clarification of additional safety related issues, including differences in groundwater chemistry and, in particular, depth to saline groundwaters between coastal and inland sites (e.g. see SSI, 2002). These issues are, however, not addressed further here.

Considering that the discussion of the possible safety advantages of recharge area repositories has been going on in public for almost 6 years, since 2000, one might expect at this late date, that a primary objective of SKB's current analysis would have been to compare different sites in eastern Småland with regard to important hydrogeologic parameters that tend to increase predicted safety of a subsurface repository. This part of the work was not carried out by the current authors.

Should SKB acknowledge that hydrogeologic conditions can be found to improve safety margins of a nuclear waste repository and that sites that maximize this factor can be sought would not be the same as admitting that current sites are not good enough. Rather, the contribution of hydrogeology to safety is only one of several factors to be weighed by SKB when selecting an optimal site. The potential value of additional radiologic safety margins at actual sites that optimize the hydrogeologic barrier should have been thoroughly evaluated and considered by SKB when proposing their final repository site. The current report is only a first step towards achieving this goal.

Hydrogeologic reasons for good sites: The figures provided in the EHRB report show that the best locations are clearly clustered in particular regions of eastern Småland. These locations appear in patterns. One of the results of greatest interest and importance in safe siting of a repository based on the type of analysis done by EHRB is to examine the spatial patterns of best locations and to develop an understanding of the hydrogeologic reasons for the advantages provided by these particular locations. This would allow model analysis that is based on many conceptual models to be used in a prospective manner to find advantageous sites, as suggested by Voss and Provost (2001). Indeed, I believe that this should be a primary point of analysis described in the subject report, but it was not included.

One such cluster is in the Virån catchment, beginning in the north several kilometers east of Hultsfred and trending south-southeast for about 25 km (Figure 1). This cluster passes the eastern margins of the Hultsfred-east candidate site and all or part of this cluster appears in most of the selections of best sites shown in the report. Comparison with topography (Figure 2-3 of EHRB) and topographic gradient (Figure 4-3 of EHRB) maps shows that this cluster occurs within an elevated area of very low topographic gradient – a plateau. It should not be a surprise that repository sites below a broad smooth inland plateau would have longer flow paths, longer transport times and lower specific flux than other sites. Such areas of 'best sites' with many contiguous best locations would provide a robust region in which to locate a recharge-area repository with rather long paths lengths and travel times. In the cluster indicated in the figure, some contiguous groups of best locations cover areas of maybe 20 km^2, large enough for securely locating a repository within a region of good hydrogeologic properties with regard to subsurface flow. The authors present various combinations of '1000 best sites' in the above-mentioned figures but never present the type of interpretive discussion begun just above to elucidate the reasons for the locations of good sites.

Demonstration of site selection and comparison: EHRB never proceeded to the next steps of using the modelling analysis as a prospective tool to select sites that are advantageous and then to compare sites with one another. These are both necessary steps in optimizing the hydrogeologic barrier function of the site finally selected for a repository. As part of this review, I have attempted to take these 'next steps' as a demonstration, albeit in a limited manner due to time available for this review. I carried out a quick analysis of modelling results created by EHRB (and kindly provided in data files by SKB via Johan Holmén), in order to find hydrogeologically advantageous sites. I also compared one of these with the Laxemar site. The site

I compared turns out to be superior to Laxemar in terms of path length and travel time. It may not be difficult to demonstrate that there are other inland sites superior to Laxemar that can be found among EHRB model results, even given the conservative nature (discussed later) of the EHRB model cases.

2- General comments on the report, modeling assumptions and techniques

- The hydraulic conductivity values for ‘intact bedrock’ in various lithologies seem high to me by a couple of orders of magnitude (listed in Table 2-1 of EHRB). This concern is tied to the question of what is meant by ‘intact bedrock’ and the importance of local fracturing, at small scales not explicitly modeled in the regional model. Indeed, the third most important factor controlling flow path length was found, by the authors, to be the existence of local fracturing. How much local fracturing is included in the type of rock represented in Table 2-1? It would seem to be a lot. It is certainly not clear how to separate scales of fracturing when assigning conductivity values and discrete fractures or zones. Further, the separation of ‘intact rock’ from fracture zones seems to be arbitrary, as in many cases, the ranges of conductivity of both are similar. This question underlies the analysis done and brings into question the meaning of model assumptions when permeable structures are included as discrete objects.
- The importance of local heterogeneity should have been included in the list of important factors in the conclusions; at present, I do not believe it is highlighted again after being presented as a strong factor in Sections 6.9 and 6.10.
- It is not clear which pressure values are prescribed below the Baltic Sea and what their impact is on the flow field. Do these include the higher density of the seawater? If so, the equivalent freshwater heads should increase with distance from shore (i.e. with depth of seawater). Does this cause a reverse flow from the sea towards shore in the constant density model, and if so, how does this impact results for the inland flow field?
- There are aspects of the variable-density computer code that are described but never used in the analysis. Particularly, the discussion of dead-end diffusion and multi-rate diffusion is of no practical use in the report.
- The fact that flow path length does not increase monotonically with distance from the shore is not interesting because it is self-evident, though EHRB apparently have spent significant effort to prove this. Such behavior would not normally be expected in any hydrogeologic system with real (not perfectly smooth) topography. The plots and analysis of flow path length with distance from shore to have little value in explaining how the flow field functions. It is not the distance from shore that is being discussed as a factor in finding optimal hydrogeologic conditions for a repository site, but rather any conditions in any location that provides long flow paths, long travel times and low specific flux; most such locations will be in groundwater recharge areas. The only reason that previous discussions of optimizing location reflects against coastal sites is because only coastal sites have been selected by SKB.
- The conclusions lack a discussion of the hydrogeologic factors that provide the best conditions for optimizing the hydrogeologic safety margins and should indicate which areas in the region best fulfill these criteria, given the analysis of the conceptual models considered.
- The conclusions lack a discussion of other possible conceptual models that were not considered via modeling, but that may be of interest for further analysis.
- It is suggested that the brines are stagnant (implying very slow flow) because of their great ages. This view seems typical of most SKB reports. It is quite possible that brines are not stagnant and that the reason for great age is a very long flow path. Along such a flow path, brine velocities may be as high as shallower freshwater velocities. While the brine tends to act as a barrier to freshwater flow, it may not itself be static.
- The initial conditions for variable density flow simulation are either uniformly increasing concentrations with depth, or a depth-function of the topography. This does not match the steady state concentration conditions calculated previously by Voss and Provost (2001) or those used by Follin and Svensson (2003). Further, these initial conditions are not synchronized with the topographically-driven flow in the freshwater above. Both assumptions are not natural and will thus generate their own artificial flows caused by density imbalances in the assumed distributions. The impact on re-

sults for flow paths of type of initial conditions selected (those in the present study and those previously reported) were not evaluated and may be important in these simulations.

3- Assumptions that tend to shorten lengths of modeled flow paths

- EHRB assigned a depth-dependent decrease in hydraulic conductivity, K. The variability of existing K data with depth is so great that such assignment has very high uncertainty. One can easily argue that there is actually no trend, or that there is only a generally higher value in the uppermost 200 m than below. High K values, as high as near the surface, can be found at any depth. The same is true for low K values. In most model cases considered by EHRB, a depth-decrease in K has been applied to lithologic units and to vertical and horizontal deformation zones. This assumption decreases modeled path lengths by effectively bringing the flow 'bottom' of the model closer to the modeled ground surface. Depth decrease of hydraulic conductivity is found to be an important factor controlling the flow field, and this overshadows the effects that many other features exert on the flow field. This choice by EHRB has caused modeled paths to be shorter in most models they considered because most models include the depth dependence. The impact of vertical conductivity variation needs to be evaluated independently of other model features if an objective analysis is to be carried out.
- Regarding diabase dikes, if they indeed have an impermeable core and permeable crust, then they should generate springs wherever they outcrop in a groundwater discharge area. This may be one way to check their actual hydrogeologic behavior. Also, I believe that the model assumes that the diabase dikes interrupt the hydraulic continuity of conductive fracture zones; this appears to be an uncertain assumption and its impact on the flow results might be tested by assuming the opposite as well. This assumption may tend to shorten flow paths.
- The lateral boundaries are considered to be impermeable in the modeling because they are located at divides in surface water systems. While this may be a correct assumption for the upper 10m of the system, this is almost certainly incorrect for greater depths. At greater depths, other conditions (based on patterns heterogeneity and more regional gradients) control flow across the selected boundary location (as mentioned in the report). The closed lateral boundaries at depth in the modelling would tend to shorten flow paths and travel times because paths that would normally cross these boundaries at depth are here forced to discharge. Modeled sites with good properties near the model boundaries would be less likely given this aspect of the model construction. No model tests were carried out to evaluate the impact of these boundary conditions on results.
- Most cases considered use the ground surface topography as the water table boundary condition on the top surface of the model. It is clear that this would exaggerate local gradients, decreasing modeled path lengths, whereas in the real world, the water table is smoother than the topography. The report considers one kind of smoothing: decreasing top boundary condition heads in inflow areas by a few meters (Cases 5J1, 5J2). However this is only one possible smoothing and it is applied only to a model with a shallow bottom and decreasing K with depth. The impact on path lengths of a smoother groundwater table might be evaluated more thoroughly and objectively with other smoothing approaches and for other hydrogeologic model structures.
- For a model that considers possible flow in a 100 km region, setting the model bottom at 2500m depth would not be reasonable unless it was certain that the bedrock was impermeable below this depth. However, there is no indication that this is the case in Sweden's bedrock. As mentioned above, the depth dependency of K is highly uncertain and high K values have been measured at all depths explored in Sweden. The deepest model considered had a bottom at 3300 m, and it also included a depth-dependent decrease in K. Not only was this model not deep enough to evaluate the effect of bottom boundary depth, but it also reduced the impact of the bottom location on the flow field by significantly decreasing conductivity before the depth of the bottom. Using such a shallow model bottom is a critical modeling constraint that shortens the length of flow paths in the model.

- The bottom of the model was set to a constant value of -2500 m for most simulations. This precludes deeper flow paths that may exist for some sites. The discussion provided about stagnant brine being a flow boundary is partly true, inasmuch as the brine velocity should mostly be much lower than freshwater velocity. However, there are not only two fluids separated by a sharp interface as suggested by the discussion and approach, but a full range of mixtures of freshwater and brine. Brine concentration increases gradually with depth. Thus, fluid velocities of the mixture should decrease gradually with depth and there is no sharp bottom to the flow field as modeled. Previous simulations by Voss and Provost (2001) with a 10 km deep model and full variable density simulation indicate that the brine mixtures do flow, and not necessarily in the same direction as topographic water-table gradients. Further, the previous simulations show that there are windows to the deep brine system, from which paths of fresh groundwater recharge enter the deep salty flow system. These are among the longest paths in the flow field with the longest travel times. The approach used in the reviewed report excludes the existence of such deep flow paths and this excludes the possibility of finding repository locations in such windows to deep flow. These may be the best locations in the region.
- Following a more than 10ka simulation starting from the initial conditions, the salt distribution achieved is sometimes peculiar (e.g. Figure 6-17 Case 1s1), wherein there remains a high concentration gradient near the bottom of the model due to incomplete flushing by freshwater. This may indicate a need for a deeper model wherein the saltwater would move downward beyond the current bottom boundary in some locations within the 10ka period. During long periods, the brines may migrate considerable distances laterally and vertically; the shallow model boundary may prevent some of this migration from occurring in some modeled cases. This would tend to reduce modeled path lengths from repository depth.

4- Comparison of sites using 7 modeled cases

OVERALL PHILOSOPHY
There may exist inland sites with very long (regional scale) flow paths, but it is not an absolute requirement that SKB find the absolutely best sites that have flow paths ending in the sea. Inland, there are likely good sites that are significantly better than Laxemar or other coastal sites in terms of the primary hydrogeologic barrier factors for radiologic safety: long flow paths and long travel times. To demonstrate the point that sites with advantageous hydrogeologic barrier function may be found and compared, I only attempted to identify and compare a single site that is relatively better than Laxemar, and not necessarily the "best" one that recharges the longest regional-scale flow path.

An analysis with multiple conceptual models is the first important step towards building confidence in such a site. There are many ways to sort and rank locations, given the type of data provided by the EHRB modeling. My search for good locations did not only attempt to find the locations with the longest path lengths and travel times. Rather I tried to select sites that optimized four extreme hydrogeologic safety characteristics:

> The first part of this approach is intended to find sites for which the shortest paths and times are the longest of all possible locations in the region. The reason for this objective is that site safety is most compromised by short paths and travel times – so one goal should be to find sites that have the fewest (or longest) short paths and travel times. I began by considering the 10 percentile length and time statistics for each 1 km^2 block reported by EHRB and selected the best 10% of these among all ca. 6000 blocks in the modeled region, for each of 7 model cases. Each block in the model was given a score of between 0 and 7, depending on the number of model cases in which it appeared among the selected blocks.
>
> The second part of this approach is intended to find sites for which the longest paths and times are the longest of all possible locations in the region. The reason for this objective is that site safety is most improved by long paths and travel times – so one goal should be to find sites that have the longest paths and travel times. I ranked all locations in the region by the 90 percentile statistics for length and time, seeking the 10% of blocks with the longest paths and times among all blocks in the modeled region, for each of 7 model cases. Each block in the model was given a score of between 0 and 7, depending on for how many model cases it appeared among the selected blocks.
>
> Comparison of scores for both sets of blocks selected by the above criteria (i.e. longest short times and longest long times) showed that many blocks that performed well for several models were in the same spatial locations.

One requirement of a site with robust superior hydrogeologic properties is that there should be several contiguous blocks with good properties included in the site, indicating that the site exists because of some overriding hydrogeologic factors in the vicinity. Laxemar was represented by 6 contiguous blocks within the existing site boundary (though most of these were not in either list of selected blocks), and other good sites I found from the above manual optimization had between 4 and 8 contiguous blocks.

EXAMPLE COMPARISON SITE: SITE A
For example, I have illustrated results for one of the good sites found as described just above. I called it Site A. I believe it is just east of the Hultsfred east site considered a few years ago by SKB. Site A is also within the example region of interest for superior sites shown on Figure 1. In the EHRB report, some locations within Site A were also selected to be among the locations in the model area that have both the 1000 longest median paths and 1000 longest median times for two series of models (Series 2 in Figure 7-22, and Series 4 in Figure 7-23 of

EHRB). The actual location of this site does not matter here; the objective of this analysis is only to show that such sites can be identified using the type of analysis reported by EHRB, and that these may be better than Laxemar. Site A is only an example. The map of Site A and Laxemar is Figure 2. There is a small dot on the map for each block in the model and colored circles for the blocks within each site.

Site A consists of 8 contiguous blocks (8 km^2) and Laxemar consists of 6 blocks (6 km^2). (These 6 were picked by Prof. Anders Wörman, KTH, and me to fit completely within the site boundary, and most closely approximate the Laxemar site, given the discretization used in the modeling.) See Table 1 for coordinates.

MODELS IN THIS COMPARISON

I had intended to use Series 2 from the report, but I found that the variable-density model had very different block coordinates and numbering from the constant-density model. This meant that it would have been too much work to include the variable-density model results in my Excel analysis - however, the EHRB report showed that, for their particular models, the impact of variable-density on their results were minimal – so if we accept this, ignoring their variable-density models should not change the result I am reporting. I selected most of Series 2 model cases from EHRB (Cases 1, 2, 3, 4, and 5). Then, instead of the variable-density models, I added two other constant-density models, (Cases 8A and 8B). These are like Case 5 (the EHRB base case) but with added local (stochastically-generated) heterogeneity; each reflects a different realization. The belief previously expressed by many scientists was that local heterogeneity would significantly shorten flow paths and would 'break' the regional flow paths, even in regional recharge areas. In total I have 7 models in my series (Cases 1, 2, 3, 4, 5, 8A and 8B).

AVAILABLE DATA FROM MODELS

For each block, statistics were kindly provided by Johan Holmén for path length (L) and travel time (T) (min and max, 10%, 50% and 90% percentiles of the distribution within each block). There is one set of values for each modeled case.

COMBINING STATISTICS FROM DIFFERENT MODELS

I took these block statistics and calculated an average value considering all 7 models. One might have more belief in or criticism of some models than in others, leading to possible weighting when doing such averaging. However, for this analysis, I considered all 7 models to be equally likely and took a simple average to create combined statistics.

RESULTS OF COMPARISON

-- *Site A vs. Laxemar for Each Statistic and for Each Model*

Considering individual statistics (min L, 10% L, 50% L, 90% L, max L, min T, 10% T, 50% T, 90% T, and max T) for each of the 7 model cases, Site A is better than Laxemar in 94% of the individual statistics (66 of 70 possible instances). Site A is about 12 times better than Laxemar overall when simultaneously considering path length and travel time. Here, 'overall' means the average of all 70 values of the individual ratio of each length and time statistic for Site A to that of Laxemar.

Considering only path length, L, for all of the 7 model cases, Site A is better than Laxemar in 97% of the individual statistics (34 of 35 possible instances). Site A is about 4 times better than Laxemar overall considering only path length in the 7 models. Here, 'overall' means the average over all 35 values of the individual ratio of each length statistic for Site A to that of Laxemar.

Considering only travel time, T, for all 7 model cases, Site A is better than Laxemar in 91% of the individual statistics (32 of 35 possible instances). Site A is about 21 times better than Laxemar overall considering only travel time in the 7 models. Here, 'overall' means the average over all 35 values of the individual ratio of each time statistic for Site A to that of Laxemar.

--Site A vs. Laxemar for Each Statistic as Averaged Over All Models

Considering the average of each statistic for all 7 model cases, Site A is superior to Laxemar for each available statistic (see Table 2).

The shortest travel times are improved most for the Site A site compared with Laxemar: 30 times for 50% T, 27 times for 10% T, and 29 times for min T.

Path length statistics are about 4 or 5 times better for Site A than Laxemar.

The bar charts of Figure 3 show the combined (average) value for all 7 models for each path length and travel time statistic for Site A and Laxemar. The charts show that Site A is superior to Laxemar for every combined path length statistic and for every combined travel time statistic. Site A combined path lengths range from 10 km to 28 km, in comparison with Laxemar lengths ranging from 2 km to 8 km. Site A combined travel times range from 30 ka to 700 ka, in comparison with Laxemar times ranging from 1 ka to 140 ka.

Summary of results: For all statistics and no matter how these were compared among the 7 different model cases, Site A has superior hydrogeologic barrier properties in comparison with Laxemar in terms of both greater path lengths and travel times.

Table 3 provides all data from the 7 models used in this analysis. We noticed that the highest travel time reported by EHRB is exactly 1000127 years. Though model times were greater, no greater numbers were reported for some technical reason. “1000127” appears often in Site A results, most often for the higher percentile times in 6 of the 7 model cases. For Laxemar, the number occurs only for the two highest time statistics (90% and max) in only 2 of the 7 cases. Thus, modeled travel times at Site A are even greater than reported in this analysis, while under-reporting of Laxemar travel times is much less significant. This means that the travel time advantage of Site A over Laxemar is actually greater than found in the present analysis.

5- Conclusions

DEMONSTRATION OF SITE SELECTION AND SITE COMPARISON
The models developed by SKB are complex and varied providing a wide variety of possible groundwater flow fields for study. [Despite this, I have specific criticisms of some important aspects of the models that likely cause flow paths to be shorter than in reality (e.g. bottom too shallow, lateral boundaries are no-flow, etc.).] In my comparison analysis, I included models with the highest level of local detail in heterogeneity, two models with stochastically generated local structures that are thought to short-circuit long flow paths. Thus, we have a highly conservative analysis of the flow field, inasmuch as short flow paths have been given strong preference in the way most of the models are set up.

Remember that the comparison results presented in this review are for many models of the sites and should be robust; of course this was the whole intent of making an analysis with many conceptual models. In addition, this reviewer believes that the model cases set up by EHRB tend to produce conservatively short flow paths and travel times. Thus, we should truly believe that Site A has much better properties for the hydrogeologic barrier than Laxemar with overall longer paths and travel times. [The EHRB report falls short of providing what was needed from SKB at this time, inasmuch as these kinds of comparisons were not made.]

For the model cases considered, other sites may be found with better hydrogeologic safety characteristics than Laxemar. The approach used here was intended to select sites that maximize the shortest and longest path lengths and travel times (rather than maximizing only the longest ones). Particularly for Site A, the shortest paths and travel times are significantly improved over the shortest paths and travel times for Laxemar, a site that would never have been selected if using thse site-selection criteria.

Despite the conservativeness of the EHRB analysis, it is still possible, on the basis of their results, to find inland sites with superior hydrogeologic safety margins. This was demonstrated by comparing one inland site and Laxemar. SKB has not used hydrogeology as a positive siting factor, rather as something to work against and that may spoil safety. This reviewer believes that the EHRB and current analyses bears out the idea that regional flow can be used to benefit the radiological safety of a high-level nuclear waste site in Sweden. Indeed, sites in or near major recharge areas can be found with longer flow paths and longer travel times and that provide a hydrogeologic barrier to escaping radionuclides of much greater effect than sites in or near a major discharge area such as Laxemar.

CONSIDERATIONS CONCERNING HYDROGEOLOGIC BARRIER FUNCTION
Relation of path length to travel time: Results from the EHRB report show that path length L and travel time T do not increase in proportion to each other for site statistics as one might expect from overly simple consideration of the statistics based on a single streamline and Darcy’s Law. For Site A, the improvement in travel time statistics is greater than the improvement in path length statistics in comparison with Laxemar. These differences would imply different improvements in the F-parameter when considering alternative length or time forms that define the parameter.

Extra retardation of long paths for some nuclides: Moderate increases in the F-parameter may strongly decrease peak doses and increase transport times of some radionuclides. The relation between the value of F and dose is not necessarily linear. Thus, even a site with only moderately longer path lengths or travel times may disproportionately increase the effectiveness of the hydrogeologic barrier.

Effect of lateral spread of radionuclide plume: Higher path length also implies greater subsurface volume of rock within an escaping radionuclide plume. The lateral spread of the plume is due to heterogeneous flow distribution resulting in transverse dispersion of solutes in terms of the classical conceptual description of solute transport. Plumes tend to become wider with greater transport distance from their source. This implies lower concentrations of radionuclides within the plume and lower solute concentrations (and doses) at points where the plume discharges. Concentration would be approximately inversely proportional to the cross-sectional area of the plume – with a large reducing effect on the dose obtainable at any part of the cross section. A plume of only 10 times greater cross-sectional radius would have 100 times lower concentrations of radionuclides. A plume would widen as it moved away from the repository, so longer path length would imply a wider plume and lower doses at any point where the plume discharges.

Though doses will be much lower than if the flow path is short and discharges in a small region of the surface, it may be argued that one disadvantage of lateral spread is that the discharge will be distributed over a larger area of the ground surface. It is also possible that even if the plume widens along its path in the subsurface, it may refocus if its discharge is concentrated in small regions of the ground surface.

Lateral mixing does not impact the predicted effect of the F-parameter on retardation (this effect is independent of concentration) but it reduces doses at any point because of the concentration decrease due to mixing with non-contaminated ground water. Lateral spreading effects and impacts on radiological safety require further study using three-dimensional groundwater flow and transport models.

Geometric factors impacting available surface for sorption/diffusion: There are two geometric behaviors of three-dimensional plumes related to flow in fractured rock that would tend to increase the retardation of radionuclides more as a function of path length than would be predicted by simple application of the F-parameter to one-dimensional flow paths from the repository to the discharge point. Both behaviors are caused by changes in the area available for radionuclide sorption and diffusion into the side rock that occur along the plume's path through the rock. Current analysis assumes only a constant area (per rock volume or per flowing water volume) available for sorption/decay along the entire travel path of a radionuclide plume.

Both behaviors noted here consider an individual radionuclide plume that begins with a very small cross-sectional area near a leaking canister. Both behaviors deal with modes of transport-scale-dependence of the area available for sorption/decay of radionuclides.

1- In a network description of the flowing structures in the rock, when the plume splits between two channels at some downstream location (either in different fractures or within the same fracture) then the available area for sorption/diffusion increases for the plume water. Each time the plume branches into additional paths, this area increases; thus the area and the F-parameter increase with travel distance. This behavior assumes that the plume water does not mix laterally with water on other paths. Paths may both split and coalesce, but the overall effect is of more available surface area when the distance of travel through the rock is greater than would have been available had the travel distance been short.

2- When the initially-narrow plume spreads laterally, mixing with non-contaminated groundwaters, parts of the plume may experience zones of much higher available surface area for sorption/diffusion, such as zones containing fracture breccia. Thus, the available area for sorption/decay should increase with increasing travel distance through the bedrock, increasing the F-parameter with distance travelled.

All of the effects discussed above (extra retardation for certain nuclides, transverse spreading that decreases concentrations, branching plumes, and plumes sampling larger volumes of the bedrock with extra travel distance) tend to enhance the safety contributed by the hydrogeologic barrier of a recharge-area repository more than by simple proportionate increase of the F-parameter by the increased path length or travel time. It is not simple to quantify the increase in hydrogeologic barrier function implied by these processes, but it is clear that these effects would make the standard one-dimensional analysis a conservative estimate of retardation. The added safety provided may be an additional reason to prefer sites that provide the longest possible paths. More analysis would be required to quantify these effects.

Acknowledgements

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	x-origin		y-origin		
	1429064		6329723		
N	XINIC		YINIC		**SITE**
4351	86504	1515568	31526	6361249	**A**
4407	87514	1516578	30478	6360201	**A**
4408	87502	1516566	31506	6361229	**A**
4462	88503	1517567	30524	6360247	**A**
4463	88524	1517588	31473	6361196	**A**
4516	89496	1518560	29501	6359224	**A**
4517	89493	1518557	30481	6360204	**A**
4518	89467	1518531	31490	6361213	**A**
5947	**118513**	**1547577**	**36499**	**6366222**	**Lax**
5948	**118490**	**1547554**	**37496**	**6367219**	**Lax**
5970	**119496**	**1548560**	**36482**	**6366205**	**Lax**
5971	**119498**	**1548562**	**37481**	**6367204**	**Lax**
5993	**120508**	**1549572**	**36491**	**6366214**	**Lax**
5994	**120512**	**1549576**	**37474**	**6367197**	**Lax**

Table 1 – Locations of blocks within Site A (A) and Laxemar (Lax). N is the block number used by EHRB, XINIC and YINIC are local coordinates to which x-origin and y-origin must be added to obtain map coordinates, as given in the adjoining columns.

Averages for all 7 models (1,2,3,4,5,8A,8D)	**L min**	**L 10**	**L 50**	**L 90**	**L max**
A	9837	11068	17326	23109	27739
Lax	1935	2348	4008	6203	7784
A/Lax	5	5	4	4	4

Averages for all 7 models (1,2,3,4,5,8A,8D)	**T min**	**T 10**	**T 50**	**T 90**	**T max**
A	30448	47733	204164	555480	697288
Lax	1062	1766	6898	95347	139678
A/Lax	29	27	30	6	5

Table 2 – Averages of each statistic among all 7 model cases. Time T in years, Length L in meters. Ratio (A/Lax) for each statistic is also included.

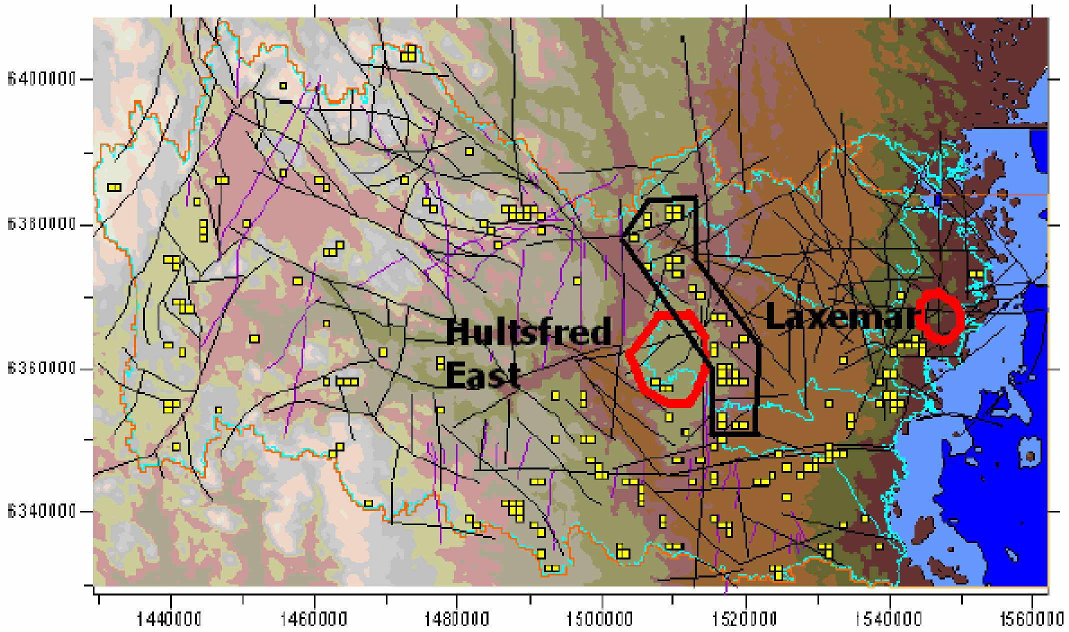

Figure 1 *– Modified from Figure 7-8 in Ericsson and others (2006). The figure shows blocks from one modeled case (8As2 with variable-density flow and local heterogeneity) that are among the 1000 blocks with longest travel times, lowest specific flux, and longest path lengths. The* ***red regions*** *are the approximate locations of the Hultsfred East and Laxemar sites. The* ***black region*** *includes a band of good sites within the eastern portion of a topographic plateau.* <u>*Site A*</u> *(used for comparison in this review) is within the second cluster of blocks from the southern end of this region.*

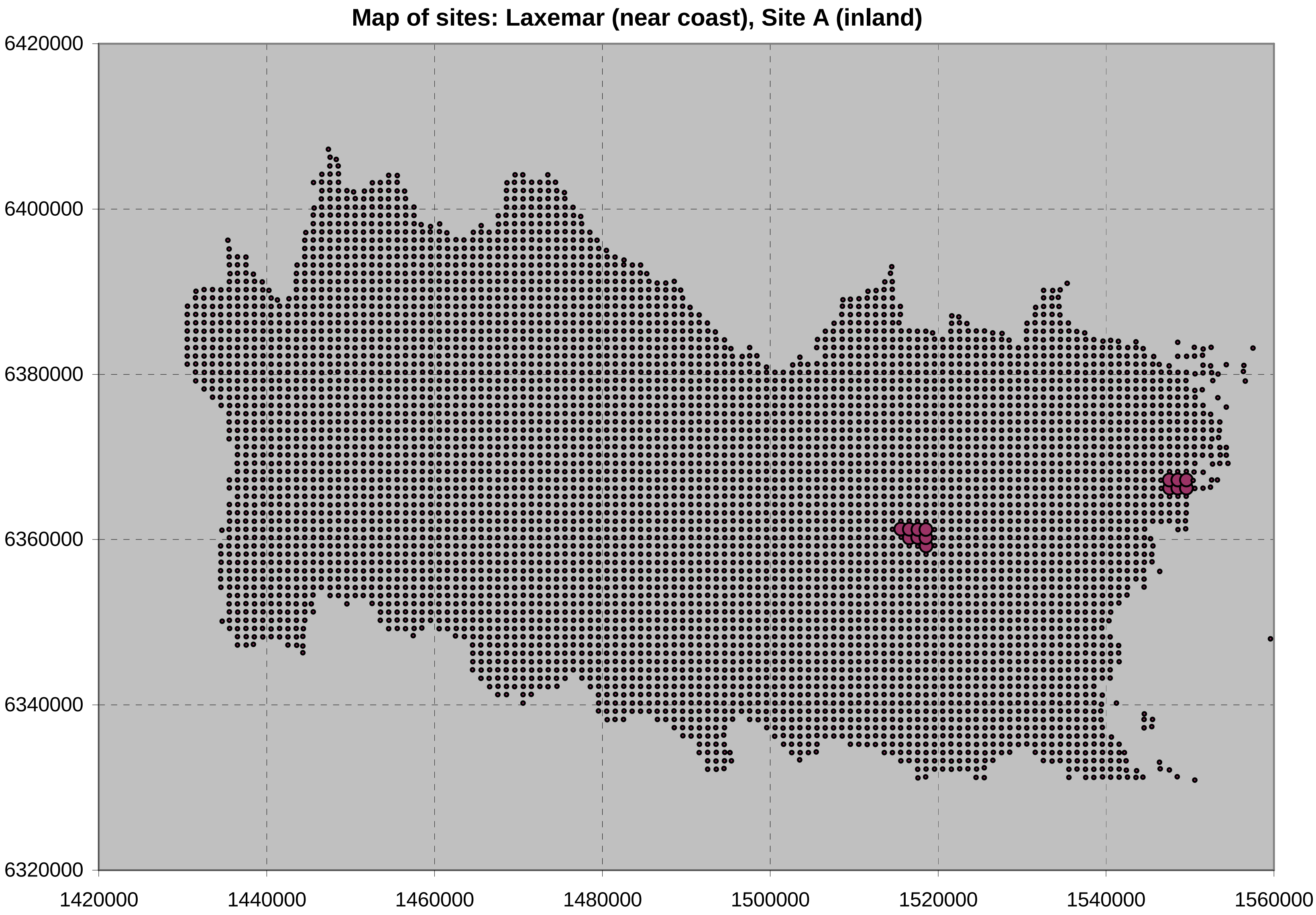

***Figure 2** – Locations of Site A (inland) and Laxemar (near coast).*

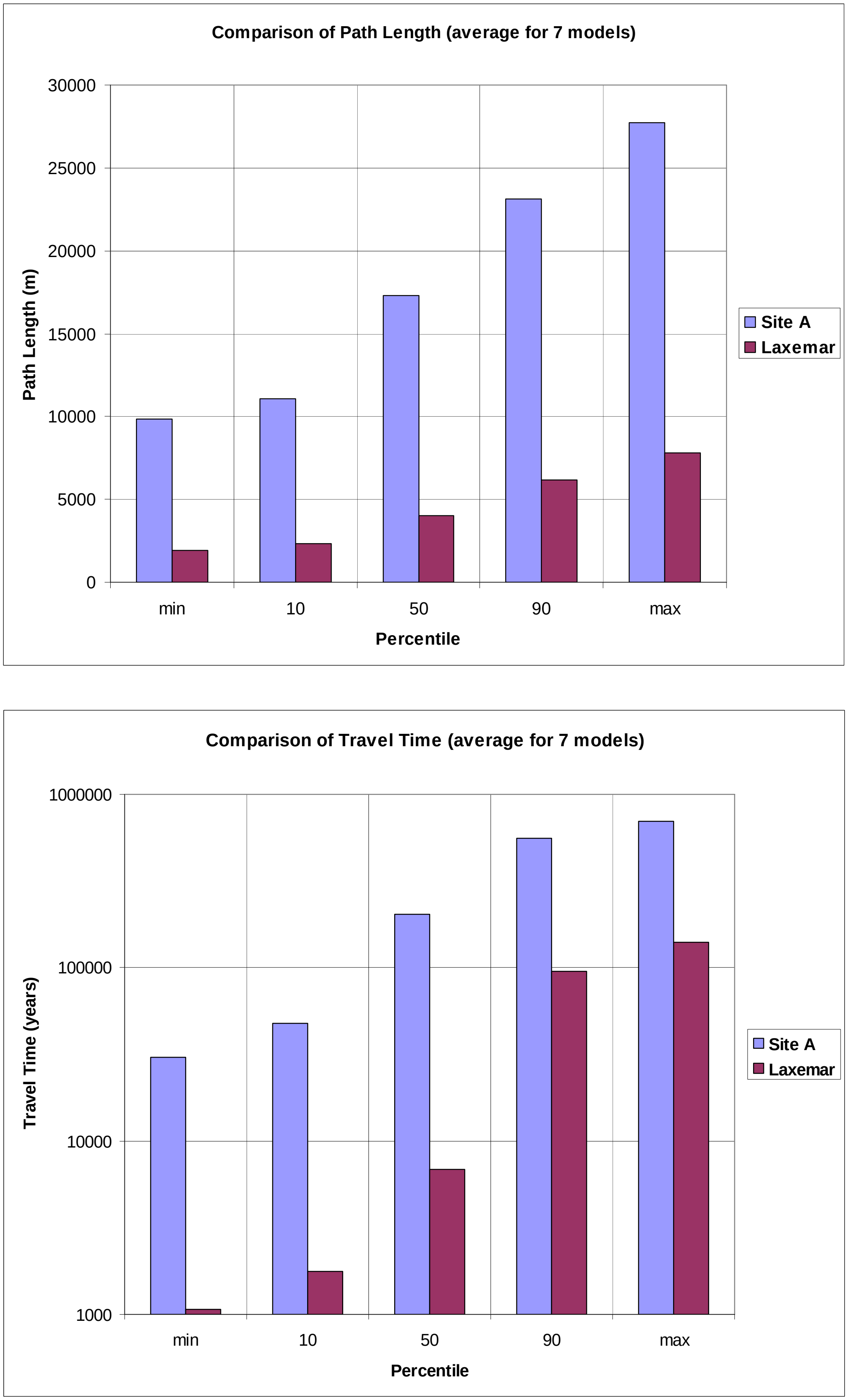

Figure 3 – Visual comparison of each average statistic among all 7 model cases between Site A and Laxemar.

Table 3: see caption below.

1	1	1	1	1	1	1	1	1	1
minL	*10%L*	*50%L*	*90%L*	*maxL*	minT	10%T	50%T	90%T	maxT
44861	*45475*	*46620*	*47547*	*48193*	1000127	1000127	1000127	1000127	1000127
38725	*40170*	*43840*	*44710*	*46502*	74336	107480	1000127	1000127	1000127
12480	*13268*	*44729*	*45407*	*46672*	11948	14306	1000127	1000127	1000127
10683	*13068*	*40010*	*43568*	*45678*	10627	14760	107708	1000127	1000127
10294	*11009*	*12873*	*44773*	*45369*	8868	9260	14630	1000127	1000127
6527	*7598*	*9872*	*41898*	*42791*	6186	6897	9904	1000127	1000127
10562	*10986*	*42805*	*44394*	*46380*	9814	10000	1000127	1000127	1000127
9086	*9568*	*11468*	*14646*	*43752*	6903	7652	9679	12539	1000127
791	*991*	*4426*	*6947*	*8073*	622	1680	6531	10307	12856
2873	*4141*	*8587*	*10443*	*11003*	3526	7292	15249	30389	33937
3084	*3383*	*4871*	*6544*	*7068*	3082	3657	7388	8697	10505
2145	*2904*	*4599*	*8343*	*9251*	2456	3946	7721	19352	21008
1051	*1302*	*3434*	*4590*	*5448*	1178	1822	5412	8132	9492
1129	*1351*	*2036*	*6218*	*6913*	884	1115	2291	11837	12759

2	2	2	2	2	2	2	2	2	2
minL	*10%L*	*50%L*	*90%L*	*maxL*	minT	10%T	50%T	90%T	maxT
46855	*52896*	*57219*	*58430*	*60996*	22725	63564	91901	92134	92482
39933	*40839*	*43788*	*45248*	*45673*	9888	11188	15184	19078	19136
44676	*45524*	*56616*	*58748*	*59191*	15210	18987	90571	92310	92437
37476	*38277*	*40309*	*43155*	*43450*	8348	9657	11743	15143	15170
39166	*39434*	*43768*	*47557*	*58343*	9631	9663	15144	25277	92146
33680	*34023*	*35061*	*35851*	*36192*	6694	6767	7727	8491	8540
34177	*35960*	*37343*	*38446*	*38702*	6696	8216	8403	9599	9621
36848	*37249*	*39574*	*44668*	*44987*	7328	7355	8544	18729	18784
4708	*4872*	*5267*	*5647*	*5743*	826	888	1109	1303	1372
5768	*6031*	*6786*	*7634*	*8069*	1329	1484	1698	1923	2109
3490	*3643*	*4318*	*4987*	*5121*	707	722	875	1104	1189
4814	*5093*	*5838*	*6704*	*7091*	1189	1233	1492	1693	1785
2864	*3045*	*3670*	*4097*	*4492*	667	697	796	991	1100
4219	*4376*	*4960*	*5853*	*6238*	996	1067	1255	1445	1514

3	3	3	3	3	3	3	3	3	3
minL	*10%L*	*50%L*	*90%L*	*maxL*	minT	10%T	50%T	90%T	maxT
1335	*1597*	*5878*	*12568*	*40380*	261	357	4670	1000127	1000127
664	*677*	*7724*	*14040*	*14817*	168	277	4867	407222	1000127
675	*803*	*6241*	*12665*	*14522*	221	243	3725	1000127	1000127
621	*905*	*7621*	*12909*	*39128*	300	334	3429	9112	1000127
729	*1245*	*8202*	*11096*	*14413*	225	317	3861	1000127	1000127
1363	*1606*	*3617*	*7911*	*39223*	413	587	1795	5100	1000127
2407	*2923*	*4042*	*6604*	*9764*	650	720	1353	3287	7047
529	*862*	*3756*	*12520*	*13760*	95	207	1790	8092	1000127
582	*623*	*1072*	*3413*	*4066*	63	144	491	2851	3332
753	*2256*	*4838*	*7331*	*10594*	474	1218	3437	1000127	1000127
850	*952*	*4305*	*6435*	*9136*	235	289	3325	5394	23460
646	*1621*	*5334*	*8864*	*10414*	343	506	3434	1000127	1000127
520	*597*	*1034*	*2578*	*3330*	71	105	363	1218	1687
816	*1392*	*2529*	*4356*	*5511*	245	366	1038	2402	3859

Table 3: see caption below.

4	4	4	4	4	4	4	4	4	4
minL	*10%L*	*50%L*	*90%L*	*maxL*	minT	10%T	50%T	90%T	maxT
2377	*2518*	*4243*	*17051*	*23760*	1071	1119	16887	1000127	1000127
681	*892*	*4689*	*12724*	*15803*	666	726	6567	117114	224712
1018	*1186*	*10449*	*13984*	*19352*	737	930	39914	177010	230157
825	*2972*	*10721*	*17891*	*18635*	541	2184	64835	241499	244483
874	*1672*	*4678*	*13223*	*19374*	448	845	6763	113677	245209
1512	*1644*	*2733*	*4055*	*11978*	614	730	2367	7046	49159
1992	*2105*	*2917*	*12016*	*17629*	1099	1226	3467	32328	237397
1009	*2765*	*3885*	*12393*	*12710*	338	1656	7794	68215	86955
687	*873*	*1373*	*3360*	*5375*	205	284	1000	3826	11898
2241	*2722*	*5663*	*8892*	*9987*	1875	3411	31769	94624	300368
1193	*1244*	*4534*	*5201*	*5690*	793	879	6371	18259	24737
1220	*2042*	*3865*	*6693*	*9737*	791	2283	12290	64682	234366
621	*684*	*1246*	*2671*	*5407*	265	351	655	4265	20535
1137	*1443*	*2002*	*3070*	*5990*	465	794	1830	6658	44226

5	5	5	5	5	5	5	5	5	5
minL	*10%L*	*50%L*	*90%L*	*maxL*	minT	10%T	50%T	90%T	maxT
2383	*2510*	*3997*	*18087*	*18809*	2144	2264	46086	1000127	1000127
762	*969*	*5803*	*16445*	*19161*	2206	6990	74582	1000127	1000127
1094	*2156*	*15348*	*19120*	*19408*	10772	19286	390528	1000127	1000127
934	*4314*	*11501*	*13027*	*15114*	7613	36122	328340	389507	456040
967	*1661*	*12824*	*15575*	*18927*	977	1686	367728	1000127	1000127
2106	*2214*	*8643*	*10456*	*10729*	4533	7617	65635	263171	291619
3875	*4380*	*9649*	*10402*	*10775*	4773	4971	53494	74285	95104
1161	*1435*	*5536*	*12184*	*13717*	373	666	9479	211369	1000127
694	*880*	*1416*	*4852*	*6147*	335	465	1976	7741	16263
3621	*4108*	*6735*	*10592*	*11432*	3904	9508	44674	204783	321996
2206	*2690*	*3749*	*5438*	*6212*	738	1815	6090	22509	36951
2397	*2681*	*4338*	*5964*	*7268*	425	746	10582	39921	68363
717	*757*	*1650*	*2784*	*3936*	96	109	905	2416	7308
1367	*1438*	*2335*	*3143*	*3658*	239	569	1644	7356	10350

8A	8A	8A	8A	8A	8A	8A	8A	8A	8A
minL	*10%L*	*50%L*	*90%L*	*maxL*	minT	10%T	50%T	90%T	maxT
2252	*2461*	*4661*	*20992*	*31917*	780	5370	20573	1000127	1000127
4597	*13982*	*18555*	*21576*	*22348*	39634	248836	1000127	1000127	1000127
15761	*15866*	*16356*	*18512*	*22819*	298492	771776	1000127	1000127	1000127
4370	*7732*	*16408*	*21217*	*24377*	27944	57245	1000127	1000127	1000127
1815	*1948*	*15222*	*16013*	*18284*	2350	2506	1000127	1000127	1000127
2434	*2773*	*10540*	*19062*	*19590*	3955	4726	170613	1000127	1000127
3671	*6442*	*13847*	*15625*	*17927*	3334	29656	85291	191896	1000127
1368	*1612*	*7714*	*15181*	*17100*	1507	1907	32608	1000127	1000127
899	*1169*	*3482*	*7401*	*10811*	315	531	5696	30059	221560
3096	*3669*	*6985*	*13157*	*14505*	2438	4124	36221	1000127	1000127
2473	*3048*	*5387*	*8603*	*9686*	1800	2010	10797	52518	95289
2455	*3240*	*5227*	*7688*	*10351*	1001	3261	9855	70782	237124
686	*777*	*1467*	*2234*	*4060*	69	108	617	2308	7740
1328	*1858*	*2768*	*4821*	*6157*	291	398	3365	10120	35391

8D	8D	8D	8D	8D	8D	8D	8D	8D	8D
minL	10%L	50%L	90%L	maxL	minT	10%T	50%T	90%T	maxT
2412	2548	3940	16273	20107	1461	1804	12807	1000127	1000127
3367	3877	15270	18658	22603	11868	14207	392166	1000127	1000127
3779	9410	15888	17693	18662	15329	41148	324227	1000127	1000127
2162	8047	14823	18138	19842	4935	31059	111948	815660	1000127
5480	8294	15191	17850	18040	21358	36982	158153	1000127	1000127
4033	4513	9926	14992	39199	4982	7020	92568	305422	1000127
4195	6425	13944	17542	18077	10061	19810	106319	942432	1000127
1244	2512	7402	16761	17709	539	1046	23797	426854	527359
1120	1240	1553	7488	11415	663	924	1654	11859	110024
2012	3353	7108	8978	12944	2796	5777	12612	99589	227013
1569	2906	6170	10795	11179	799	1662	6299	80179	220437
3710	4039	5196	6349	12784	4988	5416	13493	36224	367522
746	894	2822	4934	9527	53	105	688	13194	80689
1959	2298	3359	4424	5124	355	410	4714	11298	23973

Table 3 – Data analyzed from Site A (black) and Laxemar (red). Includes 8 blocks for Site A and 6 blocks for Laxemar in order shown in Table 1. One data set shown for each of the 7 model cases considered. Length statistics in meters and time statistics in years. (The travel time of 1000127 years, appearing in statistics from most of the above model cases is an arbitrary maximum time reported by EHRB. Where this value is reported, the actual travel time predicted by the model is greater.)

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SSI report

STATENS STRÅLSKYDDSINSTITUT, SSI, är en central tillsynsmyndighet som verkar för ett gott strålskydd för människan och miljön, nu och i framtiden.

SSI sätter gränser för stråldoser till allmänheten och för dem som arbetar med strålning, utfärdar föreskrifter och kontrollerar att de efterlevs. SSI håller beredskap dygnet runt mot olyckor med strålning. Myndigheten informerar, utbildar och utfärdar råd och rekommendationer samt stöder och utvärderar forskning. SSI bedriver även internationellt utvecklingssamarbete.

Myndigheten, som sorterar under Miljödepartementet, har 110 anställda och är belägen i Solna.

THE SWEDISH RADIATION PROTECTION AUTHORITY (SSI) is a central regulatory authority charged with promoting effective radiation protection for people and the environment today and in the future.

SSI sets limits on radiation doses to the public and to those that work with radiation. SSI has staff on standby round the clock to respond to radiation accidents. Other roles include information, education, issuing advice and recommendations, and funding and evaluating research.

SSI is also involved in international development cooperation. SSI, with 110 employees located at Solna near Stockholm, reports to the Ministry of Environment.

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