Statens strålskyddsinstitut
Swedish Radiation Protection Authority

Avd. för avfall och miljö

PM

Datum: 2004-08-30

Vår referens

Författare:

Björn Dverstorp
Anders Wiebert

SSI:s synpunkter på SKB:s redovisning av grundvattnets regionala flödesmönster och sammansättning, och deras betydelse för lokalisering av ett slutförvar

Med stöd av regeringens beslut den 1 november 2001 angående SKB:s val av platser för platsundersökningar har SSI begärt att SKB bättre ska utreda betydelsen av grundvattnets strömningsmönster och kemiska sammansättning för SKB:s val av platser för platsundersökningar. Frågan som SSI velat få belyst är om en inlandslokalisering av ett slutförvar kan bedömas ha sådana fördelar för förvarets långsiktiga skyddsförmåga att det hade varit motiverat att ta med även Hultsfred i platsundersökningarna.

Nedan redovisar SSI sina synpunkter på den kompletterande redovisning som SKB publicerat under 2003. SSI:s gransknings-PM är ett underlag till samrådsmötet om platsundersökningar med SKB, SKI och SSI den 1 september 2004. Oskarshamns kommun har tidigare framfört önskemål om att få ta del av SSI:s synpunkter på frågan om in- och utströmningsförhållanden. SSI har därför inkluderat Oskarshamns, Östhammars och Hultsfreds kommuner på sändlistan.

SSI:s sammanfattande bedömning

SSI anser inte att SKB:s redovisning på ett övertygande visar att det från strålskyddssynpunkt var riktigt att utesluta lokaliseringsalternativet Hultsfred Östra från fortsatta undersökningar. Tvärtom tycks de resultat som presenterades och diskuterades vid mötet mellan SKB och myndigheterna den 23 april 2004 bekräfta den tes som tidigare lagts fram av Clifford Voss vid US Geological Survey (ung. den amerikanska motsvarigheten till Sveriges Geologiska Undersökningar), nämligen att det kan vara möjligt att hitta platser i inlandet där grundvattnets strömningsmönster förbättrar förvarets långsiktiga skyddsförmåga. En sådan plats kan vara en del av lokaliseringsalternativet Hultsfred Östra. Denna plats har också fördelen att grundvattnet troligen är sött på förvarsdjup. För att bekräfta eller förkasta resultaten behöver dock ytterligare modelleringsarbete genomföras.

En bedömning av ett slutförvars långsiktiga skyddsförmåga kommer alltid att vara förknippad med stora osäkerheter. Enligt SSI:s uppfattning bör SKB därför redovisa att man i varje steg av slutförvarsprogrammet har utvärderat, och tagit till vara på, möjligheterna att begränsa de långsiktiga strålskyddsmässiga konsekvenserna, med hänsyn taget till ekonomiska och samhälleliga faktorer. Detta är en del av de i SSI FS 1998:1 (SSI, 1998) föreskrivna principerna för strålskyddsoptimering och användning av bästa möjliga teknik och kommer att bedömas av SSI vid tillståndsprövningen för slutförvaret för använt kärnbränsle. Det borde därför ligga i SKB:s intresse att genomföra en mer genomgripande utvärdering av de eventuella fördelar som kan ges av grundvattnets strömningsmönster och sammansättning för lokaliseringsalternativet Hultsfred Östra.

Bakgrund

Grundvattnets strömning i berggrunden och grundvattnets salthalt är två faktorer av betydelse för bedömningen av säkerheten hos ett slutförvar för använt kärnbränsle. Båda dessa faktorer kan ha betydelse för hur förvaret långsiktigt utvecklas i den geologiska miljön liksom hur eventuellt utläckande radionuklider transporteras med grundvattnet upp till den marknära miljön.

I viss utsträckning går det att göra platsspecifika bedömningar av dessa frågor redan utifrån existerande förstudiedata, dvs. innan mer detaljerade undersökningar med t.ex. provborrningar inletts på en kandidatplats. Exempelvis är ett sött grundvatten att förvänta på många platser som befann sig över den högsta kustlinjen efter föregående nedisning. Vid kustnära platser är vanligen grundvattnet salt på förvarsdjup. Topografisk information kan användas för att göra bedömningar av grundvattnets lokala och regionala rörelser. SSI har tidigare påpekat att en utvärdering av dessa faktorer kan och bör göras innan platser väljs för slutförvarets lokalisering (SSI, 2001 och 2002 och SKB, 2001 och 2002). För ett slutförvar innebär längre transportvägar i berget att radioaktiva ämnen som läcker ut från förvaret kvarhålls eller fördröjs i berget i större utsträckning. För vissa radioaktiva ämnen, med halveringstider i storleksordningen tusentals år, kan denna fördröjning innebära att farligheten hinner avta innan de når miljön. Sådana långa transportvägar anses vara förknippade med i inlandet belägna regionala inströmningsområden.

Grundvattnets salthalt har störst betydelse för hur de olika lerbarriärerna (bufferten och återfyllnaden) utvecklas på kort och lång sikt. Förekomst av salt grundvatten påverkar även bergets förmåga att fördröja transporten av vissa radioaktiva ämnen.

Två amerikanska forskare, Voss och Provost vid US Geological Survey har i en tidigare studie för Statens kärnkraftinspektion, SKI, illustrerat hur man med modellstudier kan analysera hur olika platser skiljer sig åt med avseende på transportvägarnas längd och den tid det tar för radionuklider att transporteras från ett slutförvar till markytan och miljön (Voss och Provost, 2001). Det bakomliggande syftet med arbetet var att utforska om det är möjligt att hitta platser där grundvattnet som strömmar genom förvaret behöver lång tid på sig att nå markytan. En slutsats från studien var att metoden kan användas för att hitta sådana områden i inlandet och man bedömer att delar av SKB:s förstudieområde Hultsfred Östra kan vara ett sådant regionalt inströmningsområde. För kustnära områden konstaterar Voss och Provost däremot att strömningsvägarna från ett slutförvar överlag är kortare eftersom grundvattnet strömmar uppåt eller ut i havet i dessa områden (utströmningsområden). För att kunna tillgodoräkna sig en motsvarande fördröjning av radioaktiva ämnen för ett kustnära förvar ställs därför större krav på att hitta en plats där berget lokalt har låg vattengenomsläpplighet.

Tidigare granskning av SKB:s platsval

Myndigheterna har tidigt väckt frågor kring den säkerhets- och strålskyddsmässiga betydelsen av inlands- respektive kustnära lokalisering av ett slutförvar. Redan i granskningen FUD-program 95 (SKI, 1996) begärde regeringen (Miljödepartementet, 1996) att SKB mer ingående skulle redovisa de faktorer som bör styra valet av en lämplig plats, vilket ledde till SKB:s redovisning av rapporten Nord-Syd/Kust-inland (SKB, 1998). SKI framförde i sin granskning av detta material att SKB ytterligare bör belysa betydelsen av in- och utströmningsområden (SKI, 1999).

SKB presenterade i en komplettering till FUD-program 1998, den s.k. FUD-K (SKB, 2000), krav och kriterier för lokaliseringen av ett slutförvar för använt kärnbränsle. I redovisningen angav SKB också vilka platser man önskade inleda platsundersökningar vid. SSI lämnade i ett yttrande den 27 april 2001 synpunkter på redovisningen till SKI (SSI, 2001).

I yttrandet över FUD-K pekade SSI på brister i SKB:s motivering av valet av platser. SSI menade att beslutsunderlaget, där SKB:s senaste säkerhetsanalys (SKB, 1999) utgjorde ett viktigt referensmaterial, i detta tidiga skede inte gav tillräckligt stöd för att hävda att strålskyddskraven kunde förväntas uppfyllas med goda marginaler på samtliga kandidatplatser. SSI angav därför att SKB i större omfattning borde utforska möjliga skillnader mellan de olika platserna för att tillgodose att den plats som bäst kunde förväntas uppfylla de långsiktiga strålskyddskraven ingick bland de platser som valdes, även om den bedömdes vara sämre ur andra aspekter (industrietablering, samhälle, etc.).

Denna syn på lokaliseringen av slutförvaret är i överensstämmelse med miljöbalkens (SFS 1998:808) lokaliseringsprinciper som enligt SSI:s förmenande anger att en plats lämplighet i första hand avgörs om skyddet av människors hälsa och miljön och en hållbar utveckling främjas. SSI:s syn har även stöd i de principer för platsval för slutförvar som har tagits fram av den internationella strålskyddskommissionen (ICRP, 2000) och kärnenergibyrån vid OECD (OECD/NEA, 1999). Dessa internationella instanser pekar på vikten av att samtliga åtgärder som kan minska på risken för framtida strålskyddskonsekvenser bör utredas och beaktas vid val av förläggningsplats för ett slutförvar. Även det internationella atomenergiorganet ger utryck för en liknande syn i en preliminär version av rekommendationer rörande geologisk slutförvaring (IAEA, 2003).

I granskningen av SKB:s utvärdering av de olika lokaliseringsfaktorerna pekade SSI särskilt på frågan om grundvattenströmningens betydelse för val av inlands- eller kustförläggning liksom grundvattnets salthalt. Lokaliseringsalternativet Hultsfred intog som inlandsförläggning en särställning bland de aktuella platserna. Dels för att grundvattnet på förvarsdjup kan förväntas vara sött till skillnad från de mer kustnära platserna. Dels för att grundvattnets regionala strömningsförhållanden skulle kunna vara fördelaktigare i inlandet.

SSI:s övergripande slutsats i yttrandet över FUD-K var att det inte var klart att den plats som bäst kunde förväntas uppfylla de långsiktiga strålskyddskraven ingick bland de platser som valts för platsundersökningar. SSI framförde därför att det inte kan uteslutas att SKB kan behöva ”…styrka, och eventuellt revidera, det val av platser som gjorts”.

Regeringsbeslut över SKB:s platsval

I regeringens beslut (Miljödepartementet, 2001) över SKB:s redovisning av det föreslagna platsvalet anger regeringen att ”…bolaget (SKB) inte bör utesluta Hultsfred från platsvalsprogrammet innan vissa frågeställningar av geohydrologisk art har utretts ytterligare” och hänvisar bland annat till de synpunkter som SSI fört fram. Regeringen utgår vidare ”…från att bolaget överväger de synpunkter som framkommit under granskningen av bolagets underlag för val av platser för platsundersökningar”.

SSI:s yttrande inom samrådet för platsundersökningar

Frågor rörande SKB:s platsval har följts upp i det samråd mellan SKB och myndigheterna som regeringen föreskrev i beslutet över FUD-K. Redan på det första samrådsmötet den 27 november 2001 (SKB, 2001), då SKB presenterade sina preliminära planer för arbetet med in- och utströmningsfrågor, framförde SSI och SKI att SKB bör inkludera Småland i sin studie. När SKB senare presenterade sin projektplan på det samrådsmöte som hölls den 5 juni 2002 (SKB, 2002) framgick det att SKB ändå planerade att fokusera sin modellering till Norduppland. SSI upprepade då sin tidigare synpunkt att studien bör inkludera Småland.

SKB presenterade sina slutsatser från projektet vid ett möte den 16 december 2002. Materialet var dock inte granskningsbart förrän sammanfattningsrapporten (SKB, 2003) och de två underliggande tekniska rapporterna (Follin och Svensson, 2003 och Holmén *et al.*, 2003) var publicerade vilket dröjde ytterligare något år.

På myndigheternas begäran hölls ett möte mellan SKB och myndigheterna och respektive organisations konsulter den 23 april 2004 där rapporterna diskuterades (Bilaga 1). Till detta möte hade SSI:s konsult Clifford Voss dels granskat SKB:s rapporter, dels gjort ytterligare beräkningar (Bilaga 2 och 3). Voss nya beräkningar bekräftade resultaten från USGS tidigare modelleringar, nämligen att de östra delarna av intresseområdet i Hultsfred Östra kan vara ett regionalt inströmningsområde med hydrogeologiska fördelar. Vid mötet medgav även SKB:s konsult att de modelleringar av Småland som han gjort på uppdrag av SKB givit samma fördelaktiga resultat för detta område. Detta framgick dock inte av det sätt som konsulten valt att presentera beräkningarna på.

SSI:s granskning av SKB:s redovisning

Nedan sammanfattar SSI de viktigaste synpunkterna på SKB:s redovisning av frågor kring grundvattnets regionala flödesmönster och sammansättning och deras betydelse för lokaliseringen av ett slutförvar. Granskningen omfattar den sammanfattande rapporten SKB R-03-01 (SKB, 2003) som är SKB:s svar på myndigheternas tidigare synpunkter, samt de två tekniska underlagsrapporterna (Follin och Svensson, 2003 och Holmén *et al.*, 2003), vilka redovisar modellsimuleringar av grundvattencirkulationen i östra Götaland respektive norra Uppland.

Som stöd för SSI:s granskning har SSI låtit Clifford Voss vid US Geological Survey (USGS) göra en teknisk granskning av SKB:s modelleringsrapport för östra Götaland (Bilaga 2) samt den sammanfattande rapporten (Bilaga 3). Voss är en internationellt erkänd hydrologiexpert som har utvecklat beräkningsmodeller för grundvattenströmning. Han är också en av författarna till den tidigare studien av in- och utströmningsområden i östra Götaland som gjorts på uppdrag av SKI (Voss och Provost, 2001).

Frågor kring in- och utströmningsområden

SSI anser inte att de ytterligare utredningar som SKB presenterat ger tillräckligt stöd för SKB:s slutsats i sammanfattningsrapporten att ”…det inte finns anledning att göra skillnad mellan inlands- och kustnära förläggning av ett djupförvar”.

Den mer omfattande modelleringen för Norduppland (Holmén *et al.*, 2003) visar visserligen att lokala förhållanden som variationer i lokal topografi, bergets heterogenitet och marknära förhållanden (jordlager, sjöar och vattendrag m.m.) medför att det inte finns några tydliga skillnader i grundvattnets strömningsmönster beroende på avstånd från kusten. Beräkningarna visar att det kan finnas platser med förhållandevis långa strömnings- och transportvägar från ett slutförvar till biosfären, både i inlandet och i mer kustnära områden. Det valda modelleringsområdet är dock relativt kustnära och har en flack topografi vilket, enligt SSI:s bedömning, innebär att man inte kan förvänta sig att hitta regionala inströmningsområden och därtill kopplade platser med mycket långa transportvägar. Även om SSI anser att studien givit viktig kunskap inför de fortsatta platsundersökningarna, ger den således inte svar på frågan om det kan löna sig att söka efter platser med utpräglade regionala inströmningsförhållanden längre in från kusten, t.ex. i Hultsfreds kommun.

SKB:s studie av grundvattenströmningen i östra Götaland (Follin och Svensson, 2003) är enligt SSI:s uppfattning mer relevant för de frågeställningar som framförts av SSI och SKI i platsvalet. Problemet med denna studie är att den fokuserar på att belysa svagheterna i den tidigare modellering som genomförts av USGS på SKI:s uppdrag (Voss och Provost, 2001), istället för att på ett genomgripande och förutsättningslöst sätt belysa frågorna kring in- och utströmningsområden och förekomst av salt grundvatten.

SSI har tidigare framfört att USGS studie ska ses som en möjlig metod att belysa betydelsen av in- och utströmningsförhållanden – inte som en fullständig analys (SSI, 2002). SKB:s studie är i allt väsentligt en reproduktion av USGS studie med den skillnaden att SKB använt en finare areell modellupplösning. De skillnader som framkommit på grund av olika modellupplösning är i och för sig intressanta, men SKB:s studie tillför enligt SSI:s uppfattning inte något väsentligt i den grundläggande frågan. Voss granskning av SKB:s modelleringsrapport för östra Götaland visar dessutom att stora delar av den kritik som framförs av SKB angående det tekniska genomförandet av USGS tidigare modelleringsstudie kan diskuteras.

SSI delar Voss bedömning att SKB:s studie i själva verket bekräftar flera av slutsatserna i USGS rapport, t.ex. att en del av modellområdet i Hultsfred Östra kan ha fördelen att ge mycket långa transportvägar i berget för radioaktiva ämnen som läcker ut från ett slutförvar. Detta redovisas dock inte i slutsatserna i SKB:s rapport.

SSI har inga invändningar mot SKB:s slutsats att lokala topografiska förhållanden kan leda till lokala cirkulationsceller och därmed korta transportvägar även i inlandet. Detta är för övrigt i enlighet med resultaten från USGS tidigare studie. Frågan som SSI önskat få belyst är istället om det går att göra troligt att det finns områden med långa transportvägar i berget och om sådana platser kan ge väsentliga fördelar för slutförvarets långsiktiga skyddsförmåga. SSI anser inte att SKB:s modelleringsstudie utformats för att ge svar på denna fråga. SSI anser att SKB:s analys borde ha innefattat en systematisk analys av olika modellbeskrivningar av bergets heterogenitet och vattengenomsläpplighet och andra förutsättningar av betydelse för grundvattnets cirkulationsmönster (t.ex. i linje med vad SKB redan gjort för Norduppland). Eftersom kunskapen om bergets egenskaper på djupet är begränsad bör man söka efter områden som ger fördelar i form av långa transportvägar för flera antaganden om bergets heterogenitet.

Förekomst av sött och salt grundvatten

SKB:s sammanfattande rapport (SKB, 2003) innehåller en kortfattad genomgång av frågor kring grundvattnets sammansättning och dess betydelse för ett slutförvars funktion. SKB medger att djupet till salt vatten sannolikt är större under inströmningsområden än under utströmningsområden och att bräckt grundvatten vid ett kustnära förvar kan utgöra en teknisk komplikation vid utformningen av återfyllnad i tunnlar. Kapselns och bentonitbuffertens långtidsfunktion äventyras dock inte så länge man uppfyller kravet på att salthalten understiger 100 gram per liter grundvatten, enligt SKB. Höga salthalter kan också medföra att vissa radioaktiva ämnen får en sämre förmåga att fastläggas (sorbera) i berget och därmed blir mer lättrörliga. SKB hänvisar dock till att känslighetsanalyser inom SR 97 visat att detta inte är ett stort problem.

Mot bakgrund av SKB:s redovisning konstaterar SSI att det finns flera fördelar med att välja en inlandsförläggning med sött grundvatten på förvarsdjup. Det framgår dock inte av SKB:s slutsatser på vilket sätt dessa fördelar värderats i platsvalet. Enligt SSI:s bedömning bör det vara möjligt att komma längre i diskussionen av salthaltens betydelse för lokaliseringen. Även om det finns en övre gräns för den acceptabla salthalten bör fördelarna med att välja en plats med lägre salthalt redovisas. Så vitt SSI kan förstå påverkar en ökande salthalt både buffertens och kapselns isolerande funktioner även under gränsvärdet på 100 gram/liter. Om det är en fördel att sträva efter låga salthalter bör detta framgå och värderas vid platsvalet.

SKB:s slutsats att saltets påverkan på återfyllnaden av tunnlarna endast är ett tekniskt problem förutsätter att SKB hinner utveckla ett återfyllnadsmaterial som uppfyller funktionskraven för de salta grundvatten som kan förväntas på den aktuella slutförvarsplatsen. SKB har nyligen redovisat en studie kring olika återfyllnadskoncept där man bl.a. pekar på behovet av ytterligare forskning (Gunnarsson *et al.*, 2004). Det framgår av denna rapport att marginalerna är förhållandevis små för klara återfyllnadens mekaniska och hydrauliska funktionskrav i ett salt grundvatten av den typ som finns på Äspö. Av redovisningen framgår också att marginalerna sannolikt skulle vara betydligt större för en förvarsplats med sött grundvatten. Denna direkta koppling mellan metoden att återfylla slutförvaret och SKB:s tidigare platsval har påpekats av SSI både i yttrandet över FUD-K (SSI, 2001) och FUD-01 (SSI, 2002). Om det krävs ett stort och osäkert utvecklingsarbete för att komma till rätta med problemen kring återfyllnaden, anser SSI att även denna aspekt bör värderas vid valet av platser för platsundersökningar.

Bilagor

1. SKB, Mötesanteckningar från expertmöte mellan SKB, SSI och SKI den 23 april 2004, SSI dnr 2004/780-26, 2004.
2. Voss, C. I., Review of: “On the role of mesh discretization and salinity for the occurrence of local flow cells” by Sven Follin and urban Svensson (SKB R-03-23), SSI dnr 2004/780-26, 2004
3. Voss, C. I., Review of: ”Grundvattnets regionala flödesmönster och samman-sättning – betydelse för lokalisering av djupförvaret”(SKB R-03-01), SSI dnr 2004/780-26, 2004.

Referenser

Follin, S.och Svensson, U., On the role of mesh discretisation and salinity for the occurrence of local flow cells, Results from a regional-scale groundwater flow model of Östra Götaland, SKB R-03-23. Svensk Kärnbränslehantering AB, Stockholm juni 2003.

Gunnarsson, D., Börjesson, L., Keto, P., Tolppanen, P. och Hansen, J., Backfilling and closure of the deep repository – Assessment of backfill concepts, SKB R-04-53, Svensk Kärnbränslehantering AB (SKB), Stockholm, juni 2004.Miljöbalk (SFS 1998:808)

Holmén, J., Stigsson, M., Marsic, N., och Gylling, B., Modelling of groundwater flow and flow paths for a large regional domain in northeast Uppland, A three-dimensional, mathematical modelling of groundwater flows and flow paths on a super-regional scale, for different complexity levels of the flow domain. SKB R-03-24. Svensk Kärnbränslehantering AB (SKB), Stockholm, december 2003.

IAEA, Geological Disposal of Radioactive Waste, Draft Safety Requirements, DS154, draft, 2003-02-10.

ICRP, Radiation Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste, ICRP publication 81, Pergamon Press, Oxford and New York, 2000.

Miljödepartementet, Regeringsbeslut angående FUD-program 95, 1996-12-19, nr 25, 1996.

Miljödepartementet, Regeringsbeslut angående komplettering av FUD-program 98, 2001-11-01, nr 22, 2001.

OECD/NEA, Confidence in the Long-term Safety of Deep Geological Repositories: Its development and Communication, OECD, Paris, 1999.

SKB, Nord-syd/Kust-inland, Generella skillnader i förutsättningarna för lokalisering av djupförvar mellan olika delar av Sverige, Svensk Kärnbränslehantering AB (SKB), Stockholm, november 1998.

SKB, Djupförvar för använt kärnbränsle. SR97 – Säkerheten efter förslutning, Del 1 & 2, Svensk Kärnbränslehantering AB (SKB), Stockholm, november 1999.

SKB, Samlad redovisning av metod, platsval och program inför platsundersökningsskedet, Svensk Kärnbränslehantering AB (SKB), Stockholm, december 2000.

SKB, Mötesanteckningar från samrådsmöte mellan SKB, SSI och SKI den 27 november 2001, SSI dnr 624/3948/02, 2001.

SKB, Mötesanteckningar från samrådsmöte mellan SKB, SSI och SKI den 5 juni 2002, SSI dnr 624/2075/02, 2002.

SKB, Grundvattnets regionala flödesmönster och sammansättning – betydelse för lokalisering av djupförvaret, SKB R-03-01, Svensk Kärnbränslehantering AB (SKB), Stockholm, mars 2003.

SKB, Mötesanteckningar från expertmöte mellan SKB, SSI och SKI den 23 april 2004, SSI dnr 2004/780-26, 2004.

SKI, SKIs utvärdering av SKBs FUD-program 95, Statens kärnkraftinspektion (SKI), SKI Rapport 96:48, Stockholm, maj 1996.

SKI, SKIs utvärdering av SKBs FUD-program 98, Statens kärnkraftinspektion (SKI), SKI Rapport 99:16, Stockholm, april 1999.

SSI, Statens strålskyddsinstituts föreskrifter om skydd av människors hälsa och miljön vid slutligt omhändertagande av använt kärnbränsle och kärnavfall, SSI FS 1998:1, Statens strålskyddsinstitut (SSI), Stockholm september, 1998.

SSI, SSI:s granskning av SKB:s komplettering av FUD-98, SSI Rapport 2001:12, Statens strålskyddsinstitut (SSI), Stockholm, maj 2001.

SSI, SSI:s granskning av SKB:s FUD-program 2001, SSI Rapport 2002:3, Statens strålskyddsinstitut (SSI), Stockholm, februari 2002.

Voss, C. I. och Provost A. M., Recharge-area nuclear waste repository in Southeastern Sweden, Demonstration of hydrogeological siting concepts. SKI Rapport 01:44, Statens kärnkraftinspektion (SKI), Stockholm, November 2001.

2004/780-26

Minutes of Meeting

DOCUMENT ID	VER	AFFILIATION	PAGE
			1 (5)
SUBJECT NO	VALID FROM		VALID UNTIL
AUTHOR			DATE
Jan-Olof Selroos			2004-08-05
REVIEWED			DATE
APPROVED			DATE

DISTRIBUTION
Participants
Participants Consultation Meeting on August 31, 2004

Expert meeting on Groundwater Recharge and Discharge Modelling, April 23, 2004

Participants:

Adrian Bath, SKI (Consultant)
Sten Berglund, SKB
Emma Bosson, SKB
Erica Brewitz, SSI
Björn Dverstorp, SSI
L-O Ericsson, CTH
Sven Follin, SF Geologic
Joel Geier, SKI (Consultant)
Johan Holmén, Golder Associates
Michael Jensen, SSI
P-O Johansson, Artesia
Fritz Kautsky, SKI
Marcus Laaksoharju, Geopoint
Maria Nordén, SSI
J-O Selroos, SKB
Eva Simic, SKI
Anders Ström, SKB
Björn Söderbäck, SKB
Öivind Toverud, SKI
Cliff Voss, SSI (Consultant)
Anders Wiebert, SSI
Shulan Xu, SSI

Below the main discussion points and tentative conclusions are listed. No attempt to exhaustively summarise the presentations by Sven Follin and Johan Holmén is done. The presentations are appended as Appendix 1 and 2.

It is also noted that much of the discussion initiated by SSI staff and representatives concerned issues related to SKB's reasons for choosing the selected site-investigation sites. Since this topic clearly was outside the scope of the expert meeting, no attempt

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel and Waste Management Co
Postal address Box 5864, SE-102 40 Stockholm
Visiting address Brahegatan 47
Telephone +46 8 459 84 00 *Fax* +46 8 661 57 19
www.skb.se
Corp id SE556175201401 *Seat* Stockholm

is made in these minutes to summarise the questions and ensuing discussion related to this issue.

1. J-O Selroos welcomed the participants, and explained the objectives of the meeting. In short, SKB wished to provide detailed presentations of the two reports SKB R-03-23 and R-03-24, and also provide answers to detailed questions concerning the performed modelling.

   A proposed change in the agenda was accepted; both presentations were to be given before lunch, and then all discussions to be held after lunch.

2. Presentation by Sven Follin on SKB R-03-23 (appendix 1).
   Sven began with pointing out that the specific objective of SKB R-03-23 was to understand the role of the resolution of the computational grid for the extended conclusions drawn by Voss and Provost, which were based on a coarsely discretised numerical model (SKI Report 01:44). In a way SKB R-03-23 is merely a follow up on Voss and Provosts own recommendation of a repeated modelling but with a much finer discretisation. All other assumptions made by Voss and Provost were unchanged in SKB R-03-23.

   Sven continued by noting that the transient model by Voss and Provost (SKI Report 01:44) was stated to be run to **near** steady-state, although it was not explicitly stated by the authors in the report how long simulation time this required in their particular study nor what initial condition for the salinity they used. In the study by Follin and Svensson a linear salinity gradient was used as an initial condition and the simulation results were checked at different time slices between 40 ka years to 500 ka. In conclusion, decreasing transient effects were seen in SKB R-03-23 with visible differences in the particle tracking even at very long simulation times. Hence, it has been hard to judge when to terminate the present simulations since the simulation time will affect the results (i.e., how close to steady-state should simulations be run?).

   Also, Sven pointed out that Holocene hydrogeology has not been taken into account in the modelling; i.e. the different stages of the Baltic Sea are not represented, which means that there is little hydrogeological realism in any of the two models.

   A few results worth noting are:

   - Salinity is important to include as is acts as a ‘floor’ resulting in more shallow flow cells.

   - A comparison between DarcyTools and GEOAN reveals that both codes give the same results.

   - Site data supports that strong local flow cells should develop. Modelling supports that discharge predominantly takes place close to starting positions. In the modelling, it is necessary to account for both salinity and shore-line displacement.

- None of the two studies (Voss and Provost or Follin and Svensson) is a good representation of crystalline bedrock but a continuum approximation without geology-based heterogeneity and anisotropy behind the macroscopic hydraulic properties used.

3. Presentation by Johan Holmén on SKB R-03-24 (Appendix 2).
   Johan presented the modelling methodology and the different cases analysed, where an increasing complexity level in the modelling provided an insight into the effects of such complexities. The issues analysed were
   - importance of the local and regional topography
   - importance of cell size in the numerical model
   - importance of depth of domain represented in the numerical model
   - importance of regional fracture zones
   - importance of local lakes
   - importance of areas covered by a clay layer
   - importance of a modified topography
   - importance of the shore level progress and the transient behaviour of the regional flow
   - importance of density dependent flow

   The general conclusions provided were that repository positions at a depth of about 500 m below ground surface and with large flow path lengths and large breakthrough times can be found at many different places within the domain studied. There was no general trend that the best positions are found as far as possible from the sea. Considering the distribution of flow paths from repository depth, the most important parameters are the topography and the position of the sea.

   Finally, a model used for prediction of the flow path distribution needs to include the local topographic undulation in such detail that the model is capable of reproducing the influence of the undulation on the groundwater flow field.

   Björn Dverstorp commented that it would be interesting to see if the pattern of recharge/discharge changes when the model depth is varied. Johan replied that the sensitivity to depth was studied in some detail, indicating that only the higher percentiles (of flow path length) were affected when increasing the depth up to 4 000 meters.

4. Presentation by Cliff Voss.
   Cliff made some general observations. These include that you have to study several models (conceptualisations) of the bedrock, and analyse several potential sites in order to find a site that is ideal; this implies making "hydrology your friend". Cliff critised R-03-23 for only addressing one conceptual model and a few sites. Cliff also suggested that the vertical resolution in all models presented was too low.

   Cliff had made an additional 2D study with higher resolution than the original model, but without salinity. The model confirmed the earlier results, i.e., the eastern parts of Hultsfred Östra provides long transport paths to the Baltic Sea. Cliff claimed that the same results also are observed in Sven's study; i.e., long transport paths from Hultsfred Östra Östra. Finally, Cliff stated that his original model indeed had been run to steady-state, and that the discretisation around Hultsfred was on the same order of magnitude as in Sven's study (1500 m in Cliff's study compared to 500 m in Sven's study).

Concerning the vertical resolution, Johan Holmén told the audience that he had performed some extra simulations with his model using a vertical resolution twice as fine as in the original case. Only minor differences in results were observed for this case (not included in the report).

5. General discussion

Björn Dverstorp claimed that Sven's study is not sufficient as a reply to the request by the authorities. It is mainly an invalidation study of Cliff's report rather than an exhaustive analysis of the issues related to inland/coast and recharge/discharge.

SKB answered that SKB R-03-23 alone is not the reply to the authorities. Rather, SKB R-03-23 in conjunction with R-03-24 and R-03-01 (the summary report in Swedish called "Grundvattnets regionala flödesmönster och sammansättning – betydelse för lokalisering av djupförvaret") constitute the formal reply. The specific objective of SKB R-03-23 was to understand the modelling presented in SKI Report 01:44.

Anders Wiebert rephrased Björn's point, claiming that Sven's study rather was a confirmation study of Cliff's work, since both studies provide more or less the same answers.

Björn Dverstorp wondered if SKB believes there is no need to understand the regional flow situation in future analyses and/or for siting purposes, since it is claimed that local conditions and resulting F-factors govern radionuclide transport. Jan-Olof Selroos answered that it is important to understand regional flow in order to have a credible model. However, recharge/discharge patterns are not a siting factor.

Joel Geier pointed out that none of the models presented include anisotropy or variation with depth. Johan Holmén replied that for the Forsmark case, data provided by Walker et al (1997) indicate that above 1000 m depth there is not much decrease in hydraulic conductivity (SKB TR-97-23).

L-O Ericsson pointed out that the quaternary deposits may need to be included with greater detail since they likely affect resulting gradients.

Björn Dverstorp wondered if it is easier to understand local properties than regional ones. No comprehensive answer was provided at the meeting, but the author of the minutes believes that local properties are easier to understand due to the greater data availability usually characterising the local scale.

Anders Wiebert claimed that differences in salinity related to an inland or coastal location had not been addressed sufficiently in the provided reports. Marcus Laaksoharju replied that if reducing conditions prevail (which is the likely case), inland and coastal sites are equally favourable.

L-O Ericsson wondered if there are any plans to try to characterise recharge and discharge areas in the site-investigation programme. Sven Follin replied that one cannot expect to be successful with such an endeavour due to the flat topography (Forsmark case).

Adrian Bath pointed out that there typically is a vertical heterogeneity in chemical properties. This may be due to either temporal variability in the top boundary condition, or to an influence of a lateral variability. The temporal changes are believed to be most important. Adrian also stated that chemistry cannot provide any easy answers on the topic of recharge and discharge patterns, but that it is time now to try to incorporate chemistry into the overall picture.

Concerning the analysis of the location of a repository in SKB R-03-24, Björn Dverstorp wondered if different results would have been obtained if let say 1000 or 5000 particles instead of 500 had been used when defining the most suitable location. Specifically, maybe a clearer areal distribution indicating a suitable repository site would have been obtained. Johan Holmén replied that indeed larger areas would have been identified if a greater number of particles had been used (this follows from simple geometrical reasoning since each point represents an area). Björn thus concluded that these areas could have been found if a less restrictive criterion had been used.

Joel Geier stated that when the resolution is increased beyond some value, you also need to look at rock properties in greater detail. Specifically, the formation of local flow cells will be damped by anisotropy and tight hill tops. L-O Ericsson replied that data from the Swedish well archive supports the hypothesis that the pressure head closely follows the topography. The effect of tight hill tops should thus not be of any great importance.

Cliff Voss raised the question how the top surface should be handled in the analyses; i.e., how fine should the resolution at regional scale be. Is a grid spacing of 50 m or 500 m enough? Cliff claimed that since the water table is much smoother than the topography on a fine enough scale, a finer resolution will not necessarily always provide better results. Joel Geier indicated that a horisontal resolution below a km scale may not be meaningful for regional scale applications. P-O Johansson replied that it seems rough to have a discretisation of 500 m or more on a regional scale since the surface undulation has a more pronounced local component for typical Swedish conditions. Johan Holmén pointed out that since groundwater systems are recharged from above (precipitation), it is likely that even systems with highly heterogeneous topography will be saturated close to the surface if the precipitation is sufficient (the typical Swedish case). Thus, increased resolution will as a rule result is better simulations.

Review of: "On the role of mesh discretization and salinity for the occurrence of local flow cells" by Sven Follin and Urban Svensson (SKB R-03-23)

Clifford I. Voss
U.S. Geological Survey
6 July 2004

This review consists of Summary Comments, General Comments, Detailed Comments, and New Simulations.

The Summary Comments provide the main result of the review, without reference to details.

The General Comments provide more-detailed explanations of the main review comments.

The Detailed Comments provide specific views of the report on a page-by-page basis. There are some points in this part that are not considered elsewhere and some suggestions for future analysis.

The New Simulations section provides some new results that are used to motivate some of the review comments.

Note: The report by Voss and Provost (2001) is referred to as **VP** and the report by Follin and Svensson (2003) as **FS**.

Summary Comments:

Although the intention of the FS report was to disprove the suggestions made by the VP report that an inland site located within a major recharge area for groundwater might provide a higher margin of hydrogeologic safety than a coastal repository, it was not successful in doing so.

The VP report had stated that inland sites, properly selected, are generally more advantageous than coastal sites. For this discussion, advantageous sites are defined as those with relatively long flow paths and travel times from a repository to the discharge points. Sites within local groundwater flow cells, i.e. where the recharge and discharge areas are in close proximity, are not advantageous for safety. Sites within regional flow cells, near the beginning of regional flow paths, in major groundwater recharge areas, would be advantageous.

FS attempted to disprove the suggestions of VP by remodeling the Östra Götaland region, containing Hultsfred, Oskarshamn and Simpevarp sites considered by SKB. The main FS thesis was that VP had not discretized finely enough and that if this were done properly, local flow cells would be found within inland repository sites, particularly within the Hultsfred East site.

FS used two different model meshes; one mesh matched that of the VP report and the other was more-finely discretized. In these models, FS used only a single representation of the bedrock fabric, one with equivalent horizontal and vertical permeability. The main FS results are provided for the Hultsfred site.

FS found that in both the VP model mesh and in the finer model, most pathlines from the Hultsfred East site starting at repository depth ended in local discharge areas in close vicinity to the site and only some of the pathlines reached the Baltic Coast (in contrast with the findings of VP). FS used this result to argue that the VP modeling and suggestions about advantageous siting in recharge areas were wrong as follows: FS implied that in their more-finely discretized model, the local flow cells dominated over regional flow cells and that there would be no advantage at an inland site over a coastal site.

This result and conclusion of FS do not negate the suggestions of VP for two reasons:

> First, both the coarser VP model and finer model that FS ran have about the same number of paths from the Hultsfred site discharging locally. This means that discretization is not a critical factor that caused VP to obtain incorrect results and to miss the local flow cells that only a finer mesh could represent. Both meshes gave FS the same result!
>
> Second, FS placed starting points for paths over the entire East Hultsfred site (according to statements by S. Follin at the SKB presentation of the FS report, 23 April 2004, Stockholm) despite the fact that the western portion of the site was known to have a local discharge area. (It had been pointed out by the VP report that the eastern portion of East Hultsfred was in the regional recharge area – not the western portion.) By simulating a combination of paths within a local flow cell on the west with those emanating from the regional recharge area in the eastern portion of East Hultsfred, FS obscured the advantageous portion of the area for siting.

Indeed, the main suggestions of the VP report were that (1) advantageous recharge areas should be located by numerical model analysis and that, (2) because the bedrock is complex and could never by described with certainty, many hydrogeologic representations of bedrock structure and properties should be used when locating a site with long flow paths. A single model showing that a site is advantageous or not advantageous is clearly insufficient. Further, VP indicated that a site that is advantageous in many conceptualizations may provide greater hydrogeologic safety margins than a site that has short flow paths in many conceptualizations. The FS report did not deal with either point: (1) there was no attempt made to find advantageous locations within the region – particularly the eastern portion of East Hultsfred noted by VP was not considered; (2) only one bedrock conceptualization was used.

In conclusion, the suggestions of the VP report that some inland sites may provide a higher margin of hydrogeologic safety than coastal sites are still valid and are not negated by the SF report.

General Comments:

- FS missed the main points of VP's report. Please reread VP's conclusions (page 53-54) to review VP's thrusts.
    - VP stated that the modeling should be used as a means of finding better sites. FS did not try to find good sites. FS only focused on trying to show that there were local flow cells reaching to repository depth in two sites evaluated by VP.
    - VP stated that 'better' sites are those with longer flow paths (distance and/or time) emanating from the repository. VP stated that because the rock properties will always be unknown at the scales required, a site should show good performance in the model <u>irrespective of the properties assigned to the bedrock</u>. VP suggested that a variety of bedrock models be used to evaluate and compare sites. FS evaluated only *two sites* using only *one representation of the bedrock*. Thus, FS's results are not robust with respect to the uncertainty in the bedrock properties. Other bedrock models may give quite different results.
    - VP stated that, irrespective of the properties of the bedrock, coastal sites are <u>always</u> within or near the regional discharge areas, while inland sites have at least a chance of being in regional recharge areas with longer paths. Furthermore, irrespective of the bedrock properties, inland sites may have a better chance of providing higher hydrogeologic safety margins than coastal sites. FS did not deal with this question.
- FS's two main technical criticisms of the VP modeling analysis are that (1) VP did not discretize sufficiently in the lateral directions (and thus missed simulating the deeper local flow cells) and (2) that VP results were not at steady state (somehow causing modeled flow paths to become longer).
    - (1) FS indicated that there was little difference in the results of their fine model and that of VP for the Hultsfred site, because VP's model was already nearly as fine in that area. Thus, VP had discretized almost as finely as FS in the region where it was important to do so, and so FS should have obtained similar simulation results. This directly contradicts FS's criticism concerning insufficient discretization in VP's models.
    - (2) FS "assumed" that VP results were not at steady state, but this is incorrect; all of VP's TDS concentration distributions were at steady state. On the other hand, most of the FS results are not at steady state, according to FS's own description, thus weakening their ability to compare with VP's results.
- The FS report is only a partial and incomplete response to VP's work.
    - FS did not consider the same properties of the bedrock as shown by VP in most of VP's report. FS considered only the case of isotropic permeability (1:1) although VP had demonstrated results for four anisotropies.
    - Thus, FS results are not all comparable to VP results.
    - FS results do not directly disagree with VP's results, which also demonstrate and discuss the occurrence of deeper local flow cells for bedrock with relatively high vertical permeability.

- FS covered arbitrary areas of each repository site with particles that were tracked, rather than using the parts of the sites that belong to regional recharge areas. VP had indicated that is it the easternmost portion (several km) of Hultsfred-east that was a regional recharge area for all bedrock models considered by VP. In VP's models, the westernmost portion of Hultsfred-east also discharged in a local flow cell (to the nearby stream system). (This was clear even in the very coarse 2D model representation shown in VP's Figure 9.) FS did not try to find the contiguous regions below Hultsfred that belong to the regional recharge area, but covered the *entire site* with a repository, contrary to the intent of such a modeling study to seek recharge area sites. Indeed, a more careful siting analysis would be required than carried out by FS (and demonstrated by VP) to find appropriate locations for a recharge-area repository.
- FS used rather coarse vertical discretization in their model with only about 6 grid layers above repository depth. The shallow flow field is complex, with opposing velocity directions in close proximity to one another. Thus, it is not clear that this level of discretization (only 6 or 7 layers) is sufficient to correctly resolve the shallow local flow cells. It is also not clear whether this would cause them to be simulated as too deep or too shallow, and how it would affect the flow paths through the repository.
- This reviewer carried out several simulations on a very fine 2D cross sectional mesh, finer than FS and VP but with the same 500 m elevation database describing the topography. The cross section is along an east-west line that crosses the Hultsfred-east site, close to the one shown in FS Figure 2.3 left. The simulation considers only constant-density flow to a depth of 3 km. The reduced depth of the model acts in a similar manner to deep salt waters, reducing the depth of the shallow freshwater flow cells. New results for the 10:1 Case that was described in VP, confirm VP's result that a Hultsfred repository in the eastern portion of Hultsfred-east would have long flow paths (~40 km) ending at the Baltic. Results for the only case shown by FS, 1:1, show that discharge areas may be closer than for the 10:1 Case. However, the new simulations show that for appropriate location of the repository within the eastern portion of Hultsfred-east, the shortest path length would still be long (~20 km to the closest major discharge point) with some radionuclides still reaching the Baltic. Thus, this reviewer cannot reproduce FS's result that 90% of particles released below the Hultsfred-east site discharge at Hultsfred in the immediate vicinity of the site, when a very fine mesh is used (finer than FS) and when the repository location is selected carefully. Probably, FS obtained this result simply because the repository was placed in the wrong portion of Hultsfred East.

Detailed Comments:

Abstract – last paragraph – Indeed the presence of brines does limit the shallow freshwater flow cells to lesser penetration depth as stated by FS. To go a step beyond this thought, consider that if the repository is placed in salty water it is more-likely to be on a regional flow path. Thus, contrary to the statement in the abstract, the variable density of the fluid brings regional flow paths to shallower depths. (Regions near bedrock springs discharging some brine, a hydrologic indication that the deeper flow system has reached shallow depths, would be avoided in siting a recharge-area repository, because these are discharge regions.)

page 13 – paragraph 2 – The FS expansion of the model domain to include more of Vättern Lake has absolutely no consequence in comparison with the model by VP. The VP model already included all opportunity for groundwater to discharge to the lake, half of which was included in the VP model domain. Apparently, FS included more of the lake only because they were considering a purely rectangular area, rather than an irregular area like VP. Thus, there is no important impact of including more of the lake.

Page 14 – end of paragraph 1 – FS consider the isotropic permeability case (1:1), while most of VP's results were shown for the 10:1 and 1:10 cases. This makes comparison of some results from VP and FS models less relevant, as discussed in later comments.

Page 15 – top paragraph – The FS discussion comparing local topographic gradients, when measured at different resolutions of topography, is flawed in three ways.

1- FS state that the topographic gradient is much greater when based on the 50m-elevation data grid than it is for the 500m grid. It is clear that the gradient will increase <u>without bound</u> for higher and higher resolutions of the topography. For very high resolution, e.g. high enough to clearly indicate the existence of a boulder or cliff, the slope of the topography is vertical at the sides of the boulder and at the cliff. If FS included a '1cm' grid, their upper Figure 2-5 plot would include a preponderance of nearly infinite local gradients, and all values would be much higher that what is already shown. Indeed, FS Figure 2-5 (bottom) demonstrates this effect, though the general conclusions drawn are not cogent. While this reviewer agrees that an elevation grid may be too coarse to capture aspects of the topography salient to the groundwater flow system, it is not clear *just how fine* the grid must be in order to represent the water table sufficiently well for the purposes of model analysis.
2- The water table, which is the means of driving groundwater flow in the model analyses, is in reality not a perfect image of the topography as assumed by both FS and VP. For example, it does not follow sharp rises and drops in the elevation of the ground surface (obviously, it does not climb vertically up cliffs). It is certainly a <u>subdued and smoothed</u> version of the topography. (Note, there is some smoothing implicit in the elevation database, which lacks elevation data between grid points.) In addition, other localized dynamic hydrologic effects impact the elevation of the water table independently of the

topography; neither VP nor FS considered the effects of this. However, the wavelength and amplitude (width and depth) of subsurface flow cells depend strongly on the frequency and amplitude of variations of the water table, not the topography. Though local gradients, when measured at very small scale (e.g. 50m database) all generate subsurface flow cells, the short wavelength variations that are calculated between adjoining elevation data points, penetrate the subsurface the least of all wavelengths. Thus, the short wavelengths are damped out with increasing depth, and longer wavelengths affect deeper regions. Thus, the discussion of the importance of higher-resolution topographic databases to groundwater flow may be moot because the water table is a smoothed version of the topography and because sharp local variations tend to generate only the shallowest flow cells. Further, some smoothing of the topography is appropriate when setting the model's water table in this manner.

3- FS combine two very different aspects of 'resolution' into one, which they refer to as 'mesh discretization'. This causes their discussion to be unclear. In fact, the discretization of the model mesh is a completely separate concept from the discretization (or resolution) of the digital elevation database. For example, a model can be based on a 500m-elevation database while employing a grid with 50m spacing.

Page 16 – paragraph 2 – FS use only 6 or 7 layers of model cells above the repository. This may still be a coarse discretization vertically and FS (and VP) did not consider the consequences of vertical discretization. It is not clear to this reviewer whether poor vertical discretization would increase or decrease the depth of flow cells, or whether the effect would change from place to place.

Page 17 – top paragraph – FS refer to Zijl (1999) who confirms the statements made above by this reviewer about penetration depth of cells generated by different scales of topography variation. Zijl (1999, page 143) gives an approximate formula (based on two-dimensional cross-sectional analysis) to calculate the penetration depth of cells in a homogeneous anisotropic medium as:

$$\delta=\lambda(K_v/K_h)^{1/2}$$

where δ is the penetration depth, λ is the wavelength of the water table variation, and K_v and K_h are vertical and horizontal hydraulic conductivities, respectively. Of course, the amplitude of the surface variation also affects penetration depth (as shown by FS in Figure 2-7 from Toth) and this is not taken into account by Zijl's formula. Simple application of Zijl's formula implies that a wavelength of 100m, the minimum that can be calculated from the 50m elevation grid, would generate a flow cell of depth 34m when the vertical permeability is 10 times lower than the horizontal, a depth of 100m for isotropic conditions, and a depth of 300m when the vertical permeability is 10 times higher than the horizontal. Though FS referred to Zijl, FS did not carry out a Fourier analysis of wavelengths in the modeled region to which Zijl's analysis could have been applied. This would have been a more-appropriate analysis than the one presented in relation to Figure 2-5 by FS, and in the subject paragraph. FS do not draw any quantitative conclusions from Zijl, and so the reference they make is not very useful.

Page 17 – paragraph 2 – The statements in this paragraph do not follow from the previous discussion on topography and deal instead with variable density flow. FS neglect to realize that a variable density flow field (compared with a constant density flow in the same system) has both shorter and longer flow paths, though they imply that all flow paths from a repository would be shorter. However, this is not a point of importance, because the subsurface in Sweden really has variable-density fluids and can only be considered within this reality. Discussion of constant-density groundwater flow in these contexts is not useful or meaningful.

Page 17 – last paragraph – FS state that VP overlooked the possible correlation of topography with fracture zones (and permeability). This was intentional in VP. This reviewer would further point out that FS also neglected this aspect in their analysis. Both VP and FS employ a homogeneous permeability distribution; indeed FS agree that the continuum approach is "applicable" on the "scale treated" (see last sentence of Conclusions – page 38). In any case, the impact of correlation between permeable zones and topography on the pattern of subsurface flow cells is not obvious, even if permeable zones tend to occur in topographic lows. Evaluation of this question would require further research (that should be done before site selection!)

Page 19 – paragraph 2 – FS report that because VP used closed vertical sides (especially in the south and west) in their model, flow is rerouted eastward (implying that some of the long regional paths found in VP within the area of repository sites were enhanced by this effect). However, all discharge (and recharge) in VP's model was through the top surface alone. Thus, discharge in the VP model could just as easily occur upwards to the Baltic along the southern edge of the domain as it could along the eastern edge. FS do not apply the same criticism to the eastern boundary, which has the same condition as all other vertical sides of the VP model. FS's criticism of this aspect of the VP model is thus not correct. Furthermore, as mentioned by FS, the southern boundary is far from the area of interest and even if FS were correct, probably has little effect there; however, though FS questioned this, they did not prove that there was any effect of concern to the main VP results in the area of repositories.

Page 20 – top paragraph – FS suggest that the steady-state flow and concentration distribution depends on the initial conditions. Clearly, steady-state conditions never depend on the initial conditions, by definition. This would only be a problem if FS did not run their simulations long enough to achieve steady state (which may be the case considering the large size of the FS model and the computational effort thus required to achieve steady conditions).

Page 20 – paragraph 2 – FS suggest that it may not be appropriate to use the steady flow field to evaluate today's conditions (indeed VP first stated this), considering the long transient response of the variable-density flow field, especially using the salt generator introduced by VP. Provost, Voss and Neuzil (1998, SKI Report 96:11) showed that the brine system can return to nearly its interglacial steady state in a few ten-thousands of years, using parameters in a model quite similar to those in VP. Though it may not be necessary, it would be possible to

search for robust recharge-area repositories using a three-dimensional model similar to VP or FS, with glacial climate changes on the top surface such as in the above-mentioned study by Provost and others.
FS are particularly concerned about shoreline displacement; however, this reviewer sees that a more distant shoreline would simply generate longer flowpaths from the repository sites.

Page 20 – paragraph 3 – FS use only the Case 1:1 of VP; unfortunately, this makes direct comparison impossible for most aspects, because VP showed results mainly for the extreme possible cases of 1:10 and 10:1.

Page 23 – paragraph 1 – FS indicate that VP began their steady state simulations to obtain steady salinity distributions with a linear salinity gradient in the vertical direction. This is not the case; VP began simulations with results of previous steady salinity simulations and allowed the new simulation to reach a new steady state.

Page 23 – There should be absolutely no role of the initial condition for salinity in this work. To be clear, there are 2 simulations necessary for studying the flow field. The first takes the longest time to run – it generates the steady-state flow/concentration field for the model domain. The second somehow traces the resulting steady flow field with particles or tracer. This reviewer is guessing that FS had overly long simulations for the former (because of the size of their fine model) and thus became inadvertently focused on this aspect.

Page 24 – paragraph 2 – Why didn't FS treat the coastal sites in the same detail as the Comparison site (which is purely imaginary) and Hultsfred? This aspect of the comparison with VP is sorely missing and may call into question motivations for the conclusions FS reached that the conclusions of the VP report were not well founded.

Page 24 – last paragraph – FS have the opinion that VP modeling results were not at steady state. However, they based this opinion on comparison of results of their model for Case 1:1 with those of VP for Case 10:1 or 1:10 (which one they compared with is not stated). The flow fields for all three cases are significantly different and thus FS's result for Case 1:1 at 40ka cannot be compared to VP's result for Case 10:1 at steady state. Thus, FS have an incorrect opinion. Indeed, all of the VP Cases were at steady state.

Page 25 – top Figure 4-4 – Showing the side of the model results is not as representative as showing the inside of the model. There may be different effects at boundaries. The insides of the models may look more similar, especially a slice through the Hultsfred or coastal repositories. Thus, this figure may be misleading – one cannot know from what is shown.

Page 33 – top paragraph – FS find that 90% of their particles discharge within and near the Hultsfred site in both their model A (VP's model) and in their more uniformly discretized Model B. This seems to negate FS's argument that finer discretization impacts the flow cells – both models give the same result. One conclusion of this is that it is only necessary to use higher resolution elevation data in the region around the site in a model; at distance, lower resolution suffices. Note that this is exactly what VP had done in their study. If true, then 3D simulation of these sites becomes more practical computationally.

It is not clear to this reviewer why so many particles discharge directly above the site in the FS model. Indeed the nearly the same mesh discretization and the same elevation database was used in VP's original model, though the results are quite different. Indeed, FS mentioned that one reason for the similarity in the number of particles discharging above in the two models that they ran was exactly their similarity in this area.

A new modeling study that also shows a very different flow field from FS was carried out by this reviewer and is briefly described later.

Page 34 – paragraph 2 – Again, FS suggest that VP models were not at steady state. This is not so – FS have compared models of different Cases because FS did not simulate the same Cases as mainly reported by VP.

Page 35 – Figure 4-14 – FS show results at 40ka, not at steady state. This is not comparable with VP's results, which were at steady state. FS show no path results for steady state conditions at Hultsfred, only for transient conditions at 40ka. Thus, none of these FS results can be carefully compared with VP steady results.

Page 35 – paragraph 2 – It is no surprise that variable fluid density has to be taken into account for model analysis of these questions. This reviewer agrees with FS. The section seems to be more of a demonstration for those who do not yet understand this basic fact.

Page 37 – paragraph 2 – As mentioned above, it is not certain how any possible correlation of permeability structure and topography (if it exists at all) would affect flow cell configurations. Correlation may enhance regional, rather than local flow paths, though FS suggest the opposite. FS criticize VP for neglecting to analyze this aspect of regional flow in VP's report. Indeed, VP's report was only intended as a first step in evaluating the possibility of recharge-area siting of Sweden's repositories and it showed that there might be some increased safety benefit in recharge area siting. Preferably, this concept should have been more-carefully considered by authorities prior to actual siting and site characterization. It is also clear that more work needs to be done to evaluate the concept now.

Page 37 – paragraph 3 – As discussed above, there should be no unusual impact of the VP model boundaries in the south and west on regional flows because the same boundary conditions are used along all vertical sides of the model. Even if there were some effect, it would be minor in the repository regions of interest, far from the boundaries in question.

Page 37 – last paragraph – Unfortunately, many of the FS results are not given for steady-state flow fields. This is one reason that they cannot be directly compared with the steady results of VP.

Page 38 – first paragraph – This reviewer agrees that climate changes and glaciation will have a strong impact on the flow field and need to be considered in a more careful study. Indeed, VP suggested that climate changes should be included in a follow-up study. However, the effect of post-glacial rebound and coastal regression is clear – many regional flow paths must reach the coast before discharging and thus will become even longer, giving even more advantage to a recharge-area siting on these paths. Thus all of the sites considered, including the present coastal ones, could have longer flow paths.

Page 38 – paragraph 3 – As discussed above, FS did not prove that VP results were not at steady state. Their conclusions concerning this are based on inappropriate comparisons of different models that do not have comparable flow fields.

Page 38 – paragraph 4 –
This reviewer finds that FS did not seek locations of advantageous repository sites and their point that “local flow cells appear to occur throughout Östra Götaland” is not well based on the results they obtained. Indeed, FS did not seek areas without local flow cells! This reviewer strongly disagrees with that implication of FS that no such areas exist. To demonstrate this point this reviewer ran some new model simulations as described below.

New Simulations:

This reviewer made some cross-sectional analyses using a much finer mesh than that of FS using the 500m elevation data. Indeed, the vertical discretization in the cross section is significantly finer than both VP and FS. The objective was to carefully simulate all small shallow flow cells above repository depth. The cross section is along an east-west line that crosses the Hultsfred-east and coastal sites, close to the section shown in FS Figure 2.3 left. The region above the repository depth was vertically discretized into 30 to 40 elements in comparison with only 7 used by FS. Though the model was constant density, it only reached 3km depth, to roughly represent the influence of the brines acting as a barrier to deep freshwater flow cells. The model mesh, repository locations, and physiographic features are shown in **Figure 1**. Though the model is simplified, this reviewer believes that it gives roughly the same response as would a three-dimensional variable-density model.

The results are similar to that found for VP for the Case 10:1.**Figure 2** shows that time of travel (return flow time) from repositories near the coast are several orders of magnitude lower that from a repository in the eastern portion of the East Hultsfred site. Water recharged over the entire Hultsfred East site travels in two directions, the western recharge discharges to the Silverån-Emån stream system (**Figure 3**) and the eastern portion discharges to the Baltic Sea (**Figure 4-top**). Indeed, much of the eastern portion of Hultsfred East is a regional recharge area. This reviewer could not reproduce any shallow flow cells above this part of the Hultsfred repository; all flow is downward at repository depth. (Inspection of modeled velocity fields, not shown, confirms this.) The western portion of Hultsfred East is near a major stream valley and indeed, water passing through this region at repository depth discharges nearby in the Silverån-Emån stream system. This is in agreement with the statements of VP that it is the eastern portion of Hultsfred East that very long flow paths (~40 km) may be achieved. By placing the repository over the entire Hultsfred East site and not only the eastern portion, FS guaranteed that most of the discharge would be local - to the stream valley. In comparison, the plume from coastal repositories is shown in **Figure 4-bottom**.

A second set of simulations by this reviewer was done for the only Case shown by FS, 1:1, isotropic bedrock permeability. Results for the 1:1 Case (**Figure 5**) indicate that some discharge areas from the eastern portion of East Hultsfred (**Figure 5-top**) may be closer to the release point than for the 10:1 Case. Despite this, for appropriate location of the repository within the eastern portion of Hultsfred-east, the shortest path length would still be long (~20 km to the closest major discharge point to the east, which is about halfway to the coast) with some radionuclides still reaching the Baltic on a deeper path. **Figure 5** also compares plumes from a Hultsfred and coastal repository for this bedrock representation. For both bedrock cases shown here, the inland repository has significantly longer discharge paths.

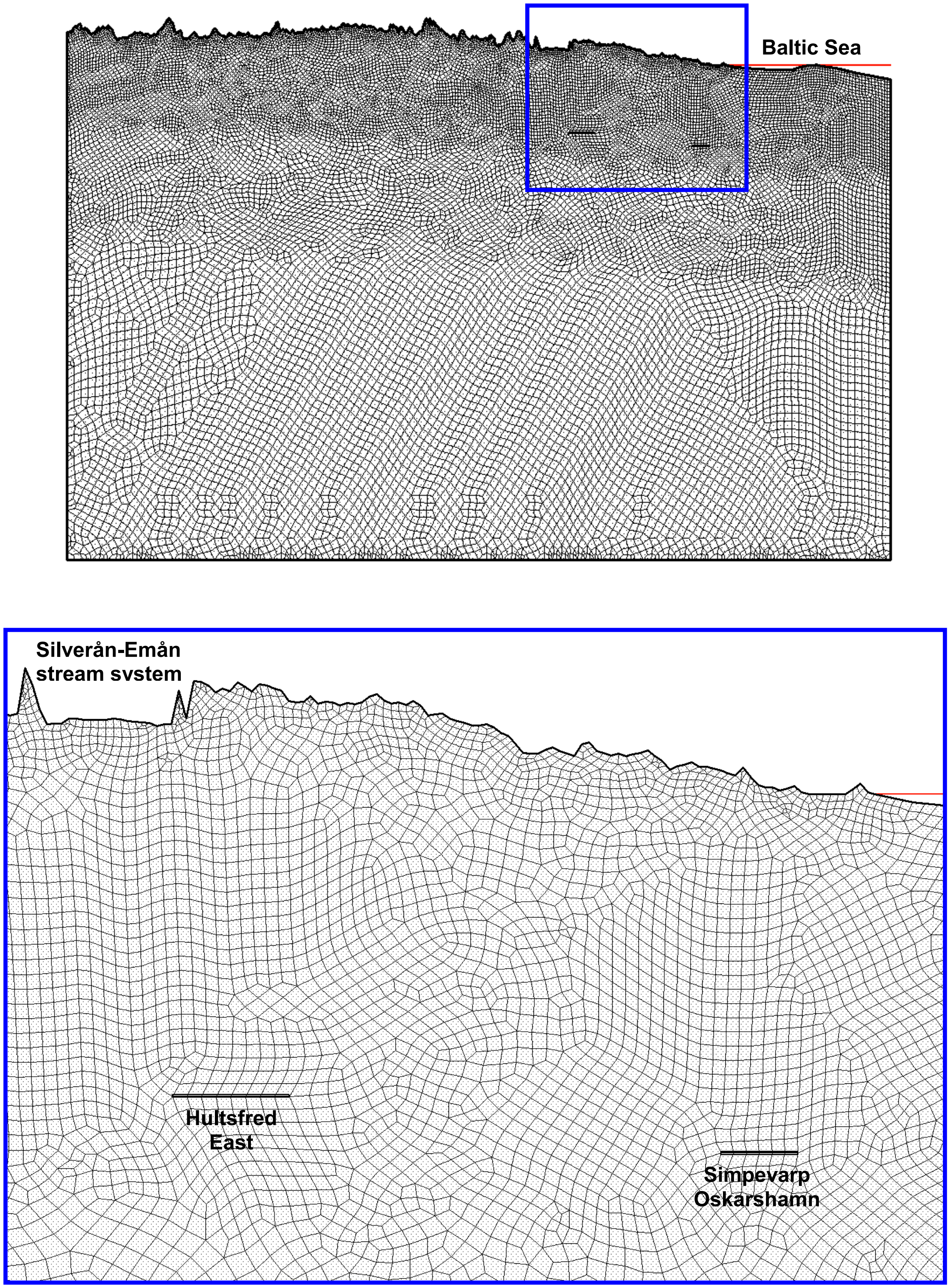

Figure 1 – 2D finite element mesh along east-west section through sites (entire mesh and close view of coastal portion) showing repository sites at 500m depth.

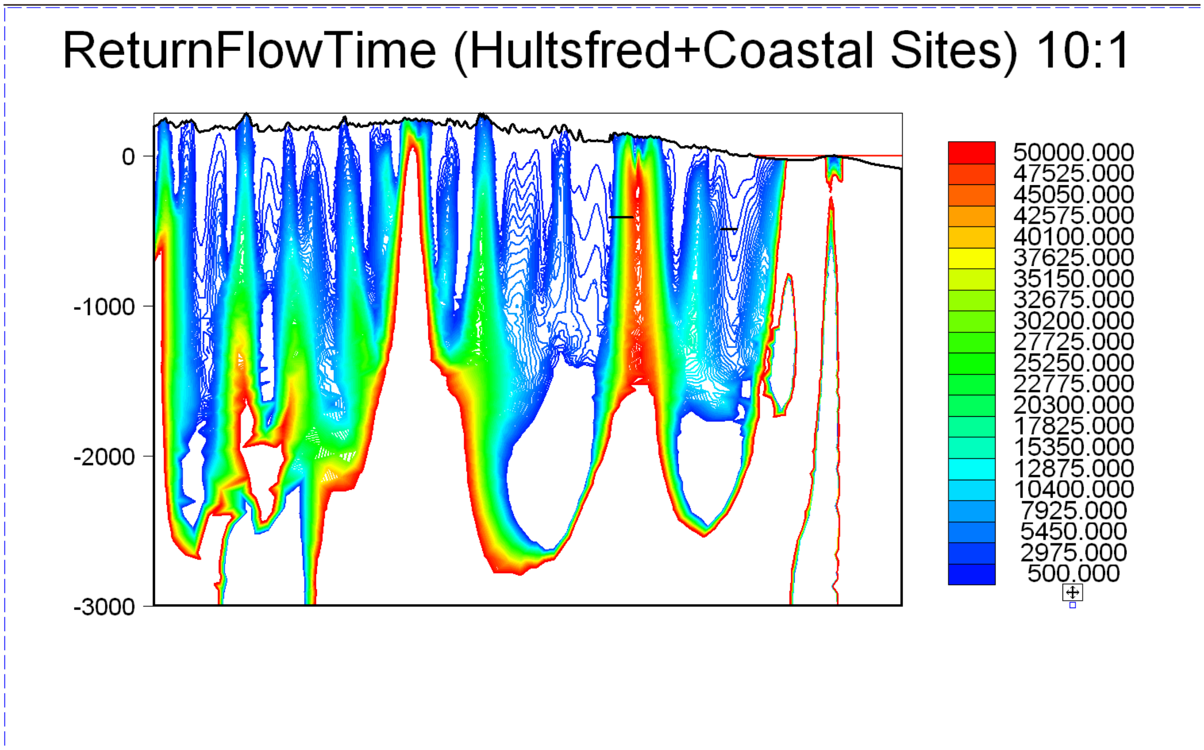

Figure 2 – Return flow time (time before discharge for each point underground) (times given in years and are relative). Relative times in eastern part of East Hultsfred about 50000 years; times at coastal sites about 500 years.

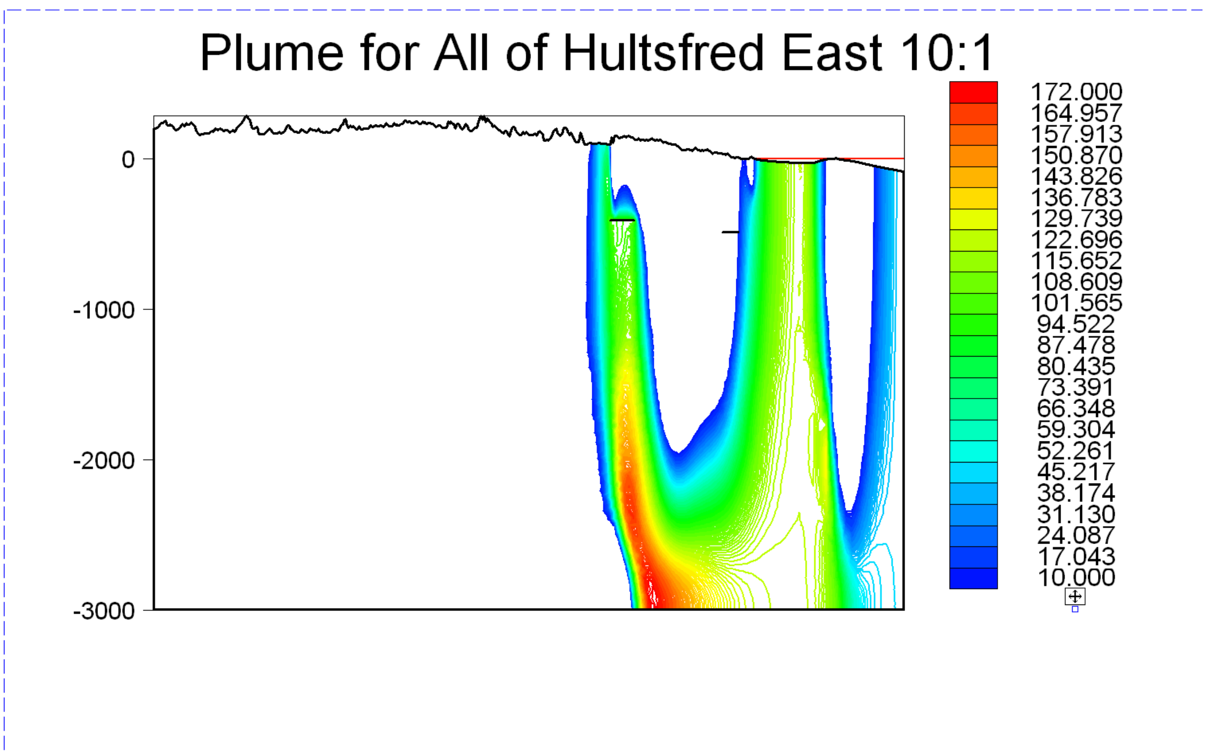

Figure 3 – Steady-state plume from repository located in entire Hultsfred-East site. Note that discharge occurs both to Silverån-Emån stream system and to coast.

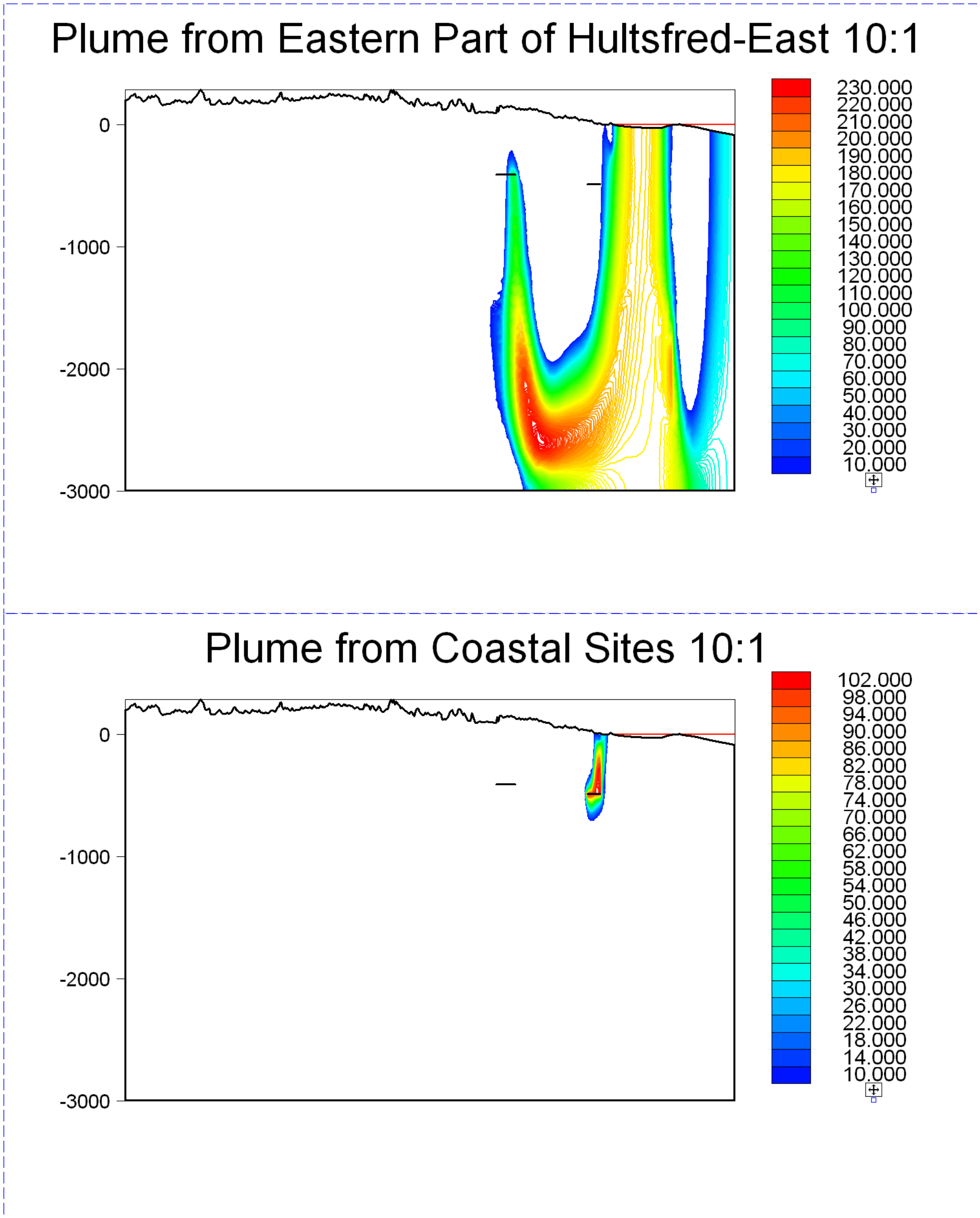

Figure 4 – Comparison of steady-state plumes from repository located in eastern part of Hultsfred-East site and coastal sites for 10:1 bedrock permeability. (Concentration values are relative.)

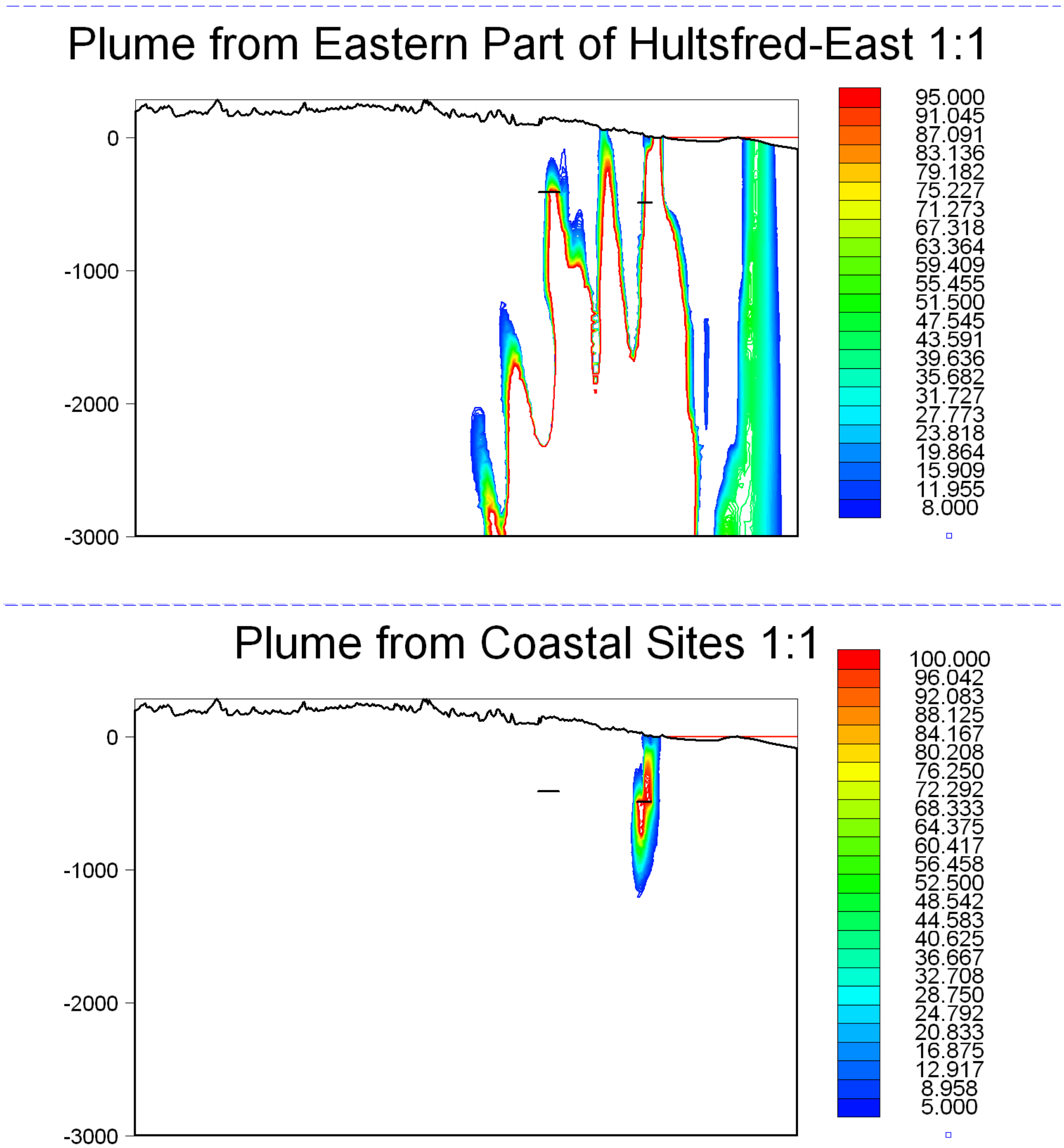

Figure 5 – Comparison of steady-state plumes from repository located in eastern part of Hultsfred-East site and coastal sites for 1:1 bedrock permeability. (Concentration values are relative.)

Review of "Grundvattnets regionala flödesmönster och sammansättning - betydelse för lokalisering av djupförvaret" (SKB R-03-01)

Clifford I. Voss
U.S. Geological Survey
6 July 2004

Summary Comments:

The primary thrust of the report is to determine the importance of groundwater flow fields with particular regard to the importance of recharge and discharge areas in regions considered for safe location of high-level nuclear waste repositories. Additionally, the report considers the impact of salt content of fluids on safe repository siting.

I find that the report is not successful in making sound and convincing arguments for the conclusions that are put forward, that (1) there is no safety difference between inland recharge area and coastal discharge area sites in terms of potential repository safety, and that (2) salt concentration in groundwater at a site location does not have important impact on repository function and hydrogeologic barrier safety. More comments on each of these conclusions are provided on the following pages.

Overall, the report presents scant new information or interpretations. It reads and has the technical level similar to a textbook on basic hydrogeology rather than of an interpretive study. It is highly repetitive of concepts and interpretations with the same statements being reproduced in many places. The report is far too long for what it provides. I can see little information provided herein that would move SKB's waste isolation program forward. Further, this report was based on unpublished and unfinished results from two reports in progress, and now that these reports are published, the conclusions drawn in the present report may require revision. Indeed, as a result of discussions at the SKB presentation of modeling reports R-03-23 and R-03-24 on 23 April 2004, Stockholm, and information that became available there, particularly regarding the first one, it seems that the conclusions concerning inland repository locations require significant revision.

(1) Recharge and discharge area siting.

The main argument in this report follows the argument of Follin and Svensson (2003, SKB R-03-23). It is stated that groundwater flow in inland areas is controlled largely by local topographic gradients that cause local flow cells to reach deeper than repository depth. This causes inland sites to have discharge areas near a repository, just as discharge from coastal sites is no further than the nearby seacoast. This thesis contrasts with the results of Voss and Provost (2001, SKI Report 01:44), who found that inland sites within recharge areas might have flow paths several orders of magnitude greater in length and travel time than coastal sites.

Specific disagreement centers on results for the Hultsfred site. Based on the work by Follin/Svensson, the report being reviewed here points out that flow paths from the East Hultsfred site will discharge nearby. This is in contrast with what was found by Voss/Provost, that the Hultsfred site has an advantageous repository region with very long flow paths to the discharge points. The reason given here for the difference in results of the two studies is that the Voss/Provost model was insufficiently discretized to reproduce the local topographic variations at the site and thus, could not reproduce the local flow cells.

In fact, this reviewer has shown in detail (see review of SKB R-03-23) how this was not at all the case. Voss/Provost had pointed out a region in East Hultsfred within a regional recharge area having very long flow paths and long travel times. Not considering this region separately, Follin/Svensson had placed starting points for flow paths in the western portion of the East Hultsfred site, the region that has a discharge area in the nearby stream system, as well as in the area from which the long flow paths emanate. The many flow paths within the local flow cell on the west obscured the advantages of the eastern region in their study, though some of the long eastern flow paths are visible in their figures.

Indeed, the discretization of Follin/Svensson in a region surrounding Hultsfred was not much finer than that used by Voss/Provost, and they found that both discretizations gave the <u>same</u> result for Hultsfred, and so they effectively matched the results of Voss/Provost. Discretization differences between the models had little impact on the flow paths from the eastern part of East Hultsfred, the area that Voss/Provost pointed out as being in a regional recharge area with very long flow paths and long travel times.

Thus, Follin/Svensson failed to show that discretization of Voss/Provost was insufficient for studying flow fields and also failed to show that inland local topographic variations generate flow cells that reach to repository depth. Thus, most of the arguments presented in the presently reviewed report concerning recharge or discharge area siting of a repository are founded on incorrect information from Follin/Svensson, and are therefore themselves incorrect.

Clearly, this report makes it apparent that inland sites can have longer paths than coastal sites. This is repeated several times, especially in reference to inland sites having a larger downstream area of impact, e.g. from page 85's conclusions:

> *"Den primära skillnaden mellan ett inlandsbeläget och ett kustbeläget djupförvar är att grundvattnet som passerat ett inlandsförvar kan ha ett längre väg och därmed ett större potentiellt påverkansomrade i avrinningsomradet an ett förvar beläget nära kusten."*

Here this is paradoxically used an argument "in favor of" near coast siting; it seems that the authors are not convinced by their own argumentation made elsewhere regarding the non-existence of long flow paths from inland sites!

Thus, a corrected discussion in this report must return to the main factor for retention of decaying radionuclides, the F parameter and the impact of long paths and travel times. On page 75 it is stated that it would be advantageous to have long paths by placing the repository inland below a recharge area. This increases both path length and travel time, important factors in the F parameter. However, on page 75, this possibility was immediately dismissed based on the previous discussions about local flow cells and short flow paths due to high local topographic gradients inland. As pointed out above, the conclusions about these inland aspects are wrong, so the added safety factor of long paths cannot be dismissed so handily. Long flow paths and travel times are possible from appropriately located inland sites (Voss and Provost, 2001), and these would potentially increase the F parameter by several orders of magnitude giving a significant increase of the hydrogeologic safety margin relative to coastal sites.

(2) Siting with regard to local salt concentration

The report correctly states that salt concentrations affect the groundwater flow field; this is well known. The report also states that to properly represent the flow field, groundwater flow modeling of sites with varying salt concentration must account for variable fluid density. This is also correct and well known. In fact, the existence of salt water makes the local flow cells penetrate to lesser depths than they would in a constant density fluid. This fact makes it 'easier' to place a repository within the deeper salty flow system, below the superficial local cells – the one with long flow paths. This point is not brought out in the discussion.

Further, it is pointed out that salt content decreases the swelling potential of bentonite fill, and decreases the sorptive capacity of the bedrock for some radionuclides. This reviewer cannot judge the correctness of these statements, but wishes to point out that near-coast sites will have higher salt content than inland sites (as stated in the report). This would make inland sites more desirable with respect to these factors. However, the report states that these factors are insignificant with respect to safety and this reviewer cannot judge the accuracy of this statement. Thus, some questions here may benefit from further expert consideration.