From: Cavallaro, Kathleen [mailto:Kathleen.Cavallaro@NRCan-RNCan.gc.ca]
Sent: November 28, 2012 4:41 PM
To: DGR Review / Examen DFGP [CEAA]
Cc: Hollington, Kathleen; McCauley, Dave; Dixit, Aruna; Clarke, John; Richard, Linda; Blais-Stevens, Andrée
Subject: NRCan Disposition of OPGs Response to Panel IRs related to NRCan IRs on hydrogeology

Hello,

Please find attached NRCan's Disposition of OPGs Response to Panel IRs derived from NRCan IRs on hydrogeology for the Deep Geologic Repository (DGR) project.

NRCan's review of OPG's responses to DGR JRP IRs derived from NRCan's IRs related to seismicity, Stratigraphy and Sedimentology and hydrogeochemistry is ongoing.

Regards,

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Natural Resources Canada’s Response to Ontario Power Generation’s (OPG) Response to the Joint Review Panel’s (JRPs) Information Requests (IRs) for the Deep Geologic Repository (DGR) project

Prepared by: Natural Resources Canada (NRCan)
Date: November 27, 2012

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1. Introduction

NRCan is participating as a federal authority in the JRP's environmental assessment of the DGR Project, providing specialist and expert information and knowledge within the meaning of s. 20 of the *Canadian Environmental Assessment Act, 2012* (CEAA 2012).

Representatives from NRCan have reviewed OPG's response to the DGR JRP Information Requests (IRs) derived from NRCan's original information requests related to hydrogeology. These comments were submitted to the JRP in May 2012 and were included in the JRP Information Request Package #4 submitted to OPG on July 3rd, 2012. OPG's response is provided in the following documents:

- Ontario Power Generation, Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Responses to a Sub-set of Package #4 Information Requests, letter with attachment from Albert Sweetnam to Dr. Stella Swanson dated September 6th, 2012.
- Ontario Power Generation, Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Responses to a Sub-set of Package #4 Information Requests, letter with attachment from Albert Sweetnam to Dr. Stella Swanson dated August 27th, 2012.

NRCan's review of OPG's responses to DGR JRP IRs derived from NRCan's IRs related to seismicity, Stratigraphy and Sedimentology is forthcoming. The following submission responds to OPGs Response to JRP IRs related to NRCan's hydrogeology comments, mainly:

- **EIS-04-125** - NRCan Comment # 1 (Part 2 of IR package – September 14, 2012): IR partially addressed – Clarification included with disposition for EIS-04-127.

- **EIS-04-126** - NRCan Comment # 2 (Part 1 of IR package – August 27, 2012): Unresolved - Disposition included with Disposition for EIS-04-127.

- **EIS-04-127** - NRCan Comment # 3 (Part 2 of IR package – September 14, 2012): Unresolved – Disposition and New Information Request developed.

- **EIS-04-128** - NRCan Comment # 4(Part 2 of IR package – September 14, 2012): Resolved. NRCan has no further requests.

- **EIS-04-129** - NRCan Comment # 5 (Part 2 of IR package – September 14, 2012): Unresolved – Disposition developed.

2. Summary Table of Dispositions and Additional Information Requests

The following summary table is based on section 4 and provides a summary of NRCan's dispositions. It also includes one additional information request in relation to hydrogeology.

JRP IR #	EIS Guideline Section	Original IR and OPG Response	NRCan Disposition/Additional Information Request
EIS-04-125	10.1.3; 11.4.3	**Original Information Request** **Information Request:** Use refined vertical discretization in the numerical hydrogeologic models to ensure explicit representation of thin permeable units where horizontal advective solute transport may be significant based on the results of site characterization, and provide the modelling results. Evaluate the influence of averaging the hydrogeologic parameters of two distinct lithologies on the modelling of the vertical diffusive solute transport through the cap rock sequence (i.e are the consequences of using average parameters conservative?). Explain how average hydrogeologic parameters for the Queenston and Georgian Bay/Blue Mtn.formations were obtained (PSR, Table 4-4). **Context:** The coarse vertical resolution of hydrostratigraphic units 4A and 4B implemented in the numerical groundwater flow and transport model does not ensure an accurate representation of horizontal advective mass flux in these units. The averaging of hydraulic properties of thin permeable layers with those of adjacent low-permeability layers causes an underestimation of horizontal porewater velocities and, therefore, of solute mass transport. Hydrostratigraphic unit 5 encompasses the Upper Ordovician cap rock sequence. Porosity data for this interval shows a bimodal distribution (Geology TSD Fig. 5.6.1-9), as may diffusion coefficient (Fig. 5.6.1-10) and permeability (Descriptive Geosphere Fig. 4.16) if more data were available. The two sample populations reflect the presence of shale beds and 'hard beds' (limestone and/or siltstone) in the unit. For the modelling the hydraulic properties of the two populations are averaged. **OPG Response** A detailed description of the development of the regional and Bruce nuclear site conceptual hydrogeologic models, including parameter assignment is provided by Sykes et al. (2011, Section 2) and INTERA (2011, Section 4.15). An assessment of confidence in conceptual and numerical model realizations is provided in Sykes et al. (2011, Section	<u>**NRCan disposition:**</u> The coarse vertical resolution of hydrostratigraphic units 4A and 4B implemented in the regional and site-scale groundwater flow and transport models presented in the Hydrogeologic Modelling (NWMO DGR-TR-2011-16) and Geosynthesis (NWMO DGR-TR-2011-11) reports does not ensure an accurate representation of horizontal advective mass flux in these units. The averaging of hydraulic properties of thin permeable layers with those of adjacent low-permeability layers causes an underestimation of horizontal porewater velocities and, therefore, of advective solute mass transport. The vertical resolution of hydrostratigraphic units 4A and 4B implemented in the site-scale Post-closure Safety Assessment Groundwater Modelling report (NWMO DGR-TR-2011-30), on the other hand, faithfully reproduces the thickness and hydraulic properties of the Salina A1 Upper Carbonate and Guelph units as identified in the DGSM report (NWMO DGR-TR-2011-24).

JRP IR #	EIS Guideline Section	Original IR and OPG Response	NRCan Disposition/Additional Information Request
		7) and INTERA (2011, Section 4.16). Numerical simulations, including illustrative sensitivity, mass transport and paleohydrogeologic scenarios at various scales are described in NWMO (2011, Sections 4 and 5), Sykes et al. (2011), GEOFIRMA (2011) and GEOFIRMA and QUINTESSA (2011). A brief description outlining the application of numerical groundwater models to assess, among other factors, model parameterization in terms of the understanding of groundwater system evolution and Deep Geologic Repository (DGR) safety is provided below. The DGR Geosynthesis process necessitated that the numerical analyses of the groundwater system within the sedimentary sequence be conducted at time and space scales commensurate with the data available and nature of the geologic forcing. A specific focus for the analyses performed was to illustrate and test the understanding of groundwater system properties and behaviour at time scales relevant to demonstrating DGR long-term safety. Four different numerical models were used to assess the influence of hydrogeologic parameter and boundary condition uncertainty, groundwater system hydrostratigraphy (geometry) and long-term perturbations (e.g., glaciation) on predicted response. Further work focused on assessing site-specific analogues that examined the distribution of environmental tracers and occurrence of anomalous over- and under-pressures within the host and confining bedrock formations. These analogues provided insight in the adequacy of formation property up-scaling, the long-term preservation of formation properties and governing mass transport processes. The combined results of the analyses provide a basis to illustrate overall groundwater system evolution, stability and resilience to change that support an assessment of postclosure safety. A description of the modelling approach and results is described by Sykes et al. (2011) and NWMO (2011, Sections 4 and 5). With specific reference to the derivation of rock mass hydraulic conductivities and effective diffusion coefficients (De) for the Ordovician shales, numerical results yield formation properties that are consistent with, or potentially lower than applied. A description of the derivation of the properties for the Ordovician shales and a comparison against international sites is provided in NWMO (2011, Sections 7.2.2 and 7.3). Sykes et al. (2011, Section 7.2.8), examining the occurrence of the observed under-pressures, noted from analyses that the vertical hydraulic conductivities in the Ordovician sediments must be on the order of 10-14 m/s or lower for formation pressures to be preserved. Laboratory estimates of De yield extremely low values when compared to international results, typically 10-12 m2/s or less. For lithologic variation the approach of using arithmetic and harmonic means to estimate formation scale anisotropies was employed; the Georgian Bay formation, for example, is described by NWMO (2011, Section 5.3.5). A further assessment of how parameter uncertainty influences predicted DGR safety is provided by postclosure safety assessment as described below. For the postclosure safety assessment, site-scale numerical models were developed based on the Descriptive Geosphere Site Model (DGSM) (INTERA 2011). These numerical models covered different vertical extents,	NRCan concludes that the proponent has only partially addressed IR EIS-04-125. NRCan's clarifications in relation to the original information request and recommendations for disposition of this comment are grouped with disposition recommendations related to EIS-04-127.

JRP IR #	EIS Guideline Section	Original IR and OPG Response	NRCan Disposition/Additional Information Request
		depending on the purpose of the model, but included explicit discretization of all relevant formations. In particular, those models that extended through the Silurian sediments explicitly included the permeable Guelph and A1 Upper Carbonate formations. See for example, the detailed permeabilities used in the Normal Evolution Reference Case (NE-RC) as shown in Figure 4.1 of the Gas Modelling report (GEOFIRMA and QUINTESSA 2011), and the geological layering in Figure 4.2 of the Groundwater Modelling report (GEOFIRMA 2011). In many of the postclosure analyses, no horizontal gradients were included within the Guelph and A1 Upper Carbonate formations, which maximized the potential impacts at the peak dose location directly above the repository. However, the importance of horizontal gradients within these formations was specifically assessed in the Normal Evolution Horizontal Gradient case (NE-HG). The impacts of this gradient on groundwater flow and solute transport are discussed in Section 5.4 of the Groundwater Modelling report (GEOFIRMA 2011). The implications on postclosure safety are summarized in Section 7.3.2.9 of the Postclosure Safety Assessment report (QUINTESSA et al. 2011). These results confirm that the dose consequences remain low whether or not advective transport within the Guelph and A1 Upper Carbonate formations are included, and that it is conservative to ignore this transport for estimating peak dose consequences.	
EIS-04-126	10.1.3; 11.4.3	**Original Information Request** **Information Request:** Use revised hydraulic parameters to represent the Shadow Lake layer in the numerical hydrogeologic model in order to reflect a continuous basal permeable unit across the model domain, and provide the results. **Context:** Hydrostratigraphic Unit 8, consisting of Cambrian sandstones and overlying Shadow Lake deposits, forms a permeable basal unit that is continuous over the domain of the hydrogeologic model. The permeability of the Shadow Lake Formation may be significantly enhanced beyond the erosional limit of the Cambrian, where it un-conformably overlies the Precambrian on the flanks of the Algonquin Arch. NRCan notes that the hydraulic conductivity for the Shadow Lake Formation presented in Table 4.19 of the DGSM report (NWMO DGR-TR-2011-24) was not measured at the DGR site but rather was derived from values measured elsewhere, as reported in the literature (NWMO DGR-TR-2011-24, p.268).	**NRCan disposition:** NRCan considers this information request to be unresolved. NRCan requests that the proponent revise hydraulic parameters for the Shadow Lake Fm. in order to reflect a continuous basal permeable unit across the model domain. The recommendation for disposition of this comment is grouped with disposition recommendations related to IR EIS-04-127.

JRP IR #	EIS Guideline Section	Original IR and OPG Response	NRCan Disposition/Additional Information Request
		OPG Response	
		OPG Response: The numerical representation of the Shadow Lake Formation was based on the best available geologic and hydrogeologic information. Beneath the Bruce nuclear site the Shadow Lake Formation is 5 m thick, approximately 17m above the Precambrian crystalline basement. The formation is a hydrostratigraphic unit across the entire regional domain with an assigned horizontal hydraulic conductivity of 10-9 m/s. While alternative simulations of increased hydraulic conductivity within the Shadow Lake Formation were not performed, a sensitivity case was run in which the upper 20 m of the Precambrian surface beneath the entire regional domain was assigned a hydraulic conductivity of 10-8 m/s (Sykes et al. 2011, Section 4.4.5). Given that the Cambrian sandstone pinches out approximately 10 km or less east of the DGR site and that it is absent over the Algonquin Arch, the Shadow Lake occurs directly on the Precambrian rock for most of the up-dip portion of the regional scale model domain. Results for an increased horizontal hydraulic conductivity case for the Shadow Lake will not be materially different from the Precambrian sensitivity case. The results for the Precambrian sensitivity case indicate that Mean Life Expectancies did not materially change from the Base Case simulation for a conservative, non-decaying, non-sorbed tracer released at the DGR horizon. Further, similar comparison of estimated Péclet numbers indicated virtually no change to Base Case simulations, a reflection of the insensitivity of the mass transport processes in the confining Ordovician sediments to the occurrence of an underlying laterally extensive and more permeable bedrock formation. It is worth noting that estimates of dose consequence arising from drinking the groundwater within the Cambrian directly beneath the DGR were performed (QUINTESSA et al. 2011, Section 7.1.2). Although the groundwater within the Cambrian is not potable (Total Dissolved Solids = 225 g/L), the estimated peak hypothetical dose is about 0.002 mSv/a at 1.5 million years.	
EIS-04-127	10.1.3; 11.4.3	**Original Information Request**	
		Information Request: Use revised boundary conditions in the regional hydrogeologic model to ensure that observed hydraulic gradients and porewater velocities, both updip (Guelph, Cambrian) and down-dip (Salina A1 Upper Carbonate), are reproduced, and provide the modelling results. **Context:** The lateral "no-flow" boundary conditions imposed on the regional hydrogeologic model preclude influx across the western boundary and updip flow from the Michigan Basin in the high-permeability Niagaran and Cambrian Formations, despite observations to the contrary at the Bruce site (DGR-TR-2011-24, Table 4.16, p.291). Horizontal advective mass transport in these units cannot be considered negligible with respect to vertical diffusive transport in	**NRCan disposition:** Using the regional-scale groundwater flow and solute transport models, the proponent investigated the sensitivity of DGR performance metrics to lateral boundary conditions in the higher conductivity units (Salina A1 Carbonate, Niagaran, Cambrian) where horizontal advective transport could be significant (sec. 4.4.4, NWMO DGR-TR-2011-16). However, the scheme used by

JRP IR #	EIS Guideline Section	Original IR and OPG Response	NRCan Disposition/Additional Information Request
		the intervening Ordovician Formations. **OPG Response** The sensitivity of predicted groundwater system behaviour, in particular, performance measures (i.e., groundwater velocity, mean life expectancy (MLE), Péclet number) to assumed hydrogeologic lateral boundary conditions was assessed by Sykes et al. (2011, Sections 4.4 and 7.2.2). The assessment included the sensitivity simulations that explored groundwater system response to 'open' lateral boundary conditions under base case and paleohydrogeologic scenarios (Sykes et al. 2011; simulation fr-base-hbc, Section 4.4.4; simulation fr-base-paleo-open-bnd, Section 5.6.10). The assessment provides evidence that the assumed lateral boundary conditions do not materially influence the diffusion dominant mass transport within the hosting and confining Ordovician bedrock formations. With respect to the confined and saline Salina A1 Upper Carbonate, Guelph (Niagaran) and Cambrian aquifers that bound the Ordovician sediments, precise numerical estimates of regional hydraulic gradients and advective flow rates will be influenced by a number of factors. These include: i) regional bedrock hydrostratigraphy; ii) regional groundwater salinity distributions; iii) regional aquifer and aquitard hydraulic conductivity distributions; and iv) paleo influences (e.g., the hydro-mechanical influence of glacial ice-sheet advance and retreat across the domain). As these regional data do not exist, the manipulation of regional lateral boundary conditions alone will not yield non-unique or materially improved results at the scale of the Bruce nuclear site. In this circumstance, several precautionary points are noteworthy with regard to the occurrence, relevance and treatment of advective horizontal groundwater flow in the bounding confined aquifers. • Park et al. (2009) show that for increasing total dissolved solids (TDS) concentrations with depth, there can be a static brine region because the surface driving forces cannot lift the brine located at depth. Within this region the groundwater is essentially stagnant. Over the entire Michigan Basin, the gravitational driving force imposed by topography is minimal; the gradients attributed to the gravitational driving force are larger in the regional-scale domain, as determined by the elevation difference between the Niagara Escarpment and Lake Huron, than they are across the Michigan Basin (Lake Michigan and Lake Huron have the same elevation). From this perspective, the results of the regional-scale model can be deemed to be conservative. • The Niagaran Group has been characterized sufficiently such that the sub- and outcrop portions of the units are included in the regional-scale domain. While the Guelph (Niagaran Group) has been truncated to the south by the selection of the regional-scale domain, the units of the group become deeper south of the regional domain and potential paths in a southward direction to the biosphere are significantly longer than those estimated by the analyses of this study. • The Cambrian sandstones and carbonates are absent over the Algonquin Arch while the unit thickens and	the proponent to generate horizontal gradients in these units does not appear to reproduce the magnitude or the direction of head gradients observed at the site. According to the proponent's scheme (p.109, NWMO DGR-TR-2011-16), flow in the Niagaran and Cambrian is topographically driven (down-dip) whereas field observations indicate that it is directed *updip*. In site-scale groundwater flow and solute transport modeling (sec. 4.5, NWMO DGR-TR-2011-16), the proponent investigated the near-field migration of a conservative tracer from the proposed location of the repository in the Cobourg Formation. However, the proponent did not consider horizontal gradients in the three high-conductivity units. In paleohydrogeologic analyses (sec. 5, NWMO DGR-TR-2011-16), the proponent investigated the case of open lateral boundaries in the high-conductivity units allowing horizontal flow (sec. 5.6.10, NWMO DGR-TR-2011-16). However, transport modeling considered the migration of a tracer from the surface to the repository rather than the other way around. Using the 3D Simplified (3DS) groundwater flow and solute transport model, the

JRP IR #	EIS Guideline Section	Original IR and OPG Response	NRCan Disposition/Additional Information Request
		deepens both to the west and to the south; the Cambrian outcrop is north of the regional-scale domain. A MLE of 44 Ma (million years) was predicted in the assessment of the lateral boundary condition (Sykes et al. 2011; Section 4.4.4). The extension of the regional-scale domain to include the Cambrian outcrop would result in a longer flow path and hence a longer MLE; the analysis presented in Section 4.4.4, which includes permeable pathways to the biosphere at the domain boundary for both the Niagaran Group and the Cambrian, is thus conservative. • The paleohydrogeologic analysis of Sykes et al. (2011, Section 5.6.10) investigated the role of open or freely draining lateral boundaries for high conductivity units such as the A1 Carbonate, Niagaran Group, and the Cambrian Formation. The approach applied a specified head boundary condition equal to the initial condition for the entire 120,000 years for select lateral boundary nodes. The tracer distribution for the analysis is undifferentiated from that of the base-case paleohydrogeologic simulation. • For the postclosure safety assessment, site-scale numerical models were developed based on the Descriptive Geosphere Site Model (DGSM) (INTERA 2011). These numerical models covered different vertical extents, depending on the purpose of the model, but included explicit discretization of all relevant formations. In particular, those models that extended through the Silurian sediments explicitly included the confined Guelph and Salina A1 Upper Carbonate aquifer. In many of the postclosure analyses, no horizontal gradients were included within the Guelph and Salina A1 Upper Carbonate formations, which maximized the potential impacts at the peak dose location directly above the repository. However the importance of horizontal gradients within these formations was specifically assessed in the Normal Evolution Horizontal Gradient case (NE-HG). The impacts of this gradient on groundwater flow and solute transport are discussed in Section 5.4 of the Groundwater Modelling report (GEOFIRMA 2011). The implications on postclosure safety are summarized in Section 7.3.2.9 of the Postclosure Safety Assessment report (QUINTESSA et al. 2011). These results confirm that the dose consequences remain low whether or not advective transport within the Guelph and A1 Upper Carbonate are included, and that it is conservative to ignore this transport for estimating peak dose consequences. The assessment approach above provides a reasoned basis to understand the limited role of the confined Salina A1 Upper Carbonate, Guelph and Cambrian aquifers on the long-term performance and safety of the proposed DGR. In this circumstance, further refinement of the regional scale groundwater numerical model to improve predictions at the DGR site scale is not considered of consequence to DGR long-term performance.	proponent conducted Performance Safety Assessments (PSA) for various normal evolution and disruptive scenarios (NWMO DGR-TR-2011-30). In scenario NE-HG, the proponent investigated the effects of horizontal hydraulic gradients in the thin permeable Silurian units (sec. 5.4, NWMO DGR-TR-2011-30). However, because the 3DS model does not include the Cambrian (sec. 4.2.2, NWMO DGR-TR-2011-30), the effects of a horizontal gradient in this permeable unit were not considered in the Groundwater Modeling PSA. NRCan concludes that the proponent has not performed any additional groundwater flow and solute transport analyses aimed at addressing Panel Information Requests EIS-04-125, EIS-04-126 and EIS-04-127. NRCan's recommendations for disposition of the proponent's response to these IRs are as follows: **NRCan New Information request # 1** Develop a modified version of the FRAC3DVS-OPG regional groundwater flow and solute transport model, and its embedded site-scale sub-model, incorporating the following features: • Refined vertical discretization of hydrostratigraphic units 4A (Salina A1

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			Upper Carbonate) and 4B (Guelph Fm.) to ensure explicit representation of their thicknesses and hydraulic properties as reported in the DGSM report (NWMO DGR-TR-2011-24) • Revised hydraulic parameters for the Shadow Lake Fm. in order to reflect a continuous basal permeable unit across the model domain. • Revised boundary conditions to ensure that observed hydraulic gradients and porewater velocities, both updip (Guelph, Cambrian) and down-dip (Salina A1 Upper Carbonate), are reproduced at the site. Use the modified regional groundwater flow and solute transport model to investigate performance metrics for scenarios involving long-distance updip migration of radionuclides in the Guelph and basal clastic unit, and report results. Use the modified embedded site-scale groundwater flow and solute transport sub-model to investigate tracer migration for scenarios including that of hypothetical discrete fracture zones hydraulically connected to the Cambrian/Shadow lake Formations, and report results. **Context for New Information Request** The Salina A1 Upper Carbonate unit and

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<tr><th>JRP IR #</th><th>EIS Guideline Section</th><th>Original IR and OPG Response</th><th>NRCan Disposition/Additional Information Request</th></tr>
<tr><td></td><td></td><td></td><td>the Guelph, Cambrian/Shadow lake Formations are thin, permeable layers that represent potential preferential pathways for relatively rapid horizontal advective radionuclide transport away from the repository site. In order to investigate the fate of radionuclides migrating laterally beyond the boundaries of the DGR, and various near-field scenarios, the regional and embedded groundwater flow and transport models must faithfully represent hydrogeological observations from these units.</td></tr>
<tr><td>EIS-04-128</td><td></td><td>Original Information Request
Information Request:
Explain and justify why the conceptual model of solute transport that is described in Sudicky and Frind (WRR, 18(6), 1634-1642, 1982), featuring horizontal advective-dispersive transport along high-conductivity layers with diffusive vertical transport into adjacent low-conductivity "matrix" formations, was not used.

Context:
Given that significant horizontal advective-dominated transport of tracers is occurring in the permeable Salina Upper A1 Carbonate, Guelph and Cambrian units, as well as in the Devonian, the proponent's purely 1D conceptualization of the tracer transport problem is questionable. In particular, the model ignores lateral mass fluxes in the intermediate and deep groundwater systems at the Bruce site.

OPG Response
OPG Response:
As part of Geosynthesis activities, the numerical code MIN3P was used to perform one-dimensional (vertical) numerical simulations of mass transport within the near horizontally layered sedimentary sequence. In particular, the simulations were performed to explore whether observed vertical distributions of 18O and Cl within Ordovician and lower Silurian formation porewaters could be ascribed to diffusion processes occurring on geologic time scales (i.e., 300 million years). The conceptual and numerical models, including a description of model justification, properties,</td><td>NRCan disposition:
As part of Geosynthesis investigations (sec. 4.5.2, DGR-TR-2011-11), the proponent describes a 1D numerical model that is used to test the "diffusion from above" conceptual model for observed tracer profiles through the Ordovician formations at the Bruce site. However, given that significant horizontal advective-dominated transport is found to occur in the permeable Salina A1 Upper Carbonate, Guelph and Cambrian units, as well as in the Devonian, the proponent's purely 1D conceptualization of the transport problem is questionable and may explain the relatively poor model fit to observed tracer profiles. In order to improve model fit, NRCan suggested that the proponent investigate an alternate conceptualization analogous to that</td></tr>
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JRP IR #	EIS Guideline Section	Original IR and OPG Response	NRCan Disposition/Additional Information Request
		boundary conditions, porewater compositions and results, is documented in NWMO (2011; Sections 4.5.1, 4.5.2 and 4.5.3). The conceptual model of mass transport described by Sudicky and Frind (1982), which includes advective-diffusive mass transport in fractured porous media, was not used in this specific case because the analysis assumed that mass transport in the low-permeability bedrock was entirely diffusion dominated. The numerical modelling was not intended to be unique, but rather was intended to provide a reasoned illustrative test as to the potential role of diffusive processes governing solute transport within the deep groundwater system. Similar illustrative modelling approaches have been described by Mazurek (2010) for diffusion dominated sedimentary systems elsewhere. The results of the MIN3P numerical analysis support the hypothesis that solute transport in the Ordovician sediments is diffusion dominant. The illustrative numerical modelling, coupled with additional evidence, including: i) the low formation rock mass hydraulic conductivities estimated during in-situ borehole testing (NWMO 2011; Section 5.2.2); ii) assessment of observed anomalous under-/over- pressure head conditions with regard to the interpretation of deep groundwater system properties and stability (NWMO 2011; Section 5.5); iii) the low effective diffusion coefficients for the Ordovician shales and carbonates (INTERA 2011; Section 4.4); and iv) interpretation of an evaporated seawater origin for Ordovician sedimentary rock pore fluids (NWMO 2011; Section 4.3.3), provides strong evidence corroborating the results of the reasoned assessment and the appropriateness of the modelling approach.	described in Sudicky and Frind (WRR, 18(6), 1634-1642, 1982). These authors describe a model featuring longitudinal advective and dispersive transport along thin permeable layers with lateral diffusion into adjacent low-permeability matrix. NRCan agrees with the proponent that vertical transport within the Ordovician sediments is diffusive, however, transport within the Salina A1 Upper Carbonate, Guelph and Cambrian is largely advective. It is for these very reasons that NRCan proposed a more realistic model of tracer transport at the site that could potentially better match observations and thereby yield greater confidence in the proponent's understanding of diffusive mass transfers between tight Ordovician host rocks and intercalated thin beds where advective transport is dominant. Although the proponent's rationale for rejecting the suggested alternate model of tracer transport is not compelling, NRCan considers this information request to be resolved.
EIS-04-129		**Original Information Request** **Information Request:** Use a base of the 3D simplified hydrogeologic model lowered to the top of the Precambrian in order to assess lateral advective radionuclide transport in the Cambrian unit, as was done for the Salina A1 Carbonate and Guelph units in the NE-HG calculation case, and provide the results.	**NRCan disposition:** NRCan considers this information request to be unresolved. The arguments advanced by the proponent for not including the Cambrian unit within the 3D Simplified

JRP IR #	EIS Guideline Section	Original IR and OPG Response	NRCan Disposition/Additional Information Request
		Context: Placing the lower boundary of the 3DS model at the top of the Cambrian sandstone effectively precludes consideration of horizontal advective transport of radionuclides within this unit. **OPG Response** **OPG Response:** An assessment of lateral radionuclide and contaminant migration in the Cambrian unit was not performed due to the depth and regionally confined nature of the aquifer and, because a postclosure analysis of a hypothetical conservative scenario (described below) estimated the public dose consequence to be many times less than the DGR dose criterion of 0.3 mSv/a. The Cambrian unit represents a confined aquifer within the deep groundwater system at the base of the sedimentary sequence beneath the Bruce nuclear site. The aquifer is saline and non-potable with groundwater Total Dissolved Solid concentrations of approximately 225 g/L. At a regional scale, the aquifer is not readily accessible: i) it is isolated by the thick overlying system of Ordovician and Silurian aquitard/aquicludes; ii) the aquifer pinches out several kilometers east of the Bruce nuclear site; and iii) the nearest Cambrian outcrop is more than 100 km from the DGR site. Multidisciplinary information gathered during site-specific investigations indicates that vertical transmissive connections between the Cambrian and overlying confined Silurian aquifers (Guelph and Salina A1 upper carbonate) do not exist. The evidence supporting the above information and isolated nature of the Cambrian aquifer is provided by NWMO (2011; Sections 2.2, 2.3, 4.4, 5.2, 5.4, and 8). To assess the dose consequence of radionuclide and contaminant migration from the DGR into the Cambrian aquifer, a postclosure analysis was completed. The analysis considered the hypothetical situation of drinking the groundwater within the Cambrian directly beneath the DGR (QUINTESSA et. al. 2011; Section 7.1.2). Although the groundwater within the Cambrian is not potable or readily accessible, the estimated peak hypothetical dose is about 0.002 mSv/a at 1.5 million years. This estimate is approximately 100 times less than the DGR public dose criterion of 0.3 mSv/a. Lateral advective or diffusive migration within the Cambrian aquifer would lead to lower predicted dose consequences. Given the strength of evidence supporting the hydrogeologic isolation of the Cambrian unit and the above predicted postclosure dose consequence, further assessment of lateral migration within the Cambrian is not considered necessary as it does not materially change the DGR Safety Case.	(3DS) groundwater flow and solute transport model are not compelling: While Cambrian groundwater is saline and non-potable, groundwater in the Guelph Formation is even more so (Table 4.17, NWMO DGR-TR-2011-24) yet this unit was included in the 3DS model; While the Cambrian per se may pinch out east of the Bruce site, it is likely that a thin permeable basal clastic unit persists eastward over the Algonquin Arch (see IR EIS-04-126); While the nearest Cambrian outcrop may be more than 100 km from the Bruce site, advective transport velocities in the Cambrian are quite high; Without the supporting analyses requested in IR EIS-04-129, the proponent's claim that lateral advective transport in the Cambrian would lead to lower predicted dose consequences is conjecture. Regardless of whether or not this conjecture is correct, it is a matter of due diligence for the proponent to investigate a scenario corresponding to hydrogeological conditions actually observed at the site. As previously requested in IR EIS-04-129, NRCan requests that the proponent incorporate the Cambrian unit in the 3DS model and report on Performance Safety Assessment modeling that investigates near-field radionuclide migration in the presence of horizontal hydraulic gradients

JRP IR #	EIS Guideline Section	Original IR and OPG Response	NRCan Disposition/Additional Information Request
			in the Salina A1 Upper Carbonate, Guelph and Cambrian formations, as observed at the site.

3. NRCan's Dispositions and Additional Information Requests in Response to OPG's Response to Panel Information Requests (Hydrogeology)

3.1. Documents Cited

- NWMO DGR-TR-2011-24, Descriptive Geosphere Site Model, report prepared by Intera Engineering Ltd., March 2011.
- NWMO DGR-TR-2011-16, Hydrogeologic Modelling, report prepared by Sykes, J.F., Normani, S.D., Yin, Y., March 2011.
- NWMO DGR-TR-2011-11, Geosynthesis, report prepared by Nuclear Waste Management Organization (NWMO), March 2011.
- NWMO DGR-TR-2011-30, Postclosure Safety Assessment: Groundwater Modelling, report prepared by Geofirma Engineering Ltd., March 2011.

3.2. Dispositions and Additional Information Requests

- **EIS-04-125** – Partially addressed - Clarification included with disposition for EIS-04-127.
- **EIS-04-126** - Unresolved - Disposition included with Disposition for EIS-04-127.
- **EIS-04-127** - Unresolved - Disposition and New Information Request developed.
- **EIS-04-128** - Resolved. NRCan has no further requests.
- **EIS-04-129** - Unresolved – Disposition developed.

IR# EIS-04-125 (NRCan Technical comment no. 1)

Issue: Representation of hydrostratigraphic unit 4 in hydrogeologic modeling
EIS Guidelines section(s): 10.1.3; 11.4.3

Original Information Request:
Use refined vertical discretization in the numerical hydrogeologic models to ensure explicit representation of thin permeable units where horizontal advective solute transport may be significant based on the results of site characterization, and provide the modelling results.

Evaluate the influence of averaging the hydrogeologic parameters of two distinct lithologies on the modelling of the vertical diffusive solute transport through the cap rock sequence (i.e are the consequences of using average parameters conservative?). Explain how average hydrogeologic parameters for the Queenston and Georgian Bay/Blue Mtn.formations were obtained (PSR, Table 4-4).

Context:
The coarse vertical resolution of hydrostratigraphic units 4A and 4B implemented in the numerical groundwater flow and transport model does not ensure an accurate representation of

horizontal advective mass flux in these units. The averaging of hydraulic properties of thin permeable layers with those of adjacent low-permeability layers causes an underestimation of horizontal porewater velocities and, therefore, of solute mass transport. Hydrostratigraphic unit 5 encompasses the Upper Ordovician cap rock sequence. Porosity data for this interval shows a bimodal distribution (Geology TSD Fig. 5.6.1-9), as may diffusion coefficient (Fig. 5.6.1-10) and permeability (Descriptive Geosphere Fig. 4.16) if more data were available. The two sample populations reflect the presence of shale beds and 'hard beds' (limestone and/or siltstone) in the unit. For the modelling the hydraulic properties of the two populations are averaged.

OPG Response:

A detailed description of the development of the regional and Bruce nuclear site conceptual hydrogeologic models, including parameter assignment is provided by Sykes et al. (2011, Section 2) and INTERA (2011, Section 4.15). An assessment of confidence in conceptual and numerical model realizations is provided in Sykes et al. (2011, Section 7) and INTERA (2011, Section 4.16). Numerical simulations, including illustrative sensitivity, mass transport and paleohydrogeologic scenarios at various scales are described in NWMO (2011, Sections 4 and 5), Sykes et al. (2011), GEOFIRMA (2011) and GEOFIRMA and QUINTESSA (2011). A brief description outlining the application of numerical groundwater models to assess, among other factors, model parameterization in terms of the understanding of groundwater system evolution and Deep Geologic Repository (DGR) safety is provided below. The DGR Geosynthesis process necessitated that the numerical analyses of the groundwater system within the sedimentary sequence be conducted at time and space scales commensurate with the data available and nature of the geologic forcing. A specific focus for the analyses performed was to illustrate and test the understanding of groundwater system properties and behaviour at time scales relevant to demonstrating DGR long-term safety. Four different numerical models were used to assess the influence of hydrogeologic parameter and boundary condition uncertainty, groundwater system hydrostratigraphy (geometry) and long-term perturbations (e.g., glaciation) on predicted response. Further work focused on assessing site-specific analogues that examined the distribution of environmental tracers and occurrence of anomalous over- and under-pressures within the host and confining bedrock formations. These analogues provided insight in the adequacy of formation property up-scaling, the long-term preservation of formation properties and governing mass transport processes. The combined results of the analyses provide a basis to illustrate overall groundwater system evolution, stability and resilience to change that support an assessment of postclosure safety. A description of the modelling approach and results is described by Sykes et al. (2011) and NWMO (2011, Sections 4 and 5).

With specific reference to the derivation of rock mass hydraulic conductivities and effective diffusion coefficients (De) for the Ordovician shales, numerical results yield formation properties that are consistent with, or potentially lower than applied. A description of the derivation of the properties for the Ordovician shales and a comparison against international sites is provided in NWMO (2011, Sections 7.2.2 and 7.3). Sykes et al. (2011, Section 7.2.8), examining the occurrence of the observed under-pressures, noted from analyses that the vertical hydraulic conductivities in the Ordovician sediments must be on the order of 10-14 m/s or lower for formation pressures to be preserved. Laboratory estimates of De yield extremely low values when compared to international results, typically 10-12 m2/s or less. For lithologic variation the approach of using arithmetic and harmonic means to estimate formation scale anisotropies was employed; the Georgian Bay formation, for example, is described by NWMO (2011, Section 5.3.5). A further assessment of how parameter uncertainty influences predicted DGR safety is provided by postclosure safety assessment as described below.

For the postclosure safety assessment, site-scale numerical models were developed based on the Descriptive Geosphere Site Model (DGSM) (INTERA 2011). These numerical models covered different vertical extents, depending on the purpose of the model, but included explicit discretization of all relevant formations. In particular, those models that extended through the Silurian sediments explicitly included the permeable Guelph and A1 Upper Carbonate formations. See for example, the detailed permeabilities used in the Normal Evolution Reference Case (NE-RC) as shown in Figure 4.1 of the Gas Modelling report (GEOFIRMA and QUINTESSA 2011), and the geological layering in Figure 4.2 of the Groundwater Modelling report (GEOFIRMA 2011).

In many of the postclosure analyses, no horizontal gradients were included within the Guelph and A1 Upper Carbonate formations, which maximized the potential impacts at the peak dose location directly above the repository. However, the importance of horizontal gradients within these formations was specifically assessed in the Normal Evolution Horizontal Gradient case (NE-HG). The impacts of this gradient on groundwater flow and solute transport are discussed in Section 5.4 of the Groundwater Modelling report (GEOFIRMA 2011). The implications on postclosure safety are summarized in Section 7.3.2.9 of the Postclosure Safety Assessment report (QUINTESSA et al. 2011).

These results confirm that the dose consequences remain low whether or not advective transport within the Guelph and A1 Upper Carbonate formations are included, and that it is conservative to ignore this transport for estimating peak dose consequences.

<u>NRCan disposition:</u>

The coarse vertical resolution of hydrostratigraphic units 4A and 4B implemented in the regional and site-scale groundwater flow and transport models presented in the Hydrogeologic Modelling (NWMO DGR-TR-2011-16) and Geosynthesis (NWMO DGR-TR-2011-11) reports does not ensure an accurate representation of horizontal advective mass flux in these units. The averaging of hydraulic properties of thin permeable layers with those of adjacent low-permeability layers causes an underestimation of horizontal porewater velocities and, therefore, of advective solute mass transport. The vertical resolution of hydrostratigraphic units 4A and 4B implemented in the site-scale Post-closure Safety Assessment Groundwater Modelling report (NWMO DGR-TR-2011-30), on the other hand, faithfully reproduces the thickness and hydraulic properties of the Salina A1 Upper Carbonate and Guelph units as identified in the DGSM report (NWMO DGR-TR-2011-24). NRCan concludes that the proponent has only partially addressed IR EIS-04-125.

In order to provide clearer guidance for the proponent, NRCan's recommendations for disposition of this comment are grouped with disposition recommendations related to EIS-04-127.

IR# EIS-04-126 (NRCan Technical comment no. 2)

Issue: Representation of hydrostratigraphic unit 8 in hydrogeologic modeling
EIS Guidelines section(s): 10.1.3; 11.4.3

Original Information Request:

Use revised hydraulic parameters to represent the Shadow Lake layer in the numerical hydrogeologic model in order to reflect a continuous basal permeable unit across the model domain, and provide the results.

Context:
Hydrostratigraphic Unit 8, consisting of Cambrian sandstones and overlying Shadow Lake deposits, forms a permeable basal unit that is continuous over the domain of the hydrogeologic model. The permeability of the Shadow Lake Formation may be significantly enhanced beyond the erosional limit of the Cambrian, where it un-conformably overlies the Precambrian on the flanks of the Algonquin Arch.

OPG Response:
The numerical representation of the Shadow Lake Formation was based on the best available geologic and hydrogeologic information. Beneath the Bruce nuclear site the Shadow Lake Formation is 5 m thick, approximately 17m above the Precambrian crystalline basement. The formation is a hydrostratigraphic unit across the entire regional domain with an assigned horizontal hydraulic conductivity of 10-9 m/s. While alternative simulations of increased hydraulic conductivity within the Shadow Lake Formation were not performed, a sensitivity case was run in which the upper 20 m of the Precambrian surface beneath the entire regional domain was assigned a hydraulic conductivity of 10-8 m/s (Sykes et al. 2011, Section 4.4.5). Given that the Cambrian sandstone pinches out approximately 10 km or less east of the DGR site and that it is absent over the Algonquin Arch, the Shadow Lake occurs directly on the Precambrian rock for most of the up-dip portion of the regional scale model domain. Results for an increased horizontal hydraulic conductivity case for the Shadow Lake will not be materially different from the Precambrian sensitivity case. The results for the Precambrian sensitivity case indicate that Mean Life Expectancies did not materially change from the Base Case simulation for a conservative, non-decaying, non-sorbed tracer released at the DGR horizon. Further, similar comparison of estimated Péclet numbers indicated virtually no change to Base Case simulations, a reflection of the insensitivity of the mass transport processes in the confining Ordovician sediments to the occurrence of an underlying laterally extensive and more permeable bedrock formation.
It is worth noting that estimates of dose consequence arising from drinking the groundwater within the Cambrian directly beneath the DGR were performed (QUINTESSA et al. 2011, Section 7.1.2). Although the groundwater within the Cambrian is not potable (Total Dissolved Solids = 225 g/L), the estimated peak hypothetical dose is about 0.002 mSv/a at 1.5 million years.

NRCan disposition:

NRCan considers this information request to be unresolved. The hydraulic conductivity for the Shadow Lake Formation presented in Table 4.19 of the DGSM report (NWMO DGR-TR-2011-24) was not measured at the DGR site but rather was derived from values measured elsewhere, as reported in the literature (NWMO DGR-TR-2011-24, p.268). NRCan requests that the proponent revise hydraulic parameters for the Shadow Lake Fm. in order to reflect a continuous basal permeable unit across the model domain. NRCan's recommendation for disposition of this comment is grouped with disposition recommendations related to IR EIS-04-127.

IR# EIS-04-127 (NRCan Technical comment no. 3)

Issue: Horizontal advective solute transport in the Niagaran and Cambrian units.
EIS Guidelines section(s): 10.1.3; 11.4.3

Original Information Request:
Use revised boundary conditions in the regional hydrogeologic model to ensure that observed hydraulic gradients and porewater velocities, both updip (Guelph, Cambrian) and down-dip (Salina A1 Upper Carbonate), are reproduced, and provide the modelling results.

Context:
The lateral "no-flow" boundary conditions imposed on the regional hydrogeologic model preclude influx across the western boundary and updip flow from the Michigan Basin in the high-permeability Niagaran and Cambrian Formations, despite observations to the contrary at the Bruce site (DGR-TR-2011-24, Table 4.16, p.291). Horizontal advective mass transport in these units cannot be considered negligible with respect to vertical diffusive transport in the intervening Ordovician Formations.

OPG Response:
The sensitivity of predicted groundwater system behaviour, in particular, performance measures (i.e., groundwater velocity, mean life expectancy (MLE), Péclet number) to assumed hydrogeologic lateral boundary conditions was assessed by Sykes et al. (2011, Sections 4.4 and 7.2.2). The assessment included the sensitivity simulations that explored groundwater system response to 'open' lateral boundary conditions under base case and paleohydrogeologic scenarios (Sykes et al. 2011; simulation fr-base-hbc, Section 4.4.4; simulation fr-base-paleo-open-bnd, Section 5.6.10). The assessment provides evidence that the assumed lateral boundary conditions do not materially influence the diffusion dominant mass transport within the hosting and confining Ordovician bedrock formations.

With respect to the confined and saline Salina A1 Upper Carbonate, Guelph (Niagaran) and Cambrian aquifers that bound the Ordovician sediments, precise numerical estimates of regional hydraulic gradients and advective flow rates will be influenced by a number of factors. These include: i) regional bedrock hydrostratigraphy; ii) regional groundwater salinity distributions; iii) regional aquifer and aquitard hydraulic conductivity distributions; and iv) paleo influences (e.g., the hydro-mechanical influence of glacial ice-sheet advance and retreat across the domain). As these regional data do not exist, the manipulation of regional lateral boundary conditions alone will not yield non-unique or materially improved results at the scale of the Bruce nuclear site. In this circumstance, several precautionary points are noteworthy with regard to the occurrence, relevance and treatment of advective horizontal groundwater flow in the bounding confined aquifers.

- Park et al. (2009) show that for increasing total dissolved solids (TDS) concentrations with depth, there can be a static brine region because the surface driving forces cannot lift the brine located at depth. Within this region the groundwater is essentially stagnant. Over the entire Michigan Basin, the gravitational driving force imposed by topography is minimal; the gradients attributed to the gravitational driving force are larger in the regional-scale domain, as determined by the elevation difference between the Niagara Escarpment and Lake Huron, than they are across the Michigan Basin (Lake Michigan and Lake Huron have the same elevation). From this perspective, the results of the regional-scale model can be deemed to be conservative.
- The Niagaran Group has been characterized sufficiently such that the sub- and outcrop portions of the units are included in the regional-scale domain. While the Guelph (Niagaran Group) has been truncated to the south by the selection of the regional-scale domain, the units of the group become deeper south of the regional domain and potential paths in a

southward direction to the biosphere are significantly longer than those estimated by the analyses of this study.

- The Cambrian sandstones and carbonates are absent over the Algonquin Arch while the unit thickens and deepens both to the west and to the south; the Cambrian outcrop is north of the regional-scale domain. A MLE of 44 Ma (million years) was predicted in the assessment of the lateral boundary condition (Sykes et al. 2011; Section 4.4.4). The extension of the regional-scale domain to include the Cambrian outcrop would result in a longer flow path and hence a longer MLE; the analysis presented in Section 4.4.4, which includes permeable pathways to the biosphere at the domain boundary for both the Niagaran Group and the Cambrian, is thus conservative.
- The paleohydrogeologic analysis of Sykes et al. (2011, Section 5.6.10) investigated the role of open or freely draining lateral boundaries for high conductivity units such as the A1 Carbonate, Niagaran Group, and the Cambrian Formation. The approach applied a specified head boundary condition equal to the initial condition for the entire 120,000 years for select lateral boundary nodes. The tracer distribution for the analysis is undifferentiated from that of the base-case paleohydrogeologic simulation.
- For the postclosure safety assessment, site-scale numerical models were developed based on the Descriptive Geosphere Site Model (DGSM) (INTERA 2011). These numerical models covered different vertical extents, depending on the purpose of the model, but included explicit discretization of all relevant formations. In particular, those models that extended through the Silurian sediments explicitly included the confined Guelph and Salina A1 Upper Carbonate aquifer. In many of the postclosure analyses, no horizontal gradients were included within the Guelph and Salina A1 Upper Carbonate formations, which maximized the potential impacts at the peak dose location directly above the repository. However the importance of horizontal gradients within these formations was specifically assessed in the Normal Evolution Horizontal Gradient case (NE-HG). The impacts of this gradient on groundwater flow and solute transport are discussed in Section 5.4 of the Groundwater Modelling report (GEOFIRMA 2011). The implications on postclosure safety are summarized in Section 7.3.2.9 of the Postclosure Safety Assessment report (QUINTESSA et al. 2011). These results confirm that the dose consequences remain low whether or not advective transport within the Guelph and A1 Upper Carbonate are included, and that it is conservative to ignore this transport for estimating peak dose consequences.

The assessment approach above provides a reasoned basis to understand the limited role of the confined Salina A1 Upper Carbonate, Guelph and Cambrian aquifers on the long-term performance and safety of the proposed DGR. In this circumstance, further refinement of the regional scale groundwater numerical model to improve predictions at the DGR site scale is not considered of consequence to DGR long-term performance.

NRCan disposition:

Using the regional-scale groundwater flow and solute transport models, the proponent investigated the sensitivity of DGR performance metrics to lateral boundary conditions in the higher conductivity units (Salina A1 Carbonate, Niagaran, Cambrian) where horizontal advective transport could be significant (sec. 4.4.4, NWMO DGR-TR-2011-16). However, the scheme used by the proponent to generate horizontal gradients in these units does not appear to reproduce the magnitude or the direction of head gradients observed at the site. According to the proponent's scheme (p.109, NWMO DGR-TR-2011-16), flow in the Niagaran and Cambrian is topographically driven (down-dip) whereas field observations indicate that it is directed *updip*.

In site-scale groundwater flow and solute transport modeling (sec. 4.5, NWMO DGR-TR-2011-16), the proponent investigated the near-field migration of a conservative tracer from the proposed location of the repository in the Cobourg Formation. However, the proponent did not consider horizontal gradients in the three high-conductivity units.

In paleohydrogeologic analyses (sec. 5, NWMO DGR-TR-2011-16), the proponent investigated the case of open lateral boundaries in the high-conductivity units allowing horizontal flow (sec. 5.6.10, NWMO DGR-TR-2011-16). However, transport modeling considered the migration of a tracer from the surface to the repository rather than the other way around.

Using the 3D Simplified (3DS) groundwater flow and solute transport model, the proponent conducted Performance Safety Assessments (PSA) for various normal evolution and disruptive scenarios (NWMO DGR-TR-2011-30). In scenario NE-HG, the proponent investigated the effects of horizontal hydraulic gradients in the thin permeable Silurian units (sec. 5.4, NWMO DGR-TR-2011-30). However, because the 3DS model does not include the Cambrian (sec. 4.2.2, NWMO DGR-TR-2011-30), the effects of a horizontal gradient in this permeable unit were not considered in the Groundwater Modeling PSA.

NRCan concludes that the proponent has not performed any additional groundwater flow and solute transport analyses aimed at addressing Panel Information Requests EIS-04-125, EIS-04-126 and EIS-04-127. NRCan's recommendations for disposition of the proponent's response to these IRs are as follows:

NRCan New Information Request #1:

Develop a modified version of the FRAC3DVS-OPG regional groundwater flow and solute transport model, and its embedded site-scale sub-model, incorporating the following features:

- Refined vertical discretization of hydrostratigraphic units 4A (Salina A1 Upper Carbonate) and 4B (Guelph Fm.) to ensure explicit representation of their thicknesses and hydraulic properties as reported in the DGSM report (NWMO DGR-TR-2011-24)
- Revised hydraulic parameters for the Shadow Lake Fm. in order to reflect a continuous basal permeable unit across the model domain.
- Revised boundary conditions to ensure that observed hydraulic gradients and porewater velocities, both updip (Guelph, Cambrian) and down-dip (Salina A1 Upper Carbonate), are reproduced at the site.

Use the modified regional groundwater flow and solute transport model to investigate performance metrics for scenarios involving long-distance updip migration of radionuclides in the Guelph and basal clastic unit, and report results.

Use the modified embedded site-scale groundwater flow and solute transport sub-model to investigate tracer migration for scenarios including that of hypothetical discrete fracture zones hydraulically connected to the Cambrian/Shadow lake Formations, and report results.

Context for New Information Request

The Salina A1 Upper Carbonate unit and the Guelph, Cambrian/Shadow lake Formations are thin, permeable layers that represent potential preferential pathways for relatively rapid horizontal advective radionuclide transport away from the repository site. In order to investigate the fate of radionuclides migrating laterally beyond the boundaries of the DGR, and various near-field scenarios, the regional and embedded groundwater flow and transport models must faithfully represent hydrogeological observations from these units.

IR# EIS-04-128 (NRCan Technical comment no. 4)

Issue: Modeling of Bruce Site Geochemistry
EIS Guidelines section(s): 10.1.3; 11.4.3

Original Information Request:
Explain and justify why the conceptual model of solute transport that is described in Sudicky and Frind (WRR, 18(6), 1634-1642, 1982), featuring horizontal advective-dispersive transport along high-conductivity layers with diffusive vertical transport into adjacent low-conductivity "matrix" formations, was not used.

Context:
Given that significant horizontal advective-dominated transport of tracers is occurring in the permeable Salina Upper A1 Carbonate, Guelph and Cambrian units, as well as in the Devonian, the proponent's purely 1D conceptualization of the tracer transport problem is questionable. In particular, the model ignores lateral mass fluxes in the intermediate and deep groundwater systems at the Bruce site.

OPG Response:
As part of Geosynthesis activities, the numerical code MIN3P was used to perform one-dimensional (vertical) numerical simulations of mass transport within the near horizontally layered sedimentary sequence. In particular, the simulations were performed to explore whether observed vertical distributions of 18O and Cl within Ordovician and lower Silurian formation porewaters could be ascribed to diffusion processes occurring on geologic time scales (i.e., 300 million years). The conceptual and numerical models, including a description of model justification, properties, boundary conditions, porewater compositions and results, is documented in NWMO (2011; Sections 4.5.1, 4.5.2 and 4.5.3). The conceptual model of mass transport described by Sudicky and Frind (1982), which includes advective-diffusive mass transport in fractured porous media, was not used in this specific case because the analysis assumed that mass transport in the low-permeability bedrock was entirely diffusion dominated. The numerical modelling was not intended to be unique, but rather was intended to provide a reasoned illustrative test as to the potential role of diffusive processes governing solute transport within the deep groundwater system. Similar illustrative modelling approaches have been described by Mazurek (2010) for diffusion dominated sedimentary systems elsewhere. The results of the MIN3P numerical analysis support the hypothesis that solute transport in the Ordovician sediments is diffusion dominant. The illustrative numerical modelling, coupled with additional evidence, including: i) the low formation rock mass hydraulic conductivities estimated during in-situ borehole testing (NWMO 2011; Section 5.2.2); ii) assessment of observed anomalous under-/over- pressure head conditions with regard to the interpretation of deep groundwater system properties and stability (NWMO 2011; Section 5.5); iii) the low effective diffusion coefficients for the Ordovician shales and carbonates (INTERA 2011; Section 4.4); and iv) interpretation of an evaporated seawater origin for Ordovician sedimentary rock pore fluids (NWMO 2011; Section 4.3.3), provides strong evidence corroborating the results of the reasoned assessment and the appropriateness of the modelling approach.

<u>NRCan disposition:</u>

As part of Geosynthesis investigations (sec. 4.5.2, DGR-TR-2011-11), the proponent describes a 1D numerical model that is used to test the "diffusion from above" conceptual model for observed tracer profiles through the Ordovician formations at the Bruce site. However, given that significant horizontal advective-dominated transport is found to occur in the permeable Salina A1 Upper Carbonate, Guelph and Cambrian units, as well as in the Devonian, the proponent's purely 1D conceptualization of the transport problem is questionable and may explain the relatively poor model fit to observed tracer profiles. In order to improve model fit, NRCan suggested that the proponent investigate an alternate conceptualization *analogous* to that described in Sudicky and Frind (WRR, 18(6), 1634-1642, 1982). These authors describe a model featuring longitudinal advective and dispersive transport along thin permeable layers with lateral diffusion into adjacent low-permeability matrix. NRCan agrees with the proponent that vertical transport within the Ordovician sediments is diffusive, however, transport within the Salina A1 Upper Carbonate, Guelph and Cambrian is largely advective. It is for these very reasons that NRCan proposed a more realistic model of tracer transport at the site that could potentially better match observations and thereby yield greater confidence in the proponent's understanding of diffusive mass transfers between tight Ordovician host rocks and intercalated thin beds where advective transport is dominant.

Although the proponent's rationale for rejecting the suggested alternate model of tracer transport is not compelling, NRCan considers this information request to be resolved.

IR# EIS-04-129 (NRCan Technical comment no. 5)

Issue: Horizontal advective solute transport in the Cambrian Formation.
EIS Guidelines section(s): 10.1.3; 11.4.3

Original Information Request:
Use a base of the 3D simplified hydrogeologic model lowered to the top of the Precambrian in order to assess lateral advective radionuclide transport in the Cambrian unit, as was done for the Salina A1 Carbonate and Guelph units in the NE-HG calculation case, and provide the results.

Context:
Placing the lower boundary of the 3DS model at the top of the Cambrian sandstone effectively precludes consideration of horizontal advective transport of radionuclides within this unit.

OPG Response:
An assessment of lateral radionuclide and contaminant migration in the Cambrian unit was not performed due to the depth and regionally confined nature of the aquifer and, because a postclosure analysis of a hypothetical conservative scenario (described below) estimated the public dose consequence to be many times less than the DGR dose criterion of 0.3 mSv/a. The Cambrian unit represents a confined aquifer within the deep groundwater system at the base of the sedimentary sequence beneath the Bruce nuclear site. The aquifer is saline and non-potable with groundwater Total Dissolved Solid concentrations of approximately 225 g/L. At a regional scale, the aquifer is not readily accessible: i) it is isolated by the thick overlying system of Ordovician and Silurian aquitard/aquicludes; ii) the aquifer pinches out several kilometers east of the Bruce nuclear site; and iii) the nearest Cambrian outcrop is more than 100 km from

the DGR site. Multidisciplinary information gathered during site-specific investigations indicates that vertical transmissive connections between the Cambrian and overlying confined Silurian aquifers (Guelph and Salina A1 upper carbonate) do not exist. The evidence supporting the above information and isolated nature of the Cambrian aquifer is provided by NWMO (2011; Sections 2.2, 2.3, 4.4, 5.2, 5.4, and 8). To assess the dose consequence of radionuclide and contaminant migration from the DGR into the Cambrian aquifer, a postclosure analysis was completed. The analysis considered the hypothetical situation of drinking the groundwater within the Cambrian directly beneath the DGR (QUINTESSA et. al. 2011; Section 7.1.2). Although the groundwater within the Cambrian is not potable or readily accessible, the estimated peak hypothetical dose is about 0.002 mSv/a at 1.5 million years. This estimate is approximately 100 times less than the DGR public dose criterion of 0.3 mSv/a. Lateral advective or diffusive migration within the Cambrian aquifer would lead to lower predicted dose consequences. Given the strength of evidence supporting the hydrogeologic isolation of the Cambrian unit and the above predicted postclosure dose consequence, further assessment of lateral migration within the Cambrian is not considered necessary as it does not materially change the DGR Safety Case.

NRCan disposition:

NRCan considers this information request to be unresolved. The arguments advanced by the proponent for not including the Cambrian unit within the 3D Simplified (3DS) groundwater flow and solute transport model are not compelling: While Cambrian groundwater is saline and non-potable, groundwater in the Guelph Formation is even more so (Table 4.17, NWMO DGR-TR-2011-24) yet this unit was included in the 3DS model; While the Cambrian per se may pinch out east of the Bruce site, it is likely that a thin permeable basal clastic unit persists eastward over the Algonquin Arch (see IR EIS-04-126); While the nearest Cambrian outcrop may be more than 100 km from the Bruce site, advective transport velocities in the Cambrian are quite high; Without the supporting analyses requested in IR EIS-04-129, the proponent's claim that lateral advective transport in the Cambrian would lead to lower predicted dose consequences is conjecture. Regardless of whether or not this conjecture is correct, it is a matter of due diligence for the proponent to investigate a scenario corresponding to hydrogeological conditions actually observed at the site.

As previously requested in JRP IR EIS-04-129 and NRCan technical comment #5, NRCan requests that the proponent incorporate the Cambrian unit in the 3DS model and report on Performance Safety Assessment modeling that investigates near-field radionuclide migration in the presence of horizontal hydraulic gradients in the Salina A1 Upper Carbonate, Guelph and Cambrian formations, as observed at the site.