Hydrogeologic Modeling in Support of Ontario Power Generation's Proposed Deep Geologic Repository for Low and Intermediate Level Radioactive Waste, Tiverton, Ontario

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Summary

A Deep Geologic Repository (DGR) for Low and Intermediate Level (L&IL) Radioactive Waste has been proposed by Ontario Power Generation (OPG) for the Bruce nuclear site near Tiverton, Ontario Canada. This paper presents hydrogeologic modelling and analyses at the regional-scale and site-scale that were completed as part of the Geosynthesis DGR work program. As envisioned, the DGR is to be constructed at a depth of about 680 m below ground surface within the argillaceous Ordovician limestone of the Cobourg Formation. The objective of this paper is to describe modelling and analyses that have contributed toward an understanding of the long-term hydrogeologic evolution of the site and the development of the DGR Safety Case.

Introduction

Within the geologic setting of southern Ontario, the Bruce nuclear site is situated on the eastern flank of the Michigan Basin. Well logs have been used to define the structural contours at the regional and site-scale of the up to 31 bedrock units/formation/groups that may be present above the Precambrian crystalline basement. In this study, all units/formation/groups of both the regional-scale and the site-scale model (Sykes et al. 2008) are assumed to be water saturated. Two-phase air and water modelling is investigated in a one-dimensional profile of the DGR site. The regional-scale domain is restricted to a region extending from Lake Huron to Georgian Bay. From a hydrogeologic perspective, the domain can be subdivided into three horizons: a shallow zone characterized by Devonian and Upper Silurian age formations that extends to the base of the Bass Islands Formation; an intermediate zone that includes the low permeability units of the Salina and the more permeable Niagaran Group (Guelph, Goat Island, Gasport and Lions Head Formations) and extends from the base of the Bass Islands Formation to the Manitoulin Formation; and a deep groundwater domain or zone that extends from the base of the Manitoulin to the Precambrian and which includes the Ordovician shales and carbonates, such as the Cobourg Formation, with water with high total dissolved solids (TDS) concentrations that range up to 300 g/L. The deep zone also includes the permeable Cambrian Formation.

Important in the analyses of this hydrogeologic modelling study is the selection of the performance measure used to evaluate the system response and behaviour. The traditional metric of average water particle travel time is inappropriate for geologic units where solute transport is controlled by diffusion. The use of lifetime expectancy and the related groundwater age is a more appropriate metric for such a system. Lifetime expectancy can be estimated by determining the time required for a water particle at a spatial position in a groundwater system to reach a potential outflow point. Groundwater age of a water particle at a spatial position can be determined by the time elapsed since the water particle entered the system from a boundary condition. Conservative, non-decaying tracers also are used to evaluate issues such as the diffusive dominance of solute transport in the low permeability units at the DGR site.

The groundwater velocities are density-dependent and hence a fully-coupled transient flow and brine transport analysis is required for their estimation. The study methodology determined a pseudo-equilibrium solution at 1 million years after the imposition of an initial total dissolved solids distribution in the regional domain. The boundary conditions for the base-case analysis were time invariant while the hydrologic parameters are based, in part, on measurements from interim in-situ hydraulic tests conducted within the sediments at Bruce site.

Analysis and Discussion

The environmental head profile from the assumed TDS concentrations and measured pressures at the DGR boreholes indicate that the Cambrian is over-pressured relative to ground surface elevation while the Ordovician shale and limestone units are significantly under-pressured. The thin Cambrian sandstone formation pinches out 10's km east of the DGR site. An essential requirement of the abnormal hydraulic pressures within Cambrian is overlying extensive low vertical hydraulic conductivity strata. The low pressures in the Ordovician may be the result of stress relief as a result of significant removal of mass through erosion, that was at a rate that is greater than that of water influx to these low permeability units from the over- and under-lying units with higher pressure; the pressure distribution is still evolving. The low pore fluid pressures also may indicate the presence of a trapped non-wetting gas phase that would result in an effective hydraulic conductivity that is significantly less than the corresponding saturated hydraulic conductivities for the units. Consistent with both interpretations is the requirement of vertical hydraulic conductivities that are on the order of 1×10^{-14} m/s or lower for the Ordovician units. The impact of the occurrence of a gas phase in the Ordovician limestone and shale was determined in the study using two-phase air and water flow analyses with the model TOUGH2-MP.

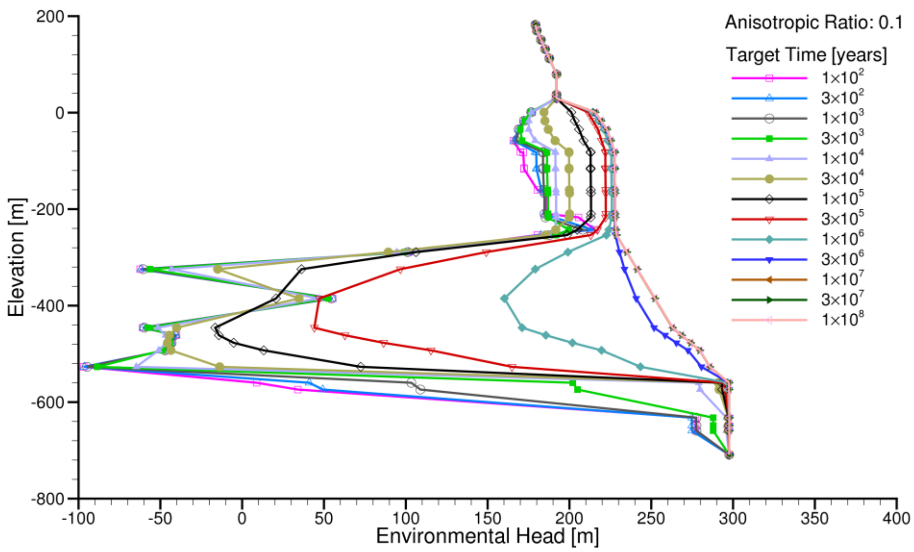

Figure 1: Predicted evolution of environmental heads with pressure support in both the Niagaran Group and the Cambrian

The saturated flow analyses to examine the time frame for the transient dissipation of the observed elevated pressures in the Cambrian and low pressures in the Ordovician units indicate that steady-state conditions will not be reached for more than 3 million years (refer to Figure 1). Using a conservative tracer, the study illustrates that solute transport in the Ordovician limestone and shale is diffusion dominant. The impact of glaciation and deglaciation on the groundwater system was investigated in a paleoclimate scenario. The model results indicate that basal melt-water does not penetrate below the units of the Salina at the DGR site. The most significant consequence of glacial loading is the generation of higher pressures throughout the rock column, with the level dependent on the one-dimensional loading efficiency of the rock mass. The estimation of the pressures during glaciation was undertaken assuming saturated flow conditions; the presence of a possible gas phase in the Ordovician would result in a different pressure distribution. The study simulations of the paleoclimate scenario support the conclusion that it is unlikely that the environmental head profile at the DGR boreholes is related to stress loading during glaciations and stress relief during deglaciation as a result of the time of ice-sheet loading relative to the duration of load relief.

Conclusions

A conclusion of the study is that the maintenance of the under-pressures in the Ordovician can be explained by the presence of a gas phase in the rock. The two-phase air water model TOUGH2-MP was used in the analyses. The higher pressure in a discrete zone of the Georgian Bay shale at a depth of 585m was explained by using an appropriate capillary pressure saturation relationship for that zone and a different relationship for the adjacent rock. An investigation of density-dependent saturated flow in a cross-section of the Michigan Basin (refer to Figure 2) yielded a favourable comparison of the simulated and measured heads at the location of the DGR for both the Cambrian sandstone and the Niagaran Group. Alternate explanations of the cause of the abnormal pressures are being investigated.

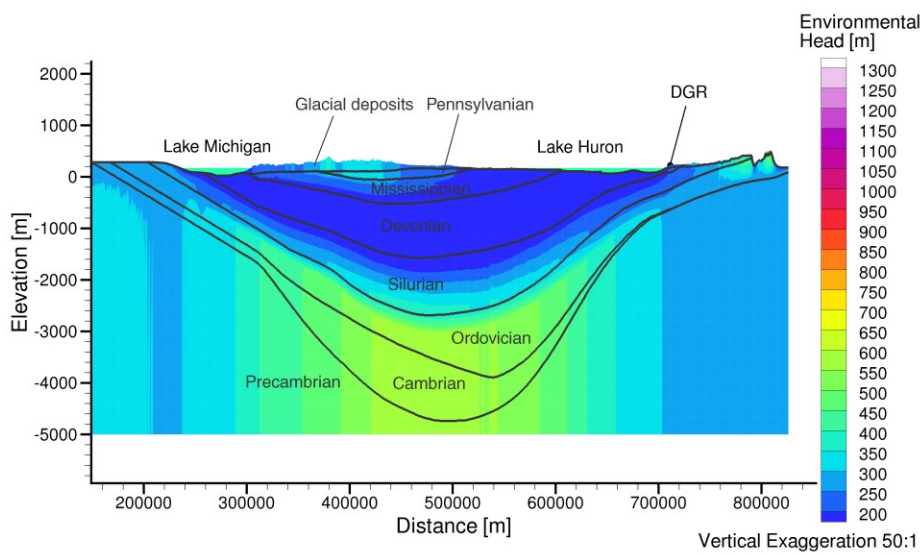

Figure 2: Transient environmental heads at 10^7 years for the Michigan Basin cross-section analysis

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References
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