OPG's DEEP GEOLOGIC

REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

Geology
Technical Support Document

March 2011

Prepared by: Golder Associates Ltd.

NWMO DGR-TR-2011-03

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EXECUTIVE SUMMARY

ES.1 INTRODUCTION

Ontario Power Generation (OPG) is undergoing a multi-year planning and regulatory approvals process for a deep geologic repository (DGR) for the long-term management of low and intermediate level waste (L&ILW). Currently, the L&ILW produced as a result of the operation of OPG's nuclear reactors is stored centrally at OPG's Western Waste Management Facility (WWMF) located on the Bruce nuclear site. Although current storage practices are safe and could be continued safely for many decades, OPG's long-term plan is to manage these wastes in a long-term management facility. Throughout this report, OPG's proposal is referred to as the "DGR Project".

The DGR Project includes the site preparation and construction, operations, decommissioning, and abandonment and long-term performance of the DGR. The proposed DGR will be constructed in competent sedimentary bedrock beneath the Bruce nuclear site near the existing WWMF. The underground facilities will include access-ways (shafts and tunnels), emplacement rooms and various underground service areas and installations. The surface facilities include the underground access and ventilation buildings, Waste Package Receiving Building (WPRB) and related infrastructure.

An environmental assessment (EA) of the proposed DGR Project is required under the provisions of the *Canadian Environmental Assessment Act* (CEAA) because the proponent (OPG) will be required to obtain a licence from the Canadian Nuclear Safety Commission (CNSC) to allow the project to proceed. The findings of the EA are presented in the Environmental Impact Statement (EIS) and Technical Support Documents (TSDs).

ES.2 APPROACH

The approach used for assessing effects of the DGR Project supports the philosophy of EA as a planning tool and decision-making process. The assessment characterizes and assesses the effects of the DGR Project in a thorough, traceable, step-wise manner. The approach used in the assessment includes the following steps:

- describe the project;
- describe the existing environment;
- screen potential project-environment interactions to focus the assessment;
- predict and assess effects, apply mitigation measures to reduce or eliminate the effect and identify residual adverse effects;
- determine significance of residual adverse effects; and
- propose a follow-up program to confirm mitigation measures are effective and the DGR Project effects are as predicted.

The assessment of effects considers direct and indirect effects of the DGR Project, effects of the environment on the project, climate change considerations, and effects of the project on renewable and non-renewable resources. An assessment of the cumulative effects associated with the DGR Project in association with existing and planned projects is addressed in Section 10 of the EIS. Effects are predicted in the context of temporal and spatial boundaries.

The temporal boundaries for the EIS establish the timeframes for which the effects are assessed. Four temporal phases were identified for the DGR Project:

- site preparation and construction phase;
- operations phase;
- decommissioning phase; and
- abandonment and long-term performance phase.

Spatial boundaries define the geographical extents within which environmental effects are considered. As such, these boundaries become the study areas adopted for the EA. Four study areas were selected for the assessment of the geology: the Regional Study Area, Local Study Area, Site Study Area and Project Area. The Project Area, although not specified in the guidelines, was defined to help describe the potential site-specific effects of the DGR Project. Each study area includes the smaller study areas (i.e., they are not geographically separate).

ES.3 VALUED ECOSYSTEM COMPONENTS

While all components of the environment are important, it is neither practicable nor necessary to assess every potential effect of a project on every component. The EA focuses on the components that have the greatest relevance in terms of value and sensitivity, and which are likely to be affected by the project. To achieve this focus, specific Valued Ecosystem Components (VECs) are identified. A VEC is considered to be the ‘receptor’ for both project-specific effects and cumulative effects. A VEC can be represented by a number of ‘indicators’, which are features of the VEC that may be affected by the DGR Project (e.g., soil quality parameters). Each indicator requires specific ‘measures’ that can be quantified and assessed (e.g., changes in soil quality parameters). In essence, the nature and magnitude of the effects of the DGR Project on these VECs has been evaluated and their significance determined.

The following VECs are used in assessing the effects of the DGR Project on the geology:

- soil quality;
- overburden groundwater quality;
- overburden groundwater transport;
- shallow bedrock groundwater quality;
- shallow bedrock groundwater and solute transport;
- intermediate bedrock water quality;
- intermediate solute transport;
- deep bedrock water quality; and
- deep bedrock solute transport.

ES.4 RESULTS

Project-environment interactions are identified and assessed for potential measurable changes. The identified measurable changes are assessed to determine whether they are adverse. No residual adverse effects are identified on soil quality, groundwater quality or solute transport.

In addition, climate change is not expected to have any effect on the conclusions reached regarding the effects of the DGR Project on soil quality, groundwater quality or groundwater flow; and the DGR Project is not expected to have any effects on renewable and non-renewable resources as a result of the geology.

Therefore, no significant adverse effects are identified for the geology VECs.

ES.5 PRELIMINARY FOLLOW-UP PROGRAM

Follow-up monitoring programs are required to:

- verify the key predictions of the EA studies; or
- confirm the effectiveness of mitigation measures, and in so doing, determine if alternate mitigation strategies are required.

The follow-up monitoring proposed for the geology recommends that monitoring of soil quality and shallow subsurface groundwater quality be performed as needed in response to a malfunction, accident or malevolent act. Follow-up monitoring of shallow subsurface groundwater flow is dependent on the results of the shaft pilot programs, which are to be established prior to excavation and construction.

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

1. INTRODUCTION

Ontario Power Generation (OPG) is undergoing a multi-year planning and regulatory approvals process for a deep geologic repository (DGR) for the long-term management of low and intermediate level waste (L&ILW). Currently, the L&ILW produced as a result of the operation of OPG-owned nuclear reactors is stored centrally at OPG's Western Waste Management Facility (WWMF) located on the Bruce nuclear site. Although current storage practices are safe and could be continued safely for many decades, OPG's long-term plan is to manage these wastes in a long-term management facility.

A key element of the regulatory approvals process is an environmental assessment (EA), the findings of which are presented in an Environmental Impact Statement (EIS). The EA considers the long-term management of L&ILW currently in interim storage at the WWMF, as well as that produced by the operation of OPG-owned or operated nuclear generating stations, in a DGR at the Bruce nuclear site in the Municipality of Kincardine, Ontario. The project location is shown in Figure 1-1. Throughout this report, OPG's proposal is referred to as the "DGR Project". The DGR Project includes the site preparation and construction, operations, decommissioning, and abandonment and long-term performance of the DGR.

The DGR will be constructed in competent sedimentary bedrock beneath the Bruce nuclear site near the existing WWMF. The underground facilities will include access-ways (shafts and tunnels), emplacement rooms and various underground service areas and installations. The surface facilities include the underground access and ventilation buildings, Waste Package Receiving Building (WPRB) and related infrastructure. All surface and underground facilities will be located within the boundaries of the OPG-retained lands near the WWMF at the Bruce nuclear site.

OPG is the proponent for the DGR Project. OPG will own, operate and be the licensee for the DGR. The regulatory approvals phase of the project, including the EA process and the site preparation and construction licensing, has been contracted to the Nuclear Waste Management Organization (NWMO). The NWMO is responsible, with support from OPG, for completing the EA, preparing the EIS and obtaining the site preparation and construction licences.

1.1 EA PROCESS AND REGULATORY CONTEXT

The EA process was initiated by the submission of a Project Description for the DGR by OPG to the Canadian Nuclear Safety Commission (CNSC) on December 2, 2005. The site preparation and construction licence application for the DGR was submitted by OPG to the CNSC on August 13, 2007. An EA of the proposed DGR Project is required under the provisions of the *Canadian Environmental Assessment Act* (CEAA) because the proponent (OPG) will require a licence from the CNSC to allow the project to proceed. Under the CEAA, the CNSC is identified as the Responsible Authority (RA); however, the Canadian Environmental Assessment Agency also has statutory responsibilities.

Under the CEAA, this type of project is identified in the Comprehensive Study List Regulations. The CNSC issued draft guidelines for a comprehensive study EA of the DGR Project, which were the subject of a public hearing held in Kincardine on October 23, 2006. Following the hearing, CNSC Commission members recommended to the Minister of the Environment that the DGR Project be referred to a review panel given the public concerns, possibility of adverse environmental effects, the first-of-a-kind nature of the project and concerns regarding the comprehensive study's ability to address all the questions raised [1].

The Minister of the Environment referred the EA of the DGR Project to a joint review panel on June 29, 2007. Draft guidelines for the preparation of the EIS were issued by the Canadian Environmental Assessment Agency and the CNSC for public review on April 4, 2008. The EIS Guidelines, a copy of which is included in Appendix A of the EIS, were finalized on January 26, 2009. The scope of the EA for the DGR Project includes the site preparation, construction, operations, and decommissioning of the above- and below-ground facilities for the long-term management of L&ILW. The EA also addresses the abandonment and long-term performance of the DGR Project.

An EA is a tool to provide an effective means of integrating environmental factors into the planning and decision-making processes in a manner that promotes sustainable development and minimizes the overall effect of a project. The methods used in the EA and presented in the EIS are consistent with the final guidelines, and are based on systematic and detailed consideration of the systems, works, activities and events comprising the DGR Project.

1.2 EA REPORTING STRUCTURE

The EA for the DGR Project is documented in an EIS, which is based on the final guidelines and the work detailed in a series of technical support documents (TSDs). In addition, there are parallel technical studies, information from which is also used in preparing the EIS and TSDs. Finally, the findings are summarized in the EIS Summary. Figure 1.2-1 illustrates the relationships between the EIS and summary report, its supporting documents, and the independent technical studies for the DGR Project.

The EIS comprises the following volumes:

- **Volume 1** consolidates and summarizes all aspects of the EIS studies. It includes a description of the EA methods, a description of the DGR Project, a description of the existing environment, an assessment of likely environmental effects, including cumulative effects, a discussion of the proposed follow-up program, and a discussion of the communication and consultation program.
- **Volume 2** contains a series of appendices that support the material in Volume 1, including a copy of the EIS Guidelines, human health assessment and a summary of the community engagement and consultation program along with copies of supporting materials.

The TSDs present information on the existing environment and describe processes used to assess the direct and indirect effects of the DGR Project on the environment. The TSDs, on which the EIS is based, are as follows:

- Atmospheric Environment;
- Hydrology and Surface Water Quality;
- Geology;
- Aquatic Environment;
- Terrestrial Environment;

- Socio-economic Environment;
- Aboriginal Interests;
- Radiation and Radioactivity; and
- Malfunctions, Accidents and Malevolent Acts.

These TSDs are also interconnected with one another. Each respective report focuses on the effects of the DGR Project on that particular environment, be it through a direct interaction with the DGR Project or through a change identified in another TSD (i.e., an indirect interaction). Cross-references are provided throughout the TSD where it relies on information predicted in another report.

It is important to note that the assessment of potential radiation and radioactivity effects of the DGR Project are documented in the Radiation and Radioactivity TSD, regardless of the physical media through which they are transported (e.g., air or water). This was done because of the special importance placed on radiation and radioactivity, and the combined effects to the receiving environment regardless of the path of exposure.

The TSDs assess the direct and indirect effects of the DGR Project as a result of normal conditions, with the exception of the Malfunctions, Accidents and Malevolent Acts TSD. The EIS Guidelines require an identification of credible malfunctions and accidents, and an evaluation of the effects of the DGR Project in the event that these accidents or malfunctions occur. All of these effects are discussed and assessed in the Malfunctions, Accidents and Malevolent Acts TSD regardless of the element of the environment that is affected. The reasoning for this is that a single accident is likely to affect multiple elements of the environment.

The independent parallel technical study reports used in preparing the EIS include the following:

- Postclosure Safety Assessment [2];
- Geosynthesis [3]; and
- Preliminary Safety Report [4].

This Geology TSD evaluates the non-radiological effects of the site preparation and construction, operations, decommissioning and abandonment and log-term performance of the DGR Project on soil quality, groundwater quality and groundwater flow. To facilitate this assessment, a description of the existing environmental features is also included.

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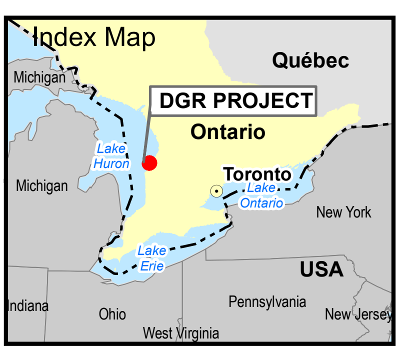

LEGEND

- City
- Highway
- Provincial Highway
- Secondary Highway

0 5 10 20 30 40 50

Kilometres

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

LOCATION OF THE DGR PROJECT

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	**FIGURE 1-1**	
GIS	BC	29 Apr. 2010		
CHECK	AB	29 Apr. 2010		
REVIEW	MAR	29 Apr. 2010		

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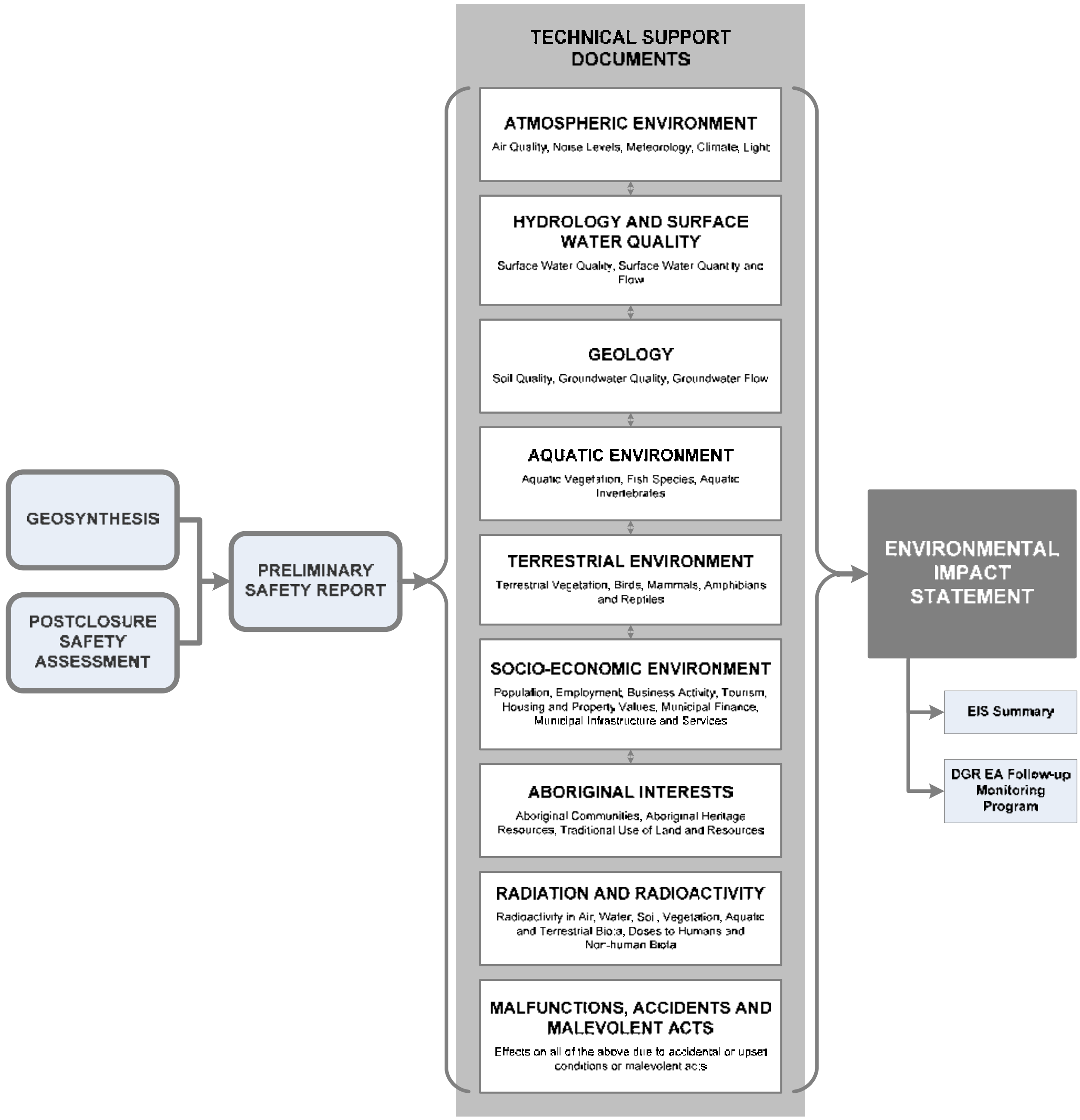

Figure 1.2-1: Organization of EA Documentation

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2. APPROACH

2.1 GENERAL SUMMARY OF EA APPROACH

The approach used for assessing the DGR Project, and documented in this TSD, supports the philosophy of EA as a planning and decision-making process. The assessment characterizes and assesses the effects of the DGR Project in a thorough, traceable step-wise manner. The approach used in the assessment is illustrated in Figure 2.1-1, and includes the following steps:

- **Describe the Project.** As summarized in Section 3, the project is described as a number of works and activities that could affect the surrounding environment.
- **Describe the Existing Environment.** The existing environment is characterized using available information and field studies, as described in Section 5. The description of the existing environment reflects the cumulative effects of past and existing projects on the environmnent.
- **Screen to Focus the Assessment.** Two screening steps, first for potential interactions and secondly for measurable change, allow the assessment to focus on where effects are likely to occur. These steps are completed using professional judgment; if there is uncertainty, the interaction is advanced for assessment. The screening steps are completed in Sections 6 and 7.
- **Assess Effects.** Where there is likely to be a measurable change, the effects on the environment are predicted and assessed as to whether or not they are adverse, as described in Section 8. If adverse effects are predicted, mitigation measures to reduce or eliminate the effect are proposed, and residual adverse effects, if any, are identified. Any residual adverse effects are then assessed in Section 10 of the EIS to determine whether they are likely to combine with the effects of other past, present or reasonably foreseeable future projects and activities in the surrounding region to produce cumulative effects.
- **Determine Significance.** All residual adverse effects are then assessed in Section 11 to determine whether the effect is significant, or not, taking into account the magnitude, extent, duration, frequency and irreversibility of the effect.
- **Propose Follow-up Programs.** Finally, follow-up monitoring is proposed to confirm that mitigation measures are effective and the effects are as predicted. Monitoring activities are described in Section 13.

The assessment of effects of the DGR Project focuses on Valued Ecosystem Components (VECs), which are elements of the environment considered to be important for cultural or scientific reasons. The geology VECs are defined and described in detail in Section 4. Criteria for determining measurable changes and adverse effects are defined for each individual VEC. The detailed methods for each of these steps, including how they are applied to this particular TSD, are described at the beginning of each of the respective sections.

The screening and assessment steps described above follow a source-pathway-receptor approach. The DGR Project works and activities represent the source of a change, a measurable change to the environment represents a pathway and the VEC represents the receptor. In some cases, VECs may act as both pathways and receptors (e.g., changes in the groundwater flow regime may affect groundwater quality).

Effects from the DGR Project may occur either directly or indirectly. A direct interaction occurs when the VEC is affected by a change resulting from a project work and activity (e.g., changes in drainage areas during site preparation can affect the VEC groundwater flow regime). An indirect interaction occurs when the VEC is affected by a change in another VEC (e.g., changes in the surface water quality [VEC in the Hydrology and Surface Water Quality TSD] could affect the overburden groundwater quality VEC).

There are many linkages and connections between aspects of the physical, biophysical and socio-economic environments in an integrated EA. The linkages to this TSD are illustrated using an information flow diagram. Figure 2.1-2 presents the flow of information related to the geology VECs and where the indirect effects are evaluated. Multi-feature VECs are evaluated in Section 7 of the EIS (e.g., Lake Huron, human health). An assessment of the cumulative effects associated with the DGR Project is addressed in Section 10 of the EIS.

The assessment is completed within the framework of defined temporal and spatial boundaries, and takes into account a precautionary approach and Aboriginal traditional knowledge, where available. These are described in further detail in the following sections.

2.2 PRECAUTIONARY APPROACH

The EA, as a forward-looking planning tool used in the early stages of project development, is based on a precautionary approach. This approach is guided by judgement, based on values and intended to address uncertainties in the assessment. This approach is consistent with Principle 15[1] of the 1992 Rio Declaration on Environment and Development and the Canadian government's framework for applying precaution in decision-making processes [5].

Throughout the EA, the DGR Project has been conservatively considered in a thorough and traceable manner. For example, at each of the screening stages, potential project-related effects are advanced if they cannot be systematically removed from consideration through application of rigorous, sound and credible scientific evidence. In addition, with the exception of malfunctions, accidents and malevolent acts, all identified residual adverse effects are assumed to occur (i.e., probability of occurrence is assumed to be 1.0), and are assessed for significance.

A further precautionary feature incorporated into the assessment method is that the evaluation of potential effects is based on changes to the existing environment and not solely on regulatory compliance. This captures and assesses changes to the existing environment that may fall outside or below applicable regulatory frameworks.

The precautionary approach adopted for the EA of the DGR Project is described further in Section 1 of the EIS, and a summary of how precaution has been taken into account in the assessment of geology is provided at the end of the assessment section (Section 8).

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[1] Principle 15 of the 1992 Rio Declaration on Environment and Development states that "Where there are threats of serious or irreversible damage, lack of full scientific certainty must not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

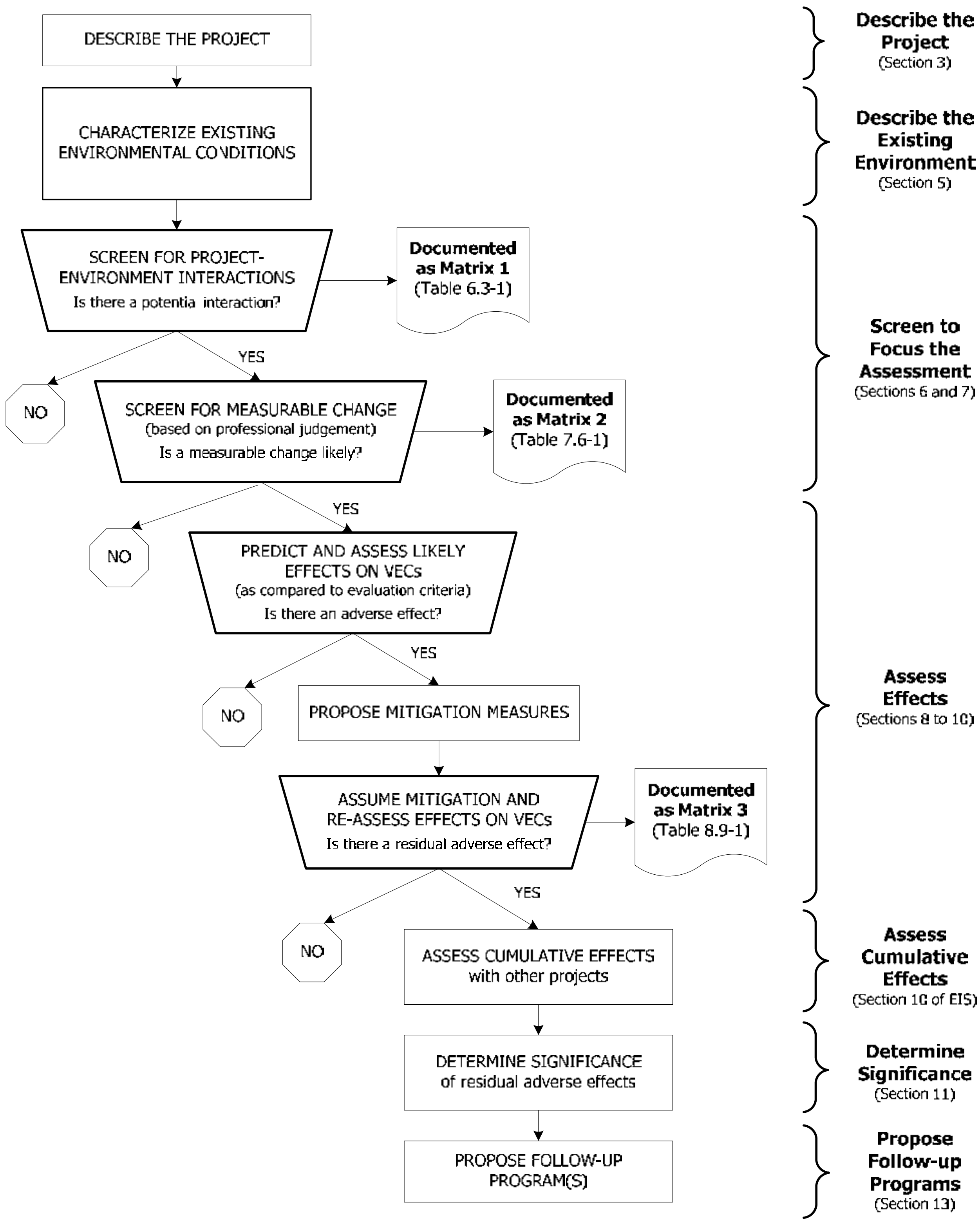

Figure 2.1-1: Methodology for Assessment of Effects

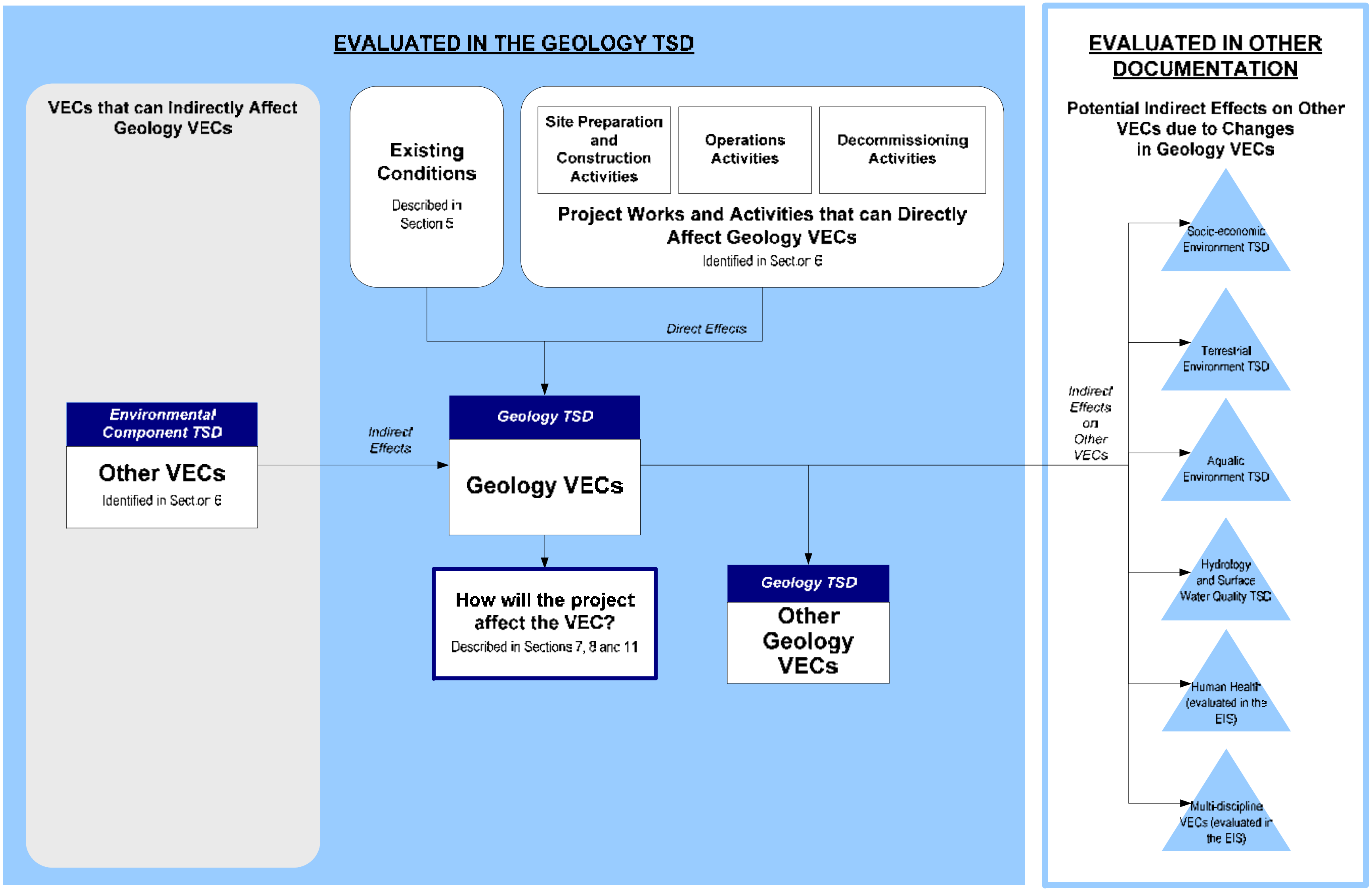

Figure 2.1-2: Information Flow Diagram for the Geology VECs

2.3 ABORIGINAL TRADITIONAL KNOWLEDGE

This EA considers both western science and traditional and local knowledge, where that information is available. Guidance provided by the Canadian Environmental Assessment Agency describes Aboriginal traditional knowledge as knowledge that is held by and unique to, Aboriginal peoples [6]. Aboriginal traditional knowledge is a body of knowledge built up by a group of people through generations of living in close contact with nature. It is cumulative and dynamic and builds upon the historic experiences of a people and adapts to social, economic, environmental, spiritual and political change.

Traditional ecological knowledge is a subset of Aboriginal traditional knowledge. Traditional ecological knowledge “refers specifically to all types of knowledge about the environment derived from the experience and traditions of a particular group of people” [7]. There are four traditional ecological knowledge categories:

- knowledge about the environment;
- knowledge about the use of the environment;
- values about the environment; and
- the foundation of the knowledge system.

In this EA, specific traditional knowledge, where available, is incorporated through the characterization of the existing environment and assessment of effects. Issues of importance to Aboriginal communities were identified as part of the Aboriginal Interests TSD through examination of available information pertaining to general ecological, socio-economic and cultural heritage interests for Ojibway and Métis peoples in Ontario. This examination identified a range of interests raised by Aboriginal communities that can be used to focus this EA relative to potential effects on residents of the Aboriginal communities in the study areas. This examination included the following:

- interests raised by Aboriginal communities according to previous studies;
- interests raised by Aboriginal communities in the context of dialogue for the DGR Project; and
- insight into traditional knowledge, and interests of general importance to local Aboriginal communities.

Throughout this TSD, it is highlighted where Aboriginal traditional knowledge and traditional ecological knowledge was available, and influenced the assessment.

2.4 TEMPORAL AND SPATIAL BOUNDARIES

The assessment of the DGR Project works and activities on the environment is conducted within the framework of temporal and spatial boundaries that are common to all of the environmental components (with some modifications). The particular temporal and spatial boundaries used in the assessment of the geology are described in the following sections.

2.4.1 Temporal Boundaries

The temporal boundaries for the EA establish the timeframes for which the direct, indirect and cumulative effects are assessed. Four temporal phases were identified for the DGR Project.

- **Site Preparation and Construction Phase**, which includes site preparation and all activities associated with the construction of the DGR Project, up until operations commence with the placement of waste. All of the construction activities at the DGR Project will occur during this phase. The site preparation and construction phase is expected to last approximately five to seven years.
- **Operations Phase**, which covers the period during which waste is emplaced in the DGR, as well as a period of monitoring prior to the start of decommissioning. Activities include receipt and on-site handling of waste packages, transfer underground and emplacement of L&ILW in rooms in the DGR, and activities necessary to support and monitor operations. The operations phase is expected to last approximately 40 to 45 years with waste being emplaced for the first 35 to 40 years. The length of the monitoring period would be decided at some future time in consultation with the regulator.
- **Decommissioning Phase**, which begins immediately after the operations phase for the DGR. Activities include preparation for decommissioning, decommissioning and may include monitoring following decommissioning. The decommissioning activities, including dismantling surface facilities and sealing the shaft, are expected to take about five to six years.
- **Abandonment and Long-term Performance Phase**, which begins once decommissioning activities are completed. This period will include institutional controls for a period up to three hundred years.

These timeframes are intended to be sufficiently flexible to capture the effects of the DGR Project. The assessment of geology considers all four phases; however, there are no works or activities in the abandonment and long-term performance phase.

2.4.2 Spatial Boundaries

Spatial boundaries define the geographical extents within which environmental effects are considered. As such, these boundaries become the study areas adopted for the EA.

The guidelines require that the study areas encompass the environment that can reasonably be expected to be affected by the DGR Project, or which may be relevant to the assessment of cumulative effects. Specific study areas are defined by boundaries to encompass all relevant components of the environment including the people, land, water, air and other aspects of the natural environment. Generic study areas for the EA are presented in the EIS. As described in the following sections, these have been modified for the Geology TSD.

Four study areas were selected for the assessment of the geology: the Regional Study Area, Local Study Area, Site Study Area and Project Area. The Project Area, although not specified in the guidelines, was defined to help describe the potential site-specific effects of the DGR Project. Each study area includes the smaller study areas (i.e., they are not geographically separate). For geology, the study areas also extend vertically below ground surface to capture potential effects. These areas are described in the following sections.

2.4.2.1 Regional Study Area

The Regional Study Area (Figure 2.4.2-1) corresponds to the regional 3-Dimensional Geologic Framework, which includes an area of approximately 35,000 km^2 surrounding the DGR. The regional geology provides a framework for understanding and extrapolating site conditions beyond the Bruce nuclear site boundary. The Regional Study Area boundary fully encompasses the regional hydrogeologic modelling domain [3]. The hydrogeologic modelling domain (approximately 18,000 km^2) is the area used to describe the regional-scale groundwater system hydrodynamics.

2.4.2.2 Local Study Area

The Local Study Area (Figure 2.4.2-2) is an area of approximately 127 km^2, including the communities of Underwood and Tiverton and the Bruce nuclear site on Douglas Point. It also includes the drainage basins of Underwood Creek, which discharge to Baie du Doré directly north of the Bruce nuclear site, Stream C, which drains through the Bruce nuclear site, and the little Sauble River and Tiverton Creek which discharge to Inverhuron Bay directly south of the Bruce nuclear site. This Local Study Area was selected because it corresponds to the local watershed for the Bruce nuclear site and surroundings, providing coverage of the local surficial and subsurface geology/hydrogeology components that could potentially be affected by the DGR Project.

2.4.2.3 Site Study Area

The Site Study Area (Figure 2.4.2-3) corresponds to the property boundary of the Bruce nuclear site, including the licensed exclusion zones on land and within Lake Huron. The Geology TSD has a particular focus on the area where the DGR Project will be located (i.e., the Project Area).

2.4.2.4 Project Area

The Project Area (see Figure 2.4.2-3) corresponds to the boundary of the OPG-retained lands at the centre of the Bruce nuclear site where the DGR Project is being proposed.

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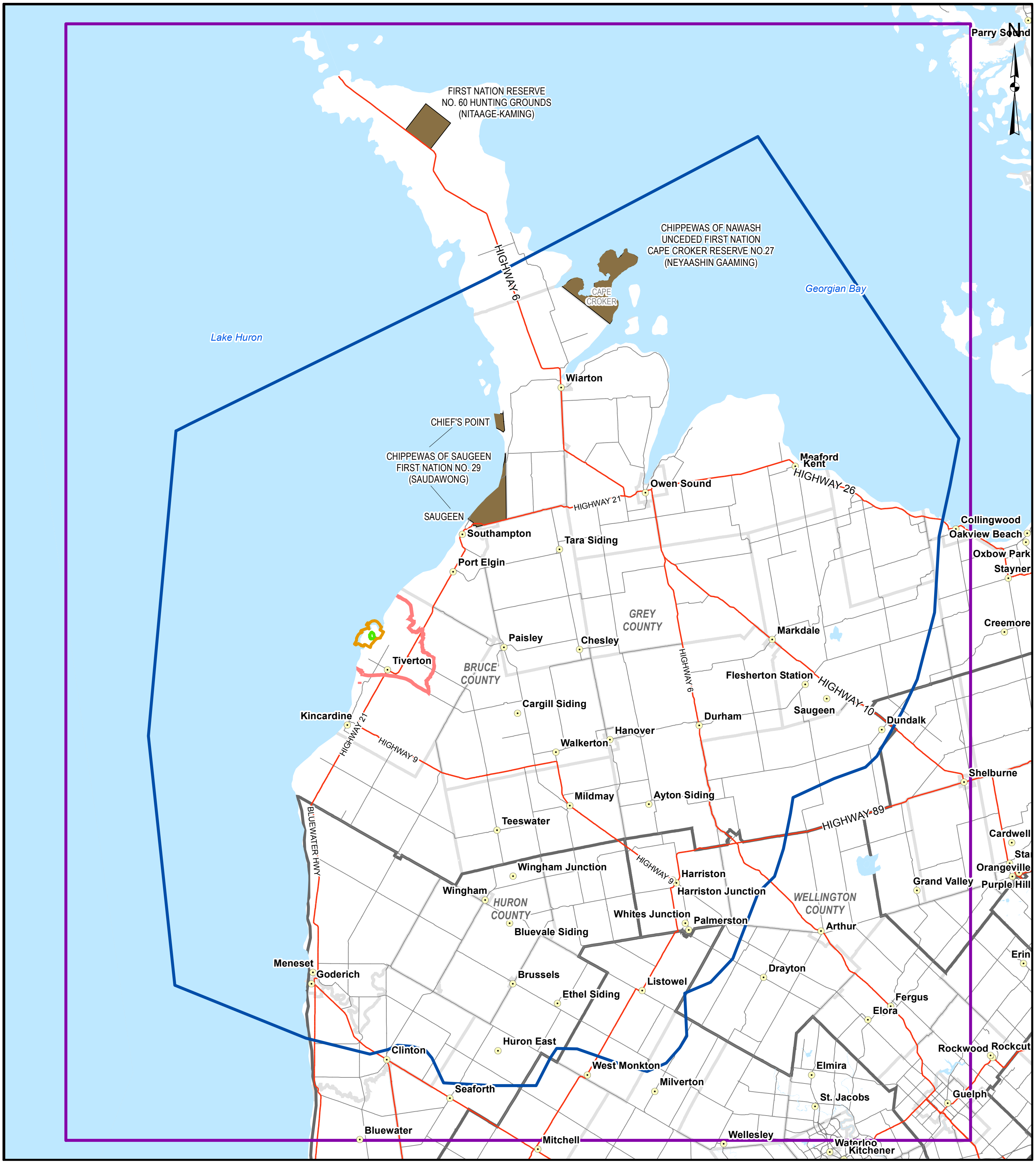

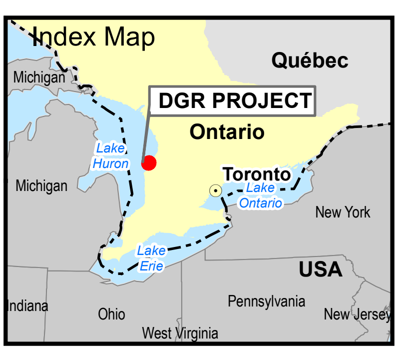

LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Local Study Area
- Regional Study Area
- Regional Hydrogeologic Modelling Domain
- County Boundary
- First Nations' Lands

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

REGIONAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	**FIGURE 2.4.2-1**	
GIS	BC	5 May. 2010		
CHECK	AB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

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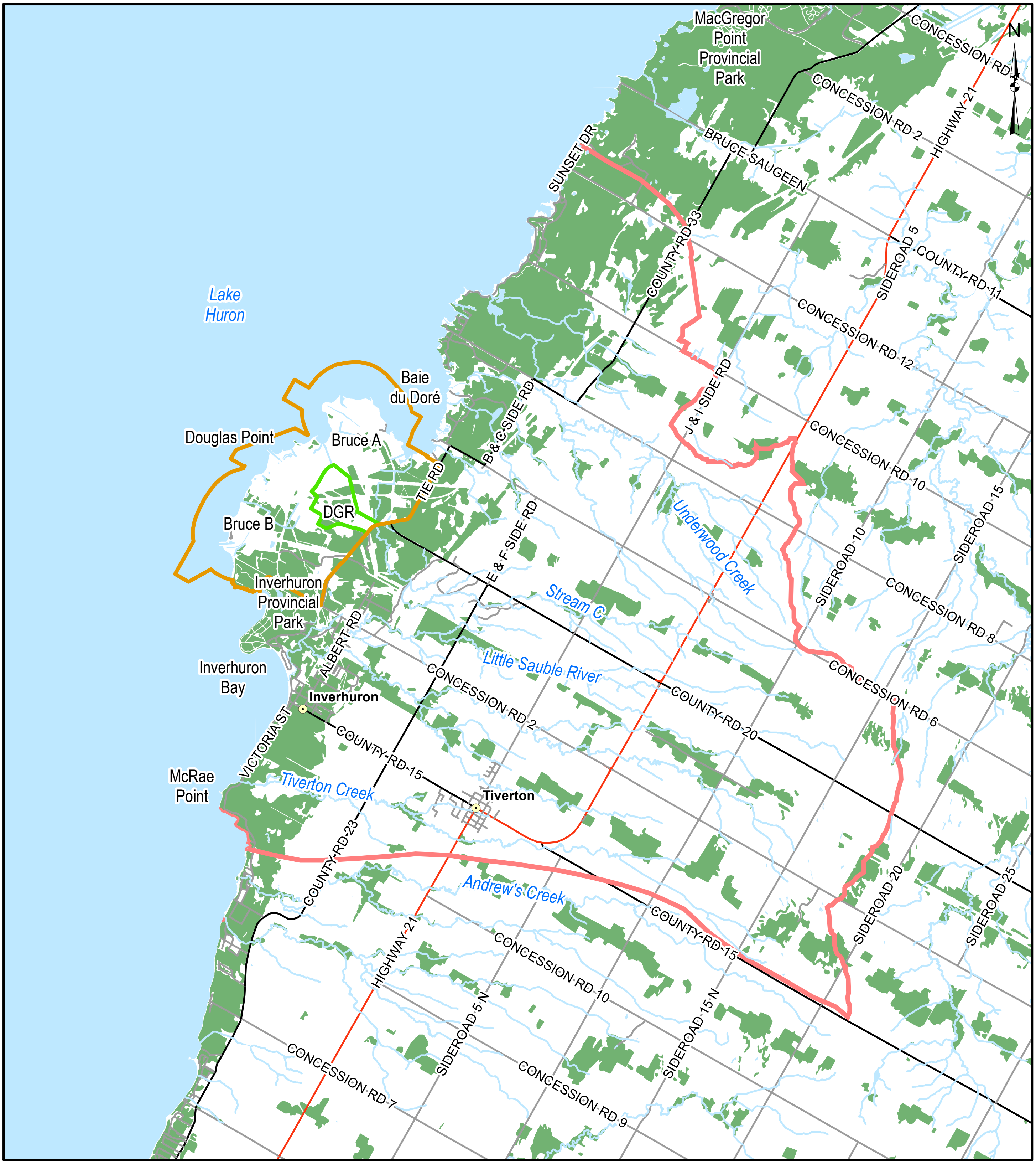

LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

LOCAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct 2007		
GIS	BC	5 May. 2010	**FIGURE 2.4.2-2**	
CHECK	AB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

[PAGE LEFT INTENTIONALLY BLANK]

0 0.5 1 2
Kilometres

LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL
SUPPORT DOCUMENT

TITLE

SITE STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	**FIGURE 2.4.2-3**	
GIS	BC	5 May. 2010		
CHECK	SM	5 May. 2010		
REVIEW	SM	5 May. 2010		

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3. PROJECT DESCRIPTION

The assessment of effects requires a detailed description of the DGR Project. The individual works and activities are the physical structures, buildings, systems, components, activities and events comprising the DGR Project. These are collectively referred to as the project works and activities. This section provides an overview of the DGR Project. The specific works and activities required for the DGR Project are summarized in the Basis for the EA in Appendix B. Further details on the DGR Project design can be found in Section 4 of the EIS and in Chapter 6 of the Preliminary Safety Report [4].

3.1 OVERVIEW

The DGR Project will receive L&ILW currently stored in interim facilities at the WWMF, as well as that produced from OPG-owned or operated generating stations. Low level waste (LLW) consists of industrial items and materials such as clothing, tools, equipment, and occasional large objects such as heat exchangers, which have become contaminated with low levels of radioactivity. Intermediate level waste (ILW) consists primarily of used reactor components and resins used to clean the reactor water circuits. The capacity of the DGR is a nominal 200,000 m^3 of "as disposed" volume.

The DGR Project comprises two shafts, a number of emplacement rooms and support facilities for the long-term management of L&ILW (Figure 3.1-1). The DGR will be constructed over a period of five to seven years. The DGR Project design is the result of a thorough comparison and evaluation of different alternative methods of implementing the DGR Project. This includes considerations such as the layout of the DGR and construction methods. The evaluation compared each of the alternative means using technical, safety, environmental and economic factors to identify the preferred alternatives. This evaluation is presented in Section 3 of the EIS. This TSD assesses the effects of the preferred alternative (i.e., the DGR Project) on the geologic environment.

3.2 SITE DESCRIPTION AND PROJECT LAYOUT

3.2.1 Surface Facilities

The surface DGR facilities will be located on vacant OPG-retained land to the north of the existing WWMF (Figure 3.2.1-1). A new crossing will be constructed over the abandoned rail bed to provide access to the proposed DGR Project site from the WWMF. The surface structures will be grouped in relatively close proximity to facilitate operations and maintenance activities, and provide a compact footprint.

The Waste Package Receiving Building (WPRB) will receive all radioactive waste packages and transfer them to the main shaft cage for transfer underground. A maintenance workshop and store for essential shaft-related spares and materials will be attached to the WPRB. An office, main control room and amenities building will also form part of the main shaft complex for administrative purposes, control and monitoring of the DGR, and receiving visitors to the DGR. An electrical sub-station will provide power to the entire facility, both surface and underground, and an emergency power supply will maintain critical systems in the event of an outage.

Waste rock piles for the complete excavated volume of rock will be accommodated to the north-east of the two shafts. A stormwater management system of ditches and a pond will be provided to control the outflow of surface runoff and sump discharge water from the site before release into an existing drainage ditch on the Bruce nuclear site, and ultimately Lake Huron (Figure 3.2.1-1). The discharge will also be monitored to confirm it meets certificate of approval water quality requirements.

3.2.2 Underground Facilities

The underground DGR facilities will be constructed in limestone bedrock (Cobourg Formation) at a nominal 680 m depth beneath the OPG-retained lands in the centre of the Bruce nuclear site (Figure 3.1-1). The overall underground arrangement enables infrastructure to be kept in close proximity to the main shaft, while keeping the L&ILW emplacement areas away from normally occupied and high use areas.

The DGR will have two vertical shafts (main and ventilation shafts) in an islanded arrangement with a services area in which offices, a workshop, a wash bay, refuge stations, lunch room and geotechnical laboratory will be provided. From this centralized area, the two panels of emplacement rooms are connected via access tunnels. A main access tunnel will be driven from the main shaft station to the east, passing the ventilation shaft and then proceeding towards the emplacement room panels. The main access tunnel will continue straight into the Panel 1 access tunnel, while a branch tunnel to the south will lead to the Panel 2 access tunnel. The length of the rooms is nominally 250 m. End walls may be erected once the rooms are filled.

The emplacement rooms will all be aligned with the assumed direction (east-northeast) of the major principal horizontal stresses of the rock mass to minimize the risks of any rock fall in the emplacement rooms.

A ventilation supply system will supply air at a controlled range of temperatures to ensure that freezing does not occur in the main shaft and the atmosphere is kept in a reasonably steady and dry state, which is suitable for workers and limits corrosion of structures and waste packages.

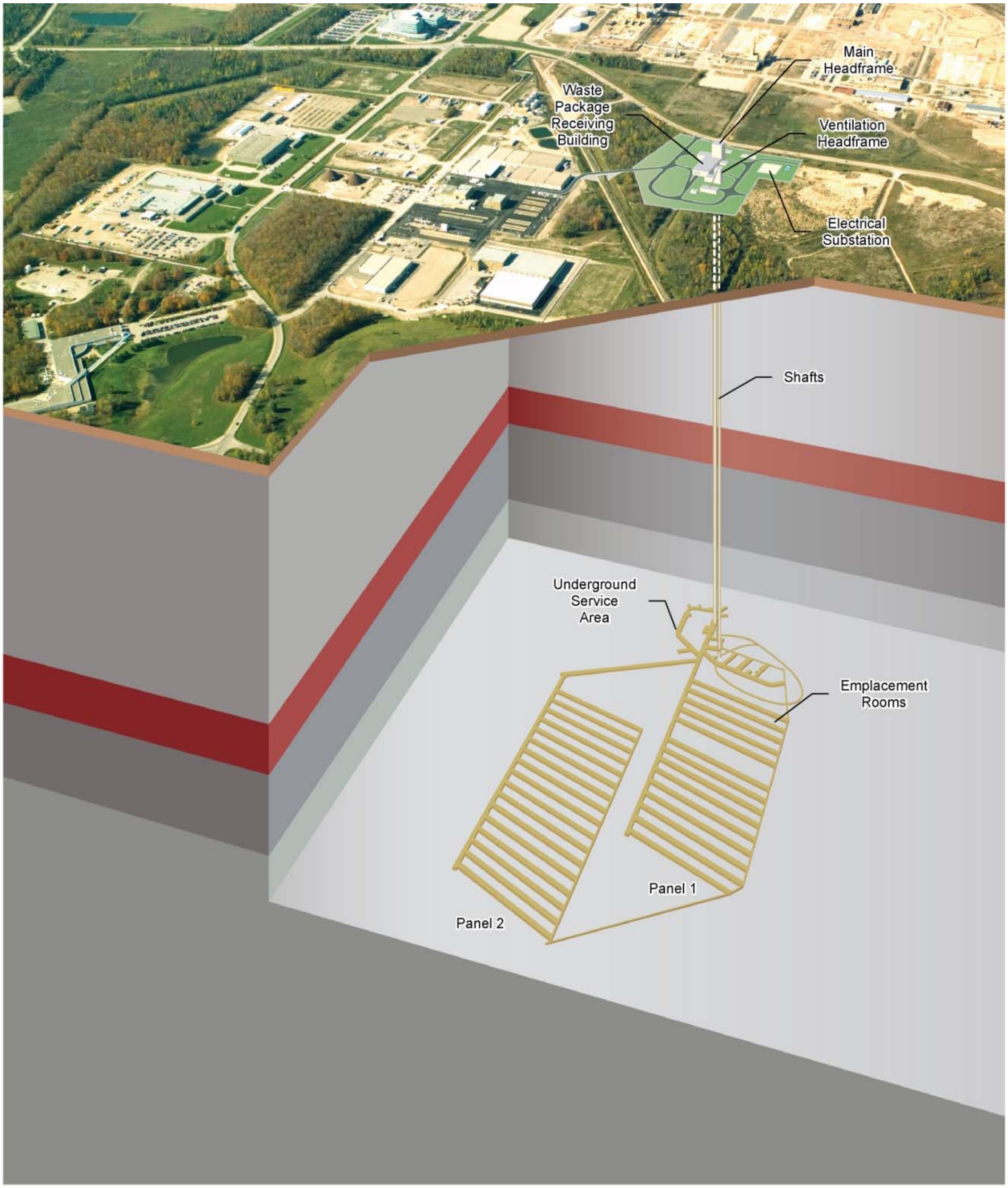

Figure 3.1-1: Schematic of DGR Project

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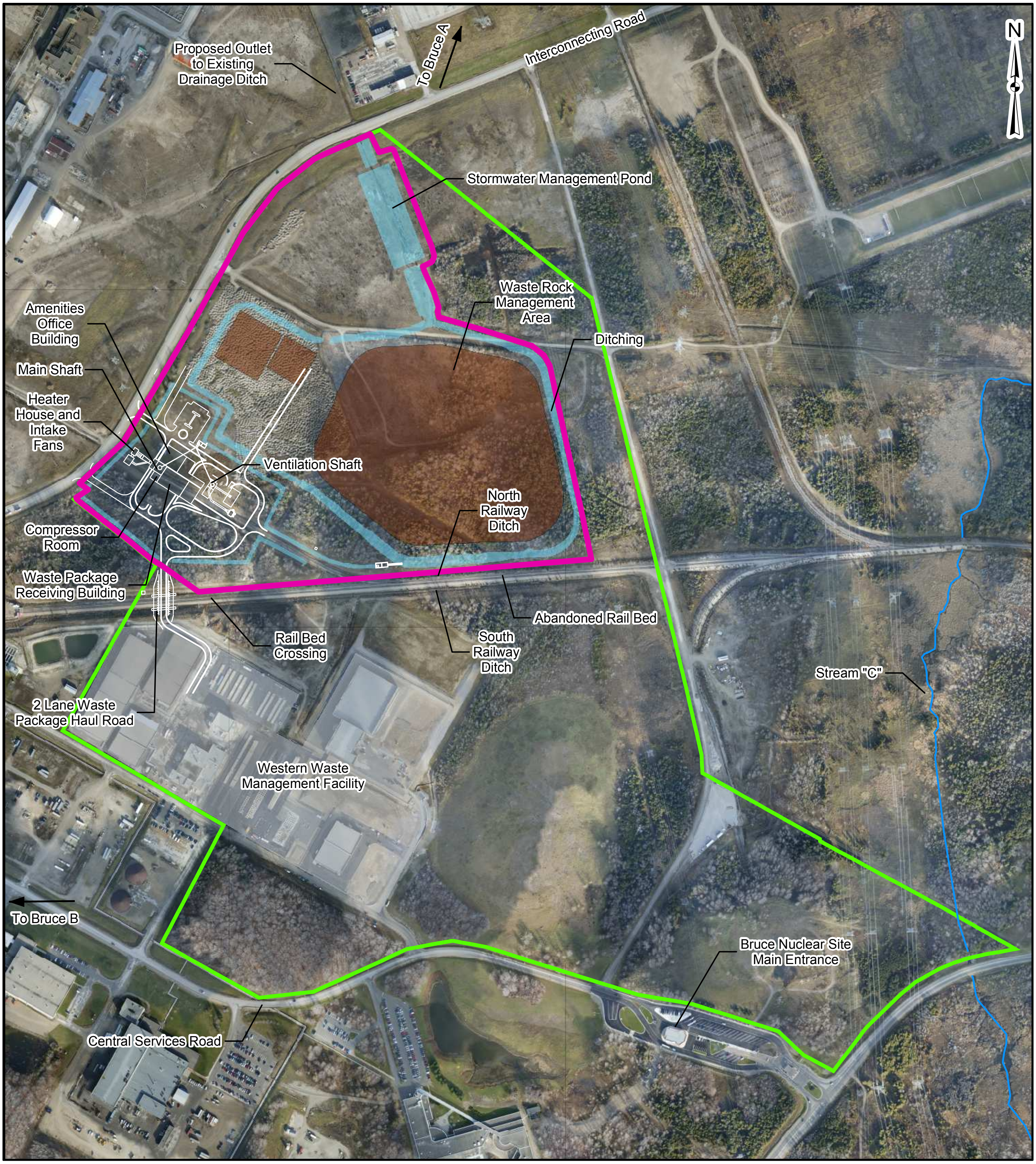

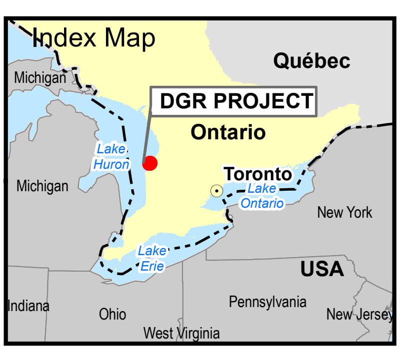

LEGEND

- DGR Project Site
- Project Area (OPG-retained lands that encompass the DGR Project)
- Soils and Rock Stockpile
- Stormwater Management System

0 125 250 500

Metres

REFERENCE

Base Data Provided by 4DM, Nov 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc.,
Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL
SUPPORT DOCUMENT

TITLE

LAYOUT OF DGR
SURFACE INFRASTRUCTURE

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	AB	16 Mar. 2010	**FIGURE 3.2.1-1**	
GIS	BC	25 Nov. 2010		
CHECK	KC	25 Nov. 2010		
REVIEW	AB	25 Nov. 2010		

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4. SELECTION OF VECS

While all components of the environment are important, it is neither practicable nor necessary to assess every potential effect of a project on every component of the environment. An EA focuses on the components that have the greatest relevance in terms of value and sensitivity, and which are likely to be affected by the project. To achieve this focus, specific Valued Ecosystem Components (VECs) are identified. The Canadian Environmental Assessment Agency states that VECs are "*Any part of the environment that is considered important by the proponent, public, scientists and government involved in the assessment process*". Importance may be determined on the basis of cultural values or scientific concerns. VECs can be an individually valued component of the environment or a collection of components that represent one aspect of the environment (e.g., water quality).

From an ecological perspective, VECs can represent features or elements of the natural environment (e.g., a local wetland or stream) considered to be culturally or scientifically important. Such features may be complex, comprising several ecological aspects, and affected by a range of pathways (i.e., routes of exposure or effect). In essence, these ecological feature VECs would encompass a number of individual VECs such as the following:

- an aspect of the physical environment (e.g., soil or groundwater quality);
- an individual wildlife species (e.g., mallard duck or creek chub); or
- a range of species that serve as a surrogate for species that interact similarly with the environment (e.g., benthic invertebrates).

A VEC is considered to be the receptor for both project-specific effects and cumulative effects. A VEC can be represented by a number of indicators. Indicators are features of the VEC that may be affected by the DGR Project (e.g., groundwater quality). Each indicator requires specific 'measures' that can be quantified and assessed (e.g., changes in groundwater quality).

VECs are identified using the expertise of the technical specialists with input from regulators and members of the public. The VECs for the DGR Project were available for discussion and comment at the open houses held in October 2007, November 2008, November 2009 and summer/fall 2010. At the November 2008 open houses the public was encouraged to add VECs to the list and to identify the VECs that were most important to them. The public also had the opportunity to provide input on the list of VECs during the public review process of the draft guidelines.

A total of nine VECs are used in assessing the effects of the DGR Project on geology. The selected VECs reflect a stratified approach to the assessment of the potential effects on geology, as the characteristics of the rock formations and their hydrogeological conditions change with depth. The rationale for selection of the VECs and the indicators used in the assessment are described in the following sections and summarized in Table 4-1.

Table 4-1: VECs Selected for Geology

VEC	Rationale for Selection	Indicators	Measures
Soil Quality	Environmental effects on soil quality could provide a pathway for effects on humans, the biological components and their corresponding VECs	• Soil quality parameters (see Section 4.2.1)	• Changes in soil quality parameters
Overburden Groundwater Quality	Environmental effects on shallow (i.e., <20 mBGS) groundwater quality could provide a pathway for effects on humans, biological components, receiving watercourses, and their corresponding VECs	• Groundwater quality parameters (see Section 4.2.2)	• Changes in groundwater quality parameters
Overburden Groundwater Transport	Effects of the project on shallow (i.e., <20 mBGS) groundwater flow direction, quantity, velocity and recharge could affect receiving watercourses	• Advective transport • Diffusive transport	• Stratigraphy • Hydraulic gradients • Hydraulic conductivity • Environmental tracers • Recharge
Shallow Bedrock Groundwater Quality	Environmental effects on shallow (<170 mBGS) bedrock groundwater quality could provide a pathway for effects on humans, biological components, receiving watercourses, and their corresponding VECs	• Groundwater quality parameters (see Section 4.2.2)	• Changes in groundwater quality parameters
Shallow Bedrock Groundwater and Solute Transport	Environmental effects on shallow (<170 mBGS) bedrock groundwater flow and solute transport could provide a pathway for effects on humans, biological components, receiving watercourses, and their corresponding VECs	• Advective transport • Diffusive transport	• Stratigraphy • Hydraulic gradients • Hydraulic conductivity • Environmental tracers • Recharge

Table 4-1: VECs Selected for Geology (continued)

VEC	Rationale for Selection	Indicators	Measures
Intermediate Bedrock Water Quality	Environmental effects on intermediate (170 to 450 mBGS) bedrock water quality could provide a pathway for effects on humans, biological components, receiving watercourses, and their corresponding VECs	• Intermediate bedrock groundwater/ porewater solute concentrations	• Changes in intermediate bedrock groundwater/ porewater solute concentrations
Intermediate Bedrock Solute Transport	Environmental effects on intermediate (170 to 450 mBGS) bedrock can occur due to solute migration, which could provide a pathway for effects on humans, biological components, receiving watercourses, and their corresponding VECs	• Advective transport • Diffusive transport	• Stratigraphy • Hydraulic gradients • Hydraulic conductivity • Environmental tracers
Deep Bedrock Water Quality	Environmental effects on deep (450 to >860 mBGS) bedrock can occur due to solute migration, which could provide a pathway for effects on humans, biological components, receiving watercourses, and their corresponding VECs	• Deep bedrock groundwater/ porewater solute concentrations	• Changes in deep bedrock groundwater/ porewater solute concentrations
Deep Bedrock Solute Transport	Environmental effects on deep (450 to >860 mBGS) bedrock can occur due to solute migration, which could provide a pathway for effects on humans, biological components, receiving watercourses, and their corresponding VECs	• Advective transport • Diffusive transport	• Stratigraphy • Hydraulic gradients • Hydraulic conductivity • Environmental tracers

Note:
This TSD considers only potential effects of the project on the geology associated with conventional (i.e., non-radiological) parameters. The potential effects of radioactivity on geology are considered in the Radiation and Radioactivity TSD. In addition, overall effects of the DGR Project on Lake Huron are considered in the EIS.

The following sections identify and justify the selection of VECs for assessing the effects of the DGR Project on geology.

4.1 VALUED ECOSYSTEM COMPONENTS

Table 4-1 outlines nine VECs, which includes a grouping of VECs as a function of rock formation depth and hydrogeologic characteristics. For the purpose of the assessment, the VECs are grouped according to stratigraphic depth intervals which are appropriate to the description and assessment of direct and indirect effects of the DGR Project on the geology/hydrogeology environment, from the ground surface to the repository level (illustrated schematically in Figure 4.1-1). This also allows a focussed assessment of the DGR Project on potential receptors, such as Stream C, Lake Huron, and water supply aquifers. Based on the stratigraphic sequence and characteristics within the sequence such as hydraulic conductivity, groundwater quality (including porewater quality), and hydraulic head distributions, the various formations at the DGR Project site were categorized into four different geologic groupings.

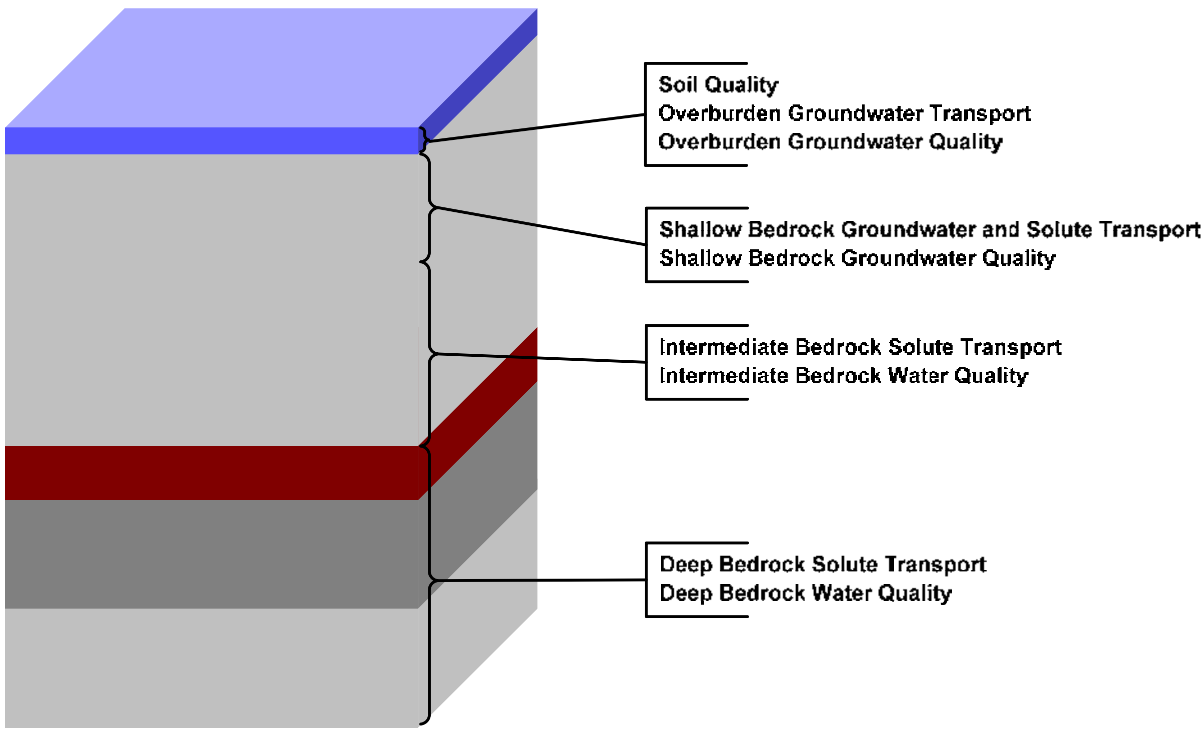

Figure 4.1-1: Conceptual Illustration of the Geology VECs

The geologic groupings and their corresponding VECs are summarized as follows:

- Overburden VECs – soil quality, groundwater quality, and groundwater transport;
- Shallow Bedrock VECs – groundwater quality, and groundwater and solute transport;
- Intermediate Bedrock VECs – water quality, and solute transport; and
- Deep Bedrock VECs – water quality, and solute transport.

A more detailed figure with these groupings and their corresponding geologic formations highlighted is shown in Figure 4.1-2. These formations are described further in Section 5.5.

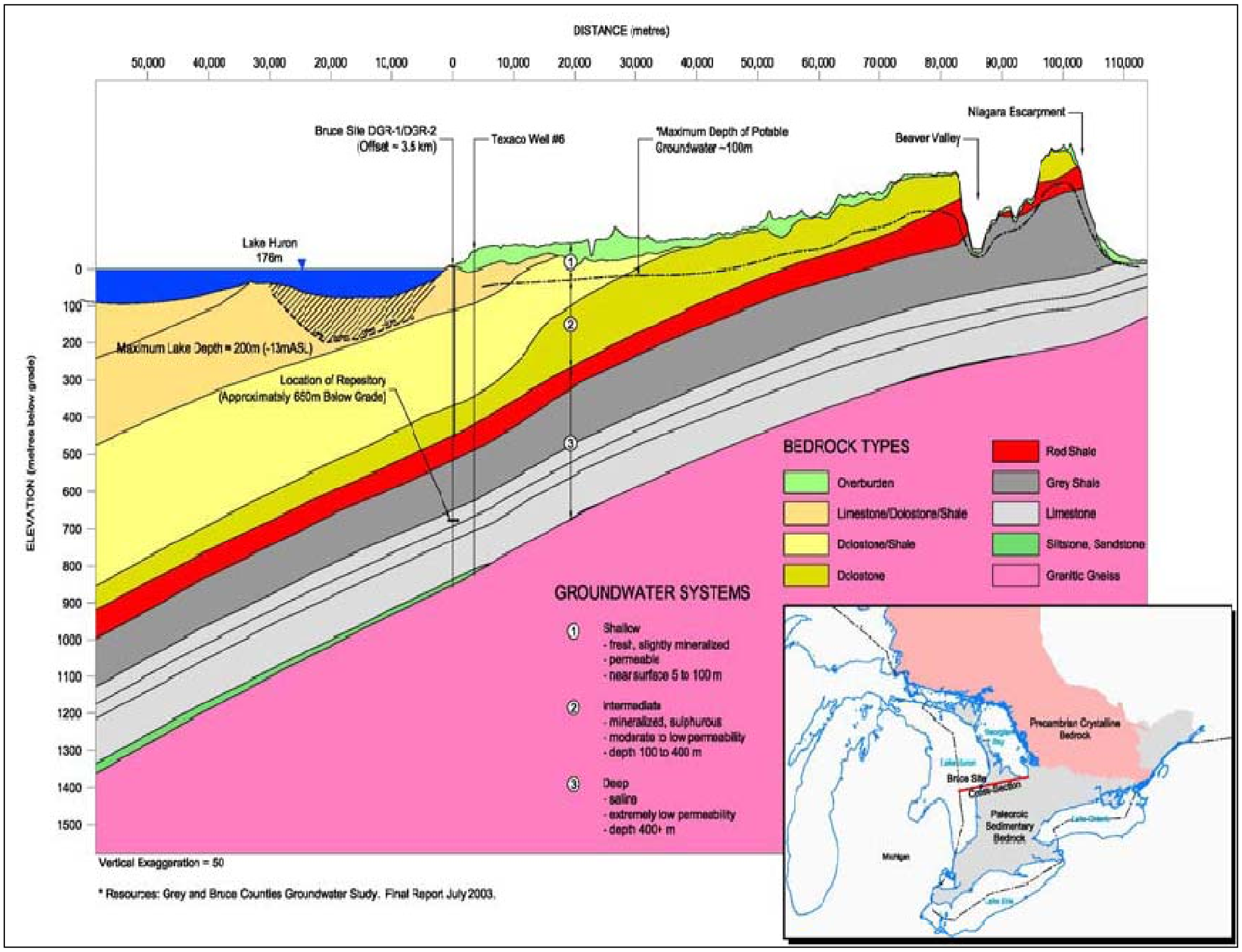

Figure 4.1-2: Simplified Cross-section of Bedrock in the Regional Study Area

4.1.1 Overburden – 0 to 20 mBGS

Soil and groundwater quality are important to consider within the overburden since environmental effects resulting from the DGR Project on shallow soil and groundwater quality can provide a pathway for effects on the biological components and their corresponding VECs. The groundwater transport regime is also important; the potential effects of the DGR Project on groundwater transport direction, quantity, velocity and recharge can affect receiving watercourses. Groundwater transport direction, quantity, velocity, and recharge are inter-connected indicators that will be discussed collectively under the general groundwater transport VEC.

4.1.2 Shallow Bedrock – Approximately 20 to 170 mBGS

The shallow bedrock grouping includes rock formations that provide potable water supplies on a local to regional basis. In addition, certain of these formations (Lucas and Amherstburg) subcrop to the floor of Lake Huron, thus providing a potential pathway through the groundwater flow regime for groundwater quality effects on the aquatic components and their corresponding

VECs. Groundwater quality is important to consider within the shallow bedrock grouping. The shallow bedrock groundwater and solute transport regime may also be affected by the construction and operation of the DGR. The shallow bedrock formations also tend to have downward hydraulic gradients.

4.1.3 Intermediate Bedrock – Approximately 170 to 450 mBGS

The intermediate bedrock grouping includes dominantly shale rock formations which can potentially provide a significant water and/or contaminant transport barrier between the DGR repository levels in the deep bedrock, and the shallow bedrock formations above. Intermediate bedrock formations do not subcrop to Lake Huron. There may be no interaction between intermediate bedrock groundwater and any receiving water courses. The local solute transport regime and water quality may also be affected by the construction and operation of the DGR.

4.1.4 Deep Bedrock – Approximately 450 to 860 mBGS

The deep bedrock grouping includes limestone and shaley limestone rock formations encompassing the repository levels at a nominal 680 mBGS. Deep bedrock formations do not subcrop to Lake Huron. There may be some interaction between deep bedrock water and intermediate bedrock water. The local groundwater flow regime and groundwater quality may also be affected by the construction and operation of the DGR.

The assessment of water quality and solute transport within the formation groupings described above will include potential effects that may arise after decommissioning of the DGR.

4.2 INDICATORS

4.2.1 Soil Quality Parameters

Soil quality comprises the characterization of soil as defined by chemical and physical analysis. Soil quality may be affected as a result of the project, resulting from the potential for the introduction of contaminants to soil as a result of DGR Project works and activities. The full depth of soil (i.e., from topsoil to bedrock surface) is considered as part of this indicator. Soil quality is assessed through the chemical analysis of selected soil samples for general chemistry parameters (pH, anions, cations, nutrients), selected metal parameters and petroleum hydrocarbon compounds (PHCs).

Soil quality data has been obtained for different locations in the Project Area and vicinity during various historical environmental investigations. This indicator is measured through the assessment of potential future changes in soil quality on an as-needed basis over the life of the DGR Project (e.g., as a due diligence measure, in response to future unforeseen events). The magnitude of a change in soil quality is evaluated through comparison with the existing soil quality, as well as through comparison with pertinent regulatory standards such as the Ontario Ministry of the Environment (MOE) 2009 Soil, Groundwater and Sediment Standards for Use Under Part xv.1 of the Environmental Protection Act [8].

4.2.2 Water Quality Parameters

Water quality includes the characterization of groundwater and porewater as defined by chemical analysis. Water quality may potentially be affected as a result of the DGR Project. Groundwater quality in the overburden and shallow bedrock will be assessed through the routine annual chemical analysis of groundwater samples for general chemistry parameters (pH, anions, cations, nutrients), selected metal parameters and petroleum hydrocarbon compounds (PHCs).

Changes in groundwater quality are evaluated through comparison with the existing groundwater quality data. The magnitude of a change is evaluated through comparison with pertinent regulatory standards, including the Ontario MOE 2009 Soil, Groundwater and Sediment Standards [8] and the Ontario Drinking Water Standards (ODWS) [9;10]. Groundwater quality data has been obtained for Bruce nuclear site during various historical environmental investigations in the vicinity of the DGR Project. In addition, groundwater quality data is available from the monitoring well network that was installed as part of the environmental monitoring at the Western Waste Management Facility (WWMF), which is within the DGR Project Area.

The intermediate and deep bedrock geology groupings include what is known as "porewater". In fact the majority of the water within the intermediate bedrock package is porewater, and all of the deep bedrock water is porewater. For the shallow bedrock package, groundwater is a mixture of porewater, and groundwater from infiltration of precipitation, because of the downward hydraulic gradients in these formations.

This TSD considers only potential effects of the project on geology associated with conventional (i.e., non-radiological) parameters. The potential effects of radioactivity on geology are considered in the Radiation and Radioactivity TSD.

4.2.3 Groundwater System

The groundwater system considers the subsurface movement of groundwater. The groundwater flow regime in the Project Area and portions of the Site Study Area may be altered as a result of the DGR Project. This indicator is measured by routine annual groundwater level monitoring of the current WWMF monitoring well network, and will continue to be measured through monitoring of this network and future monitoring locations that may be established as the DGR Project proceeds throughout all of its phases (see Section 13 – Preliminary Follow-up Programs). In addition, water level monitoring of engineering controls associated with the project, such as foundation drains, sumps, or drainage ditches, may be undertaken throughout the life of the project to evaluate potential changes in the local shallow groundwater flow regime.

For the purpose of this TSD, the groundwater flow regime includes potential changes to the hydraulic heads, groundwater quantity, flow/transport velocity, and recharge characteristics of the Project Area within each of the geology packages, as these are interconnected indicators of potential changes or effects. For example, a change to the recharge regime as a result of the project can affect water levels in the overburden and shallow bedrock, which can then affect the hydraulic gradients underneath the Project Area, resulting in changes to the groundwater flow velocity and quantity of flow (i.e., the groundwater "flux") through the Project Area. For all intents and purposes, changes to the recharge characteristics drive potential changes to the water levels in the overburden and shallow bedrock, hydraulic heads, flow velocity, and flux within and down-gradient of the Project Area.

For the intermediate and deep bedrock, porewater/groundwater movement is diffusion-dominated; the porewater is a medium for solute transport through diffusion-dominant processes. In the overburden and shallow bedrock, a combination of advective flow and diffusion are the mechanisms for solute transport (i.e., transport of chemical parameters). The presence of the shafts and repository may create localized changes to the solute transport paths, transport velocity and flux within and between the various formations.

4.3 MEASURES

The measures used to evaluate the effects of the DGR Project on soil and groundwater quality VECs will be changes to the selected indicators.

The measures used to evaluate changes in the groundwater and solute transport regimes are described in Section 4.2.3, and include stratigraphy, hydraulic gradients, hydraulic conductivity, environmental tracers and recharge. These can be used to predict changes to advective and diffusive transport.

5. DESCRIPTION OF THE EXISTING ENVIRONMENT

This section provides a description of the existing environmental conditions at the study areas for the geology and hydrogeology components of the EIS. For the purposes of this TSD, existing conditions may be loosely separated into near-surface (overburden) geology (0 to 20 mBGS) and the bedrock geology (20 to 900 mBGS). The near-surface geology may reflect existing effects of the Bruce A and B nuclear generating stations, activities at the WWMF, the Douglas Point generating station, Hydro One transmission activities and previous activities within the Bruce nuclear site.

In 2005, the NWMO embarked on a comprehensive characterization of the geology, hydrogeology, hydrogeochemistry, and geomechanics on a local to regional scale in order to prepare a credible assessment of the suitability of the site to house a deep geological repository for L&ILW. The result of these efforts, outlined in more detail below, is described in the Descriptive Geosphere Site Model [11]. The geology is quite consistent across all four study areas defined in Section 2.4.2. Therefore, the geology, hydrogeology, hydrogeochemistry and geomechanics are described in detail in the context of the Regional Study Area and the Project Area only.

The characterization of the existing environment serves as the baseline condition for which the environmental effects of the DGR Project are predicted and assessed.

5.1 EXISTING ENVIRONMENT METHODS

The description of the existing environment focuses on the VECs identified in Section 4. Information is presented for the study areas with emphasis placed on the areal extents most likely to be affected by the DGR Project. The description of the existing environment for geology and hydrogeology presents:

- a compilation and review of existing information; and
- details and results of the field programs undertaken to update existing information and fill data gaps.

The geology and hydrogeology component of the study uses the Regional, Local Areas and Project Area (defined in Section 2.4.2) to characterize the existing conditions. The Project Area is the portion of the Bruce nuclear site that is being considered for the DGR Project. The Project Area specifically includes the WWMF because of its proximity to the DGR Project and shared drainage pathways.

The effects assessment (Section 8) evaluates the potential effects of the DGR Project on the existing environment. The methods used to gather information on which to base the description of geology and hydrogeology are explained in the following sections.

5.1.1 Sources of Existing Data

5.1.1.1 Soil Quality

For the purposes of characterizing the soil quality, the following key documents are included in the compilation and review of the existing environment:

- 1978-1980 Original Investigations for the WWMF (formerly Radioactive Waste Operations Site 2 (RWOS2) [12;13]. These studies focused on the physico-chemical characteristics (e.g., cation content and exchange capacity) of the soils in the WWMF.
- 2000-2003 Phase II Environmental Site Assessment (ESA) investigations of the Bruce nuclear site [14;15;16;17].

5.1.1.2 Overburden Geology

For the purposes of characterizing the overburden geology, the following key documents are included in the compilation and review of the existing environment:

- 1978-1980 Original Investigations for the WWMF (formerly Radioactive Waste Operations Site 2 (RWOS2) [12;13];
- several investigations conducted by Ontario Hydro between 1987 and 1998 at the WWMF [18;19;20;21;22];
- 2000-2003 Phase II Environmental Site Assessment (ESA) investigations of the Bruce nuclear site and follow-up monitoring programs [14;15;16;17;23;24];
- the Postclosure Safety Assessment Report [2]; and
- OPG water level monitoring data at the WWMF [25].

5.1.1.3 Bedrock Geology

For the purposes of characterizing the bedrock geology, the following key documents are included in the compilation and review of the existing environment:

- Geosynthesis [3];
- Regional Hydrogeochemistry – Southern Ontario [26];
- Regional Geomechanics – Southern Ontario [27];
- Regional Geology – Southern Ontario [28];
- Hydrogeologic Modelling [29];
- Descriptive Geosphere Site Model [11];
- Three Dimensional Geological Framework Model [30]; and
- various other supporting technical reports, as cited throughout.

5.1.2 Field Studies

Field studies were not conducted as part of the near-surface geology component of this TSD, as it was considered that there was sufficient information from previous investigations to describe the near-surface environment for the purpose of assessing the viability of the DGR.

The deep geological drilling, instrumentation and testing program was conducted from 2006 to 2010 by OPG and NWMO for characterization of the deep geology and hydrogeology in the Project Area and vicinity. The field program involved the drilling and instrumenting of six multi-level wells (Figure 5.1.2-1), three of which were advanced from ground surface to the Precambrian basement, approximately 860 mBGS. Field studies included packer testing, non-radiological and radiological groundwater chemistry analyses, isotope studies on the groundwater and porewater from the various formations, hydraulic head distribution analysis, and geotechnical testing (e.g., competency, pressurization, tectonic indicators).

The results of these programs are summarized in Section 5.5 and described further in the Geosynthesis [3], the Deep Geosphere Site Model [11] and supporting technical studies.

5.2 TRADITIONAL KNOWLEDGE AND ABORIGINAL SHARING

As discussed in the Aboriginal Interests TSD, the local Aboriginal communities have identified a number of issues relating to previous projects at the Bruce nuclear site as well as the DGR Project and the presence of the Bruce nuclear site. Those issued that relate to geology include:

- their traditional Ojibway beliefs towards their relationship with the rock of the earth; and
- the long-term safety of the DGR.

The spiritual considerations with relation to the rock of the earth are addressed in the Aboriginal Interests TSD. The long-term safety of the DGR is assessed in this TSD, and the EIS.

5.3 SETTING

5.3.1 Project Area

The Project Area is located entirely within the fenced Bruce nuclear site (Figure 2.4.2-3). The Project Area consists of land that is designated for the management of OPG radioactive wastes. The centre of the Project Area is approximately 2 km from Bruce A, 1.6 km from Bruce B, and about 1.4 km from Lake Huron. At present, the WWMF above ground structures are located within the south-central portion of the Project Area. Former Construction Landfills Nos. 1 and 2 are located within the southeast portion of the Project Area. The central and northern portions of the Project Area are a combination of undeveloped forested lands and lands that have been cleared and historically used as a metal storage yard and a former construction pipe storage yard (North and East Storage Area on Figure 2.4.2-3).

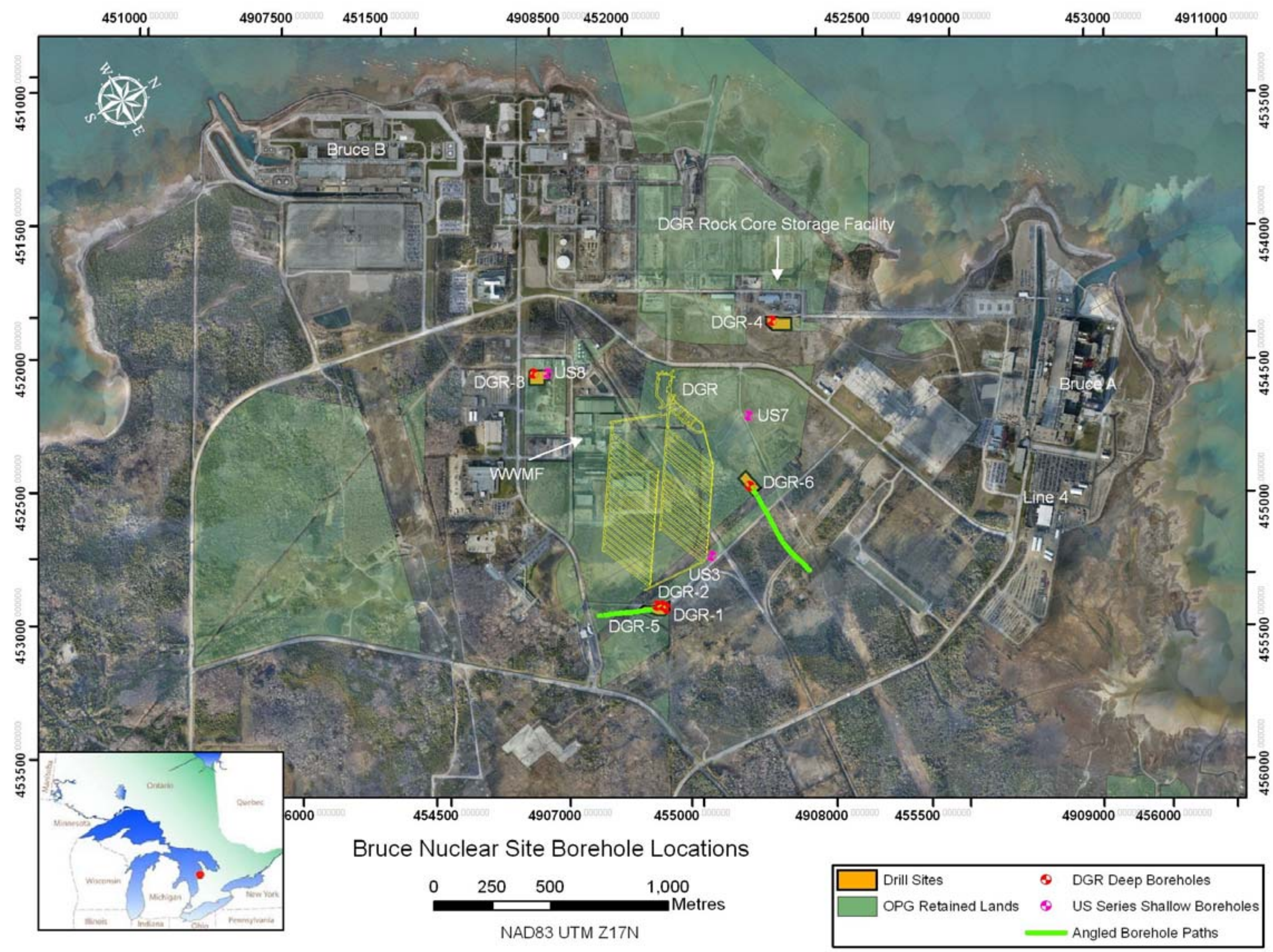

Figure 5.1.2-1: Location of Deep DGR-Series and Shallow US-series Boreholes

The topography within the Project Area ranges from 182 to 194 mASL, generally sloping gently northward and westward from the south-central portion of the Project Area. A railway embankment bisects the Project Area in an east to west orientation, and contains drainage ditches on both the north and south side of the embankment (identified in the assessment as the North and South Railway Ditches, but referred to collectively in this TSD as the Railway Ditch) at an elevation of approximately 184 mASL. Drainage ditches are also present on both sides of the access roads on the southern and northern Project Area property boundary. Within the southeastern corner of the Project Area, two substantial construction soil and rock stockpiles are present, denoted as Construction Landfill No.1 and Construction Landfill No. 2 (Figure 2.4.2-3). These stockpiles range from 10 to 16 m in height, with a surface elevation ranging from approximately 186 to 204 mASL.

Previous geoscientific investigations within the Project Area have been focused on the WWMF portion of the Project Area. There is limited subsurface information within the southeast, central, and north-central portions of the Project Area. There have also been geoscientific investigations at the former Heavy Water Plant, immediately northwest of the Project Area. Although this is outside of the Project Area, these studies are discussed in the following sections with those at the WWMF because of their similar nature and close proximity. The location of the monitoring wells within the Project and Site Study Area are presented on Figure 5.3.1-1.

5.3.2 Site Study Area

The Site Study Area (see Figure 2.4.2-3) is situated on the east shore of Lake Huron on the Douglas Point promontory, a feature of comparatively low relief that juts 2.5 to 3.0 km into the lake over a distance of approximately 5 km between Inverhuron Bay in the southwest and Baie du Doré in the north (Figure 5.3.2-1). The Douglas Point promontory is a bedrock-controlled feature with nearly flat-lying dolostone bedrock outcropping along the shoreline, resulting in the resistance of the promontory to lake erosion.

The relief of the Site Study Area varies between elevations of 176 mASL (Lake Huron level) and 195 mASL within areas above the Nipissing Bluff. The Nipissing Bluff is a comparatively low, ancient beach and shoreline bluff eroded by post-glacial phases of Lake Huron at a recessional lake stage below that of the older Algonquin Bluff shoreline.

The Nipissing Bluff face occurs between elevations of approximately 185 and 190 mASL. During this post-glacial lake stage, the Site Study Area was part of a point of land marked by the curving beach lines of the Nipissing Bluff extending to the north and south. Lake Huron subsequently continued to recede to its current level following the development of the Nipissing Bluff.

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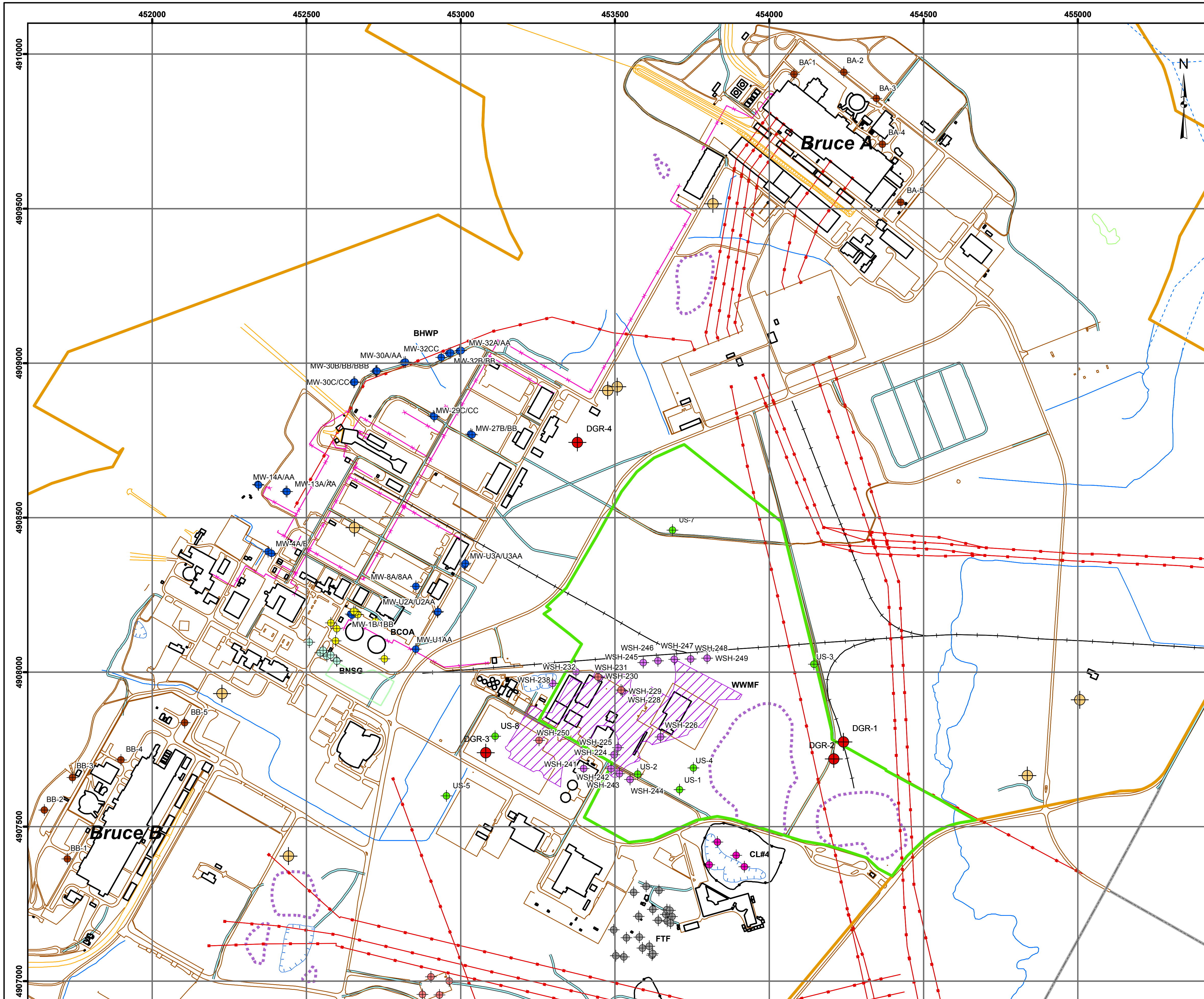

LEGEND

- DGR Wells
- New Build Well Locations
- Bunker C Oil ASTs & Delivery System Wells
- Former Bruce Nuclear Standby Generators Wells
- Former Construction Landfill 4
- Fire Training Facility Wells
- Existing Monitoring Wells
- Bruce A & B Monitoring Wells
- Bruce Heavy Water Wells
- Sand Aquifer Water Wells
- US Monitoring Wells (Deep)
- Bedrock Water Wells
- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Approximate sub-surface Sand Aquifer
- Surface Storage
- Road / Bridge
- Road Centreline
- Accessway Centreline
- Feature Edge
- Railway
- Marsh
- River or Stream
- Drain lines
- Reservoir
- Channels and Channel Slopes
- Pit
- Piles
- Provincial Park Boundary
- Transmission Lines
- Above Ground Piping
- Berms
- Buildings
- Contour - 1.5m Interval
- Section Location

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land andwithin Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2006
Datum: NAD 83 Projection: UTM Zone 17N

0 100 200 400 600 800
Meters

PROJECT
GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE
SITE STUDY AREA WITH LOCATIONS OF MONITORING WELLS

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	24 Jun. 2010		
CHECK	CK	24 Jun. 2010		
REVIEW	MAR	24 Jun. 2010		

FIGURE 5.3.1-1

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5.3.3 Local Study Area

The Local Study Area (see Figure 2.4.2-2) encompasses an area of approximately 127 km², including the communities of Underwood and Tiverton and the Bruce nuclear site development located on the Douglas Point promontory. The area was defined based upon the watersheds that drain to the Douglas Point area including Baie du Doré to the north and Inverhuron Bay to the south. The drainage systems include Underwood Creek, which discharges to Baie du Doré directly north of the Bruce nuclear site, Stream C, which drains through the Bruce nuclear site, the Little Sauble River and Tiverton Creek, which both discharge to Inverhuron Bay directly south of the Bruce nuclear site. The dominant physiographic feature within the Local Study Area, inland from Lake Huron, is the Algonquin Bluff which rises approximately 30 m. The terrain above the Algonquin Bluff, west of the Bruce nuclear site, consists of comparatively flat clay plains, which include the networks of streams discussed above, which drain westward to Lake Huron (see Figure 2.4.2-2).

5.3.4 Regional Study Area

The Regional Study Area (see Figure 2.4.2-1) comprises the regional 3-Dimensional Geologic Framework for an area of approximately 35,000 km² surrounding the DGR. The Regional Study Area boundary was delineated in order to fully encompass the Regional Hydrogeologic Modelling Domain [3]. Although there are a number of groundwater users within the Regional Study Area, these are all upgradient of the Project Area and are not expected to interact with the DGR Project. Near-surface overburden geology and hydrogeology in the Regional Study Area are not considered further in this TSD.

5.4 OVERBURDEN GEOLOGY

5.4.1 Site Study Area and Project Area

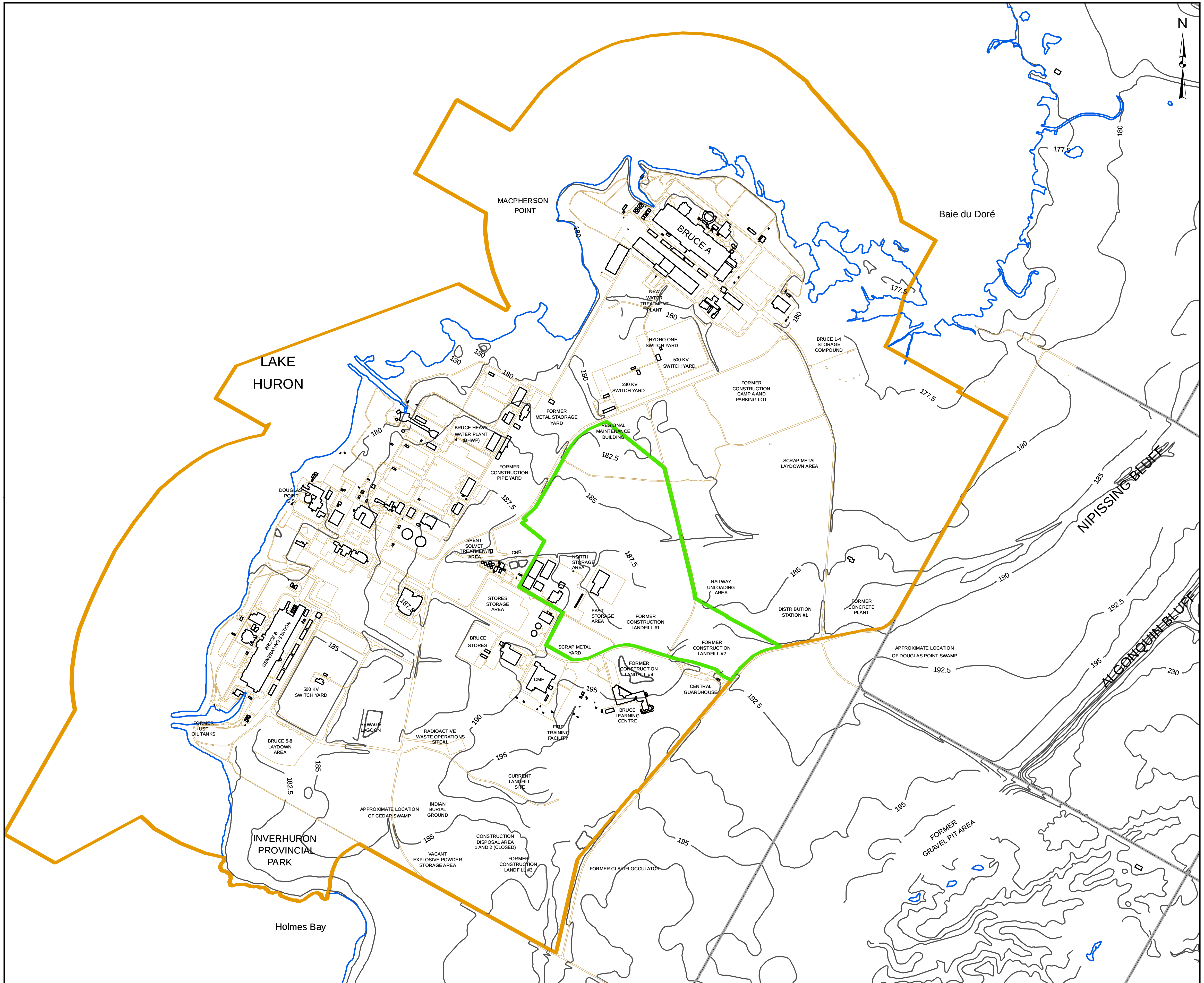
Within the Site Study Area the dominant unconsolidated surficial material consists of stony, sandy or silty till of the Elma-Catfish Creek Till unit [31]. There are also thin, approximately shoreline-parallel bands of sand and gravel beach deposits and minor gravel-dominated glaciofluvial outwash. A large portion of the shoreline also exposes the underlying dolostone bedrock of the Middle Devonian Lucas Formation.

The distribution of overburden thickness overlying the bedrock throughout the Site Study Area was characterized through contouring of the available geotechnical borehole information for the site that was previously compiled in 1986/87 by Ontario Hydro [19] and subsequently updated with additional drill holes [20].

In general terms, the thickness of overburden throughout the site study area varies from about 0 to 20 m in thickness, depending on location. Near the shoreline of Lake Huron, overburden thicknesses are low (0 to 3 m). Towards the central portion of the site study area, overburden thicknesses increase, with the maximum thicknesses (between 12 and 20 m) indicated within the Project Area lands (Figure 5.4.1-1). Recent drilling for a separate project indicates that overburden thickness increases to the northeast of the Project Area, to greater than 25 m in the vicinity of Tie Road.

The area of surficial deposits within the Bruce nuclear site that has been subjected to the most intensive hydrogeological investigation lies within the WWMF, comprising the south-central portion of the Project Area [13;12;22;21]. Generally, this portion of the Project Area consists of 13 to 18 m of surficial deposits overlying bedrock and the bedrock surface varies in elevation between 171.0 and 177.5 mASL, as shown in Figures 5.4.1-1 and 5.4.1-2, respectively. The overburden thickness beneath the northern portion of the WWMF is approximately 6 to 12 m (Figure 5.4.1-1). The overburden thickness decreases to less than 3 m beneath the former Heavy Water Plant, coinciding with a rise in the bedrock surface to elevations of between 180 and 185 mASL (Figure 5.4.1-2). Overall, the bedrock surface slopes eastward to north-eastward beneath the Project Area from elevations of approximately 180 to 168 mASL (Figure 5.4.1-2).

From the detailed WWMF site investigations, four cross-sections were prepared by others for the WWMF portion of the Project Area at the locations shown in Figure 5.4.1-2. The sections (B-B' through E-E') are shown in Figures 5.4.1-3, 5.4.1-4 and 5.4.1-5 [21;12]. Two cross-sections were prepared by others for the Heavy Water Plant, immediately northwest of the Project Area, at the locations shown on Figure 5.4.1-6. These sections (S-1, S-2) are shown in Figure 5.4.1-7.



LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Reservoir
- Road Centreline
- Site Feature
- Shoreline
- Buildings

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce Nuclear Site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
Datum: NAD 83 Projection: UTM Zone 17N

0 125 250 500 750 1,000
Metres

PROJECT
GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE
SITE STUDY AREA RELIEF CONTOURS

Golder Associates
Mississauga, Ontario

PROJECT NO. 6-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	5 May. 2010		
CHECK	AKB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

FIGURE 5.3.2-1

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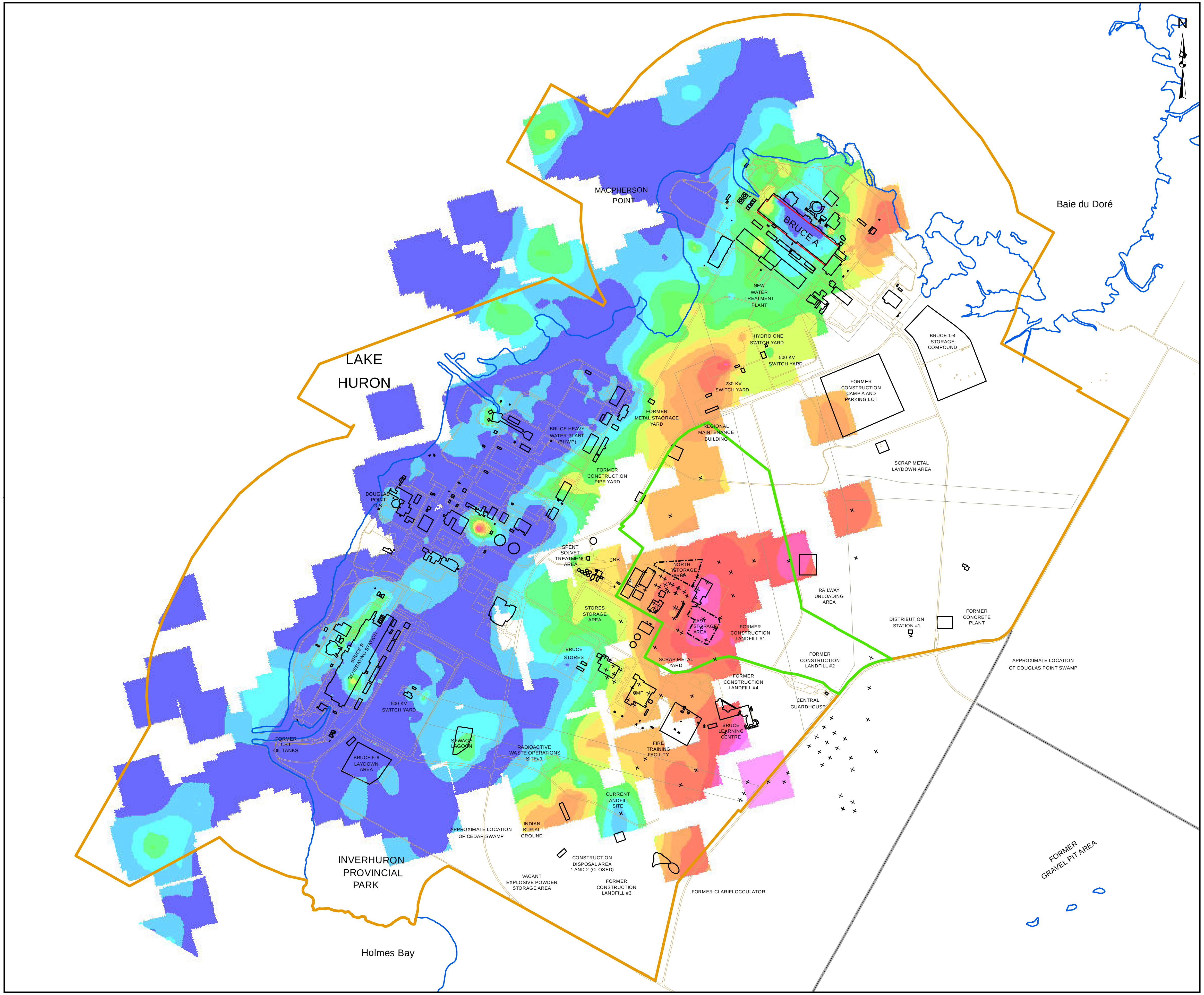
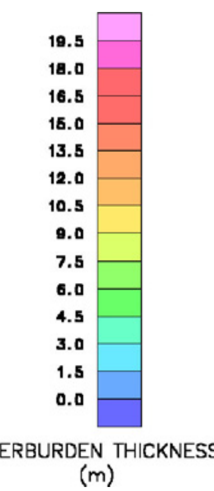


LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Road Centreline
- Site Feature
- Shoreline
- Buildings
- \+ Geotechnical Drillhole Location



NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce Nuclear Site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
Datum: NAD 83 Projection: UTM Zone 17N

0 125 250 500 750 1,000
Metres

PROJECT
GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE
PRECONSTRUCTION OVERBURDEN THICKNESS - SITE STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	5 May. 2010		
CHECK	AKB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

FIGURE 5.4.1-1

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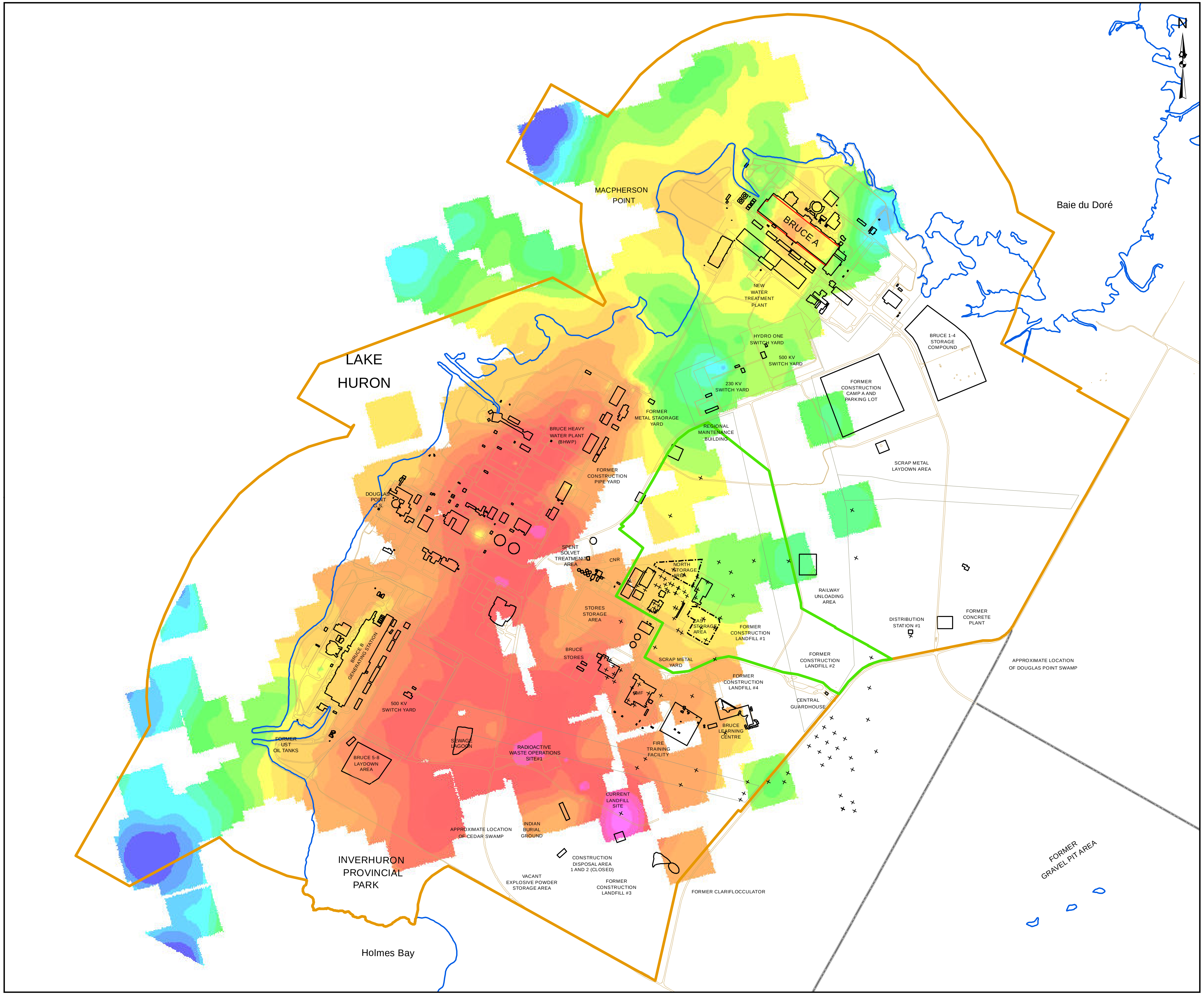

LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Road Centreline
- Site Feature
- Shoreline
- Buildings
- + Geotechnical Drillhole Location

BEDROCK ELEVATION (m)
189.0
187.5
186.0
184.5
183.0
181.5
180.0
178.5
177.0
175.5
174.0
172.5
171.0
169.5
168.0
166.5
165.0
163.5
162.0
160.5
159.0

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce Nuclear Site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
Datum: NAD 83 Projection: UTM Zone 17N

0 125 250 500 750 1,000
Metres

PROJECT
GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE
BEDROCK SURFACE ELEVATION - SITE STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006	FIGURE 5.4.1-2	
GIS	BC	5 May. 2010		
CHECK	AKB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

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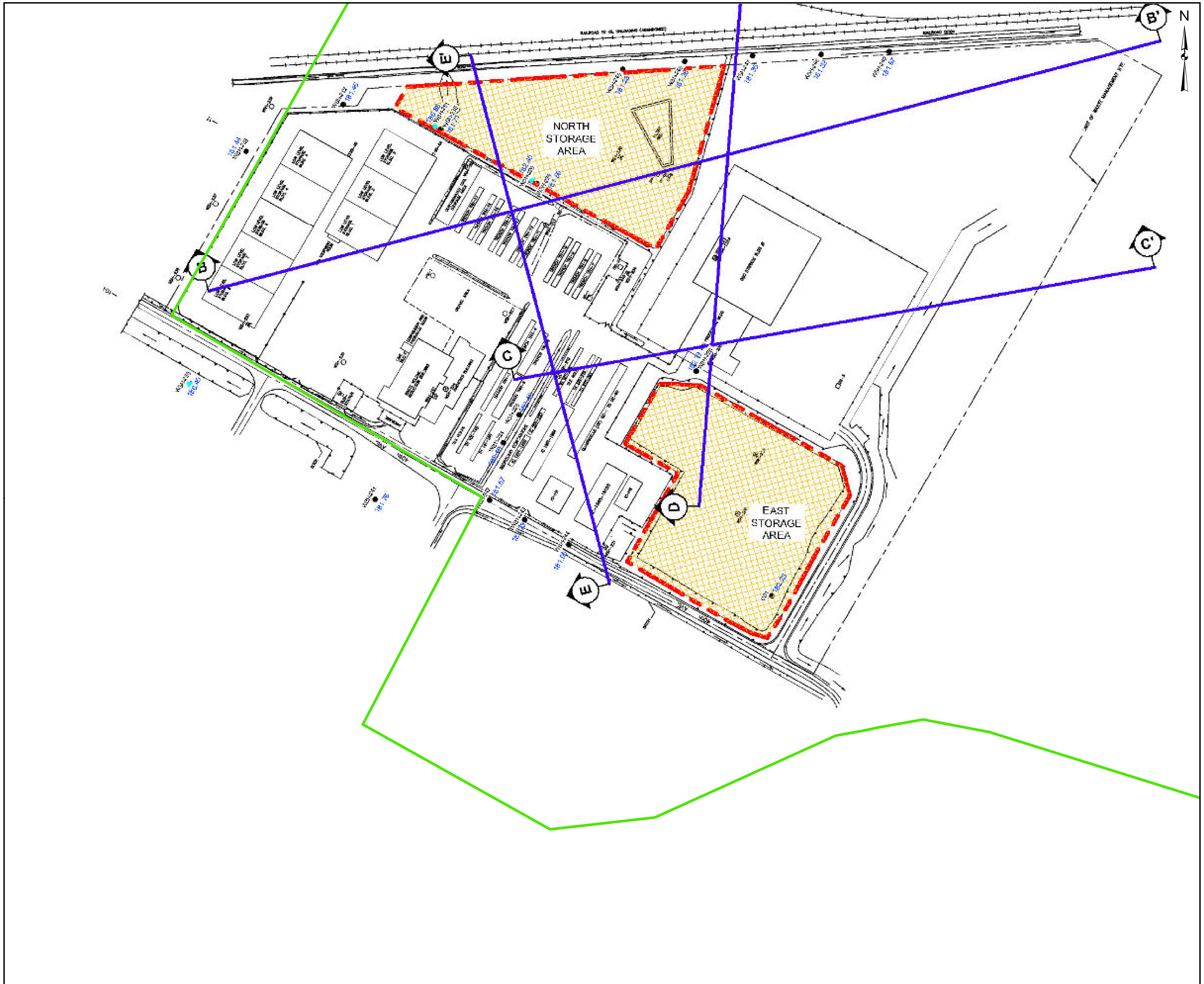

LEGEND

Project Area (OPG-retained lands that encompass the DGR Project)

- SS- SAMPLING STATION
- DV- DIVERSION MANHOLE
- IN-SERVICE-BEDROCK WATER SAMPLE HOLE
- NOT IN-SERVICE BEDROCK WATER SAMPLE HOLE
- ABANDONED BEDROCK WATER SAMPLE HOLE
- IN-SERVICE MIDDLE SAND AQUIFER WATER SAMPLE HOLE
- NOT IN-SERVICE MIDDLE SAND AQUIFER WATER SAMPLE HOLE
- ABANDONED MIDDLE SAND AQUIFER WATER SAMPLE HOLE

1.) INTERNAL FENCE OF WESTERN LOW AND INTERMEDIATE LEVEL WASTE STORAGE FACILITY.

2.) PERIMETER FENCE OF WESTERN LOW AND INTERMEDIATE LEVEL WASTE STORAGE FACILITY.

181.59 WATER LEVEL METRES

NOTES

1. WATER ELEVATIONS FROM OCTOBER 6, 2004, OR OCTOBER 2001 WHERE WAS NOT AVAILABLE, ARE PROVIDED IN METERS ABOVE SEA LEVEL

REFERENCE

1. Base map and water sample locations obtained from Ontario Power Generation in PDF format, DWG No. W-DRAW-10000-10001-Sheet-0003, Scale 1"=100'. Dated Feb. 12, 2003, REV.000, titled Western Waste Management Facility Water Sample Holes.

0 50 100 200

Metres

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

LOCATION OF CROSS-SECTIONS AND WATER ELEVATION IN OVERBURDEN AND BEDROCK WWMF PORTION OF PROJECT AREA

Golder Associates

Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006	FIGURE 5.4.1-3	
GIS	BC	5 May. 2010		
CHECK	AKB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

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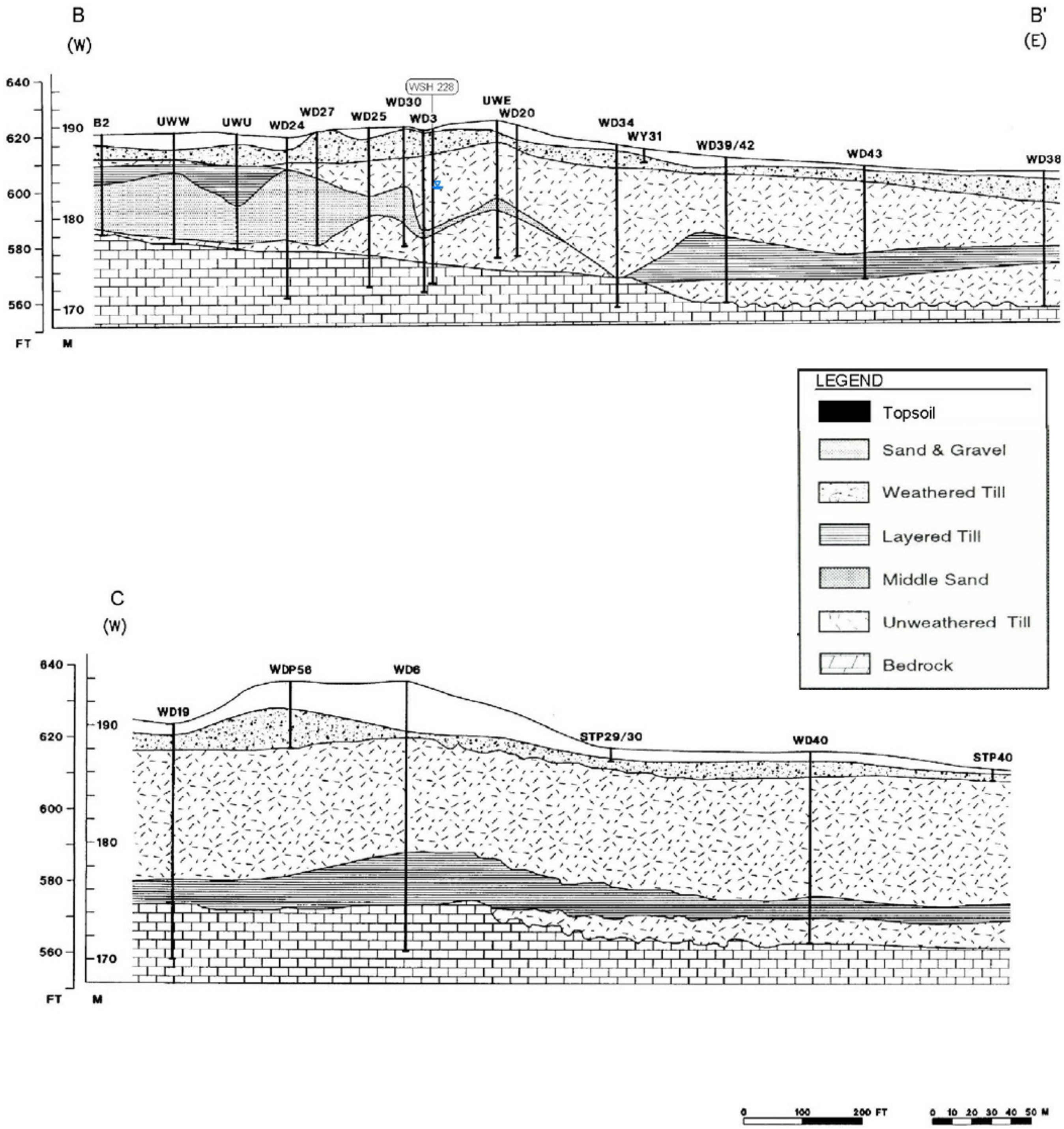

NOTES

1. LOCATION OF WSH HAVE BEEN APPROXIMATED FROM OPG FIGURE 0125 DFH 101200090 REV. 1 FIGURE 4-10 OF THE LLSB9, 10, 11, EA DATED MARCH 2004.
2. WATER LEVELS FOR OCT 2001 AND OCT 2004 WERE SUPPLIED BY OPG
3. FOR LOCATION OF SECTIONS B-B' TO E-E' REFER TO FIGURE 5.4.1-3

REFERENCE

Cross section provided by (Cherry ET. AL., 1980; Jensen. 1996A)

PROJECT

GEOLOGY TECHNICAL
SUPPORT DOCUMENT

TITLE

CROSS SECTION B-B' AND C-C'
WWMF PORTION OF PROJECT AREA

Golder Associates
Mississauga, Ontario

PROJECT No. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	FIGURE 5.4.1-4	
GIS	BC	5 May. 2010		
CHECK	CK	5 May. 2010		
REVIEW	MAR	5 May. 2010		

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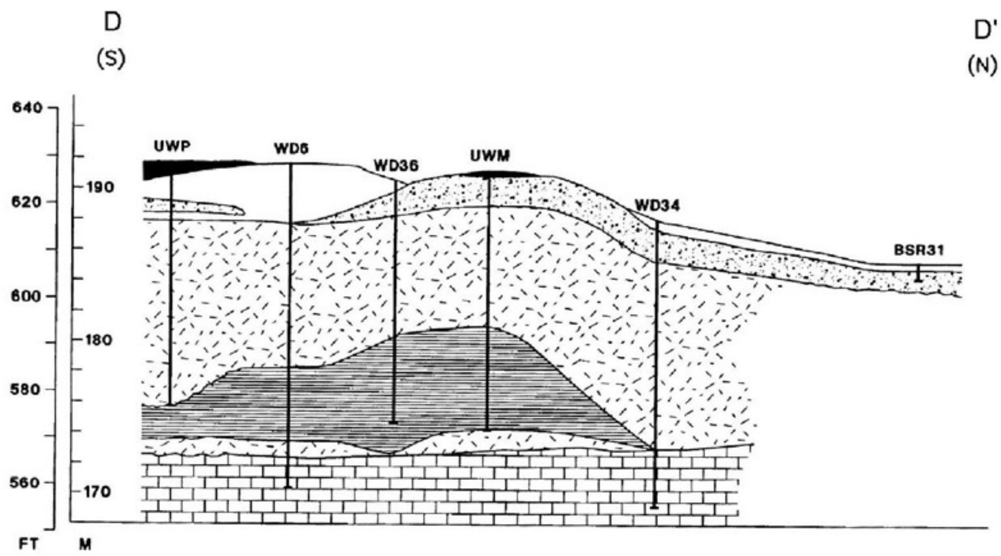

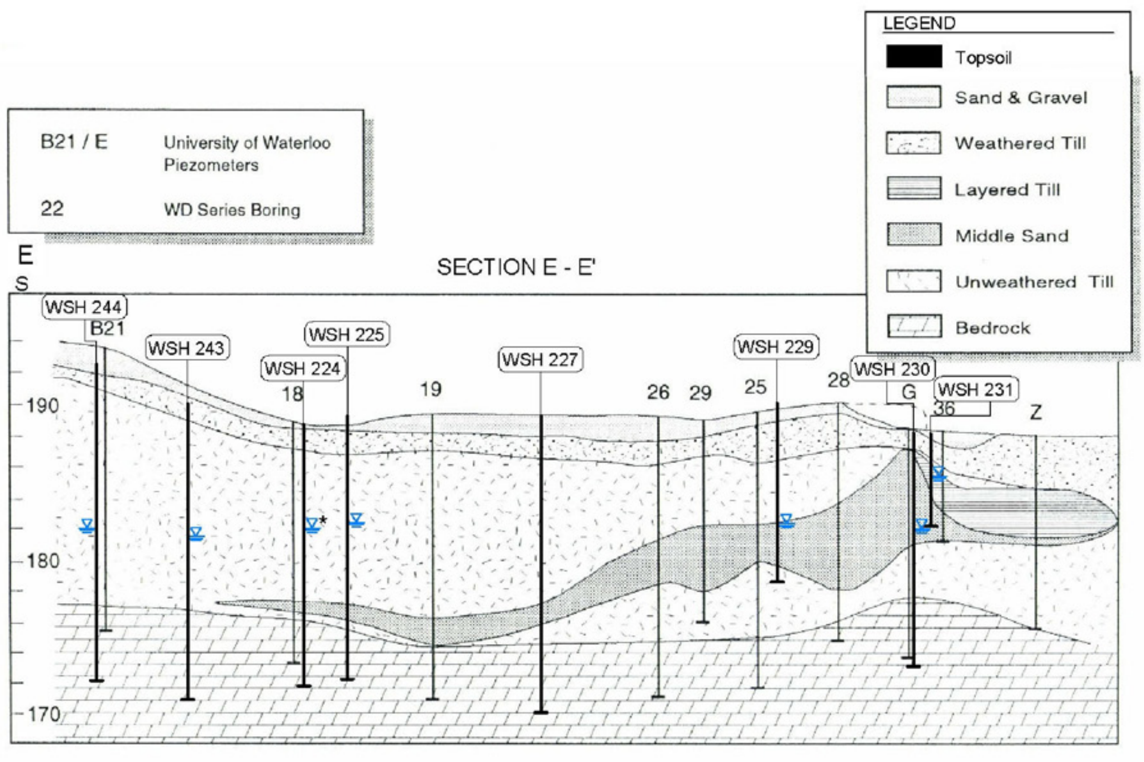

NOTES

1. LOCATION OF WSH HAVE BEEN APPROXIMATED FROM OPG FIGURE 0125 DFH 101200090 REV. 1 FIGURE 4-10 OF THE LLSB9, 10, 11, EA DATED MARCH 2004.
2. WATER LEVELS FOR OCT 2001 AND OCT 2004 WERE SUPPLIED BY OPG
3. FOR LOCATION OF SECTIONS B-B' TO E-E' REFER TO FIGURE 5.4.1-3

REFERENCE

Cross section provided by (Cherry ET. AL., 1980; Jensen. 1996A)

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

CROSS SECTION D-D' AND E-E'
WWMF PORTION OF PROJECT AREA

Golder Associates
Mississauga, Ontario

PROJECT No. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	FIGURE 5.4.1-5	
GIS	BC	5 May. 2010		
CHECK	AKB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

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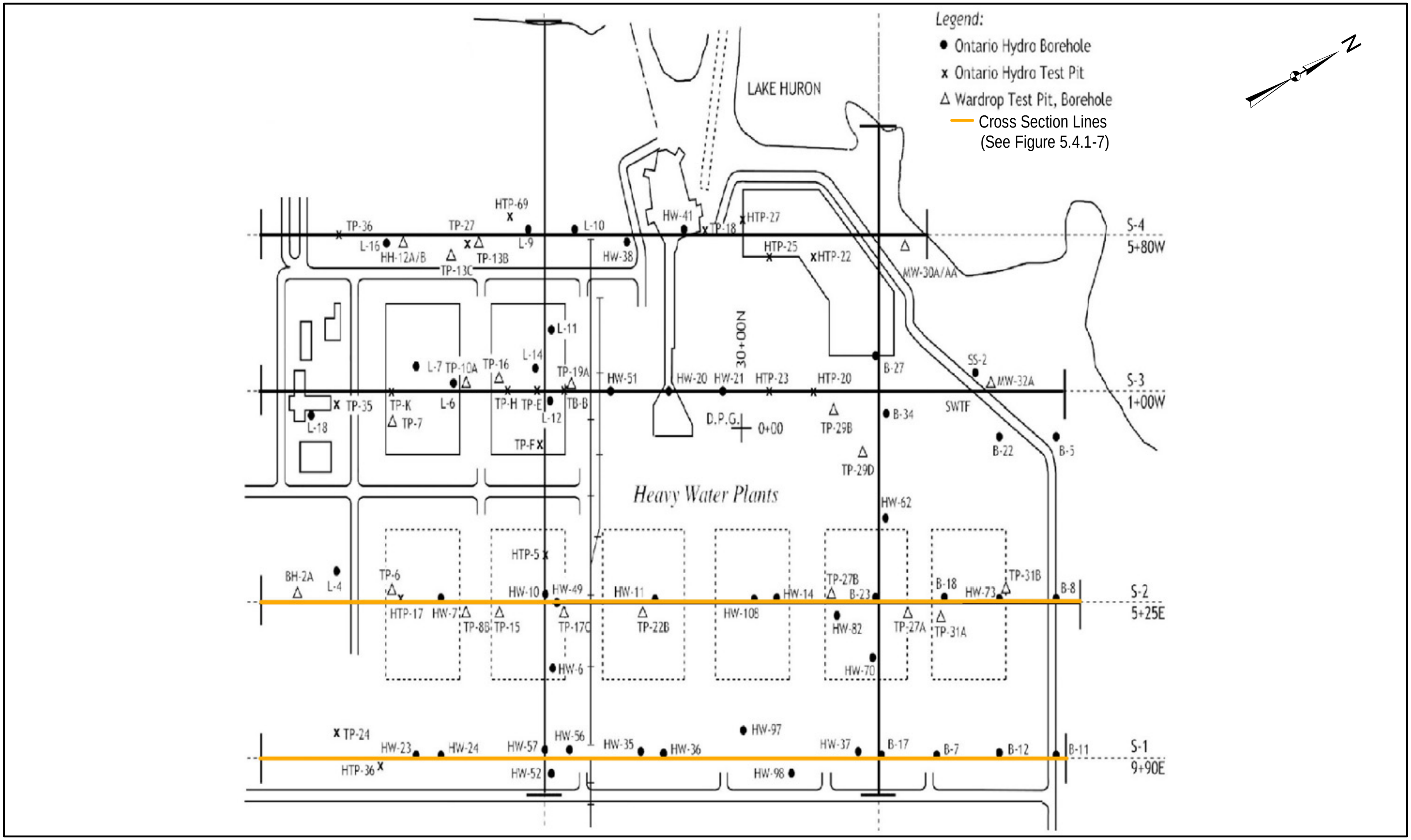

REFERENCE

Sections from Bruce Heavy Water Plant Decommissioning Environmental Assessment Study Report, Dated December 2002.

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

LOCATION MAP OF STRATIGRAPHIC CROSS SECTIONS FORMER HEAVY WATER PLANT

Golder Associates
Mississauga, Ontario

PROJECT No. 06-1112-037			SCALE AS SHOWN	R000
DESIGN	SC	31 Jan. 2008	FIGURE 5.4.1-6	
GIS	BC	5 May. 2010		
CHECK	AB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

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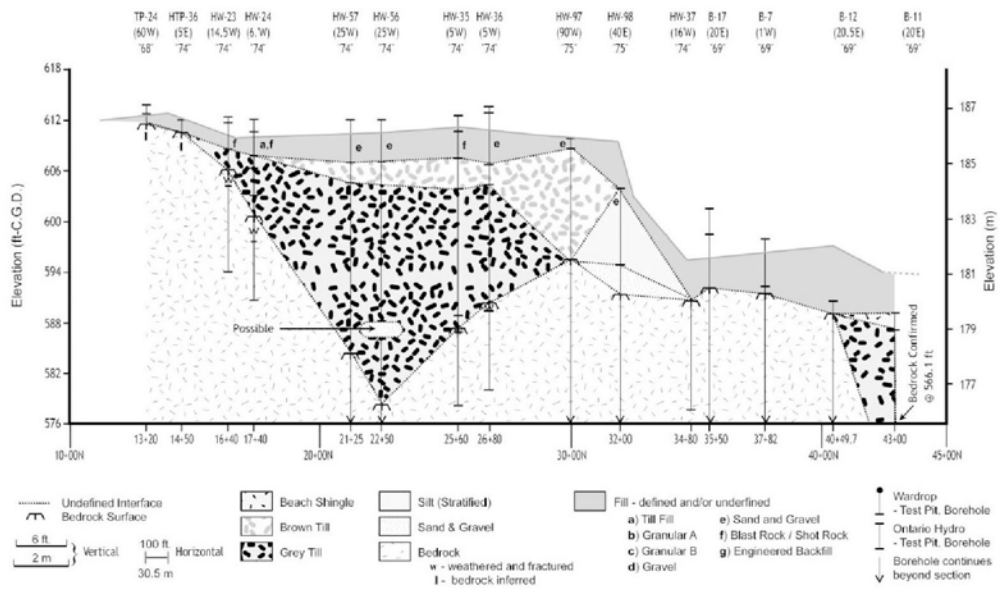
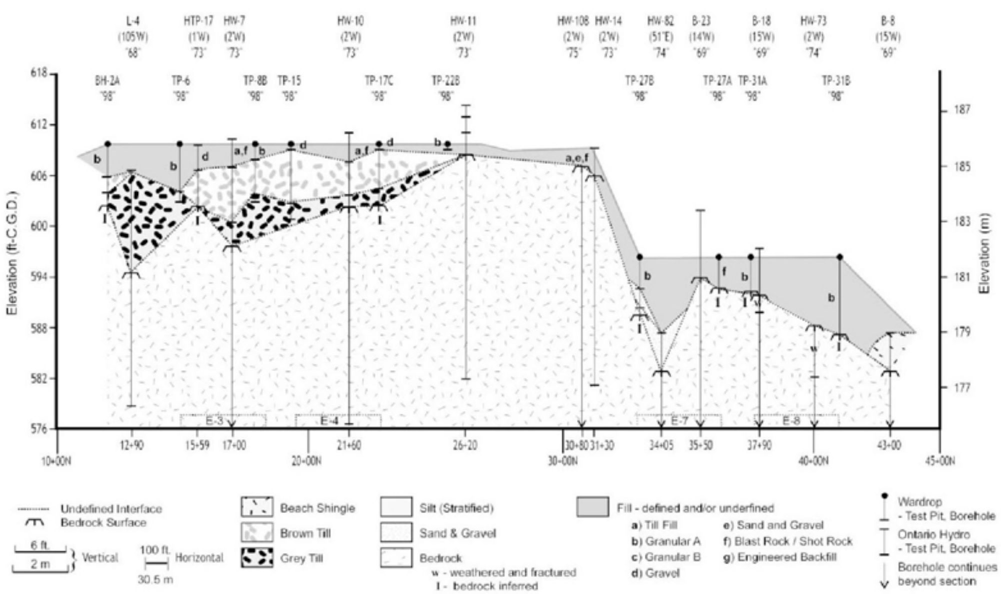


STRATIGRAPHIC CROSS-SECTION S1



STRATIGRAPHIC CROSS-SECTION S2

NOTES

Refer to location plan on figure 5.4.1-6

REFERENCE

Sections from Bruce Heavy Water Plant Decomissioning Environmental Assessment Study Report, Dated December 2002.

PROJECT

GEOLOGY TECHNICAL
SUPPORT DOCUMENT

TITLE

CROSS SECTIONS S1 AND S2
FORMER HEAVY WATER PLANT

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	FIGURE 5.4.1-7	
GIS	BC	24 Jun. 2010		
CHECK	CK	24 Jun. 2010		
REVIEW	MAR	24 Jun. 2010		

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Based on the stratigraphy encountered, the surficial deposits can be subdivided into five main layers which are listed below in descending order from ground surface downward:

- a Surficial Sand and Gravel Unit;
- an Upper Weathered Silt Till Unit;
- an Upper Unweathered Silt Till Unit;
- a Middle Sand/Layered Till Unit; and
- a Lower Unweathered Silt Till Unit [21;32;33].

The upper till has been interpreted as a continuation of the St. Joseph Till [34]. The nomenclature of the lower till is uncertain. The various units are discussed below.

5.4.1.1 Surficial Sand and Gravel Unit

The Surficial Sand and Gravel Unit contains boulders with numerous cobbles as well as beach shingle, and is generally less than 1.5 m thick in the vicinity of the WWMF portion of the Project Area. This upper sand layer is irregular in thickness and locally infills channels in the till surface. In the vicinity of the former Heavy Water Plant, this unit ranges from zero to less than 1.5 m thick, as the overburden deposits thin to the north and west. This unit has been noted to increase substantially in thickness southeast of the WWMF as a raised ancient shoreline. This surficial unit is overlain by a thin veneer of topsoil and humus (0.3 m).

5.4.1.2 Upper Weathered Silt Till Unit

The Upper Weathered Silt Till Unit consists mostly of weathered, brown silt till with fractures extending to depths of approximately 3 m. The till surface is irregular, contains depressions infilled with the surficial sand and gravel, and is comprised predominantly of carbonate (calcite and dolomite) and quartz mineral grains.

5.4.1.3 Upper Unweathered Silt Till Unit

The Upper Unweathered Silt Till Unit is a dense silt till with varying amounts of clay size rock flour. The rock flour is quartz and carbonate with minor illite and chlorite clay minerals. This till unit is greater than 10 to 15 m thick along the south side of the Project Area, and within the southwest part of the Heavy Water Plant, immediately east of the Project Area. The unit generally decreases in thickness to the north and east, and is largely absent near the Lake Huron shoreline.

5.4.1.4 Middle Sand/Layered Till Unit

The Middle Sand/Layered Till Unit is composed of beds of silty fine sand to well sorted fine sand, with occasional gravel layers, and contains interbeds of unsorted silty till from 0.03 to 0.4 m thick. The Middle Sand unit is a permeable groundwater-bearing horizon that constitutes an aquifer contiguous with, or underlying, the Upper and Lower Till Units. It occurs within the south-central portion of the Project Area, largely underneath the WWMF. The approximate lateral extent of this horizon is shown on Figure 5.4.1-8.

The Middle Sand was found to be thickest beneath the western half of the WWMF portion of the Project Area, measuring between 4 and 8 m thick (Figures 5.4.1-4 and 5.4.1-5). Toward the south edge of the WWMF portion of the Project Area, this unit thins and occurs at or near the bedrock surface. In the northwest area of the site near the Railway Ditch and LLSB3, the Middle Sand is relatively thick, up to 6 m, and occurs near ground surface. The trend of the sand horizon is from the southeast to the northwest beneath the WWMF portion of the Project Area. This unit is absent beneath the former Heavy Water Plant (Figure 5.4.1-7).

The upper surface of the Middle Sand unit occurs between approximately 180 and 186 mASL beneath the western part of the WWMF portion of the Project Area. The upper surface of this unit slopes downward to the northeast within the WWMF portion of the Project Area, where it occurs between elevations of approximately 175 to 178 mASL, at depths of approximately 6 to 8 mBGS. The distribution of the Middle Sand to the north of the WWMF and between the WWMF and Heavy Water Plant portions of the Site Study Area is not well understood because of the limited borehole information within these areas.

The Layered Till within the Middle Sand unit contains layers of both well-graded silt till and fine to coarse sand, which are hydraulically connected to the Middle Sand layer (Figures 5.4.1-4 and 5.4.1-5). In this regard, it can be considered an extension of the Middle Sand layer. The stratified or layered till unit is typically adjacent to, or overlying, the middle sand unit. Although called a till, this unit is likely of glaciolacustrine origin. The presence of sand interbeds in this layer results in increased permeability compared to the Upper and Lower Till layers.

Although discontinuous beneath the WWMF, the Middle Sand unit is considered to be an important layer to the groundwater flow system beneath the Project Area. The lateral and vertical extent of the unit is complex and has been inferred to provide vertical connection to the underlying carbonate bedrock where the Lower Till is thin or absent.

It should be noted that the Middle Sand unit is confined to the WWMF, largely south of the Railway Ditch. This unit is not known to be present within the area where the DGR shafts will be located (Figure 5.4.1-8).

5.4.1.5 Lower Unweathered Silt Till Unit

The Lower Unweathered Silt Till Unit is generally extensive beneath the WWMF portion of the Project Area; however, it has been noted that windows in the till may connect the Middle Sand and bedrock [21;22]. This unit is not laterally extensive beneath the former Heavy Water Plant, immediately east of the Project Area, where it is referred to as the Grey Till (Figure 5.4.1-5). The composition of the Lower Till is similar to the lower portions of the Upper Unweathered Till unit. In locations where the Middle Sand layer is absent, the Lower Till is not a distinct, separate layer from the Upper Till section. Occasional occurrences of sand and gravel are found between the Lower Unweathered Till layer and the bedrock surface. The distribution of the Lower Unweathered Till Unit between the WWMF and former Heavy Water Plant portions of the Project Area is not well understood because of limited borehole data but is considered to likely be continuous through this area.

0 125 250 500
Metres

LEGEND

- Approximate Sub-Surface Extent of Middle Sand Aquifer >1.2m Thick
- Project Area (OPG-retained lands that encompass the DGR Project)

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc.,
Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL
SUPPORT DOCUMENT

TITLE

MIDDLE SAND AQUIFER

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	FIGURE 5.4.1-8	
GIS	BC	5 May. 2010		
CHECK	SM	5 May. 2010		
REVIEW	SM	5 May. 2010		

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The glacial till units are generally laterally continuous, although thicknesses may vary from 0.3 to 15 m. The glacial till overlying the Middle Sand aquifer and bedrock is wedge shaped, thicker inland, and thinning towards Lake Huron. The till deposits have occasional lenses of clay, sand, and sand and gravel. Based on the available data these isolated inter-till lenses are not considered to be laterally extensive or hydrogeologically interconnected [21;33].

5.4.2 Local Study Area

The surficial geology of the Local Study Area is shown on Figure 5.4.2-1, reproduced from part of an Ontario Geological Survey Preliminary Map [31]. The thickness of Quaternary sediments in the Local Study Area is shown on Figure 5.4.2-2 and described in [28]. These unconsolidated materials consist mainly of the following: (a) ground moraine or glacial till, locally stony, sandy, silty and/or clayey, and laid down directly by the ice; (b) glaciofluvial deposits, the sand and gravel deposited by water from the melting glacier; (c) glaciolacustrine deposits, the clays, silts, and sands deposited in glacial lakes; (d) ice contact deposits formed at the margin of the glacier; and (e) sandy and/or gravelly beach deposits [31].

The surficial deposits below the Algonquin Bluff and underlying the Bruce nuclear site include silty to sandy till of the Elma (Catfish Creek) Till sequence overlying the bedrock surface (represented by 5b on Figure 5.4.2-1). This till sequence varies in thickness from about 1 m at the lakeshore up to approximately 20 m in the south-eastern part of the Site Study Area and overlying the Paleozoic rocks at the DGR drill sites [11]. The sequence locally contains interbedded sequences of sand, based on previous investigations at the Bruce nuclear site [12;35]. The till is locally overlain by sand and gravel beach deposits related to the former glacial Lake Algonquin and Lake Nipissing shorelines. The glacial Lake Nipissing shoreline is marked by the less prominent Nipissing Bluff, situated below (west of) the Algonquin Bluff (Figure 5.4.2-1). The beach deposits have been locally exploited for aggregate at pit locations along the Algonquin Bluff. The shoreline areas also include deposits of till and areas of boulders, exposed by shore erosion of the till (represented by 7b on Figure 5.4.2-1). Areas of bog and cedar swamp also occur in poorly drained areas below the Algonquin Bluff and elsewhere within other poorly drained forested areas.

5.5 BEDROCK GEOLOGY

This section describes the geological setting of the bedrock of the Bruce nuclear site at both the regional- and the site-scales. The purpose of these descriptions is to provide confidence in the understanding of the predictability of the Paleozoic sedimentary bedrock succession underlying the Bruce nuclear site (Figure 5.5-1). The information detailed below is summarized from a comprehensive description of the regional geology of southern Ontario [28], from information gathered during the detailed site characterization activities [11], publicly available literature, and from elements of the geosynthesis work program.

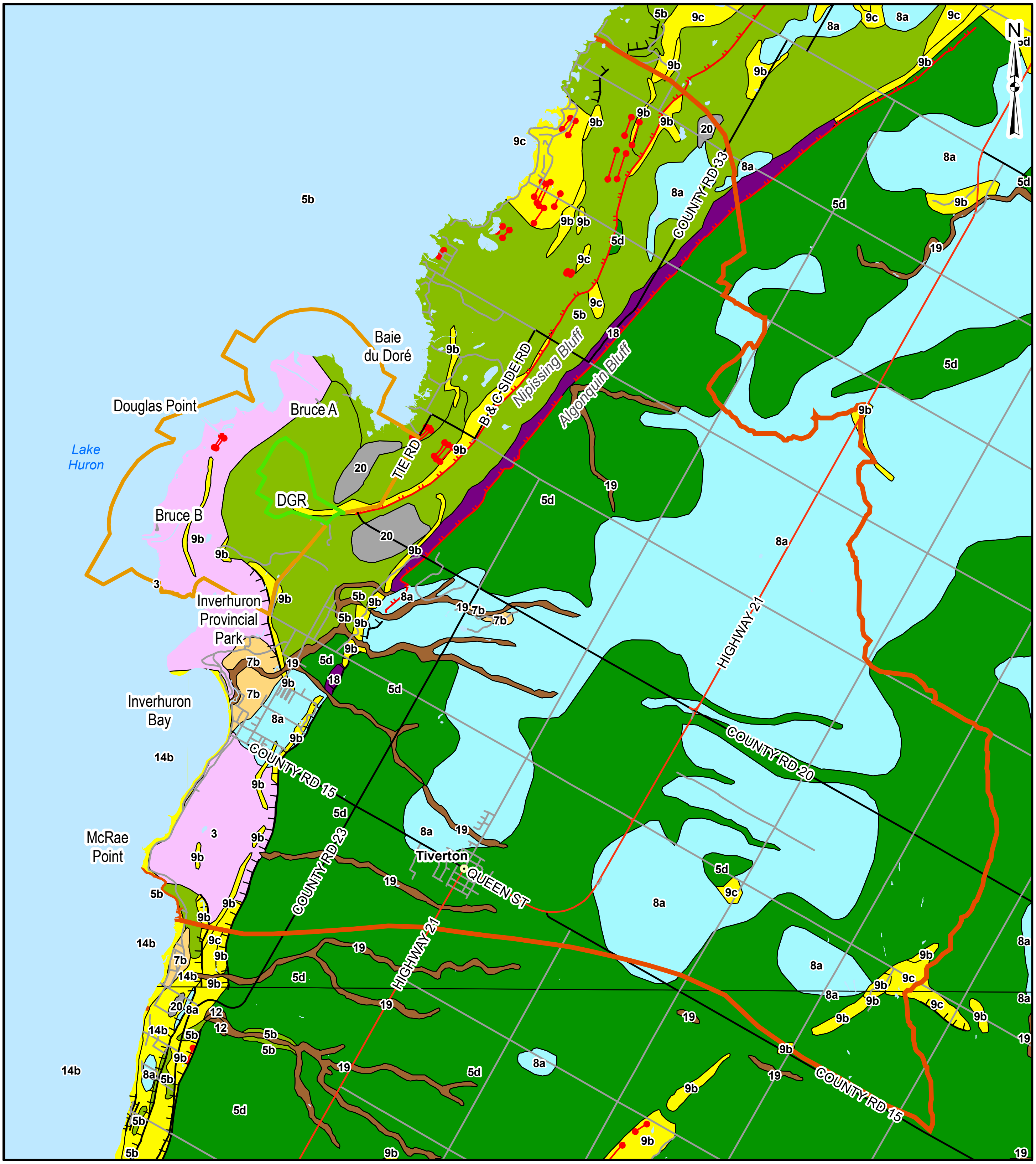
5.5.1 Regional Study Area

5.5.1.1 Regional Geological Setting

Southern Ontario is underlain by Upper Cambrian (approximately 510 Ma) to Devonian/Mississippian (approximately 359 Ma) sedimentary rocks (yellow fill on Figure 5.5-1) unconformably overlying Precambrian basement (ca. 1,600 to 542 Ma) of gneisses and metamorphic rocks of the Canadian Shield (pink fill on Figure 5.5-1). The Regional Study Area, which is centered on the Bruce nuclear site, is situated on the northeastern margin of the Michigan Basin (Figures 5.5-1 and 5.5.1-1). This area forms part of the northwestern flank of the Algonquin Arch (Figure 5.5-1), which is a subsurface basement high overlain by these Paleozoic sediments (e.g.,[36]).

The Paleozoic succession thins from a maximum of approximately 4,800 m at the centre of the Michigan Basin to approximately 850 m at the Bruce nuclear site on the flank of the Algonquin Arch. In general, the strata dip gently from all margins at between 4 and 17.5 m/km, or 0.23° to 1° toward the centre of the basin deposits in central Michigan [37;38;39]. Bedding dips reported from the southern Bruce Peninsula, and formation top dips beneath the Bruce nuclear site, all fall within this range [11;40]. Figure 5.5.1-2 presents a geological cross-section through the Bruce nuclear site.

The Regional Study Area is underlain by low to moderate relief basement rocks of the Huron Domain of the Central Gneiss Belt (Figure 5.5.1-3) and is located southeast of the surface trace of the Grenville Front Tectonic Zone (GFTZ) [36;41;42;43]. The basement geology is understood by extrapolation of inferred basement structural boundaries beneath the Paleozoic cover (Figure 5.5.1-3). This process is aided by seismic, aeromagnetic, and gravity map interpretation (e.g., [44;45]), and by geochemical, geochronological, and petrographic analyses of samples recovered from drill cuttings and core [36;41;46].



0 0.5 1 2 3 4 5

Kilometres

LEGEND

- Project Area (OPG-lands that encompass the DGR project)
- Site Study Area [1]
- Local Study Area
- beach
- bluff
- terrace
- 3: Paleozoic bedrock
- 5b: Stone-poor, carbonate-derived silty to sandy till
- 5d: Glaciolacustrine-derived silty to clayey till
- 6: Ice-contact stratified deposits
- 7: Glaciofluvial deposits
- 7a: Sandy deposits
- 7b: Gravelly deposits
- 8a: Massive-well laminated
- 9a: Deltaic deposits
- 9b: Littoral-foreshore deposits
- 9c: Foreshore-basinal deposits
- 12: Older alluvial deposits
- 14b: Littoral-foreshore deposits
- 18: Colluvial deposits
- 19: Modern alluvial deposits
- 20: Organic deposits

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007. Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

DGR LOCAL SURFICIAL GEOLOGY

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct 2007	**FIGURE 5.4.2-1**	
GIS	BC	16 Jun. 2010		
CHECK	CK	16 Jun. 2010		
REVIEW	MAR	16 Jun. 2010		

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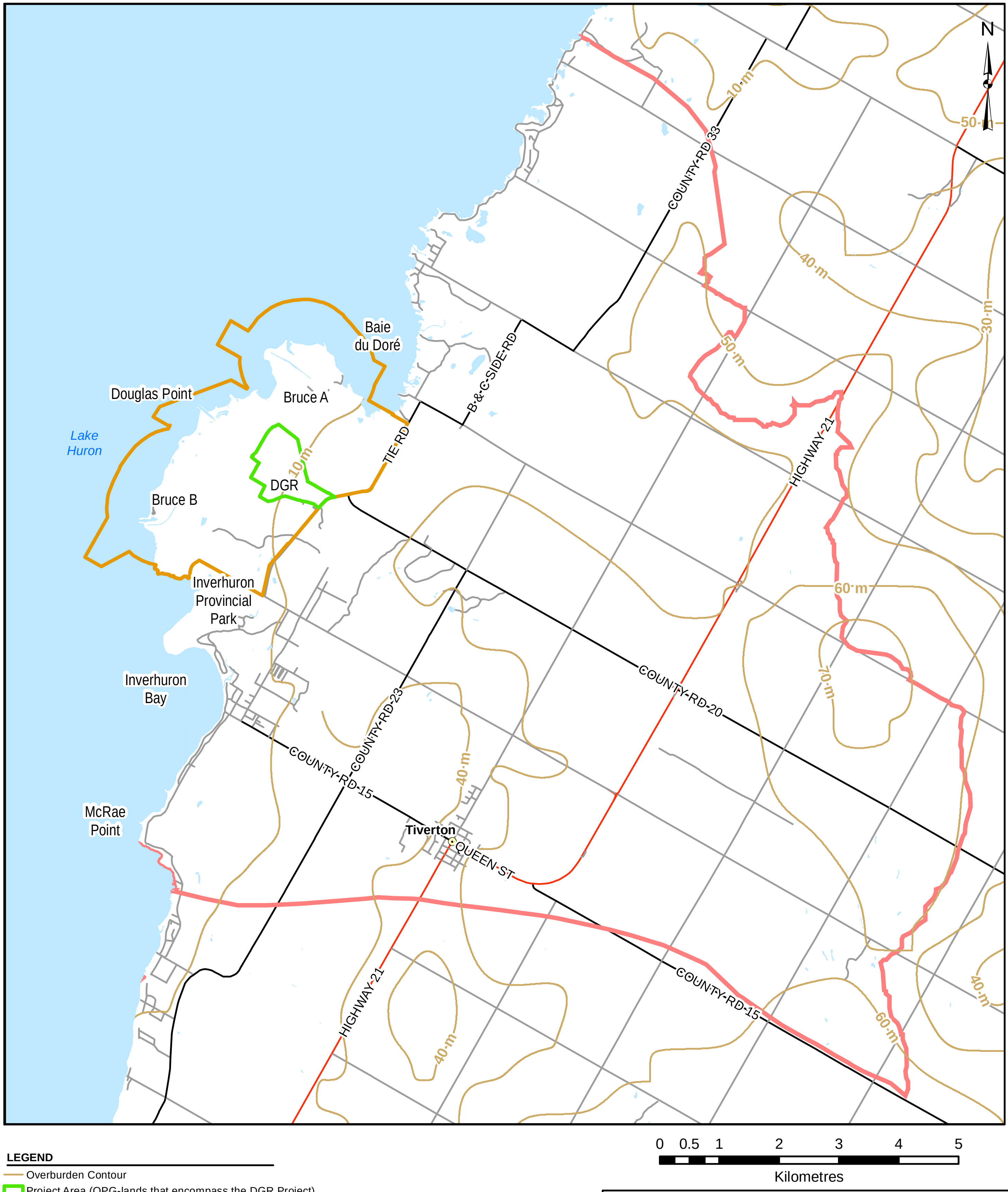

LEGEND

- Overburden Contour
- Project Area (OPG-lands that encompass the DGR Project)
- Site Study Area [1]
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007. Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

DGR LOCAL OVERBURDEN THICKNESS

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct 2007	FIGURE 5.4.2-2	
GIS	BC	16 Jun. 2010		
CHECK	CK	16 Jun. 2010		
REVIEW	MAR	16 Jun. 2010		

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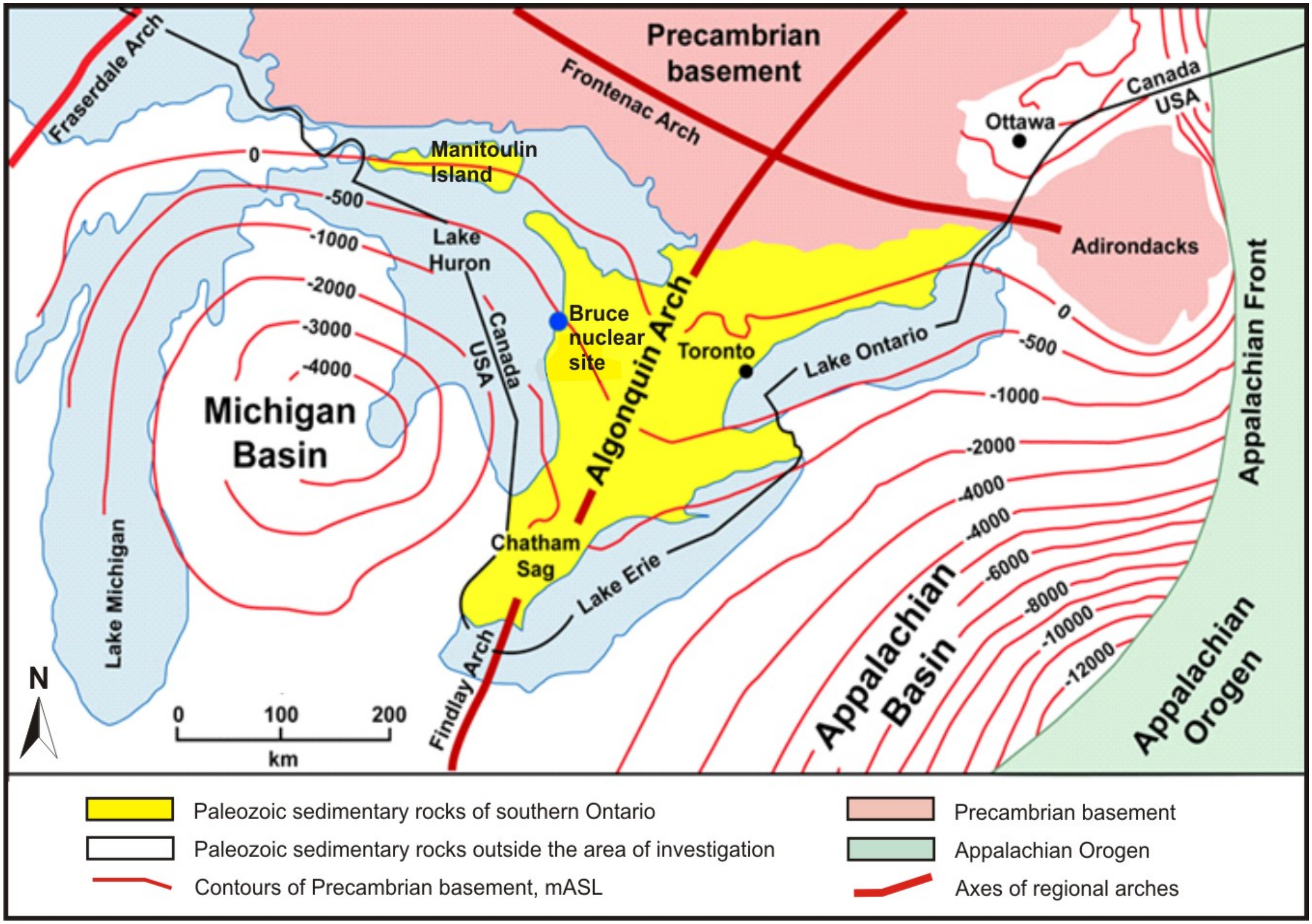
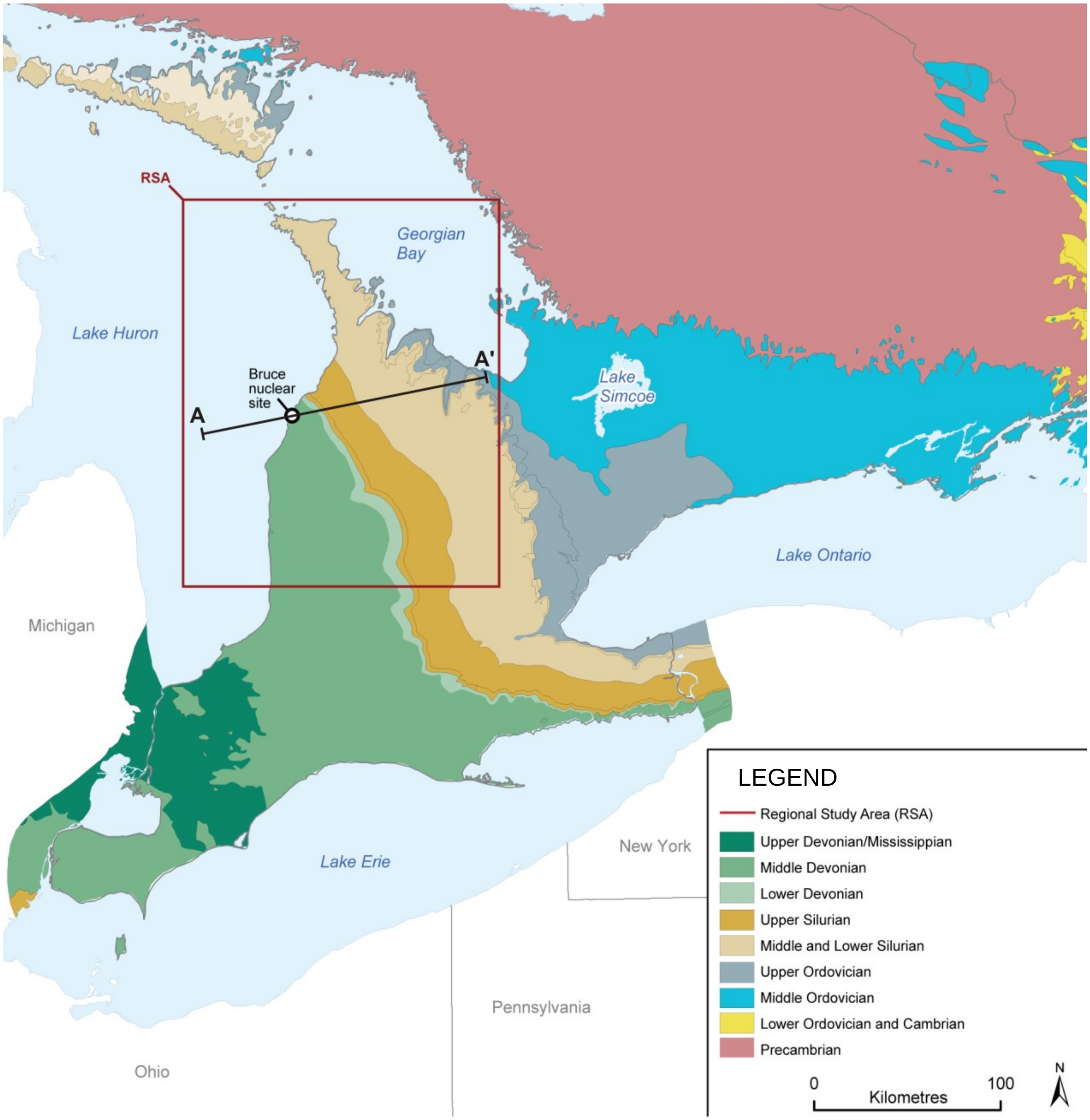
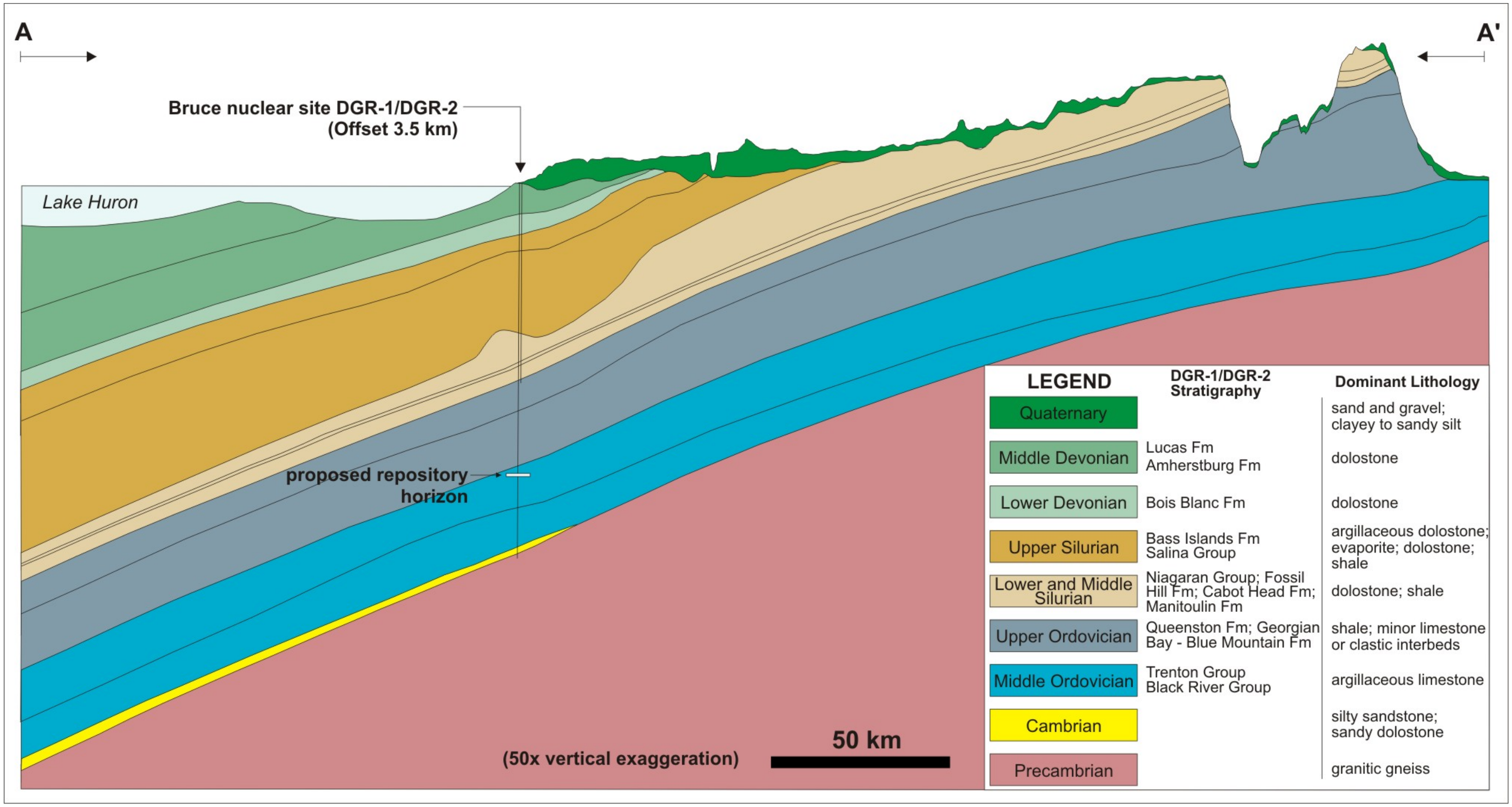


Figure 5.5-1: Geological Features of Southern Ontario



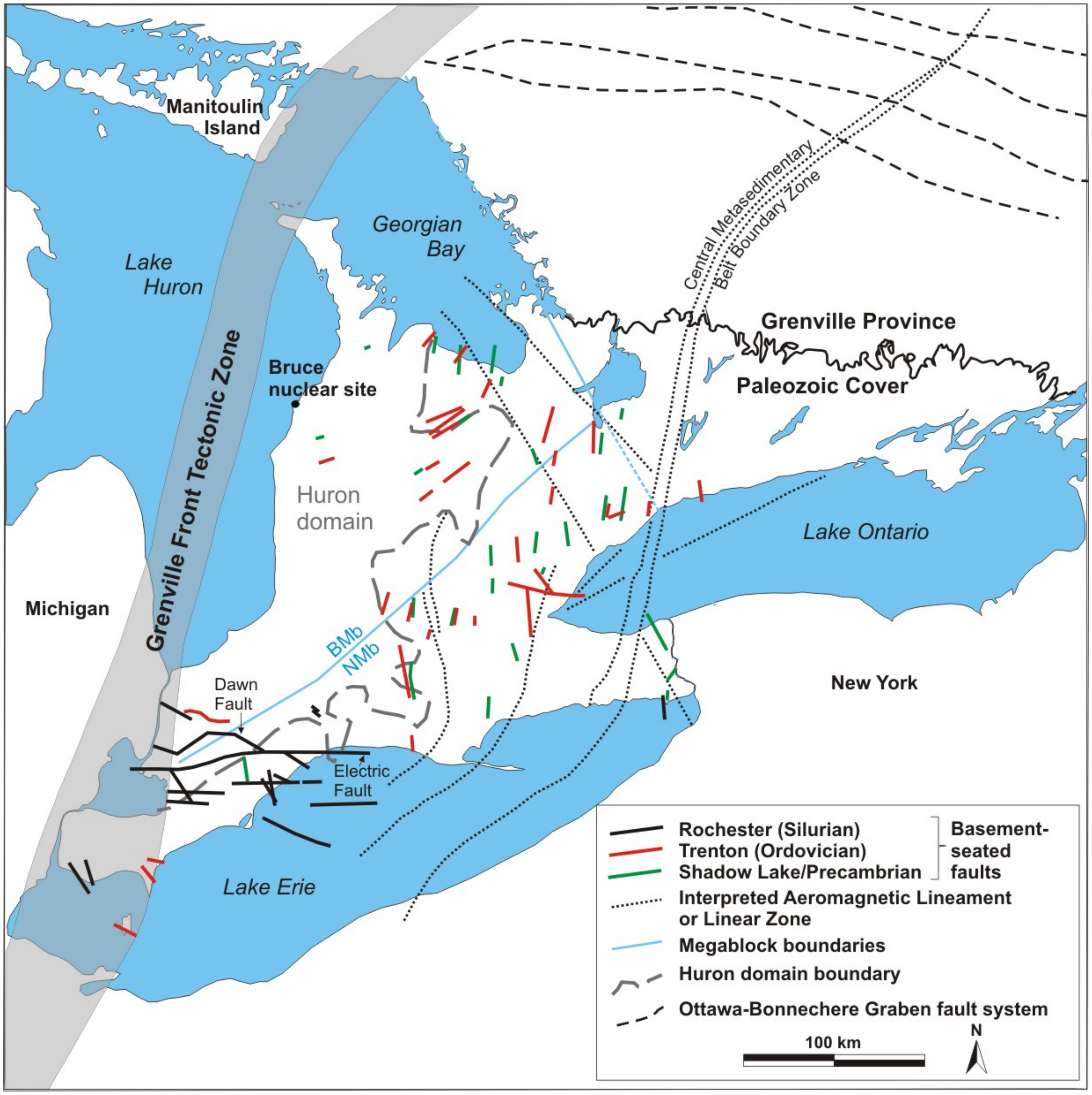
Note:
Section along line A-A' is shown in Figure 5.5.1-2. See Figure 5.5.1-4 for detailed stratigraphic nomenclature.
Source: Modified from Ontario Geological Survey bedrock geology map as drawn in [47] and [48].

Figure 5.5.1-1: Geologic Map of Southern Ontario



Note:
Fm – Formation. The subsurface trace of boreholes DGR-1 and DGR-2 have been projected onto the cross-section. Simplified stratigraphy is from [11]. Detailed stratigraphic nomenclature is shown in Figure 5.5.1-4.
Source: Modified from Figure 2.23b of [3].

Figure 5.5.1-2: Geologic Cross-section Through the Regional Study Area



Notes:
Contacts are based on field mapping and interpretations aided by subsurface drilling, borehole stratigraphic correlation, and from: [37] and compiled by [49;50;51;36;46;41;45;44;52;53;48]. BMb – Bruce Megablock; NMb – Niagara Megablock. See text for further discussion.
Source: Modified from Figure 2.5 of [3].

Figure 5.5.1-3: Interpreted Boundaries and Fault Traces in Southern Ontario

5.5.1.2 Regional Stratigraphy

The nearly flat-lying Paleozoic succession was deposited over a broad carbonate and clastic shelf and platform setting that extended from the eastern margin of the Appalachian Basin to beyond the western margin of the Michigan Basin (Figure 5.5-1). The central column in Figure 5.5.1-4 shows the Paleozoic stratigraphy that is encountered beneath the Bruce nuclear site and region [47]. Importantly, this group- and formation-scale stratigraphy is traceable from the Michigan Basin in southwestern Ontario (left column in Figure 5.5.1-4) across the arch and into the Appalachian Basin (right column in Figure 5.5.1-4). This is to be expected because depositional environments that controlled lithofacies associations evolved at a scale much larger than the Regional Study Area (e.g., [54;28], Figure 2.9 of [3]). It therefore follows that the stratigraphy throughout the Regional Study Area is generally predictable across large distances.

A three-dimensional geological framework (3DGF) model was constructed for the Regional Study Area in order to better define the stratigraphic and spatial continuity of the Paleozoic succession in a 35,000 km^2 region surrounding the Bruce nuclear site (Figure 5.5.1-5a; [30]). The model is based on observation and re-interpretation of Ontario Ministry of Natural Resources well records. The primary data source for the model construction was the Oil, Gas, and Salt Resources Library (OGSR) Petroleum Wells Subsurface Database [55;56]. At the time of model development, the Regional Study Area contained a total of 341 wells, from which 299 wells were determined useful through a data validation process [30]. Each of these 299 wells is colour-coded by well bottom formation to indicate the spatial stratigraphic control in the model (Figure 5.5.1-5b). The 3DGF model accurately reproduced regional stratigraphic relationships using these documented formation contact elevations and thicknesses. The final 3DGF model geometry is consistent with the regional geological framework based on published literature, maps and cross-sections of the region [47;48]. Armstrong and Carter [47] describe the occurrence of 31 formations, members or units within the Paleozoic succession from its Cambrian base to the Devonian Lucas Formation, the youngest exposed bedrock in the Regional Study Area (Figure 5.5.1-4). The Salina A-1, A-2, and B units are further divided into evaporite and carbonate sub-units, totalling 34 recognizable stratigraphic entities.

A recently published update of the Paleozoic stratigraphy of southern Ontario includes minor modifications to the stratigraphic nomenclature shown in Figure 5.5.1-4 [48]. The middle Silurian designation has been removed and now the Upper and Lower Silurian are separated at the top of the Eramosa Member of the Guelph Formation. In addition, the Black River and Trenton Groups are now both included in the Upper Ordovician Period. Acknowledging these recent re-interpretations, the stratigraphy at the Bruce nuclear site is organized according to the original framework shown in Figure 5.5.1-4 [47].

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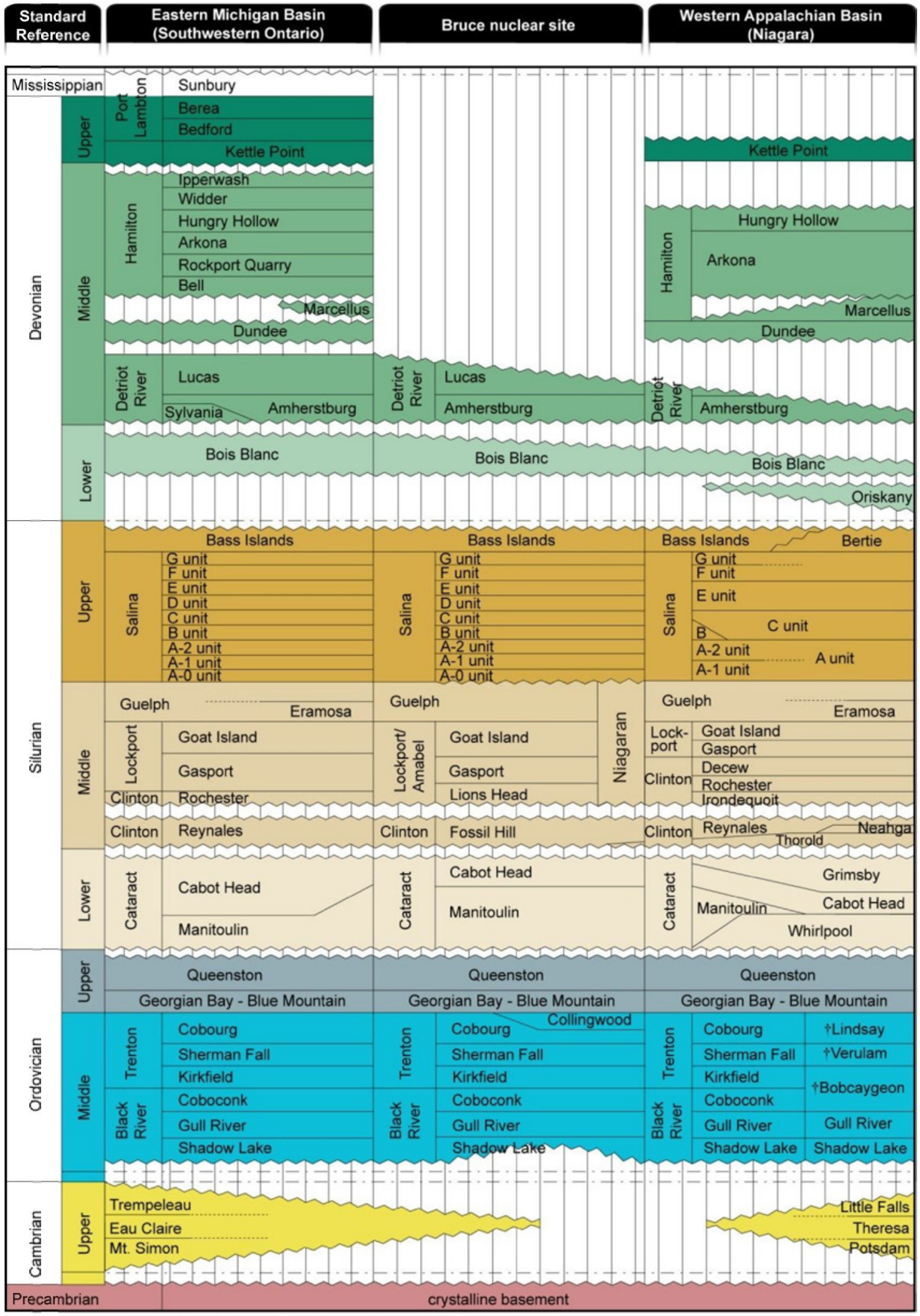

*modified from Armstrong and Carter (2006) after Winder and Sanford (1972)
†outcrop nomenclature for Southern and Eastern Ontario

NOTES

INCLUDES NOMENCLATURE FROM LOCATIONS IN THE MICHIGAN BASIN (LEFT), BRUCE NUCLEAR SITE (CENTRE), AND APPALACHIAN BASIN (MODIFIED FROM [47]).

REFERENCE

MODIFIED FROM FIGURE 2.8 IN [3]

PROJECT
GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE
PALEOZOIC STRATIGRAPHIC NOMENCLATURE OF SOUTHWESTERN ONTARIO

PROJECT No. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	**FIGURE 5.5.1-4**	
GIS	BC	10 Feb. 2011		
CHECK	BT	10 Feb. 2011		
REVIEW	MAR	10 Feb. 2011		

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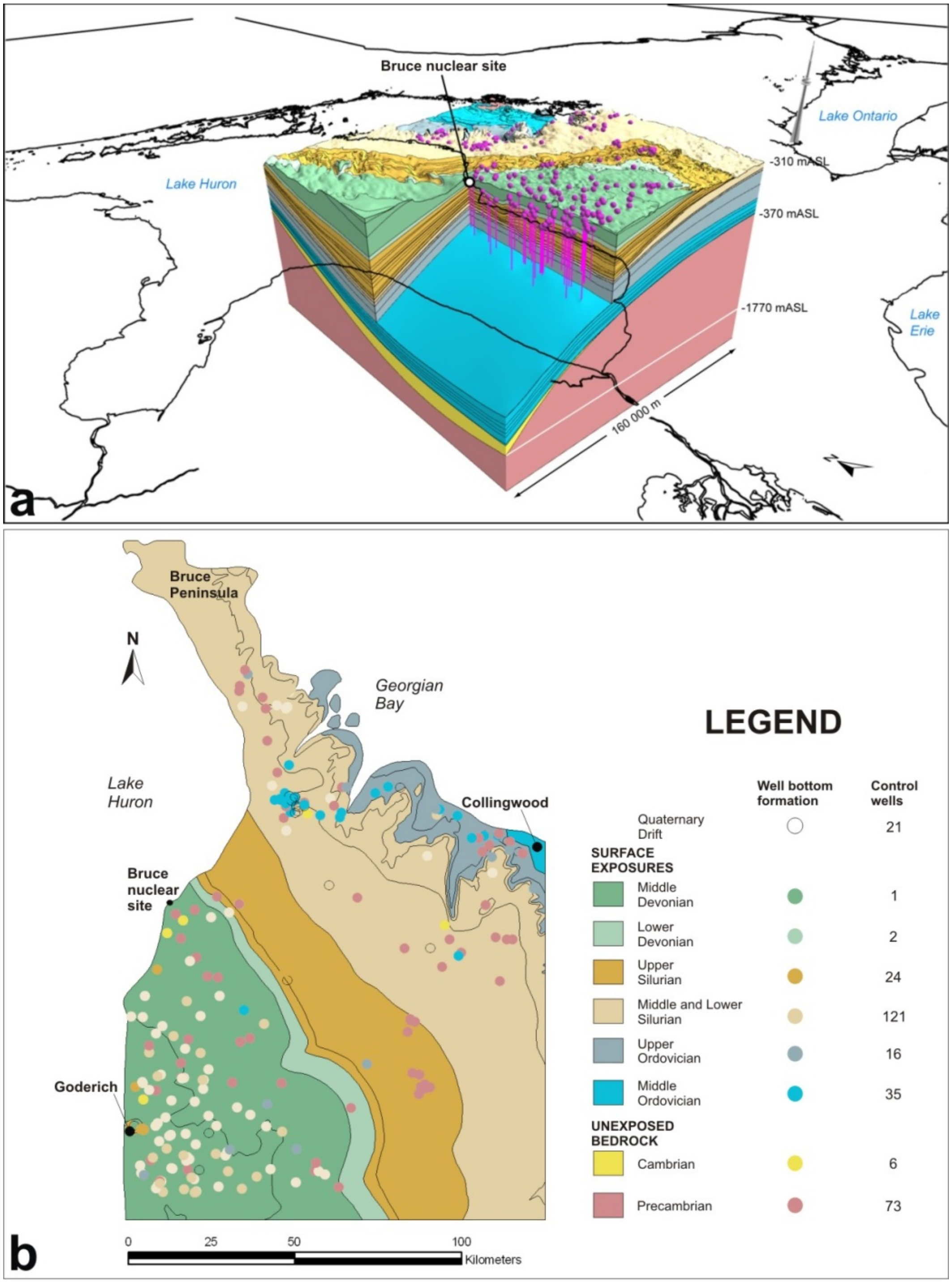


Notes:
(a) is a three-dimensional representation of surface and sub-surface geological units surrounding the Bruce nuclear site with a cut-away exposing the top of the Cobourg Formation (approximately 40x vertical exaggeration). Control point wells used to build the 3DGF model are shown as pink pins and dots.
In (b), the same control points are colour-coded to indicate the lowermost geological unit encountered in each well.
Source: [30] (Figure 1.2 therein).

Figure 5.5.1-5: Oblique (a) and Plan (b) Views of the Bedrock Geology in the Regional Study Area

5.5.1.3 Regional Tectonic History

The tectonic evolution of southern Ontario has occurred over the last, approximately 1,210 Ma, as summarized in Table 5.5.1-1. The first half of this period involved the formation of the Precambrian Grenville basement beneath southern Ontario during the development and subsequent collapse of the Grenville Orogen (e.g.,[57]). This part of the tectonic history is discussed in [3]. It is sufficient to point out that the record of this Precambrian tectonism is preserved in the form of ancient boundary zones which are traced beneath the Phanerozoic cover of southern Ontario (see Figure 5.5.1-3).

Table 5.5.1-1: Timetable of Major Tectonic Events in Southern Ontario

Time Interval Million Years Before Present (MaBP)	Tectonic Activity	Reference
1,210 – 1,180	• Regional metamorphism in CMBBZ (proto-Grenville)	[58;59;60]
1,109 – 1,087	• Magmatism and formation of Midcontinent Rift	[61]
1,030 – 970	• Main phase of Grenville Orogeny	[57;62]
970 – 530	• Extensional rifting and opening of the Iapetus Ocean	[63]
530 – 320	• Subsidence of Michigan Basin and Uplift of Frontenac and Algonquin Arches (episodic)	[64;50]
470 – 440	• Taconic Orogeny • E-W to NW-SE compression, uplift (Frontenac and Algonquin Arches)	[65;66;67]
410 – 320	• Caledonian/Acadian Orogeny • E-W to NW-SE compression, uplift(Frontenac and Algonquin Arches)	[68;69;70;71]
300 – 250	• Alleghenian Orogeny • E-W to NW-SE compression • Peak burial conditions	[68;72]
200 – 50	• Opening of the Atlantic Ocean • St. Lawrence rift system created • Reactivated Ottawa-Bonnechere Graben • NE-SW extension • Uplift	[73;74]
50 – present	• NE-SW compression (from ridge push) • Post-glacial uplift	[75]

At the basin-scale, the basement has remained relatively stable since at least the end of the Paleozoic (e.g., [76;77;78]) and, apart from localized low-level seismicity near the subsurface trace of the Central Metasedimentary Belt Boundary Zone (CMBBZ; Figure 5.5.1-3), there is no evidence for significant neotectonic activity localized along these ancient boundaries in southern Ontario [79]. This interpretation is consistent with the recognition that the Bruce nuclear site is situated within an area of low, diffuse seismicity with no identified active faults [80] or evidence of neotectonism [81].

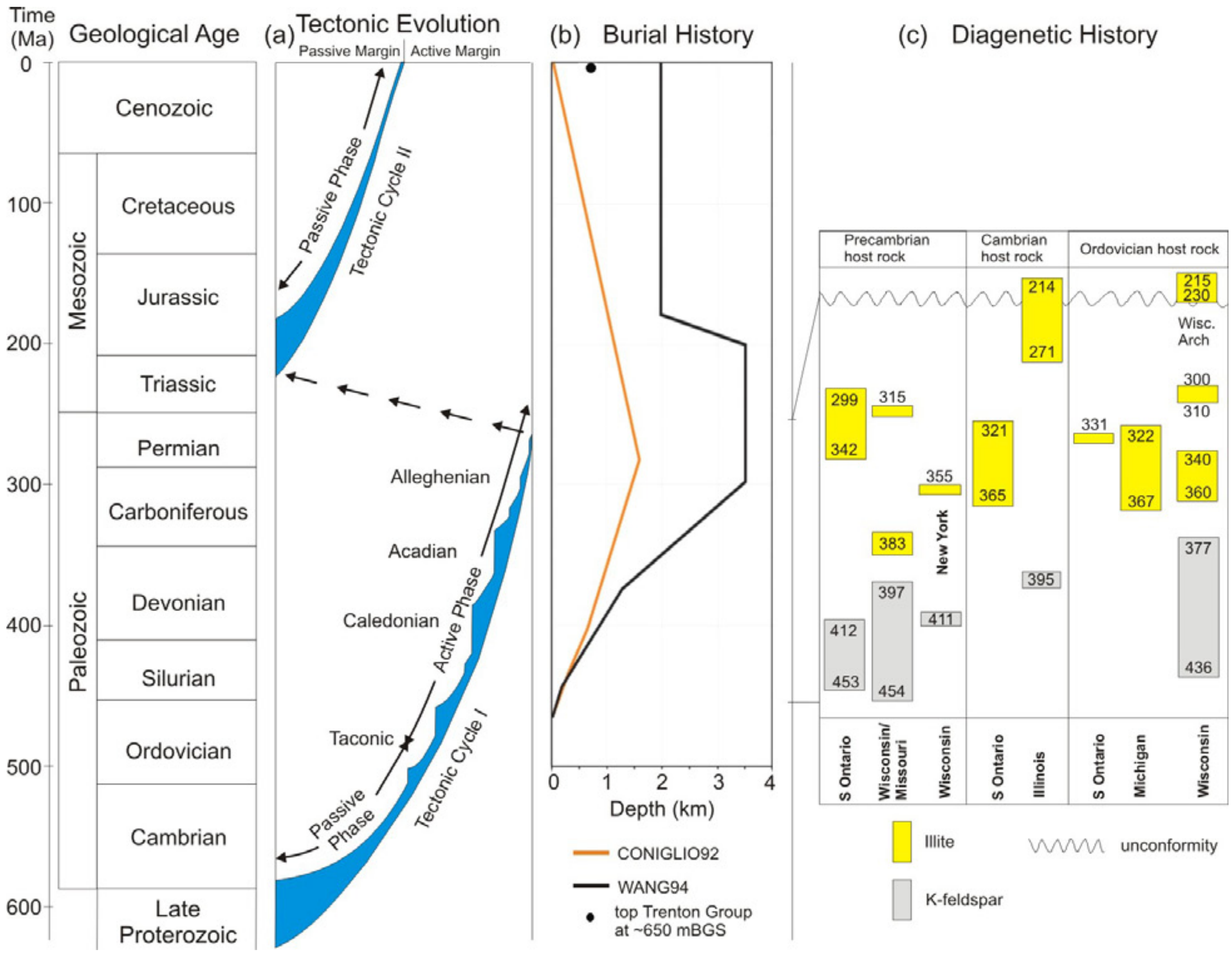
The Phanerozoic (Cambrian to present) history of southern Ontario can be explained in terms of two protracted tectonic cycles (Figure 5.5.1-6a). Tectonic Cycle I reflects the complex interaction between regional-scale tectonic forces, sedimentation, and eustatic sea level fluctuations associated with the Appalachian-Caledonian Orogen [50;64;82]. This cycle includes an initial passive phase, which correlates with an initial episode of subsidence and deposition within the Michigan Basin [50]. Early Middle Ordovician uplift of the arch eroded away much of the rock above it, preserving a regional unconformity. In the Regional Study Area, the unconformity is overlain by rocks of Cambrian age, where they are preserved, or rocks of the early Middle Ordovician Black River Group where the Cambrian is absent [47].

The active second phase of Tectonic Cycle I is characterized by several pulses of tectonic activity, including the Taconic (Ordovician), Caledonian/Acadian (Silurian Devonian) and Alleghenian (Carboniferous-Permian) orogenies (Figure 5.5.1-6a). These tectonic events controlled the deposition of the Middle Ordovician to Devonian sedimentary succession at the Bruce nuclear site [83;84;64;47]. These events are also interpreted to have played an important role in fluid migration and diagenesis (e.g., [85]).

Tectonic Cycle II comprises the Mesozoic evolution of the region and is characterized by the transition to a passive tectonic (extensional margin) cycle when the Atlantic Ocean began to open at the end of the Triassic Period, approximately 200 MaBP (Figure 5.5.1-6a). Much of the resulting tectonic activity was concentrated near the continental margin, where Triassic and Lower Jurassic rift basin deposits record the onset of continent break up (e.g., [86]). Further inland, the majority of rift-related deformation occurred in proximity to the trace of the Appalachian thrust front [87]. Pre-existing faults, including those of the Neoproterozoic to Early Cambrian (Iapetan) St. Lawrence rift system, and the Ottawa-Bonnechere Graben structure (Figure 5.5.1-4), were re-activated as a system of northeast- striking extensional normal faults and west-northwesterly-oriented transfer faults [63]. These areas of re-activation, all further than 150 km from the Bruce nuclear site, remain seismically active to the present day [88;89]. The following sections discuss the temporal relationship between the active phase of Tectonic Cycle I (Figure 5.5.1-6a), sediment burial and thermal history (Figure 5.5.1-6b), and diagenesis (Figure 5.5.1-6c). This information provides evidence to support the conclusion that tectonically-related perturbations to the Paleozoic sedimentary succession ceased in importance by the end of the Paleozoic or early Mesozoic. The reader is also referred to Section 2.2.5.3 of the Geosynthesis [3] for a more detailed treatment of the information presented below.

5.5.1.4 Burial and Thermal History

Two independent estimates of burial depth and timing are shown in Figure 5.5.1-6b. The orange curve, based on a study of Ordovician diagenesis from Manitoulin Island [90], and the black curve, based on a basin-scale analysis of apatite fission track dates [91], both indicate a late Carboniferous to early Permian timing for peak burial. These studies were undertaken near the margin (orange curve), and closer towards the centre (black curve), of the Michigan Basin, thus explaining the differences in total burial depth of 1,500 and 3,500 m, respectively. They are consistent in suggesting that approximately 1,500 m of sediment has since been eroded (Figure 5.5.1-6b).



Notes:
(a) Tectonic Evolution: Band widths represent relative tectonic intensity ([50]; modified from Figure 2.7 of [3]).
(b) Burial History: The orange curve [90] and black curve [91] provide burial duration and magnitude estimates for locations in the Michigan Basin. The (•) indicates the present day burial depth of approximately 675 mBGS for the top of the Middle Ordovician Trenton Group at the Bruce nuclear site (modified from Figure 2.12 of [3]).
(c) Diagenetic History: Duration of secondary mineralization diagenesis for southern Ontario and the region around the Michigan Basin. Documented ages (approximately 454 to 214 Ma) are indicated by number(s) within boxes (grey fill – K-feldspar; yellow fill – illite). These ages coincide with the main pulses of Paleozoic orogenesis during Tectonic Cycle I. Diagenesis schematic has been enlarged for clarity. Lines extending beyond left margin define approximate time interval relative to (a) and (b) (modified from Figure 4.1 of [3] and based on [92]). See text for further discussion.

Figure 5.5.1-6: Phanerozoic Tectonic Cycles and Burial and Diagenetic History for the Michigan Basin

Given that the top of the Ordovician succession exposed at Manitoulin Island is encountered at approximately 450 mBGS beneath the Bruce nuclear site [11], and the Bruce nuclear site is located slightly closer to the basin centre, it is reasonably estimated that approximately 1,000 m of sediment has been eroded from above the existing Paleozoic succession at the site [3].

Based on this total erosion estimate an approximate peak burial in situ temperature of 70 °C was calculated for the top of the Trenton Group limestones (Collingwood Member), which is encountered at approximately 650 mBGS beneath the site ([11]; see discussion in Section 2.2.5.3 of [3]). The estimated peak temperature is consistent with the interpretation that the Upper Ordovician shales directly above the Collingwood Member barely reached the lower threshold of the oil generation window in terms of thermal maturation (e.g., [11], their Section 3.7.4.2). At the regional-scale, the conodont alteration index designation of Legall et al. [93] indicates very limited potential for in situ petroleum generation in rocks as deep as the Middle Ordovician Trenton Group in southern Ontario [94]. This interpretation is also consistent with the above temperature estimate.

5.5.1.5 Diagenesis

Diagenetic processes that have influenced the Paleozoic rocks within the Michigan Basin include clay alteration, dolomitization, Mississippi Valley Type (MVT) mineralization, salt dissolution, precipitation of late stage cements, and oil and gas generation and migration. Some studies of the Michigan Basin document fluid inclusion homogenization temperatures and degrees of organic maturation that cannot be explained by burial history alone and therefore require the influence of additional heat sources (e.g., [90]). These same heat sources provide the mechanisms for diagenetic fluid flow. Important features of the diagenetic history of the Michigan Basin are described briefly below.

Two stages of diagenetic secondary mineral growth have produced clay mineral alteration products along the unconformable contact between the Precambrian basement and overlying Paleozoic cover (Figure 5.5.1-6c; [92]). Based on this observation, a conceptual model was suggested whereby regional brine migration was focused along the unconformity in response to hydraulic gradients and crustal motion related to Appalachian orogenesis [92]. The distribution of secondary mineral ages for the Appalachian Basin and surrounding regions, based on the radiogenic (Potassium-Argon) dating of secondary illite (yellow fill) and K-feldspar (grey fill), are shown in Figure 5.5.1-6c. As can be seen, the range of ages spans the entire active phase of Tectonic Cycle II (Figure 5.5.1-6a) and was concurrent with deposition and burial of the Paleozoic succession (Figure 5.5.1-6b). K-feldspar alteration was initiated early during the Taconic Orogeny and continued through to the end of Caledonian-Acadian Orogeny (Figure 5.5.1-6c). Illite alteration was contemporaneous with the Acadian and Alleghenian orogenies (Figure 5.5.1-6c) [95;92;96]. In the broader region, illitization is interpreted to have continued until approximately 214 MaBP (Figure 5.5.1-6c).

Hydrothermal dolomitization selectively altered the Paleozoic rocks along, and adjacent to, discrete fracture systems which in turn appear to be controlled by basement-seated faults. The timing of dolomitization events range from during or shortly after marine carbonate deposition in the Ordovician, to the late Paleozoic or early Mesozoic in correspondence with the timing of peak burial compaction. The conditions that led to dolomitization within the Regional Study Area of the Michigan Basin (i.e., basinal groundwater flow, fracture-related tectonically driven flow, and hydrothermal dolomitization) have not existed since the late Paleozoic or early Mesozoic (e.g., [90]).

The key post-dolomitization diagenetic phases are all volumetrically minor and include late stage calcite cements, MVT mineralization, and late stage anhydrite and gypsum [97;98]. MVT mineralization occurs in the Middle Silurian dolomites in southern Ontario as a minor diagenetic constituent but is not considered a commercial source of lead and zinc. Consistent with the range of secondary mineralization ages, the conditions that led to dolomitization within the Michigan Basin including theRegional Study Area (i.e., basinal groundwater flow, fracture-related tectonically driven flow, and hydrothermal dolomitization) have not existed for approximately 200 to 250 Ma (e.g.,[90]), since the time of peak burial.

Salt dissolution is typically identified at the margin of the Michigan Basin in a zone extending from the Bruce Peninsula south along Lake Huron and into southwestern Ontario. The process of dissolution is interpreted to have occurred via fluid migration through regional fractures and faults and the affected zones are brecciated and characterized by an evaporite cement filling (gypsum and/or anhydrite) enclosing dolostone clasts [50]. At the Bruce nuclear site, salt dissolution has occurred throughout the middle to lower Salina Group units. Pervasive cementation and fracture infilling has resulted in very low measured hydraulic conductivities in the Silurian rocks beneath the Bruce nuclear site [11]. Salt dissolution occurred primarily during the Late Silurian to Devonian Caledonian Orogeny. A second major salt dissolution event occurred during the Late Devonian-Mississippian Acadian Orogeny [99].

5.5.1.6 Regional Structural Overview

Figure 5.5.1-3 shows all faults known to displace the Precambrian-Paleozoic unconformity in southwestern Ontario [41;48]. This analysis is based on geophysical and borehole data, and regional compilations [49;52;100]. Within southeastern Ontario, where there is an abundance of subsurface data available, the faults have been mapped with a high degree of confidence. The faults shown in Figure 5.5.1-3 are grouped based on observation of the youngest stratigraphic unit that is offset [48]. The oldest faults only offset Cambrian strata and rocks of the immediately overlying Ordovician Shadow Lake Formation. Another group of faults offset rocks as young as the Ordovician Trenton Group limestones. The youngest mapped faults in southern Ontario offset rocks of the Silurian Rochester (Lions Head equivalent) Formation (Figure 5.5.1-3; [48]).

Within the Regional Study Area, where subsurface data are sparse, these features are inferred by subsurface structure contouring and isopach mapping, with limited well-control, and through seismic interpretation. As a result, these faults are poorly constrained in terms of location and movement history and are mapped with a low degree of confidence. Regardless, the closest interpreted fault structure is more than 25 km away from the proposed DGR footprint and it is overlain by undisturbed Ordovician strata (Figure 5.5.1-3; [48]). As well, no mapped faults within the Regional Study Area are interpreted to be younger than the limestones of the Ordovician Trenton Group [48].

In a conceptual tectonic model for southern Ontario a megablock model was proposed in which the Bruce Megablock was distinguished as a distinct tectonic unit with a simple ESE-trending fracture network from a complexly fractured Niagara Megablock to the south (Figure 5.5.1-3; [50]). This model was based on satellite lineament mapping of the Precambrian shield in conjunction with interpretation of subsurface data from southern Ontario with the fracture networks thought to be controlled by Paleozoic re-activation of pre-existing basement-seated faults [50]. While the distribution of mapped faults in southwestern Ontario appear to agree with Sanford *et al.*'s complex interpretation for the Niagara Megablock, the sparse faults mapped within the Bruce Megablock show no clear relationship with Sanford *et al.*'s tectonic interpretation (Figure 5.5.1-3; [50]).

5.5.1.7 Regional Fracture Patterns

Perhaps the best gauges of the history of tectonic forces in southern Ontario are the regionally consistent, systematic fractures, which have formed in response to loading or unloading of the rock mass. The majority of fractures observed in southern Ontario exhibit no measureable slip or dilation at the scale of observation, and are therefore classified as joints (e.g., [101]). The Regional Geomechanics - Southern Ontario report [27] provides a review of the literature with respect to joint orientation and location both regionally and through geologic time. The following section summarizes the fracture network of the Regional Study Area. The distribution of documented joint orientations within and surrounding the Regional Study Area is shown in Figure 5.5.1-7.

The fracture orientations in the Regional Study Area cluster into two major sets trending approximately NW to NNW and NE to ENE. A third set trends approximately ESE (Figure 5.5.1-7). A westerly rotation of the fractures towards the north and west, based on interpretation of measured fracture orientations in Paleozoic strata from the northern and northwestern flanks of the Michigan Basin [102], suggests that they are part of a basin-concentric fracture pattern which may have been formed due to radial tensile stresses generated during middle to late Paleozoic basin-centred subsidence [64;103].

5.5.1.8 Natural Resources

Natural resources found within the Regional Study Area include oil and gas, bedrock aggregate and salt. The following summary of the types and distribution of resources is based on the detailed description in Section 2.2.8 of the Geosynthesis [3].

Oil and Gas

Commercial quantities of oil and gas have been discovered in a total of over 300 separate pools or reservoirs within the Paleozoic succession in southwestern Ontario (as shown in Figure 2.20 of the Geosynthesis [3]) (e.g., [104;105;106]). Of more than 21,000 documented wells drilled in Ontario, only 27 petroleum exploration wells have been drilled within a 40 km radius of the proposed DGR and there is no commercially active hydrocarbon extraction at present in this area [55]. Current exploration interest is focused on targets in the southwestern tip of Ontario in Middle Ordovician carbonates and Upper Cambrian sandstones at depths of 800 to 1,000 m [107], and the majority of this is concentrated within the geographic triangle between London, Sarnia, and Chatham-Kent [28].

Note:
Joint orientations are plotted as Gaussian contoured and smoothed propeller, rose and trend diagrams. Inverhuron is immediately south of the Bruce nuclear site.
Source: Modified from Figure 2.15 of [3].

Figure 5.5.1-7: Joint Orientations In and Around Southern Ontario for the Paleozoic Cover and Precambrian Basement

From an evaluation of existing literature [28], the probability of future identification of potential economic oil and/or gas resources at, or adjacent to, the Bruce nuclear site is low. This conclusion is based on several factors:

- Although porous Cambrian sediments have been identified in core within the Regional Study Area, no commercial oil or gas accumulations were encountered during site characterization activities [11].
- None of the Silurian reefs adjacent to the DGR encountered commercially viable resources. In addition, the Bruce nuclear site is located within an inter-reef lithology [28]. Minor oil showings in the Silurian Guelph Formation from the DGR core are associated with non-commercial hydrocarbon accumulations [11].
- The Devonian Hamilton Group provides the cap rock for Devonian hydrocarbon plays; however, it is absent at the site. Similarly, the Upper Devonian Kettle Point Formation shale, which might represent good candidate biogenic shale gas plays in southwestern Ontario (e.g.,[108]), has been eroded away across the entire Regional Study Area.
- Site characterization activities found no structural, lithological, chemical or hydrological evidence to suggest that the Bruce nuclear site is proximal to an ancient hydrothermal dolomite (HTD) system [11].
- An average total organic carbon (TOC) content of the Upper Ordovician shales of less than 1.0% (Figure 3.14 in [11]), the recognition of low thermal maturity throughout the Regional Study Area, which indicates that these sedimentary rocks only reached the lower threshold of the oil window [93;109;110], and the absence of remarkable natural gas shows during drilling of the DGR boreholes [11], argues against the likelihood of commercial accumulations of either thermogenic or biogenic shale gas beneath the Bruce nuclear site [110].

Aggregate Resources

Although a number of areas in the Regional Study Area have been identified by the Ontario Geological Survey and Ministry of Natural Resources as containing significant resources of sand and gravel [28], it is concluded that none have been identified within 20 km of the Bruce nuclear site [55].

The Upper Silurian Salina Group is characterized by dolomite, shale, gypsum, and salt and has little value as a source for crushed stone aggregate.

Salt

The Salina salt has been dissolved and removed over most of the Regional Study Area and beneath the Bruce nuclear site through natural processes and therefore does not represent a commercial resource in this area.

5.5.2 Site Study Area

5.5.2.1 Bruce Nuclear Site Stratigraphy

Drilling, logging, and testing of boreholes DGR-1 through DGR-6 at the Bruce nuclear site led to the identification of 34 distinct Paleozoic bedrock formations, members, or units of approximately 840 m cumulative thickness beneath a thin veneer (7 to 20 m) of Pleistocene overburden and unconformably overlying Precambrian granitic gneiss (Figure 5.5.2-1; [11]). The reference Paleozoic sequence, based on core logging of the DGR-1 and DGR-2 boreholes, comprises 104.0 m of Devonian dolostone, 323.7 m of Silurian dolostone, argillaceous dolostone, shale and evaporite, 211.8 m of Upper Ordovician shale, 179.1 m of Middle Ordovician argillaceous limestone, 5.2 m of Ordovician siltstone and sandstone, and 16.9 m of Cambrian sandstone (Figure 5.5.2-1). A total of 1.55 m of the Precambrian basement was sampled at the bottom of DGR-2 [11]. The proposed DGR underground facilities will be located within argillaceous limestone of the Middle Ordovician Cobourg Formation and situated beneath a thick (greater than 200 m) Upper Ordovician shale-dominated sequence (Figure 5.5.1-2). The following is a brief summary of the rock units encountered based on the detailed borehole logging descriptions [11]. The Pleistocene overburden typically comprises 1 to 3 m of surficial fill, and/or sand and gravel overlying 5 to 21 m Elma-Catfish Creek till, a clayey silt to sandy silt glacial deposit [31]. The till is underlain by 0 to 2 m of basal gravel deposited at the weathered bedrock surface (see Section 5.4).

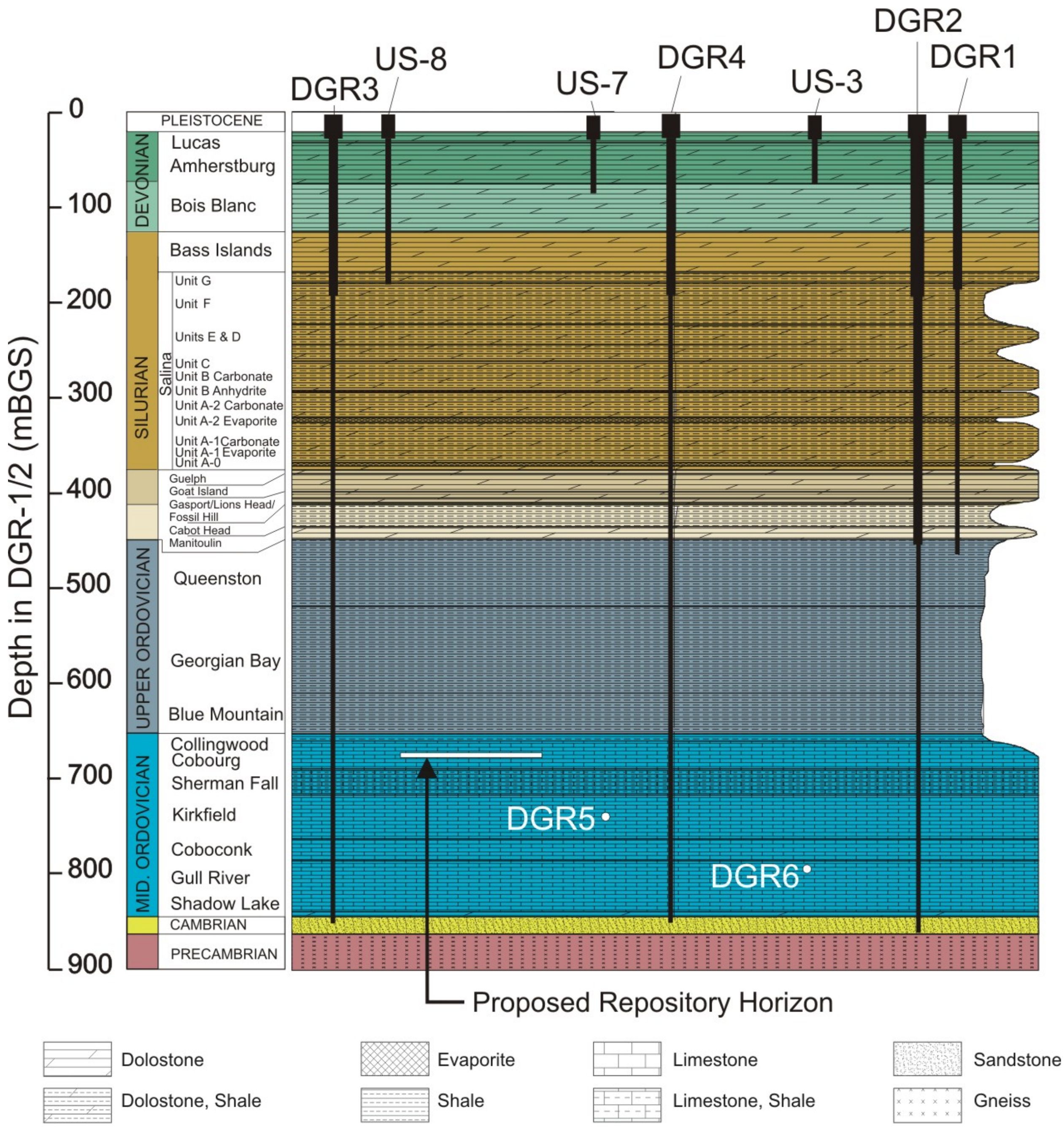
The Devonian dolostone interval includes the highly permeable rocks of the Lucas, Amherstburg, and Bois Blanc Formations. The Lucas Formation is a thin- to medium-bedded, light to grey-brown, finely-crystalline, dolostone with stromatolitic laminations and abundant calcite-filled fractures and vugs. The Amherstburg Formation is a tan to grey-brown, fine- to coarse-grained, fossiliferous dolostone, which is extensively fractured and vuggy. The Bois Blanc Formation is a light grey to brown cherty dolostone with wavy argillaceous laminae throughout. A major erosional unconformity occurs at the base of the Devonian interval.

The Silurian interval includes the Bass Islands Formation, the Salina Group of 12 Units, and the underlying Guelph, Goat Island, Gasport, Lions Head, Fossil Hill, Cabot Head, and Manitoulin formations. The Lions Head, Gasport, Goat Island, and Guelph formations have been grouped collectively as the Niagaran within the three-dimensional geological framework (3DGF) model (Figure 5.5.1-4; [30]).

The Bass Islands Formation is a light brown to tan-grey, variably laminated, very fine- to fine-grained argillaceous dolostone. It exhibits a high degree of natural fractures, which are either open or calcite infilled.

The Salina Group includes a succession of evaporites and evaporite-related carbonaceous sediments subdivided into Units A through G. They comprise tan to brown to grey, thin- to medium-bedded, dolostones to argillaceous dolostones, with shale and anhydrite interbeds, and with locally abundant gypsum and anhydrite veins. Brecciation is evident in the middle and lower part of the interval owing to salt dissolution. The A-1 Carbonate has open vuggy porosity and permeability at its top and shows oil hydrocarbons seeping from its base.

The Guelph Formation is a porous and permeable, vuggy, sucrosic dolostone with abundant halite-infilled veins, minor disseminated pyrite, and minor seeps of oil hydrocarbon. The Goat Island Member is a light brown-grey, very fine-grained, moderately fossiliferous, thin- to medium-bedded dolostone with minor chert and microstylolites.



Notes:
White dots indicate approximate depth of penetration for angled boreholes DGR-5 and DGR-6.
A recently published update of the Paleozoic stratigraphy of southern Ontario includes minor modifications to the stratigraphic nomenclature shown in this figure [48].
Source: Figure was developed based on information from [11] and modified from Figure 2.25 of [3].

Figure 5.5.2-1: Stratigraphic Sequence Encountered During Drilling at the Bruce Nuclear Site

The Gasport Formation is a blue-grey to white, fine- to coarse-grained, dolomitic limestone with bituminous laminations and stylolites throughout. The Lions Head Formation is a grey-brown, fine-grained, dolostone with sparse fossils and locally abundant chert nodules. The Fossil Hill Formation is a light brown-grey, coarse-grained, thin- to medium-bedded, fossiliferous dolostone. The Cabot Head Formation is a green-grey to red massive shale with grey carbonate interbeds and, near its base, black fossiliferous shale. The Manitoulin Formation is a grey, fine- to medium-grained, locally cherty, dolostone with minor interbeds of grey-green non-calcareous shale. Its base marks a major erosional unconformity with the underlying Ordovician shales.

The Ordovician rocks encountered are sparsely fractured and generally of very low permeability and porosity. The Upper Ordovician interval includes the shale-dominated Queenston, Georgian Bay, and Blue Mountain Formations. The Queenston Formation is a massively-bedded, red-maroon to locally grey-green calcareous shale with abundant halite near its top and minor limestone interbeds near its base (Figure 5.5.2-2). Through the middle of the unit is an interval rich in green shale with medium- to coarse-grained, grey fossiliferous, limestone interbeds. The Georgian Bay Formation is dark grey-green shale with grey, fine- to medium-grained, limestone, siltstone, and/or sandstone interbeds whose frequency decreases with depth (Figure 5.5.2-3). Minor halite-infilled fractures and a petroliferous odour are evident towards its base. The Blue Mountain Formation is predominantly dark greenish-grey shale with grey siliceous siltstone and sandstone, and fossiliferous limestone, and transitioning into dark grey calcareous shale at its base. It exhibits a petroliferous odour throughout.

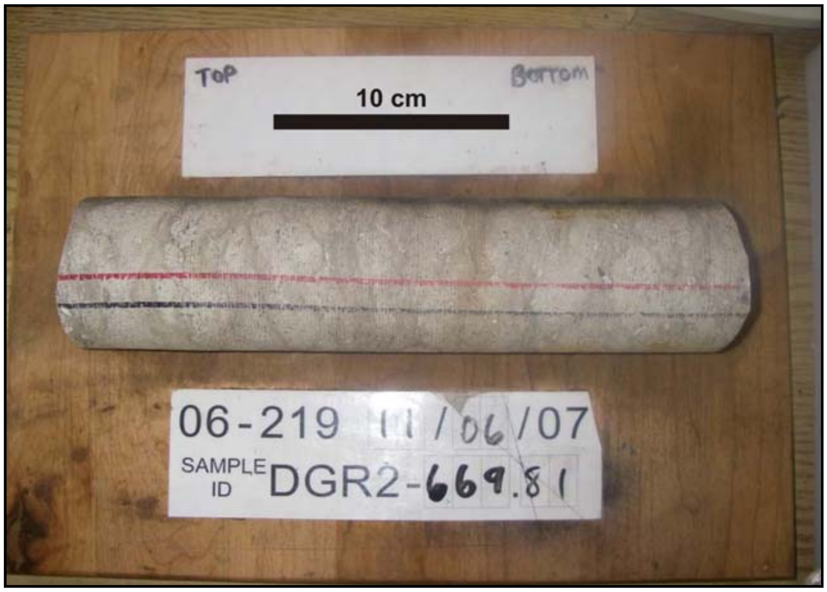
The Middle Ordovician interval includes sparsely fractured low permeability and low porosity argillaceous limestones of the Trenton and underlying Black River Groups. The Trenton Group includes the Cobourg, Sherman Fall, and Kirkfield formations. The Cobourg Formation is further subdivided based on lithology into upper and lower members. The upper Collingwood Member comprises a dark grey to black, organic-rich, calcareous shale with thin fossiliferous interbeds. It is distinctive, regionally, based on an increase in organic content but still with a predominantly carbonate composition [47]. It also has a petroliferous odour throughout and shows minor oil hydrocarbon seeps. The underlying Lower Member is characterized by coarse-grained, fossiliferous, bluish-grey to grey-brown limestone and argillaceous limestone (Figure 5.5.2-4). Unless otherwise indicated, reference to the Cobourg Formation, or simply Cobourg, throughout the rest of this chapter implies reference to the Lower Member of the Cobourg Formation.

Source: From Figure 2.29 of [3].

Figure 5.5.2-2: Core Sample of Green and Red Calcareous Shale, Upper Ordovician Queenston Formation, 454.82 mBGS, DGR-1

Source: From Figure 2.28 of [3].

Figure 5.5.2-3: Core Sample of Interbedded Shale and Limestone, Georgian Bay Formation, 542.25 mBGS, DGR-2



Source: From Figure 2.27 of [3].

Figure 5.5.2-4: Core Sample of Argillaceous Limestone from the Repository Horizon Depth, Cobourg Formation, 669.81 mBGS, DGR-2

The Sherman Fall Formation is a grey-brown, coarse-grained, argillaceous limestone interbedded with calcareous shale near its base. The Kirkfield Formation is a tan to dark grey, fine-grained, irregular-bedded, fossiliferous and argillaceous limestone with dark grey-green shale interbeds. It emits a petroliferous odour and has minor oil hydrocarbon seeps near its base.

The Black River Group, in comparison to the Trenton Group, has a lower argillaceous content overall and has a prevalent petroliferous odour with minor oil hydrocarbon seeps throughout. It comprises the Coboconk, Gull River, and Shadow Lake formations. The Coboconk Formation is a light- to medium-grey, very fine-grained, bioturbated limestone with minor dark grey-green shale interbeds and a characteristic mottled texture. Minor seeping oil hydrocarbon is observed below its mid-point, and an approximately 10 cm thick bentonite bed, interpreted as a volcanic ash layer (e.g., [111]), is observed at approximately 8 m below its upper contact. The Gull River Formation is a medium grey, fine- to very fine-grained, fossiliferous limestone with thin dark grey shale interbeds. A 60 cm thick tan dolostone horizon is traceable through the mid-point of this formation. The Shadow Lake Formation is a dolomitized silty limestone with sandy mudstone and coarser sandstone layering. The base of this unit marks an unconformity with the underlying Cambrian.

The Cambrian is a tan to orange-grey, fine- to medium-grained, silty sandstone and sandy dolostone with clasts of the underlying granitic basement, abundant calcite infilled veins and vugs, and glauconite stringers. Its base is quartzose sandstone and its upper portion is up to 100% dolomitized. Only a very small portion of the underlying Precambrian basement was intersected during drilling. It is described as a pink to grey, fine- to medium-grained, felsic granitic gneiss with extensive alteration along its upper contact and has a well-defined tectonic foliation marking an erosional unconformity with the overlying Cambrian. The Cambrian unit pinches out to the east of the Bruce nuclear site along the flank of the Algonquin Arch (e.g.,[52]).

5.5.2.2 Karst Occurrences

Based on the recognition that karst is common in exposed Ordovician, Silurian, and Devonian age bedrock throughout southern Ontario ([112]; see Section 2.2.5.5 of [3]), an evaluation of the distribution of karst beneath the Bruce nuclear site was undertaken [113]. Karstification is the process by which the flux of chemically undersaturated water through an aquifer preferentially dissolves rocks of carbonaceous or evaporitic composition. A key property of karst aquifers, and important to understanding the shallow groundwater system at the Bruce nuclear site, is that the highly-permeable channels resulting from the karstification process become interconnected to form a network in the shallow subsurface [113]. The pertinent results of the karst study are summarized below, and some examples of karst from beneath the site are shown in Figure 5.5.2-5:

- The top approximately 170 m (borehole DGR-1 reference depth) of bedrock at the Bruce nuclear site is recognized as a zone of active karst development. This zone is characterized by higher permeability than is found in the deeper units, and groundwaters that range in TDS from fresh (greater than 0.5 g/L) to brackish (approximately 5.0 g/L) near the bottom of this groundwater zone.
- With the exception of two approximately 4 m thick dolostone intervals, which display hydraulic conductivities of approximately 10^{-7} to 10^{-8} m/s [11], the groundwater system below 170 mBGS has very low hydraulic conductivities and is characterized by saline to brine groundwater or pore fluids. Despite the relatively higher permeability, the two thin aquifer zones are characterized by Na-Cl waters with TDS values in the A1 carbonate (hydrostratigraphic unit 4A, see Section 5.6) of 29 g/L and the Guelph Formation (hydrostratigraphic unit 4B, see Section 5.6) of 371 g/L (see Figure 5.7.1-5).
- The deep groundwater system in the Ordovician strata at the Bruce nuclear site is characterized by very low hydraulic conductivities ($\leq 10^{-12}$ m/s). There is no evidence that freshwater has penetrated into this deeply buried ancient system during the Quaternary and conditions suitable for karst processes are not present.

Figure 5.5.2-5 shows examples of karst features observed in the DGR core [3]. Shallow Devonian carbonates are characterized by karst features such as solution-enhanced joints and stained/weathered fractures (Figure 5.5.2-5a). Groundwater in the shallow bedrock system may preferentially flow along paleokarst horizons such as those found at the top of the Bass Islands (Figure 5.5.2-5b), particularly where modern karstification has dissolved cement infilling.

Notes:
Arrows point downhole towards stratigraphic bottom in all photographs.
(a) Core photo from shallow Devonian Lucas Formation carbonates. This interval is characterized by karst features such as solution-enhanced joints and stained/weathered fractures.
(b) Core photo from a section of the Devonian Bois Blanc Formation where present-day groundwater flow may be concentrated along a remnant paleokarst horizon near the top of the Bass Islands Formation.
Source: Figure 2.34 of [3].

Figure 5.5.2-5: Karst and Paleokarst Intervals Beneath the Bruce Nuclear Site

5.5.2.3 Predictability of the Ordovician Sedimentary Rocks

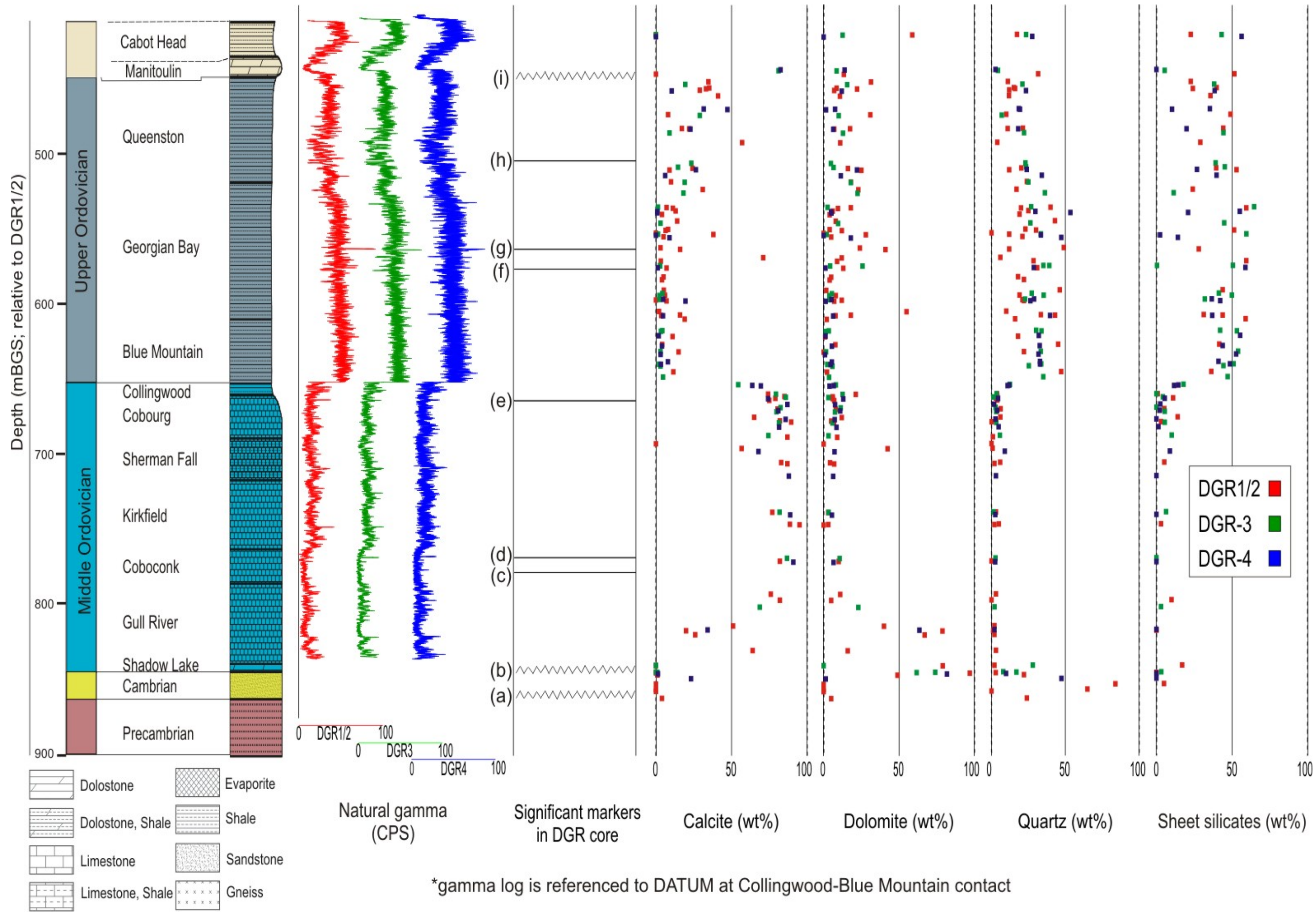
As discussed above, and based on the regional geology of southern Ontario, the site lithology (shale, evaporite, carbonate, and clastic content) defining broad facies assemblages is well predicted by the regional data [28;47;48]. Carrying on from this, in more detail, the following sections build the case for site-scale predictability based on the consistency of Ordovician unit thicknesses, mineralogy and facies distribution (e.g., Table 5.5.2-1 and Figure 5.5.2-6), and the recognition of traceable marker bed horizons across the site (Figure 5.5.2-6 and Figure 5.5.2-7).

Intersection of the Ordovician formations by the DGR boreholes, except for the deepest formations in DGR-5 and DGR-6, allows for an assessment of the uniformity in formation thickness and attitude (strike and dip) as shown in Table 5.5.2-1. From the information listed in Table 5.5.2-1 it is apparent that formation strike and dip are remarkably similar through the Ordovician. Similarly, individual and total Ordovician thicknesses are consistent between boreholes.

Table 5.5.2-1: Timetable of Major Tectonic Events in Southern Ontario

Ordovician Formation/Member	Strike	Dip	Thickness (m)				
			DGR-2	DGR-3	DGR-4	DGR-5	DGR-6
Queenston	N24ºW	0.41ºSW	70.3	74.4	73.0	70.3	69.3
Georgian Bay	N17ºW	0.61ºSW	90.9	88.7	88.7	88.6	88.2
Blue Mountain	N23ºW	0.51ºSW	42.7	44.1	45.1	45.1	45.0
Collingwood Member	N14ºW	0.56ºSW	7.9	8.7	8.4	8.6	6.5
Cobourg	N14ºW	0.60ºSW	28.6	27.8	27.5	27.1	28.5
Sherman Fall	N17ºW	0.57ºSW	28.0	28.9	28.3	29.3	28.8
Kirkfield	N18ºW	0.63ºSW	45.9	45.8	45.7	—	46.8
Coboconk	N19ºW	0.63ºSW	23.0	23.7	23.8	—	22.4
Gull River	N16ºW	0.66ºSW	53.6	51.7	52.2	—	—
Shadow Lake	N19ºW	0.56ºSW	5.2	4.5	5.1	—	—
Total Ordovician Thickness			396.1	398.3	397.8	—	—

Note:
Strike and true dip values based only on data from the vertical boreholes DGR-1 to DGR-4. The unfilled (-) boxes indicate that there is not enough information to state individual or total thicknesses.
Source: Data are from Table 3.1 and Table 3.2 of [11].



Note:
Figure is based on data from vertical boreholes DGR-1, DGR-2, DGR-3, and DGR-4 [11] and modified from Figure 2.30 of [3]. Marker units (a to i) are discussed in the text. Jagged lines at (a), (b), and (i) indicate unconformities recognized in all DGR boreholes.

Figure 5.5.2-6: Lithostratigraphy, Natural Gamma Profiles, Marker Units and Major Mineralogy of the DGR Boreholes

5.5.2.4 Lithofacies Analysis, Marker Beds and Mineralogy

In order to fully assess the degree of predictability of individual lithofacies at the site-scale, an evaluation of the lateral (horizontal) homogeneity and vertical variation of lithofacies within key Ordovician intervals was conducted (see also [3]). Vertical borehole coverage (DGR-2, DGR-3, and DGR-4) around the periphery of the proposed DGR footprint provides the data control for this analysis (Figure 5.3.1-1). Facies variations are caused by the changing dynamics of the depositional environment, and can potentially alter the hydrogeological and mechanical properties of the rock mass. If sufficient homogeneity exists, then the important geophysical, geomechanical, and hydrogeological datasets may be associated to specific lithologies. A positive correlation of intraformational facies changes between the boreholes would, therefore, allow interpolation of the lithostratigraphy across the proposed DGR footprint. The specific targets for this analysis were portions of the cap rock shales (Queenston and Georgian Bay Formations) and the host rock (Cobourg Formation) for the proposed DGR (Figure 5.5.2-6). The reader is directed to Section 2.3.4.1 of the Geosynthesis for a complete description of the lithofacies analysis [3]. Important conclusions based on this work are discussed below:

- The natural gamma ray profiles for the Ordovician section from each of boreholes DGR-1/2, DGR-3 and DGR-4, as plotted in Figure 5.5.2-6, show a consistent bimodal distribution of counts per second (CPS) values. A high CPS count in the upper interval highlights the greater than 200 m thick shale-dominated Upper Ordovician rock sequence, which represent the primary cap rock to the proposed DGR, above the low CPS count and carbonate-rich Middle Ordovician sequence.
- The general consistency in natural gamma profile distribution supports the assessment of uniform unit thicknesses and a structurally simple geometry across the site [39].
- Lithological variation is likely to occur as minor, dm- to cm-scale typically, conformable changes in quantities of mm- to cm-thick beds of shale, siltstone, or limestone as demonstrated by minor variation of the gamma ray profiles between boreholes (Figure 5.5.2-6).

This last point is not unexpected given the nature of the carbonate shelf depositional environments characteristic of the Middle Ordovician (e.g., [114]) and the clastic-dominated shallow prograding coastal plain and deltaic depositional environment characteristic of the Upper Ordovician [115].

Therefore, the Ordovician stratigraphy at the Bruce nuclear site is considered to be laterally homogeneous and predictable at the dm- to m-scale and the lithostratigraphy is considered to be consistent and predictable at the site-scale.

5.5.2.5 Marker Beds

Several laterally continuous marker beds (e.g., (c), (d), (f) and (h) in Figure 5.5.2-6) were identified during DGR core logging activities and provide a further indication of formation lateral continuity at the site-scale (Table 5.5.2-2; [39;116]). These marker beds are typically 10 to 20 cm thick beds with visually identifiable lithofacies features and/or borehole geophysical logging signatures that are distinct from the surrounding rocks. Figure 5.5.2-7 shows the Georgian Bay fossiliferous limestone bed as an example marker bed observed in the recovered core.

The lithofacies analysis discussed in the previous section also indentified other marker beds during a more detailed examination of the Ordovician units. One corresponds to a marked CPS spike in the middle of the gamma profile at the same stratigraphic depth in the Georgian Bay Formation in all boreholes (e.g., (g) in Figure 5.5.2-6). Visual core inspection confirmed that this spike is lithologically controlled and defined by the sharp transition from a distinct 3 to 15 cm thick fossiliferous limestone bed into underlying dark shale. A distinct 3 to 4 cm thick shale marker, again with a distinct CPS spike, was also identified within the Cobourg Formation (e.g., (e) in Figure 5.5.2-6).

Table 5.5.2-2: Summary of Marker Bed Descriptions, Depths and Orientations Determined from Core Logging

Formation	Marker Bed or Horizon	Depth (mLBGS)					Orientation	
		DGR-1/2	DGR-3	DGR-4	DGR-5	DGR-6	Strike	Dip
Salina F Unit	brown dolostone bed in grey shale	182.0	200.7	181.5	--	--	N32ºW	0.98ºSW
Queenston (h)	limestone bed in shale	504.3	517.7	505.6	546.0	568.6	N17ºW	0.61ºSW
Georgian Bay (f)	fossiliferous limestone bed in grey shale	576.5	589.2	577.9	622.3	649.6	N14ºW	0.56ºSW
Coboconk (d)	dark grey volcanic ash bed in grey limestone	768.8	781.0	769.0	--	876.7	N19ºW	0.55ºSW
Coboconk (c)	tan dolostone bed in grey limestone	778.7	790.5	778.3	--	888.0	N22ºW	0.54ºSW

Notes:
Lowercase letters in parentheses in first column on left refer to specific marker beds indicated on Figure 5.5.2-6.
mLBGS is metres Length Below Ground Surface. This measure takes into account the inclined nature of boreholes DGR-5 and DGR-6.
Source: Data is from Table 3.12 of [11].

5.5.2.6 Rock Mineralogy and Geochemistry

Samples of core recovered from the DGR-series of boreholes were subjected to a suite of laboratory tests to determine the intact rock mineralogy and lithogeochemistry, as well as to confirm or modify the stratigraphy and lithology of the bedrock sequence as described regionally [47;48]. Notable results for the Ordovician interval are shown in Figure 5.5.2-6 and discussed below (see also Section 2.3.5 in [3]):

- The Upper Ordovician shales are dominated by sheet silicates, with increasing amounts of quartz with depth and moderate amounts of calcite and dolomite, particularly in the Queenston Formation, and decreasing in percentage with depth. Predictably, the Middle Ordovician limestone formations consist of typically greater than 80% calcite, with the remainder being variously composed of sheet silicates, dolomite, and quartz.

- Dolomitization is evident in varying proportions in parts of the Queenston, Georgian Bay, Blue Mountain, Collingwood, Shadow Lake, and lower Gull River Formations.
- Sheet silicate content ranges between 25 to 70% within the Ordovician shales of the Queenston, Georgian Bay, and Blue Mountain Formations. Illite and mica together represent greater than 50% of the sheet silicate mineral constituents, followed by chlorite at 20 to 45% and with minor kaolinite and interstratified illite-smectite. The interstratified illite-smectite is predominantly illite, with only 5 to 10% smectite layers [117]. In all cases, the major sheet silicate mineral is illite and the minor phase is chlorite [11]. The sheet silicate content of the Ordovician limestones is typically less than 20%.
- Pyrite is the principal iron mineral throughout the entire Ordovician interval, although hematite is observed in the Queenston Formation.

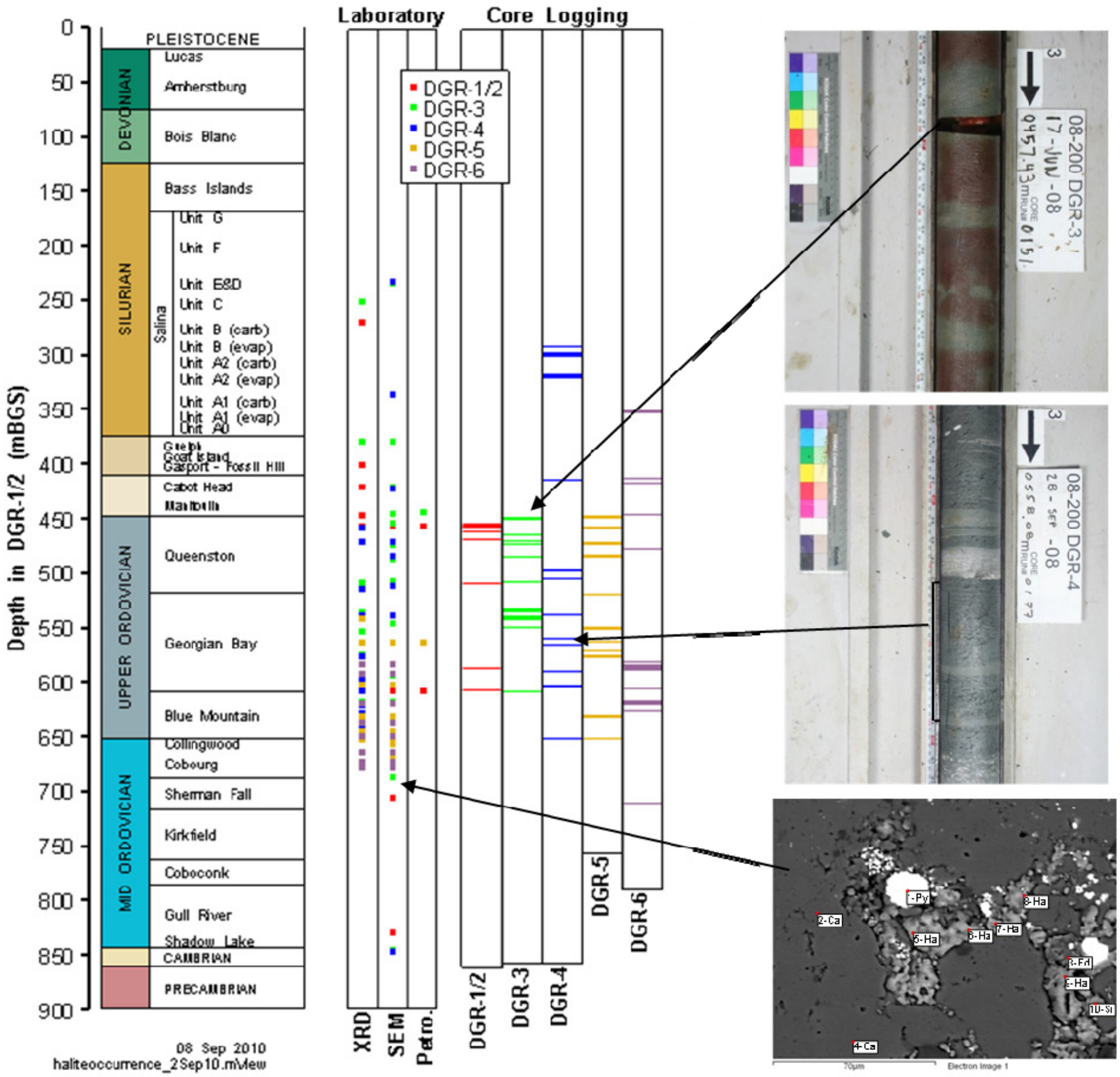
These results highlight the consistency in formation-scale mineralogical associations or trends across the site and further support the conclusion that lithofacies are predictable at the site-scale.

5.5.2.7 Fracture Filling

Self-sealing by a precipitating mineral phase is a naturally occurring time-dependent process that leads to a reduction in the hydraulic transmissivity of a fracture. When fully self-sealed, the fracture is not a preferential pathway for fluid migration. If partially self-sealed, the fracture may act as a pathway but at a lower transmissivity than when it was open.

Infilled fractures observed during core logging and by petrographic analysis may be of hydrothermal origin or result from mineral precipitation during diagenesis. The vast majority of these secondary mineral phases occur within healed discontinuities in the otherwise intact host rock (e.g., Figure 5.5.2-8). The infilling mineral phases include quartz, calcite, pyrite, anhydrite, iron oxide/hydroxide, clay, halite, and gypsum. Anhydrite is frequently observed from the Bass Islands Formation to the Coboconk Formation. Gypsum was observed in the Salina G to A2 units. Both anhydrite and gypsum are present in many samples. They are differentiated in the field based on hardness and colour. Calcite and pyrite are observed from the Amherstburg Formation to the Shadow Lake Formation. Halite distribution will be discussed in more detail below.

Shales from the upper Queenston Formation contain prominent millimetre thick halite-filled fractures bounded by a carbonate mineral lining the fracture wall (see Section 5.5.2.8). The Queenston Formation also displays calcite, anhydrite, celestite, and gypsum veins. Georgian Bay Formation shales include illite and calcite-filled veins and one approximately 0.15 mm thick halite vein was observed in thin section. Pyrite and illite veins are observed in shales of the Blue Mountain Formation. Middle Ordovician limestones exhibit dolomite veins and other infill material including iron oxide, pyrite, calcite, anhydrite, and occasionally halite [11].



Notes:

Observed halite distributions based on core logging descriptions, and XRD, SEM, and petrographic (laboratory) analyses of DGR cores ([11] and references therein). Top right: Sub-horizontal halite-filled fracture in the Queenston Formation. Middle right: Sub-vertical halite-filled fracture in the Georgian Bay Formation. Bottom right: SEM backscatter image of pore-filling halite in the Cobourg Formation (DGR-3 699.6 mBGS) with spot mineral analyses indicated by red dots.

Source: Figure 3.9 of [11].

Figure 5.5.2-8: Summary of Observations of Halite Presence in the DGR Cores

5.5.2.8 Halite Occurrences

Halite was specifically targeted for identification and distribution analysis because of its high solubility (approximately 6,000 mmol/kgw) and its role as a groundwater tracer. The presence of halite within a formation or group of formations is a strong indicator that there has been no flow of fresh, or halite-undersaturated, water through that rock sequence since the halite was precipitated [11].

Halite was detected visually during core logging, and via optical microscope, XRD, and SEM/EDS analyses (Figure 5.5.2-8; [118;11]). Halite occurrences include: mineral infilling of subhorizontal and steeply-dipping fractures; voids and cavities; a grain-boundary mineral phase within a matrix dominated by gypsum, dolomite, calcite, or silicate minerals; and, as disseminated grains and irregular, discontinuous stringers. Halite was found in abundance throughout the Upper Ordovician shales, as a minor mineral phase throughout the Cobourg, Sherman Fall, and Gull River formations, and the Cambrian (Figure 5.5.2-8; [119;118;11]). Whole-rock and clay-mineral XRD analyses yielded average halite concentrations of 0.7 wt % and 0.6 wt % in DGR-3 and DGR-4, respectively. Maximum halite concentrations were recorded in the Blue Mountain Formation with concentrations ranging from 0.5 to 1.4 wt %.

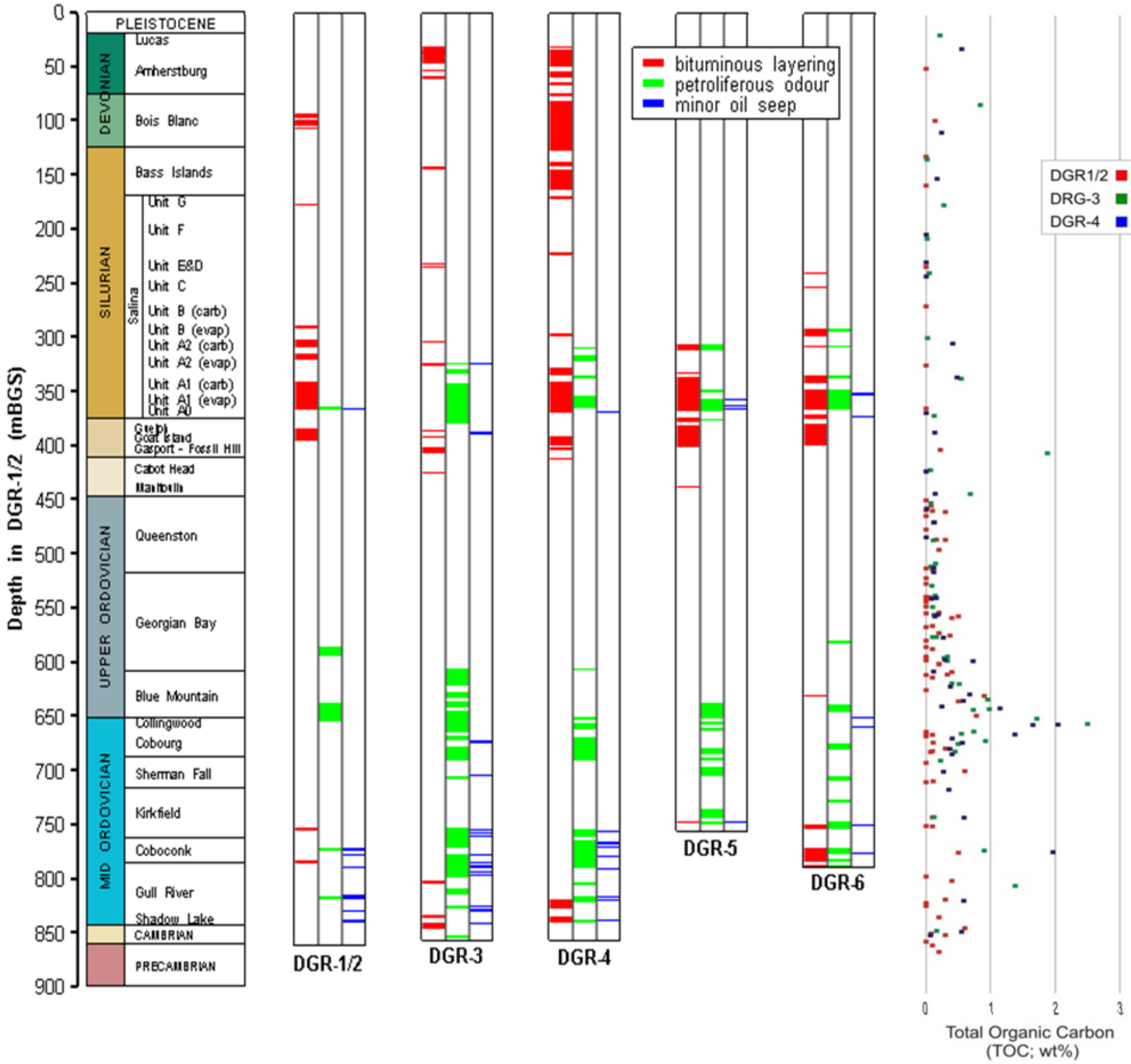
Halite was most commonly observed infilling mm-scale to hairline thickness fractures throughout the Upper Ordovician shales (e.g., top and middle right photographs in Figure 5.5.2-8). There is visual evidence that drilling fluids locally dissolved some of the vein halite (e.g., top right photograph of Figure 5.5.2-8), but where this occurred there was generally enough preserved for positive identification. In the deeper limestones, including the Cobourg Formation, a lack of open fractures is consistent with halite only being recognized as a mineral phase at the micron-scale. In these instances it was commonly observed within networks of irregular cavities between larger calcite grains (e.g., bottom right photograph of Figure 5.5.2-8).

5.5.2.9 Hydrocarbon Occurrences at the Bruce Nuclear Site

The site characterization activities found no evidence for any economical accumulation of hydrocarbon resources beneath the Bruce nuclear site [11]. However, detailed core logging and laboratory analyses provide an understanding of the distribution of hydrocarbons within the subsurface at the site (Figure 5.5.2-9) ([117], and Sections 3.7.4 and 3.7.5 of [99]). Hydrocarbon is observed in the DGR cores primarily as thin bituminous layering, indirectly as a prominent petroliferous odour, and as minor seeping or oozing of oil from vugs, fractures, and dolomitized sedimentary horizons. Figure 5.5.2-9 shows hydrocarbon distribution from all DGR boreholes. The hydrocarbon-bearing intervals are concentrated into three main horizons, which correspond, in general, to zones of elevated TOC content within the Paleozoic stratigraphic sequence (Figure 5.5.2-9). A shallow interval of prominent petroliferous odour and minor oil seeping is observed at the top of the Silurian Guelph Formation and into the overlying basal Salina units (Figure 5.5.2-9). An intermediate interval corresponds to the base of the Upper Ordovician shales, which exhibits, in general, average TOC values of less than 1.0 wt% (Figure 5.5.2-9). A deep interval comprises isolated hydrocarbon occurrences throughout the Black River Group including the base of the Kirkfield Formation of the overlying Trenton Group (Figure 5.5.2-9).

DGR core samples from locations within the Upper Ordovician shales were also evaluated by Rock-Eval pyrolysis in order to characterise their thermal maturity and kerogen source (e.g.,

[117]). It was determined that shales from the Collingwood Member and the Blue Mountain Formation are considered to be near the lower threshold of thermal maturity and of marine origin, tending to form oil rather than gas. Most of the Georgian Bay and Queenston Formation shales contain kerogen derived from a terrestrial source and are more gas prone. The limited extent of visible oil in the cores, and the burial history of the Regional Study Area, suggest that the actual temperature during maturation was towards the extreme lower end of the threshold range.



Note:
Total Organic Carbon (TOC) content plot (right side) only includes data from DGR-2, DGR-3, and DGR-4 [11].
Source: Compiled from Figures 3.15 and 3.16 of [11].

Figure 5.5.2-9: Summary of Observations of Hydrocarbon Presence in DGR Cores

5.5.2.10 Ordovician Cap Rock Seal

An assessment of the cap rock integrity and seal potential of the DGR cap rock was undertaken based upon evaluation of the seal quality of cap rocks to petroleum deposits in the Appalachian and Michigan basins [110]. The purpose of this study was to explore whether the thick package of Upper Ordovician shale rocks at the Bruce nuclear site would provide a natural barrier to migration of fluids. The cap rock for the proposed DGR includes the Middle Ordovician organic shale-rich Collingwood Member and the overlying Upper Ordovician shale-dominated Blue Mountain, Georgian Bay and Queenston formations totalling greater than 200 m of low-permeability shale-rich rocks overlying the proposed Bruce nuclear site. Main conclusions reached by the study which attest to the longevity in seal integrity of the Bruce nuclear site cap rocks include the following [110]:

- In a similar manner that seal longevity is evident from the recognition of regional over-pressures in the northern Appalachian Basin and under-pressures in the southern Appalachian Basin, the under-pressured nature of the Ordovician shales (see Section 5.6) indicates that this sedimentary package represents a long-lived and stratigraphically-controlled cap rock seal.
- Limited hydrocarbon maturation at the Bruce nuclear site is a result of subsidence that reached a total burial depth of approximately 1.5 km and certainly no more than 2 km, creating temperatures that only marginally crossed the oil generation window (approximately 70 ºC for the Collingwood Member). This lack of thermal maturity precluded the development of gas-generated natural hydraulic fractures (NHF), and this relationship was confirmed by extensive coring. In contrast, gas generating conditions within in the Appalachian Basin lead to extensive and pervasive NHF development.
- The distribution of hydrocarbons at the site, as shown in Figure 5.5.2-9, suggests that these Upper Ordovician shales provide an adequate seal.
- The youngest strata in the Regional Study Area affected by basement-seated faults are the Ordovician-aged Trenton Group limestones [48]. The lack of any appreciable volume of hydrothermal dolomite at the Bruce nuclear site [11] argues against the likelihood of a proximal major Paleozoic fault system having been active in the vicinity in the ancient past and that could have disrupted the seal integrity of the cap rocks.

Therefore, the shale-dominated cap rocks at the Bruce nuclear site represent a natural greater than 200 m thick seal that has demonstrated long-term integrity over geological time and is well suited to continue acting as a primary barrier to contaminant transport in the subsurface [110].

5.5.2.11 Site-scale Structural Geology

Studies undertaken as part of the Geosynthesis work program which focused on understanding the structural geological framework of the Bruce nuclear site included a two-dimension seismic reflection survey, a detailed fracture mapping exercise, and several aspects of the drilling and core logging activities undertaken during site characterization [38;103;11]. The important results of each of these studies are summarized below.

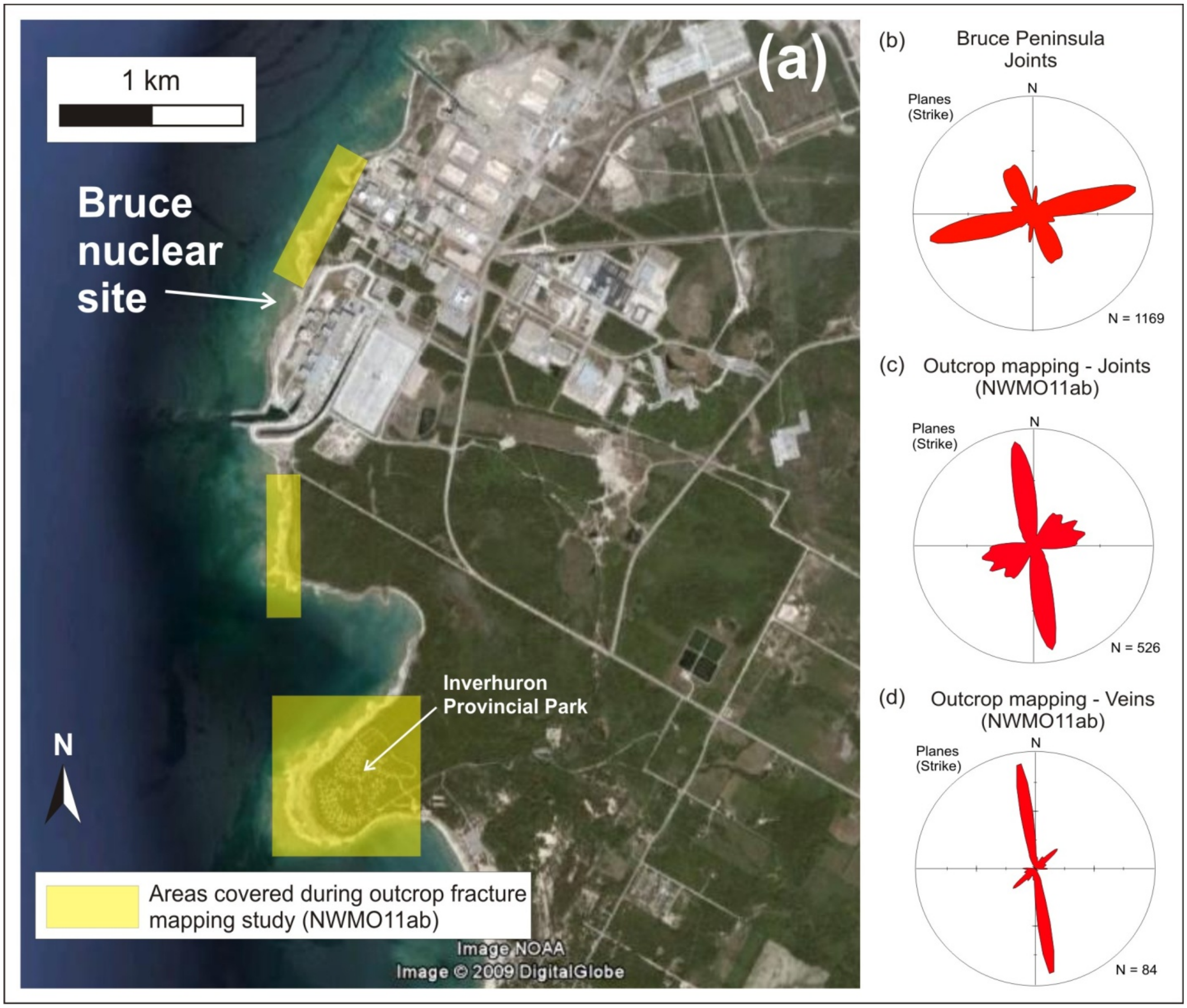
Two-Dimensional Seismic Reflection Survey

A two-dimensional (2D) seismic survey, including nine survey lines totalling 19.7 km, was conducted on the Bruce nuclear site as part of the geosynthesis work program [38]. The purpose of this 2D seismic survey was to obtain deep bedrock geological, stratigraphic and structural information for the Bruce nuclear site and to assess the predictability and continuity of the host rock for the DGR (Cobourg Formation) and the “potential” location of faults and fault zones in the subsurface within the Paleozoic bedrock. The bedrock units of primary interest were the shales and argillaceous limestones at depths of about 400 to 800 m. These strata include the Middle Ordovician limestones (Cobourg, Sherman Fall, Kirkfield, Coboconk, and Gull River formations) and overlying Ordovician shales (Queenston, Georgian Bay, and Blue Mountain formations), as well as the intervening Collingwood Member.

The 2D seismic interpretation suggested the existence of two structural features (faults) within the proposed DGR footprint. The inclined drilling of boreholes DGR-5 and DGR-6 was specifically oriented to intersect these interpreted structural features, and no evidence for their existence was found in the recovered core. Conventional oil and gas exploration techniques and expertise were used to acquire and process the data with the intent to mitigate environmental noise and obtain the best achievable data quality. However, seismic data quality was affected by poor seismic energy coupling between the heterogeneous glacial drift and underlying bedrock, as well as by anthropogenic and natural background noise, which could have resulted in the interpretation of structural features that are not actually observed in the drilled cores.

Fracture Analysis

The results of a detailed fracture mapping study undertaken near the Bruce nuclear site, with the objective of collecting brittle fracture orientation data (including a systematic examination of joint, vein, and fault features), is presented below (Figure 5.5.2-10; [103]). The analysis was undertaken focusing on accessible shoreline exposures of the Devonian Lucas Formation (Figure 5.5.2-10a; [103]). These results are also compared with joint orientation information determined during detailed core logging [11]. It is confirmed that the surface data are generally consistent with the subsurface data and that both are consistent with the regional dataset.



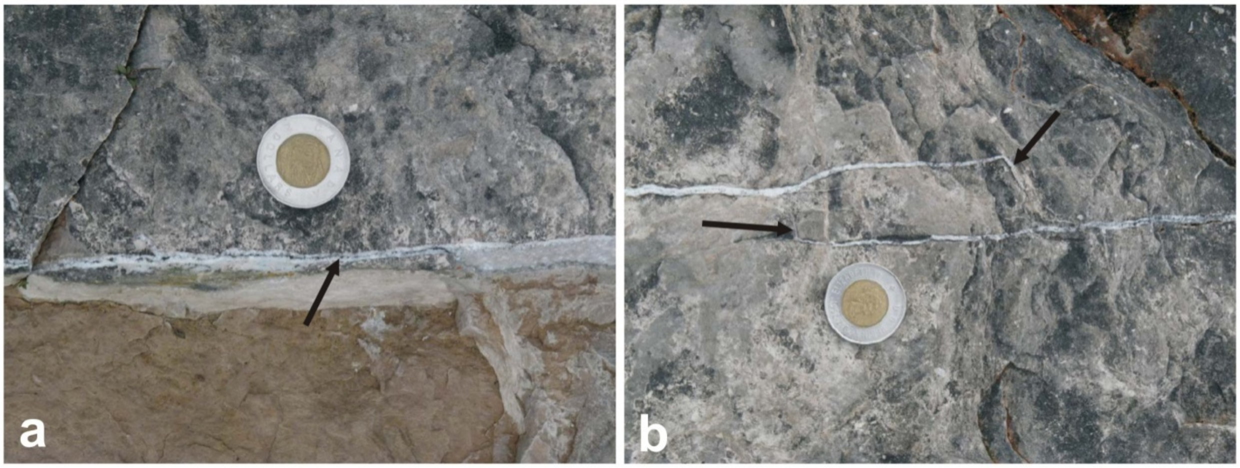
Notes:
Base map in (a) indicates areas covered during detailed outcrop fracture mapping analysis at locations proximal to the Bruce nuclear site and Inverhuron Provincial Park [103]. Rose diagrams of joint and vein data collected are shown in (b) to (d). (b) Joint orientation data from the Bruce Peninsula [40]. (c) and (d) are joint and vein orientation data, respectively, measured during detailed fracture analysis [103].
Source: Modified from Figure 2.35 of [3].

Figure 5.5.2-10: Compilation of Regional- and Site-scale Fault, Joint and Vein Data

Outcrop Data

Bedrock outcrop near the proposed Bruce nuclear site is restricted to fine- to medium-grained, light grey limestone and dolostone of the Devonian Lucas Formation (Figure 5.5.2-11). This rock is observed as discontinuous pavements along the shoreline of Lake Huron immediately adjacent to the Bruce power plant and further to the south around Inverhuron Provincial Park (Figure 5.5.2-10a). The bedrock dips at less than 1° towards the SW, in accord with both regional values and those determined from formation top picks and the marker bed study.

Bedding attitude is locally deflected due to sediment compaction over the top of 1 to 2 m diameter stromatolite mounds. At a larger scale, aerial photograph interpretation of surface bedding traces indicates that bedding layers are locally deflected into 40 to 100 m diameter dome and basin features [103].



Notes:
Calcite-filled veins in limestone (Lucas Formation) characterized during the outcrop fracture mapping study [103]. In (a), the vein trends 119^0 and is filled with calcite. A thin dark discontinuous seam of wall rock occurs in the centre of the vein (indicated by arrow), indicating its crack-seal nature. Overlapping calcite-filled veins with Interacting (bridging) tips (indicated by arrows) are shown in (b). Tip Interaction shown in (b) indicates that the veins likely propagated as fluid-pressurized cracks (hydrofractures). Coin for scale in both photos.
Source: Modified from [103] (Figures 3.6 and 3.7 therein).

Figure 5.5.2-11: Calcite-filled Veins Exposed Along the Shoreline of Lake Huron Near the Bruce Nuclear Site

Only systematic joint sets were looked at for the study. Their observable characteristics are as follows [103]:

- Both joint and vein sets share common orientations with subtle variations. Two main sets are distinguished, one trending ENE and the other NNW (Figure 5.5.2-10c and Figure 5.5.2-10d). These two statistically dominant sets overshadow a very minor third set of SE-striking joints and veins.
- Joint frequency is linked to grain size where thin beds of fine-grained micritic limestone host fractures spaced 1 to 20 cm apart while thicker beds of medium-grained limestone host fractures spaced 20 cm to 2 m apart.
- Most joints do not exceed 5 m in horizontal length while vertical joint height could not be measured accurately due to the sub-horizontal nature of the outcrop.
- Most joints are closed and tight and those with measurable aperture have been widened by solution processes (karst) or creep.
- Joints only exhibit carbonate mineral infilling (Figures 5.5.2-11a and 5.5.2-11b), with no iron oxide filling or coatings, indicating a lack of groundwater penetration along joint surfaces.

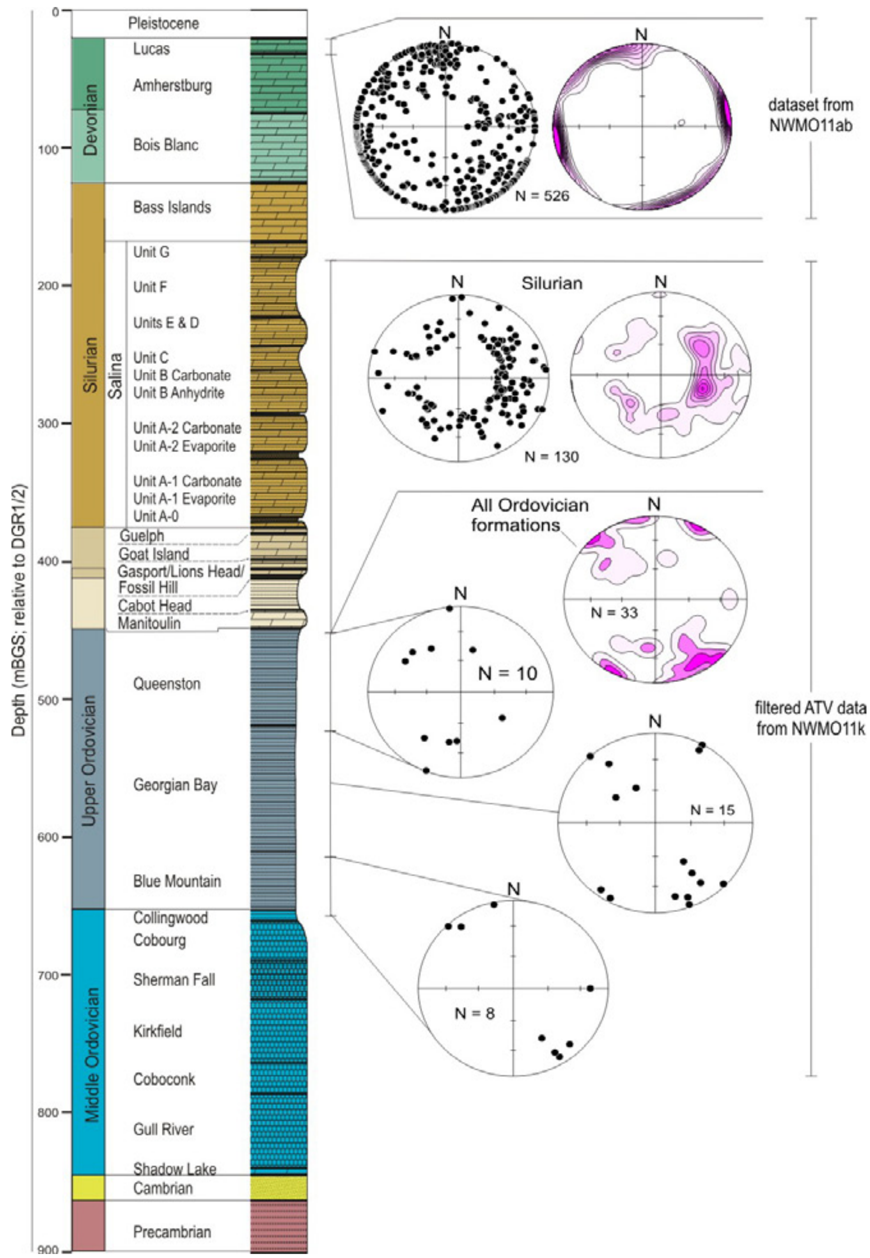
- Only one joint had plumose structure, a N-striking sub-vertical feature with sub-horizontal median line, and no other lineation pattern was observed throughout the area.
- Only 10 of the 610 measured joints and veins displayed horizontal offsets with both sinistral and dextral displacement, ranging from 2 to 150 mm, observed on both the ENE- and N-striking sets with no systematic distribution noted. No significant faults, or evidence of brittle or ductile faulting in the rocks, were observed in the study area. In several places, fracture propagation and mineral precipitation are interpreted to have been synchronous based on the curved and branching morphology of observed calcite-filled veins suggestive of multiple cycles of hydraulic fracturing and mineral precipitation (Figures 5.5.2-11a and 5.5.2-11b). Such features are indicative of fracture propagation under conditions of elevated pore fluid pressure. Given that both joints and veins share common orientations, it is likely that most fractures observed in the Lucas Formation formed under conditions of elevated pore fluid pressure. These elevated pore fluid pressure conditions were likely experienced during either Acadian or Alleghenian orogenesis [103].
- The two main NNW- and ENE-trending joint and vein set orientations determined from this outcrop-scale analysis are broadly consistent with joint orientations as determined from studies throughout the Regional Study Area and elsewhere in southern Ontario, including data from the Bruce Peninsula (compare Figure 5.5.1-7 and Figure 5.5.2-10b with Figure 5.5.2-10c and Figure 5.5.2-10d). These fracture sets appear to be part of the regional fracture system in the Silurian and Devonian strata of the Bruce Peninsula, Manitoulin Island, and northern Michigan. In particular, the NNW-trending set is concentric with respect to the outline and structure contours of the Michigan Basin. A broad basin-centred subsidence event coincided with deposition of the middle Devonian Dundee Formation and Traverse Group strata in the Michigan Basin [64]. Radial tensile stresses generated during this event provide a plausible mechanism for developing the basin-scale concentric fracture set in general, and the NNW-trending fracture set in the study area in particular [103].

The geometrical relationships discussed above suggest a contemporaneous late Paleozoic age for formation of the NNW- and ENE-trending fracture sets. A neotectonic origin for the ENE-trending fractures (e.g., [102;68]) is difficult to reconcile with an interpreted late Paleozoic timing for formation of the NNW-trending fractures given that detailed fracture mapping suggests these two sets formed contemporaneously. Recent work re-analysing the paleo-stress field of the Appalachian Basin suggests that some of these ENE-trending joint sets distributed throughout the basin are actually late Paleozoic (Pennsylvanian-Permian) in age [120]. Therefore, there is no genetic significance to the similarity in orientation between the ENE-trending fracture population and the present in situ maximum horizontal stress. The origin of the vein filling material and the timing of the main fracture forming event, for both the NNW and ENE fracture sets, is best interpreted as late Paleozoic in age [103].

Vertical Borehole Results

Boreholes DGR-1, DGR-2, DGR-3 and DGR-4 were drilled to approximate depths of 462, 862, 869 and 857 mBGS, respectively, and are subvertical, never exceeding tilts of 1.5°, 1°, 4.5°, and 4°, respectively [11]. Core logging and acoustic televiewer (ATV) images represent the primary means of structural data collection. The former gives information primarily on occurrence and approximate dip of fractures while the latter can quantify both occurrence and orientation through the analysis of the elliptical traces of fractures on the borehole wall. Figure 5.5.2-12 shows a plot of ATV-derived natural fracture data in the subsurface separated by formation, as well as data compiled during the outcrop fracture mapping study [103]. The

ATV data have been filtered to only include features that dip greater than 35° from horizontal [11]. The borehole data for the Ordovician are sparse with only 33 total measurements across all formations (Figure 5.5.2-12). This value highlights the lack of natural fractures in the subsurface beneath the Bruce nuclear site. Peak Ordovician fracture orientations trend ENE and ESE (Figure 5.5.2-12). A much larger dataset for the Silurian interval (130 measurements) exhibit a diffuse spread of data (Figure 5.5.2-12), possibly due to salt dissolution processes.



Notes:
Data is plotted as poles to the plane of measurement on equal-area lower hemisphere projections. Surface dataset is compiled from the outcrop fracture mapping study [103]. Subsurface dataset is from acoustic televiewer (ATV) logging of DGR boreholes [11].
Source: Figure 2.37 of [3].

Figure 5.5.2-12: Natural Fracture Orientations from Surface and Subsurface Datasets

Inclined Borehole Results

As noted above, vertical boreholes have an inherent sampling bias against steeply dipping structural features. Inclined boreholes DGR-5 and DGR-6 were drilled so that a statistically meaningful lateral section of rock could be sampled for quantification of the joint and vein distribution within the subsurface. The majority of steeply inclined joints within the Ordovician section occur in the Georgian Bay and Blue Mountain Formations, with only three in the Collingwood and none in the Upper or Lower Cobourg and Sherman Fall Formations.

The inclined-drilling program was also designed to test for the existence of NNW-striking vertical faults proximal to the DGR. DGR-5 was oriented such that it would potentially intersect a northward extension of one such fault structure. DGR-6 was oriented such that it would transect a similarly oriented structure at depth, if it existed, as suggested by the results of a 2D seismic reflection study [38]. Continuous core retrieved from both inclined boreholes showed no indication of the existence of either one of these potential faults [11].

5.5.3 Geology Summary

The Paleozoic sedimentary rocks beneath the Bruce nuclear site are predictable, include multiple natural barriers to contaminant transport, have low resource potential, and are located in a seismically quiet environment. A summary of the key lines of evidence which support this assertion is provided below:

- The 3DGF model geometry of the Regional Study Area is consistent with the regional geological framework based on published literature, maps and cross-sections of the region. The 34 stratigraphic formations, members, or units recognized regionally were also recognized beneath the Bruce nuclear site during site characterization activities.
- The Ordovician stratigraphy exhibits uniform unit thicknesses, traceable marker beds and predictable distributions of formation-scale lithologies, major mineralogical components and fracture in-filling minerals (including halite). A detailed lithofacies analysis determined that the Ordovician stratigraphy at the Bruce nuclear site can be considered laterally homogeneous and predictable at the dm- to m-scale between the vertical DGR boreholes spaced less than 1 km apart.
- Two inclined boreholes were directionally-drilled in order to investigate potential sub-vertical fault structures imaged by the 2D seismic survey. Continuous core retrieved from both boreholes showed no evidence of faulting.
- Present day karst features are confined to the shallow groundwater zone and this zone is effectively isolated from the deeper groundwater system beneath the site. This interpretation is supported by the observed distribution of halite within the deep system.
- No commercial oil or gas accumulations were encountered during site characterization activities. Low average TOC (less than 1%) in the Upper Ordovician shales and a low degree of thermal maturity argue against the likelihood of commercial hydrocarbon accumulations within the DGR footprint.
- The distribution of hydrocarbons at the site attest to the seal capacity of the Upper Ordovician shales and that this sedimentary interval has provided a long-lived barrier to hydrocarbon migration. The low degree of thermal maturity, which barely reached the oil window in terms of hydrocarbon generation, precluded the development of gas-generated natural hydraulic fractures which could have disrupted the Upper Ordovician seal.

5.6 HYDROGEOLOGY (GROUNDWATER AND SOLUTE TRANSPORT)

5.6.1 Regional Setting

The Geosynthesis [3] has subdivided the regional scale groundwater domain into three zones:

- a shallow zone comprising any surficial soil deposits and about 170 m of Devonian and Upper Silurian dolostones;
- an intermediate zone of Silurian shales and dolostones; and
- a deep zone of Ordovician shales and limestones, including the underlying Cambrian sandstone and Precambrian basement.

The Descriptive Geosphere Site Model [11] has further subdivided these zones into a series of nine hydrostratigraphic (HS) units (Figure 5.6.1-1). Units 1 and 2 represent the shallow zone; Units 3, 4A and 4B represent the intermediate zone; and Units 5 to 9 represent the deep zone.

5.6.1.1 Shallow Groundwater System

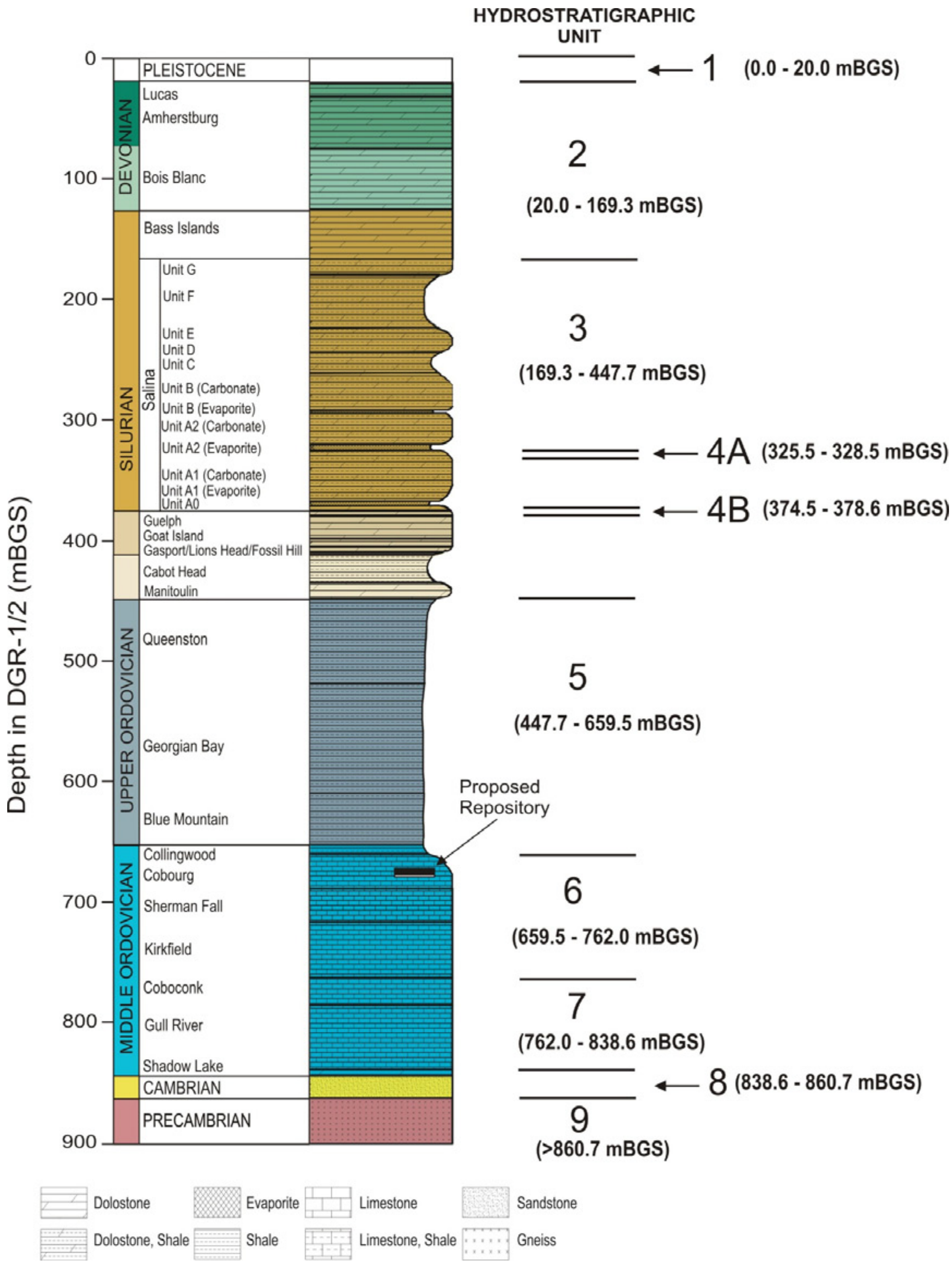
The shallow groundwater zone at the Bruce nuclear site is characterized by layers with high permeability, and a groundwater composition with relatively low total dissolved solids (TDS) concentrations (Figure 5.7.1-5) [3]. The shallow zone includes the glacially deposited Quaternary sediments, the Devonian Lucas, Amherstburg and Bois Blanc limestone and dolostone formations, and the Silurian Bass Islands Formation. The direction of groundwater flow in the shallow zone is strongly influenced by topography. Due to the low TDS concentrations, the higher groundwater velocities in the shallow zone are dependent on energy gradients that are relatively independent of fluid density. Solute transport in the shallow groundwater zone is dominated by advection and related mechanical dispersion.

Overburden at the Bruce nuclear site (HS Unit 1) is of variable thickness ranging from a thin veneer near Lake Huron to upwards of 20 m in the southeastern part of the site near US-6 and DGR-1/2 (Figure 5.1.2-1). In the vicinity of the proposed DGR at DGR-1/2, the overburden consists of 2 to 3 m layers of granular fill and basal gravel overlying and underlying 15 m of sandy silt till, which classifies the overburden as an aquitard.

An extensive database of hydraulic tests of the overburden at the Bruce nuclear site was acquired as part of radioactive waste management at the existing Western Waste Management Facility (WWMF) and other investigations [121;22;33]. The bulk horizontal hydraulic conductivity (K) for unweathered sandy silt till at the Bruce nuclear site ranges from 1×10^{-10} to 6×10^{-9} m/s, with an average or estimated value of 8×10^{-10} m/s. Horizontal:vertical K anisotropy has been evaluated at 2:1 with water loss porosity of 20%.

Specific storage values for HS Unit 1, based on literature review of similar soils, and review of on-site hydraulic testing, are estimated to be about 1×10^{-3} $m^{-1.}$

Vertical hydraulic gradients are typically about 0.1 m/m in both upward and downward directions depending upon proximity to the regional groundwater discharge area of Lake Huron.



Source: [11]

Figure 5.6.1-1: Reference Stratigraphic Column Showing Hydrostratigraphic Units at the Bruce Nuclear Site

Local perched groundwater conditions can occur within the thin surface layer of sand (or sand and gravel) and the shallow weathered till horizon due to surface infiltration collecting above the low permeability unweathered Upper Till horizon. Where this Upper Till horizon is thin, infiltration can pass into the Middle Sand aquifer, which is likely to occur beneath the southwestern portion of the WWMF portion of the Project Area, where the Upper Till is thin or absent. The Middle Sand aquifer can also directly recharge the bedrock surface where the Lower Till is thin or absent.

The extent of the Middle Sand Aquifer and the groundwater flow regime north and west of the WWMF, between the WWMF portions of the Project Area and the former Heavy Water Plant, is not defined due to a limited amount of borehole data. The direction of groundwater flow in the unweathered glacial till (till aquitard) is expected to be downward to either the Middle Sand aquifer or the carbonate bedrock aquifer in response to downward vertical hydraulic gradients.

Several monitoring wells have been installed in the vicinity of the former Heavy Water Plant as part of the 1998 ESA. In the vicinity of the former Heavy Water Plant, the overburden (fill/sand and gravel) is hydraulically connected to the underlying fractured bedrock. Groundwater levels beneath the former Heavy Water Plant are in the range of 177 to 184 mASL, with the flow in a northwest direction towards Lake Huron.

The groundwater levels in the bedrock beneath the WWMF portion of the Project Area occur between elevations of approximately 181 and 183 mASL, or about 8 to 10 m below ground surface (approximately 4 to 8 m above lake level). Therefore, the water levels in the bedrock monitoring wells rise to levels within the overlying till. In addition, site spatial variability in the groundwater flow system beneath the WWMF portion of the Project Area has been documented and simulated with three-dimensional groundwater flow models [21;22]. There are flows within the carbonate aquifer that are anomalously high, which have been attributed to "windows" through the unweathered till that separates the Middle Sand aquifer from the underlying carbonate aquifer.

There also appears to be a local groundwater divide in the potentiometric surface within the shallow bedrock, between the former BHWP and the WWMF; however, it does not seem possible that a groundwater divide could be sustained in the shallow bedrock aquifer given the high hydraulic conductivity of the shallow bedrock (2×10^{-6} to 8×10^{-8} m/s), which is generally higher than any of the overlying soil units including the Middle Sand Aquifer, a relatively localized feature. It should be noted that there is an intricate system of surface water drainage and shallow groundwater collection systems within and outside the Project Area that can affect the site hydrogeology. Between the WWMF and the former Heavy Water Plant, there are areas that are both paved and unpaved, and surface water runoff is collected by the existing drainage system which is monitored for radioactivity prior to being discharged to the Railway Ditch, and ultimately into Lake Huron [122]. Within the WWMF portions of the Project Area, most surfaces are paved and are graded to collect surface water runoff within the storm water management system, which then passes through a sampling point prior to discharge to the Railway Ditch.

Overall, the groundwater levels indicate downward hydraulic gradients from the overburden to the bedrock beneath the west-central portion of the Bruce nuclear site, within and in the vicinity of the Project Area. These downward hydraulic gradients, in the range of 40%, indicate that the dominant direction of groundwater flow in the overburden within the Project Area is downward toward the underlying bedrock.

The underlying bedrock (HS Unit 2) comprises of a permeable dolostone aquifer from top of bedrock to reference depth of 169.3 m BGS at DGR-1. It includes the Lucas, Amherstburg, Bois Blanc, and Bass Islands formations. In the DGR boreholes the Unit is 149 to 179 m thick. HS Unit 2 includes the regional groundwater supply aquifer that typically extends to depths of 50 to 100 m, and the deeper, less permeable bedrock to the top of the Salina Formation.

Extensive packer testing and observations of drilling fluid loss show that the average horizontal hydraulic conductivities in the upper 100 m range from 2×10^{-6} to 8×10^{-8} m/s, generally decreasing with depth. However, the upper part of the Bass Islands Formation in all DGR boreholes at DGR-1 reference depths of 140 to 145 mBGS contains very permeable sections with hydraulic conductivity approximating 1×10^{-4} m/s. Below 145 mBGS, the hydraulic conductivity of HS Unit 2 decreases to average values of about 1×10^{-6} m/s. The horizontal:vertical K anisotropy is assumed to be 10:1. Based on lab testing of the Bois Blanc and Bass Islands formations in DGR boreholes, an average total porosity of 7% is assumed for HS Unit 2.

Specific storage values for HS Unit 2, based on literature review of similar rock, review of on-site hydraulic testing, and calculations from lab measurements of rock compressibility and liquid porosity, are estimated to be in the range of 8×10^{-7} to 3×10^{-6} m^{-1}, generally increasing with depth.

Vertical and horizontal hydraulic gradients in HS Unit 2 are low (i.e., 0.001 to 0.01 m/m), reflecting high hydraulic conductivities, with flow gradients directed upward and laterally to the northwest toward Lake Huron.

5.6.1.2 Intermediate Groundwater System

Separating the shallow and deep groundwater zones are the layers of the intermediate groundwater zone, which extends from the base of the Bass Islands Formation to the bottom of the Lower Silurian Manitoulin Formation. Within this zone, the low permeability aquitard units within the Salina Formation, where present, isolate the topographically driven shallow flow system from that of the underlying Ordovician shale and limestone formations. The Lower to Middle Silurian dolostones form the most permeable layer in the intermediate zone.

HS Unit 3 comprises the low permeability Upper Silurian shale, dolostone and anhydrite rocks from DGR-1 reference depths of 169.3 to 447.7 mBGS. HS Unit 3 includes three aquitards: upper, middle and lower, separated by two Silurian dolostone aquifers (HS Units 4A and 4B), which are found at DGR-1 reference depths of 325.5 and 374.5 mBGS. The upper aquitard comprises the Salina Units G, F, E, D, C, B and most of A2 found at reference depths of 169.3 to 325.5 mBGS. The middle aquitard includes the Salina A1 and A0 Units found at reference depths of 328.5 to 374.5 mBGS. The lower aquitard consists of the Goat Island, Gasport, Lions Head, Fossil Hill, Cabot Head and Manitoulin formations, found at reference depths of 378.6 to 447.7 mBGS. HS Unit 3 has a combined thickness of 260.7 to 271.3 m in DGR boreholes.

Borehole straddle-packer testing shows that the average horizontal hydraulic conductivities for formations and units that comprise HS Unit 3 range from 5×10^{-14} to 3×10^{-10} m/s, with most values at or less than 1×10^{-12} m/s. Based on lab permeability testing, the horizontal:vertical K anisotropy is estimated to be 10:1. Based on lab testing, average liquid porosities for HS Unit 3 formations and units range from 1 to 20%, with a calculated bulk HS Unit 3 average value of

8.9%. The upper aquitard and the Cabot Head shale of the lower aquitard have higher average porosity (approximately 15%) than the middle aquitard and the remaining formations comprising the lower aquitard (average 3%).

Specific storage values for HS Unit 3, based on calculations from lab measurements of rock compressibility and liquid porosity, are estimated to be in the range of 4×10^{-7} to 5×10^{-6} m^{-1}, generally decreasing with depth into the more competent Silurian dolostones. Elevated specific storage values are noted for the Cabot Head shale, approximately 3×10^{-5} m^{-1}.

Pressures in the upper and middle aquitards of HS Unit 3 are moderately under-pressured, with the maximum under-pressure (approximately 70 mBGS) occurring in the middle of the sequence in the Salina C and B Units. Based on environmental heads, vertical hydraulic gradients in the upper and middle aquitards of HS Unit 3 are moderate (0.1 to 0.5 m/m) upward and downward to the maximum under-pressured zone, reflecting the low vertical hydraulic conductivities of the aquitard. Vertical hydraulic gradients in the lower aquitard are much higher (1.0 to 3.0 m/m), being both upward and downward from the high pressure zone straddling the Salina A1 and A0 Units and the Goat Island, Lions Head and Fossil Hill formations These high vertical gradients suggest that the bedrock of the bottom part of the middle aquitard and lower aquitard must be of very low permeability in order to maintain such high hydraulic gradients.

HS Unit 4 comprises two thin porous and permeable aquifers evident in core logging, borehole geophysical logging, hydraulic testing and groundwater sampling completed in DGR boreholes. The upper aquifer (4A) is found at reference depths 325.5 to 328.5 mBGS in DGR-1 and is the upper 3.0 to 3.7 m of the Salina A1 Unit dolostone in DGR boreholes. The lower aquifer (4B) is found at reference depths 374.5 to 378.6 mBGS in DGR-1 and is the entire thickness of the Guelph Formation dolostone. The lower aquifer ranges in thickness from 4.1 to 5.4 m thickness in DGR boreholes.

Borehole straddle-packer testing, and observations during targeted groundwater sampling in DGR-3 and DGR-4 show that the average horizontal hydraulic conductivities in the Silurian dolostone aquifers (4A and 4B) approximate 2×10^{-7} and 3×10^{-8} m/s, respectively. Based on core observations, the horizontal:vertical K anisotropy is assumed to be 1:1. Again, based on core observations and limited lab testing [123], an average total porosity of 7.0% is assumed for HS Unit 4A and 5.7% for HS Unit 4B.

Specific storage values for HS Unit 4B, based on calculations from lab measurements of rock compressibility and liquid porosity, are estimated to be about 1×10^{-6} m^{-1}. This specific storage value is assumed to be applicable to HS Unit 4A, based on similarity of lithology and porosity.

Vertical hydraulic gradients in both dolostone aquifers of HS Unit 4 are negligible based on the observed high permeability and limited thickness. Horizontal hydraulic gradients for HS Unit 4A are calculated from MP55 casing pressure measurements at 0.0086 m/m, with groundwater flow directed to the northwest toward Lake Huron. Horizontal hydraulic gradients for HS Unit 4B, also calculated from MP55 casing pressure measurements, are 0.0045 m/m, with groundwater flow directed to the northeast.

5.6.1.3 Deep Groundwater System

The deep groundwater zone comprises the layers beneath the Manitoulin Formation, including the Ordovician limestones and shales, the Cambrian sandstones, and the crystalline Precambrian basement. Groundwater in the deep zone can be characterized as stagnant, with high TDS concentrations that can exceed 300 g/L, and a corresponding specific gravity of approximately 1.2. The term stagnant is used to define a groundwater domain in which solute transport is dominated by molecular diffusion and unaffected by predicted groundwater velocities. Because the deep groundwater zone is isolated from any local topographic effects by the very low hydraulic conductivities of the overlying Silurian sediments, the horizontal energy gradients will be very low and strongly influenced by density gradients. The only location within the regional domain at which a significant gravitational gradient may exist is the Niagara Escarpment, where some of the formations in the deep groundwater zone sub-crop or outcrop. The most permeable formation in the deep zone is the Cambrian; however, published evidence indicates that in the vicinity of the Bruce nuclear site this layer is relatively thin and discontinuous within tens of kilometres to the east of the site.

HS Unit 5 comprises the very low permeability massive Ordovician shale sequence from reference depths of 447.7 to 659.5 mBGS in DGR-1/2. HS Unit 5 includes the Queenston, Georgian Bay and Blue Mountain formation shales, and the Collingwood Member shale of the Cobourg Formation. The Unit is 211.8 to 216 m thick in DGR boreholes.

Borehole straddle-packer testing shows that the average horizontal hydraulic conductivities for HS Unit 5 range from 2×10^{-14} to 5×10^{-14} m/s. Based on laboratory petrophysical testing, the horizontal:vertical K anisotropy is assigned a value of 10:1. Based on extensive testing by different laboratories using different testing methods, an average total porosity of 7.5% is assumed. The siltstone and argillaceous limestone hard beds that occur within the shales have lower average total porosity of 2.0%.

Specific storage values for HS Unit 5, based on calculations from lab measurements of rock compressibility and liquid porosity, are estimated to be in the range of 1×10^{-6} to 2×10^{-5} m^{-1}, generally increasing with depth into the softer Blue Mountain shales. Specific storage values for the Collingwood Member approximate 8×10^{-7} m^{-1}.

Formation pressures in the Ordovician shales are significantly under-pressured. After shut-in periods of up to 18 months, formation pressures in HS Unit 5 are not yet stable, with maximum under-pressures of about 300 mBGS, expressed as environmental water head, occurring within the Blue Mountain Formation. Based on the environmental heads, vertical hydraulic gradients in HS Unit 5 are generally strongly downward (approximately 1.2 to 1.5 m/m) toward the Blue Mountain Formation. Although the genesis of these under-pressures is ambiguous, their occurrence and persistence are clearly indicative of very low formation permeability.

It is a characteristic of HS Unit 5 that a normally-pressured zone of higher test interval compressibility and hydraulic conductivity occurs within the otherwise under-pressured and very low hydraulic conductivity aquiclude. These features appear to be associated with discrete inclined and sub-horizontal fractures.

Laboratory diffusion testing undertaken on DGR shale core samples collected from HS Unit 5 shows vertical effective diffusion coefficients for iodide of about 4×10^{-13} to 3×10^{-12} m^2/s, generally decreasing with depth and showing a horizontal:vertical D_e anisotropy of about 2:1. A bimodal distribution of iodide effective diffusion coefficient and porosity is recognized from diffusion testing based on the presence of two distinct lithologies (shale and limestone/siltstone hardbeds) within HS Unit 5. The vertical effective diffusion coefficients for the HS Unit 5 hardbeds range from 3×10^{-14} to 4×10^{-13} m^2/s. The estimated iodide diffusion porosity values are 4.5% for the massive shales, and 2% for the siltstone/limestone hardbeds within those shales.

The persistent formation under-pressures, and the uniform porewater chemistry profiles, indicate that no significant fluid flow has occurred within HS Unit 5, supporting its designation as an aquiclude.

HS Unit 6 comprises the very low permeability argillaceous limestone of the Lower Member of the Cobourg Formation — the proposed DGR repository horizon — and the underlying limestones of Sherman Fall and Kirkfield formations. HS Unit 6 is found at reference depths of 659.5 to 762.0 mBGS at DGR-2. The Unit is 101.5 to 104.1 m thick in DGR boreholes.

Borehole straddle-packer testing and some laboratory petrophysical testing shows that the average horizontal hydraulic conductivity for the formations that comprise HS Unit 6 range from 8×10^{-15} to 2×10^{-14} m/s, with bulk Unit average of 1×10^{-14} m/s. Based on laboratory petrophysical testing, the horizontal:vertical K anisotropy is assigned a value of 10:1. Based on extensive testing by different laboratories, using different testing methods, an average total porosity of 1.9% is assumed for the argillaceous limestones of HS Unit 6.

Specific storage values for HS Unit 6, based on calculations from lab measurements of rock compressibility and liquid porosity, are estimated to be in the range of 2×10^{-7} to 3×10^{-6} m^{-1}, with an average value of about 8×10^{-7} m^{-1}.

Formation pressures in the Cobourg, Sherman Fall and Kirkfield formations are under-pressured and very slow to achieve stable conditions. Stable formation pressures in HS Unit 6 have not yet been measured following shut-in periods of 15 months after initial installation of MP55 casing systems in DGR-2. The current best estimates of under-pressures in HS Unit 6 expressed as environmental heads approximate 250 mBGS. Based on environmental heads, vertical hydraulic gradients in HS Unit 6 are moderately to strongly upward (approximately 0.5 to 1.0 m/m) toward the Blue Mountain Formation. Although the genesis of these under-pressures is ambiguous, their occurrence is clearly indicative of very low formation permeability.

Laboratory diffusion testing undertaken on DGR core samples collected from HS Unit 6 shows vertical effective diffusion coefficients for iodide of about 1×10^{-13} to 9×10^{-13} m^2/s with an average value of about 3×10^{-13} m^2/s. Similar to other low permeability HS units, a horizontal:vertical D_e anisotropy of about 2:1 is determined for HS Unit 6 from available diffusion testing. Average iodide diffusion porosity was measured at about 1.3%.

The formation under-pressures and the porewater chemistry profiles indicate that no significant fluid flow has occurred within HS Unit 6, supporting its designation as an aquiclude.

HS Unit 7 comprises the low permeability Ordovician limestone sequence from reference depths of 688.1 to 838.6 mBGS at DGR-2. HS Unit 7 includes the Coboconk and Gull River formations (i.e., the Black River Group limestones). In DGR boreholes, the Unit is 75.4 to 76.6 m thick.

Borehole straddle-packer testing, and laboratory petrophysical testing, shows that the average horizontal hydraulic conductivity for HS Unit 7 ranges from 2×10^{-13} to 5×10^{-11} m/s, with some higher lab values reported in bottom of the Gull River Formation. The estimated average horizontal hydraulic conductivity for the HS Unit is 5×10^{-12} m/s. Based on laboratory petrophysical testing, the horizontal:vertical K anisotropy is assumed to be 10:1 throughout HS Unit 7. However this anisotropy estimate may be low within the Coboconk Formation if formation permeability is preferentially associated with some thin zones that are suspected to have increased hydraulic conductivity based on interpretation of borehole geophysical logs. Based on extensive testing by different laboratories using different testing methods, an average total porosity of 1.4% is assumed for the limestones of HS Unit 7.

Because there are no lab geomechanical tests on core collected from HS Unit 7, specific storage values for HS Unit 7 are estimated based on data from overlying HS Unit 6. Consequently, specific storages are estimated to be in the range of 2×10^{-7} to 3×10^{-6} m^{-1}, with an average value of about 8×10^{-7} m^{-1}.

Formation pressures and calculated fresh water and environmental heads in HS Unit 7 are normally pressured to over-pressured and achieve stable conditions quickly within several weeks to a few months of casing installation, reflecting higher formation permeabilities relative to the overlying lower permeability units. Based on environmental heads, vertical hydraulic gradients in HS Unit 7 are strongly upward (approximately 1.6 to 2.2 m/m) toward the Kirkfield Formation, reflecting over-pressuring from the deeper Cambrian sandstone. Laboratory diffusion testing undertaken on DGR core samples collected from HS Unit 7 shows vertical effective diffusion coefficients for iodide of about 5×10^{-14} to 9×10^{-13} m^2/s with an average value of about 3×10^{-13} m^2/s. Similar to other low permeability HS units, a horizontal:vertical D_e anisotropy of about 2:1 is determined for HS Unit 7 from available diffusion testing. Average iodide diffusion porosity in HS Unit 7 was measured at about 1.2%.

HS Unit 8 comprises the permeable Cambrian sandstone and the overlying permeable Shadow Lake siltstone found at reference depths of 838.6 to 860.7 mBGS at DGR-2. In DGR boreholes the Unit is estimated to be 22.1 m thick. The hydraulic properties of HS Unit 8 are dominated by the high hydraulic conductivity and hydraulic heads of the middle to lower parts of the Cambrian rocks.

Borehole packer testing, opportunistic groundwater sampling, and laboratory petrophysical testing, show that the average horizontal hydraulic conductivity for HS Unit 8 ranges from 1×10^{-9} m/s for the Shadow Lake Formation [82] and upper parts of the Cambrian sandstone, to 3×10^{-6} m/s for the bulk of the Cambrian rocks. Given the permeable nature of HS Unit 8, the hydraulic conductivity of HS Unit 8 is assumed to be isotropic. Based on extensive testing by different laboratories using different testing methods, an average total porosity of 10.1% is assumed for the Cambrian sandstones. Lower values of about 2 to 10% have been measured in the less permeable upper part of the Cambrian sequence and in the Shadow Lake Formation. The overall average total porosity for HS Unit 8 is 9.5%.

Because there are no laboratory geomechanical tests on core collected from HS Unit 8, specific storage values for HS Unit 8 are estimated based on data from overlying HS Units, known HS Unit 8 porosity, and literature review. Consequently, specific storage is estimated to about 1×10^{-6} m^{-1}.

Formation pressures and calculated fresh water and environmental heads in HS Unit 8 are significantly over-pressured with formation pressures of about 11,000 kPa and environmental heads of 350 mASL (165 m above ground surface). These pressures and heads have been consistently measured during opportunistic groundwater sampling, flow tests of the Cambrian sandstone, and with Westbay MP55 casing installations in all DGR holes. These high Cambrian Formation pressures propagate upward into the overlying Shadow Lake, Gull River and Coboconk formations. Vertical hydraulic gradients in HS Unit 8 are assumed to be negligible based on the observed high hydraulic conductivities. Horizontal hydraulic gradients for HS Unit 8 are calculated from MP55 casing pressure measurements at 0.0020 to 0.0031 m/m, with groundwater flow directed to the east away from the centre of the Michigan Basin.

Diffusion testing was not undertaken in HS Unit 8 in during site characterization activities. Based on core observations, known porosity results from testing on comparable DGR core, and scientific literature, the vertical effective diffusion coefficient for iodide in HS Unit 8 is estimated at 5×10^{-11} m^2/s, the same as for permeable HS Unit 4. The horizontal:vertical D_e anisotropy is assumed to be 1:1 based on core observations. Diffusion porosity is assumed equal to liquid porosity at 9.5%.

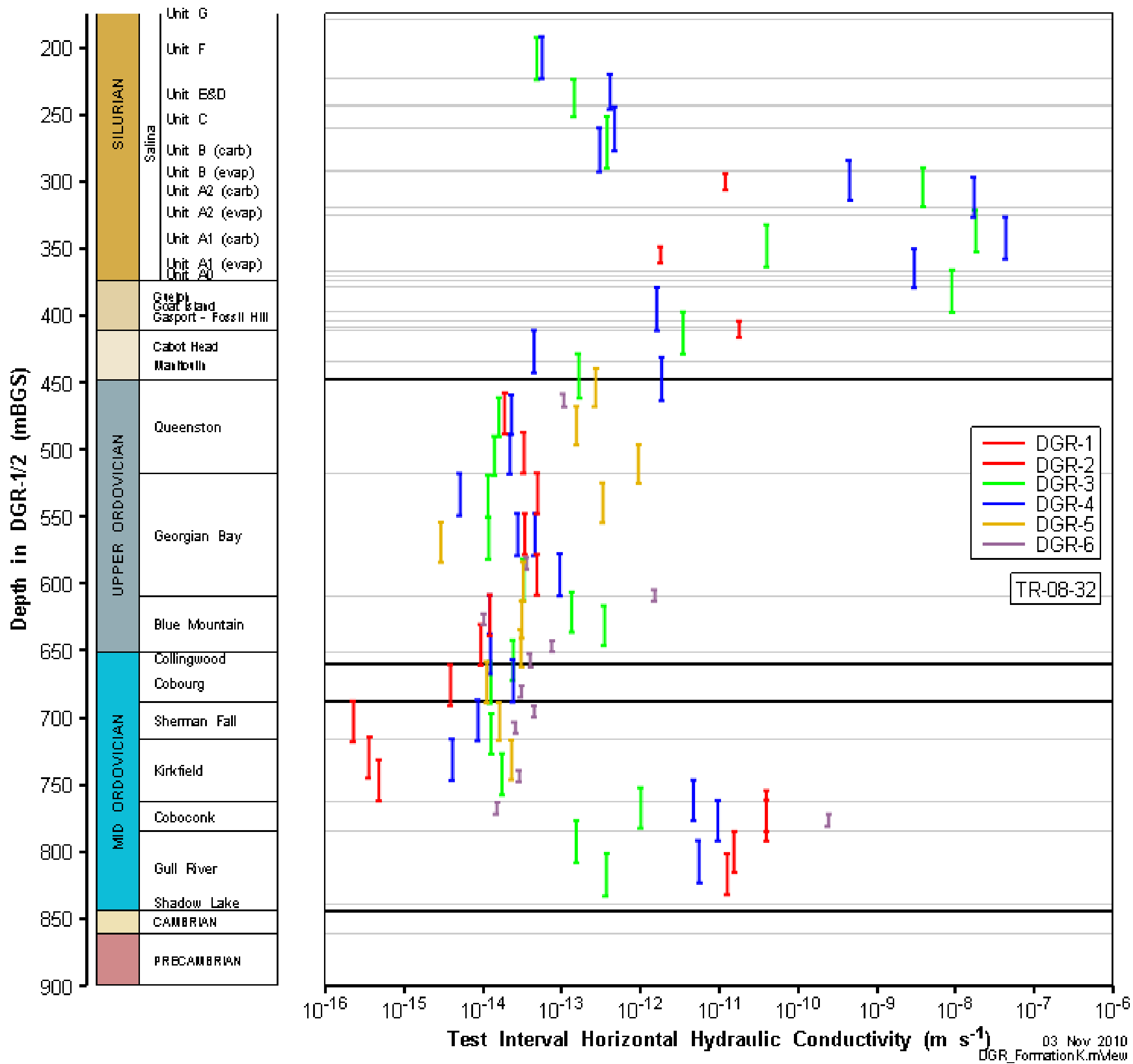
HS Unit 9 comprises the moderate to low permeability basement rock of the Precambrian granite gneiss underlying the Cambrian sandstone. At DGR-2 the Unit is found at reference depth of 860.7 mBGS. Based on appearance of the 1.55 m of core obtained from DGR-2, HS Unit 9 is comprised of competent, moderately fractured, weathered felsic granite gneiss.

5.6.1.4 Environmental Heads and Hydraulic Conductivity

Hydraulic Conductivity

The calculated formation hydraulic conductivities of DGR boreholes are summarized versus depth and formation in Figure 5.6.1-2. No straddle-packer hydraulic test results are available for the Shadow Lake Formation and Cambrian sandstone because of the installation of temporary product-injection packers (PIPs) to control formation fluid flow from the Cambrian sandstone.

The calculated test interval hydraulic conductivities in DGR boreholes below the Salina G Unit range from 1×10^{-16} to 1×10^{-8} m/s. The lowest measured test interval hydraulic conductivities of less than 1×10^{-15} m/s were determined from testing of the Sherman Fall and Kirkfield formations in DGR-2. The highest test interval hydraulic conductivities of greater than 1×10^{-8} m/s were determined for tests that included the porous and permeable sections of the Salina Upper A1 Unit and the Guelph Formation. The bedrock below the Guelph Formation to the Queenston shale has test interval hydraulic conductivities between 1×10^{-14} and 1×10^{-11} m/s. The bulk of the Ordovician shales and all the Ordovician limestones from the Cobourg Formation to the Kirkfield Formation (i.e., the Trenton Group) have very low test interval hydraulic conductivity values of less than 1×10^{-15} to 1×10^{-14} m/s. Slightly higher test interval hydraulic conductivities (9×10^{-14} to 3×10^{-13} m/s), attributed to identified single fractures or zones of closely spaced fractures, were measured within one test interval in each DGR borehole (lower Georgian Bay in DGR-2 and DGR-4, Blue Mountain in DGR-3). The deeper Ordovician limestones of the Black River Group (Coboconk and Gull River formations) have higher test interval hydraulic conductivities between 1×10^{-13} and 1×10^{-11} m/s.



Source: [11]

Figure 5.6.1-2: Profile of Test Interval Hydraulic Conductivity Estimates Determined from Field Straddle-packer Testing in DGR Boreholes

Environmental Heads

MP55 casings were installed in DGR-1 and DGR-2 on September 25 and December 13, 2007, respectively. MP55 casings were installed in DGR-3 and DGR-4 on September 28 and April 30, 2009, respectively. The original MP55 casing installed in DGR-2 was removed on June 5, 2009 and replaced with an improved MP55 casing system on December 2, 2009.

In the very low permeability formations that characterize large sections of all DGR boreholes, formation pressures are slow to equilibrate. Consequently, measured formation pressures in DGR boreholes are reported for selected monitoring dates that provide a reasonable representation of the temporal evolution of formation pressures. Figures 5.6.1-3 through 5.6.1-5 show profiles of formation pressures and environmental heads in boreholes DGR-2 through DGR-4. The pressure and environmental head data illustrated from these three DGR boreholes are remarkably similar. Preliminary pressure profiles and environmental heads were measured only during hydraulic testing of DGR-5 and DGR-6, and MP55 casings were not installed in the inclined boreholes. The profiles from the inclined boreholes are shown in Figures 5.6.1-6 and 5.6.1-7. The pressure profile from DGR-5 is consistent with those from DGR-2 through DGR-4. In borehole DGR-6; however, the results are dissimilar to those described for the other DGR boreholes, with six over-pressured intervals within the Trenton Group limestones, two normally-pressured intervals within the Ordovician shales, and four under-pressured zones within the Ordovician shales. The estimated maximum under-pressure approaches only -150 mASL.

The pressure and head data show minor under-pressure in the Salina Formation that increases to over-pressure in the Gasport to Fossil Hill formations and then rapidly transitions to significant under-pressure within the Ordovician shales and the Trenton Group limestones. All of the deeper Black River Group formations are over-pressured. Stable formation pressures are evident for the permeable formations, including the Salina Upper A1 Unit, the Guelph and the Cambrian sandstone.

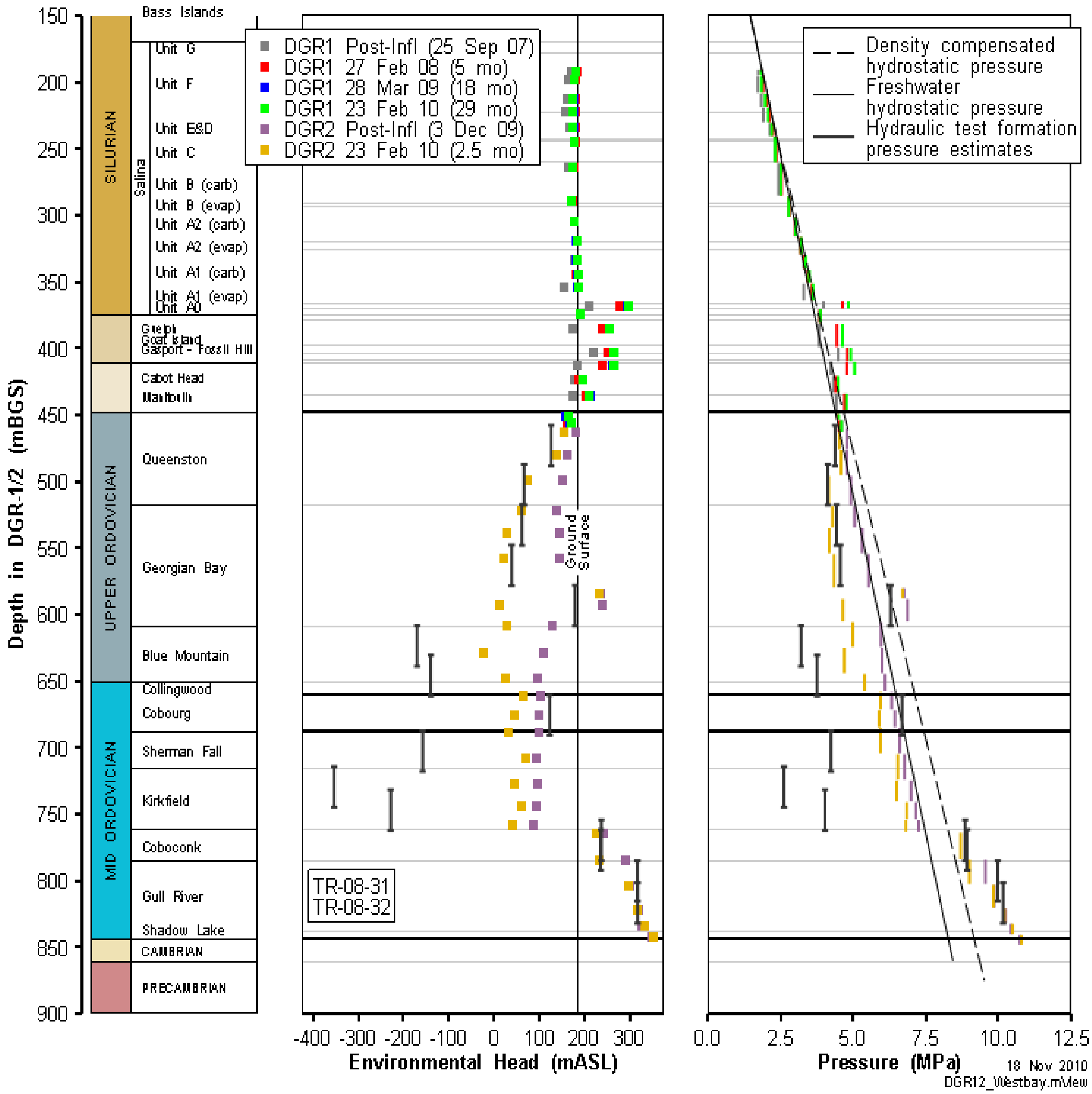


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Figure 5.6.1-3: Combined DGR-1 and DGR-2 (New) Formation Pressure and Environmental Head Profiles

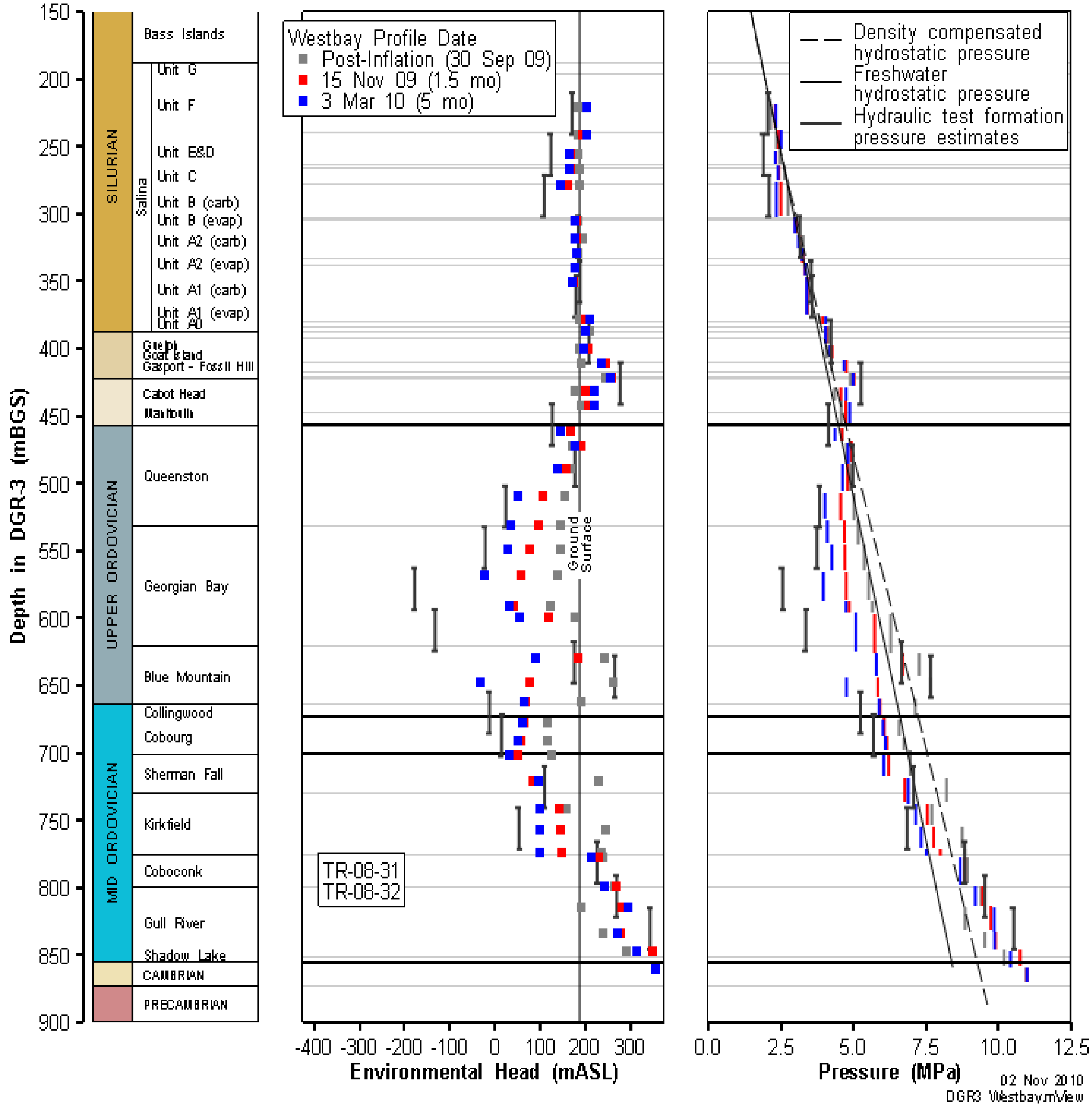

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Figure 5.6.1-4: DGR-3 Formation Pressure and Environmental Head Profiles

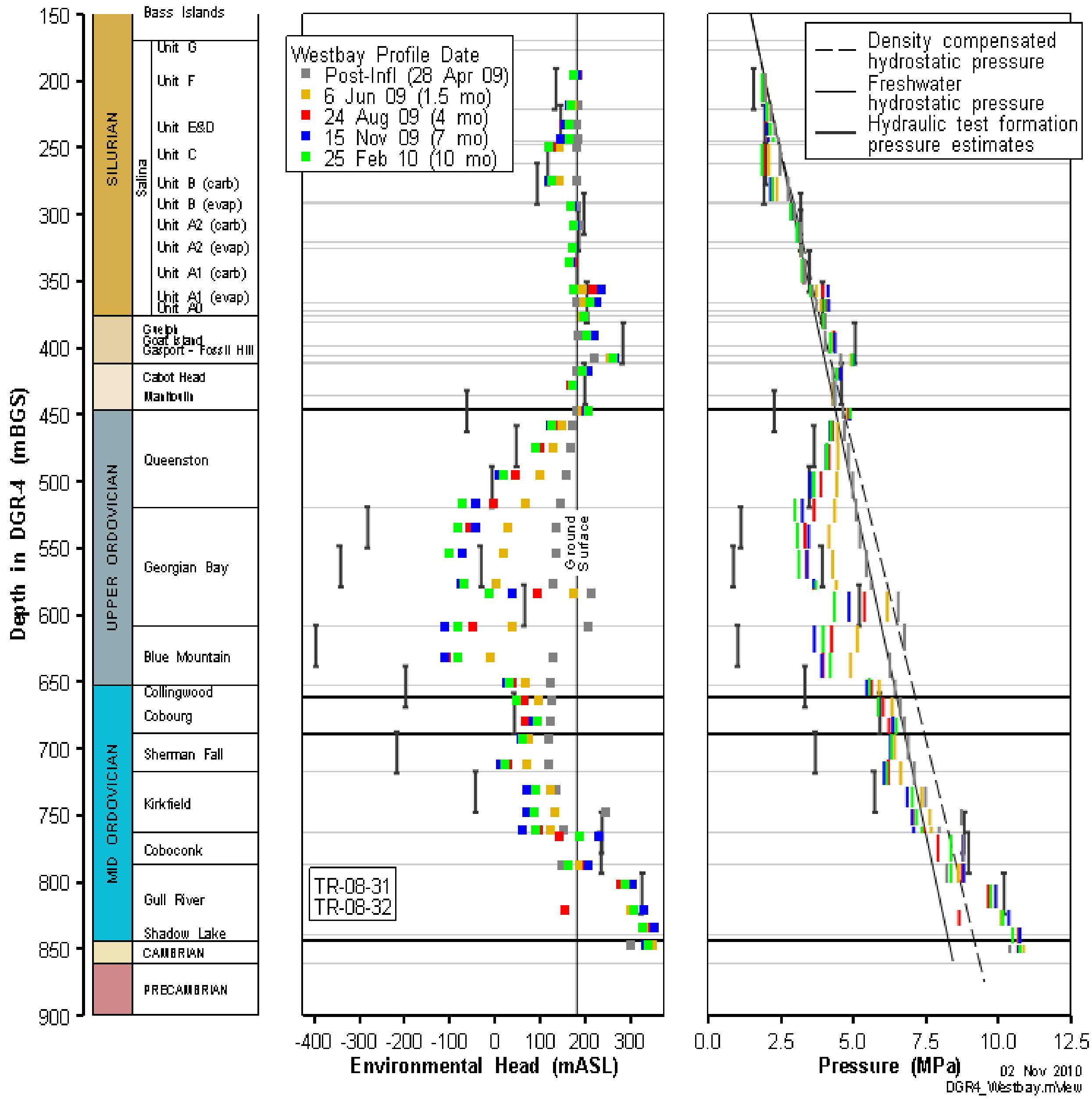

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Figure 5.6.1-5: DGR-4 Formation Pressure and Environmental Head Profiles

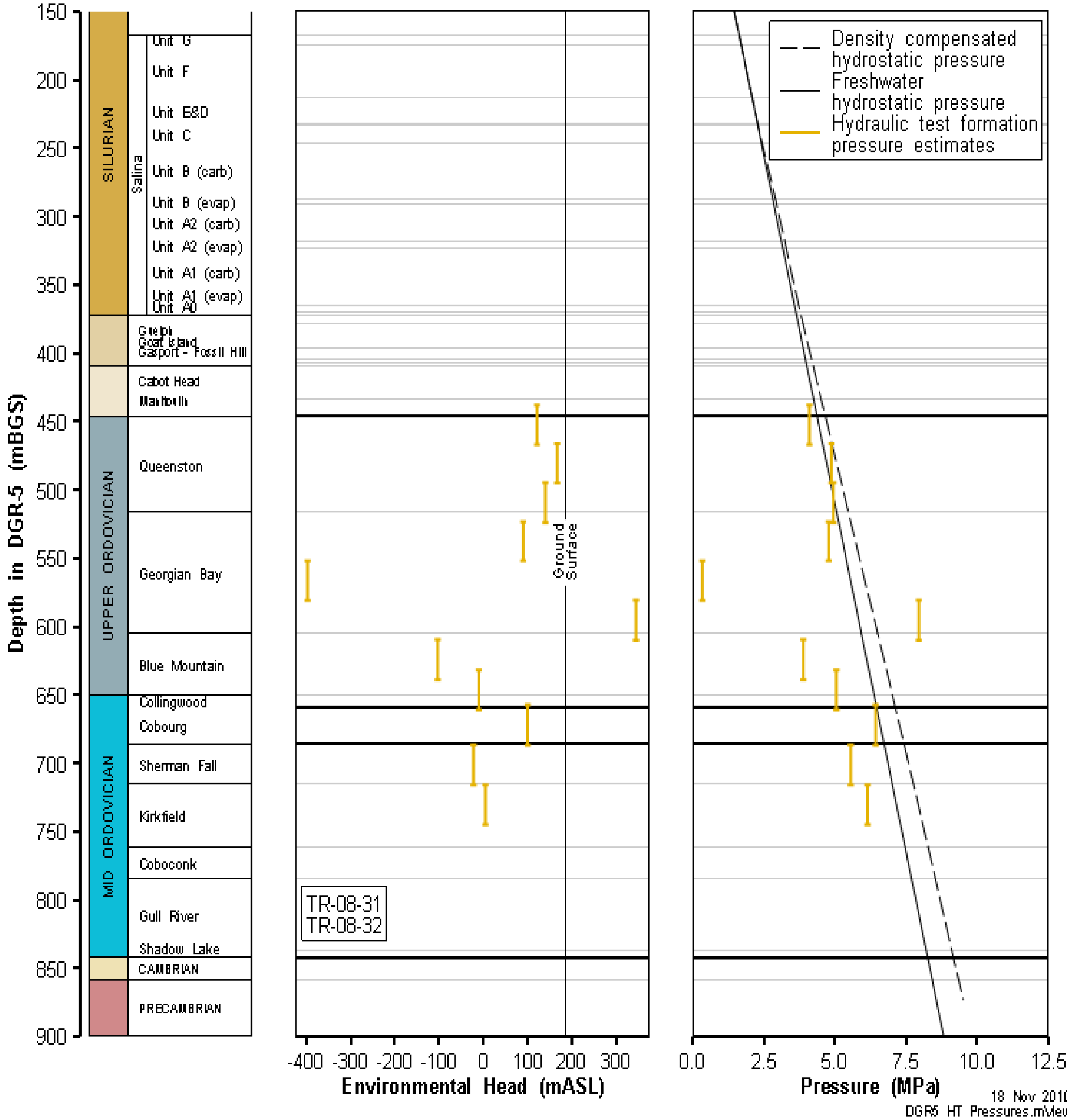


Figure 5.6.1-6: DGR-5 Formation Pressure and Environmental Head Profiles

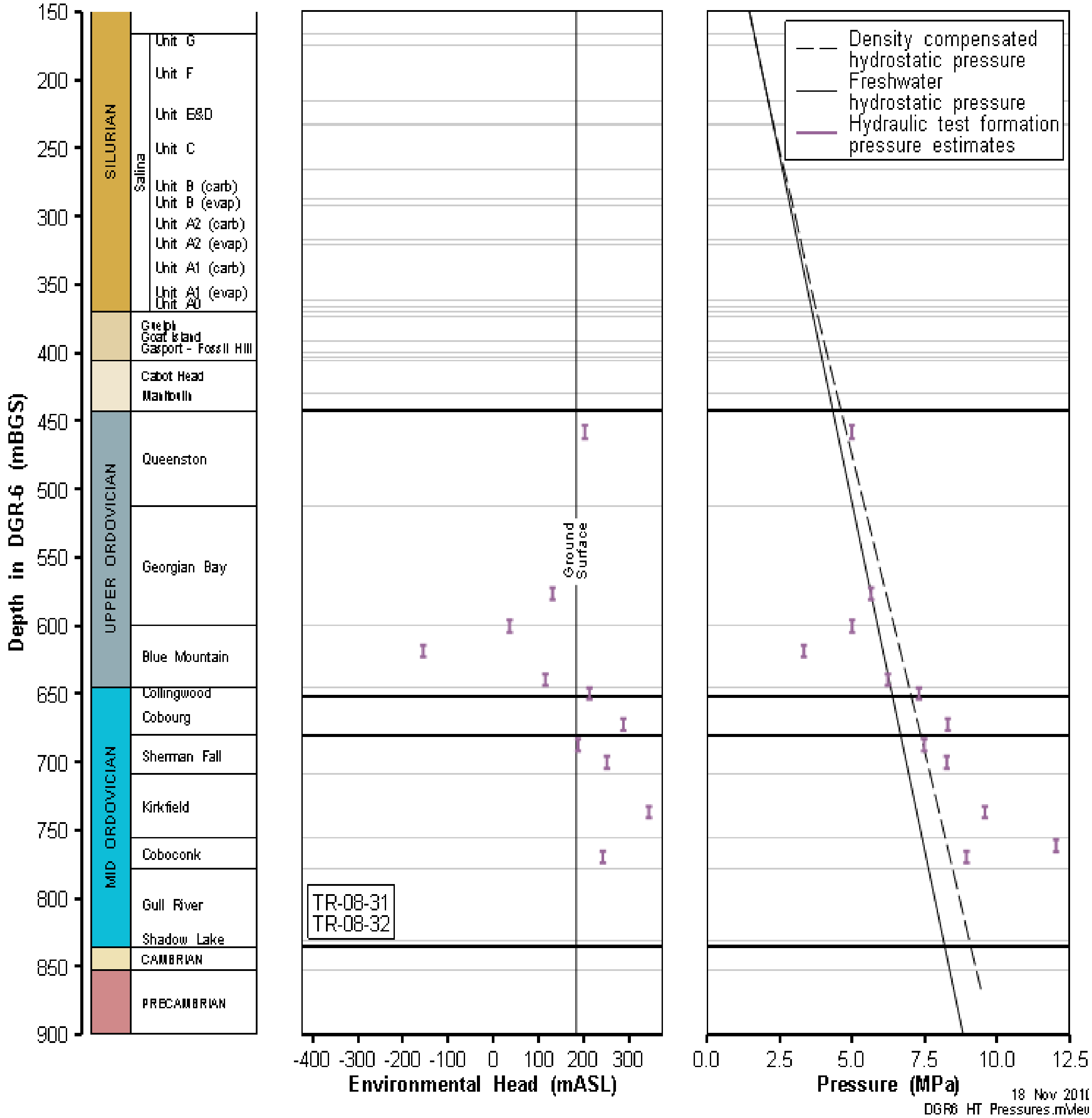


Figure 5.6.1-7: DGR-6 Formation Pressure and Environmental Head Profiles

The available pressure measurements from all the DGR borehole shows the following general environmental head conditions related to over-pressures and under-pressures:

- under-pressures in the Salina Formation, with maximum under-pressures occurring within the C and B Units and environmental heads of 70 mBGS;
- over-pressures in the Salina A1 and A0 Units, and Gasport to Fossil Hill formations, with maximum over-pressures equal to environmental heads of 75 mAGS;

- under-pressures in the Ordovician shales and Trenton Group limestones, with maximum under-pressures occurring within the Blue Mountain Formation, and environmental heads of 300 mBGS; and
- over-pressures in the Black River Group limestones and siltstones, and the Cambrian sandstone, with maximum over-pressures equal to environmental heads of 165 mAGS.

The cause of the observed under-pressures and over-pressures and heads in DGR boreholes are not evident at this time and are not in hydrodynamic equilibrium with local topography and surface water elevations.

<u>*Groundwater Flow Directions*</u>

For the deeper permeable units intersected by DGR boreholes, horizontal groundwater flow directions are calculated from measured formation pressures obtained from MP55 casings, considering the density of the aquifer fluids and the dip of the formations. Table 5.6.1-1 summarizes the results of this assessment.

Table 5.6.1-1: Formation Pressures and Groundwater Flow Directions in DGR Deep Permeable Bedrock Units

Salina Upper A1 Unit			
Parameter (Units)	**Date of Pressure Measurements**		
	October 30, 2009	**January 27, 2010**	**April 26 & 27, 2010**
Adjusted Pressures for Mid-Depth of Horizontal Permeable Unit (kPa)	DGR-1: 3408.98 DGR-3: 3348.85 DGR-4: 3297.48	DGR-1: 3402.92 DGR-3: 3332.44 DGR-4: 3294.65	DGR-1: 3400.92 DGR-3: 3348.43 DGR-4: 3300.44
Equipotential Line (Azimuth)	231	221	232
Hydraulic Gradient (m/m)	0.0086	0.0084	0.0077
Groundwater Flow Direction (Azimuth) (degrees ^{o})	321	311	322
Guelph Formation			
Adjusted Pressures for Mid-Depth of Horizontal Permeable Unit (kPa)	DGR-1: 4066.82 DGR-3: 4103.91 DGR-4: 4060.99	DGR-1: 4036.28 DGR-3: 4079.44 DGR-4: 4058.17	DGR-1: 4036.69 DGR-3: 4071.78 DGR-4: 4056.72
Equipotential Line (Azimuth)	313	344	348
Hydraulic Gradient (m/m)	0.0039	0.0032	0.0026
Groundwater Flow Direction (Azimuth) (degrees ^{o})	43	74	78

Table 5.6.1-1: Formation Pressures and Groundwater Flow Directions in DGR Deep Permeable Bedrock Units (continued)

Cambrian Sandstone			
Parameter (Units)	**Date of Pressure Measurements**		
	December 8 & 9, 2009	**January 27, 2010**	**April 26 & 27, 2010**
Adjusted Pressures for Mid-Depth of Horizontal Permeable Unit (kPa)	DGR-2: 10990.64 DGR-3: 11015.98 DGR-4: 11010.58	Unreliable data	DGR-1: 10984.09 DGR-3: 11022.60 DGR-4: 11012.38
Equipotential Line (Azimuth)	2	Unreliable data	359
Hydraulic Gradient (m/m)	0.0020	Unreliable data	0.0031
Groundwater Flow Direction (Azimuth) (degrees ^{o})	92	Unreliable data	89

The results listed in Table 5.6.1-1 show the groundwater flow directions in the Upper A1 Unit aquifer are the same as those in the shallow dolostones, being to the northwest toward Lake Huron. In contrast, the calculated groundwater flow directions for the Guelph Formation and the Cambrian sandstone are outward from the middle of the Michigan Basin toward the northeast (Guelph Formation) and to the east (Cambrian sandstone).

5.6.1.5 Porosity

Porosity was measured on DGR rock cores by several laboratories [11;124;117;125]. These laboratories reported physical and/or water loss porosity values for DGR cores as part of petrophysical, diffusion and porewater testing programs. Total porosity (also known as physical porosity) is the ratio of the pore volume to the total volume of the rock sample, and was typically determined from bulk dry and grain density data. Liquid porosity is the volume of voids occupied by liquid (pure water plus dissolved solutes and oil). Water-loss porosity is the volume of the voids occupied by pure water divided by the total volume of the sample. Total porosity should equal liquid porosity plus porosity occupied by any gas (e.g., methane).

Figures 5.6.1-8 and 5.6.1-9 show the total and liquid porosity data for the core from the Bruce nuclear site, including arithmetic formation averages, plotted against depth and bedrock formation.

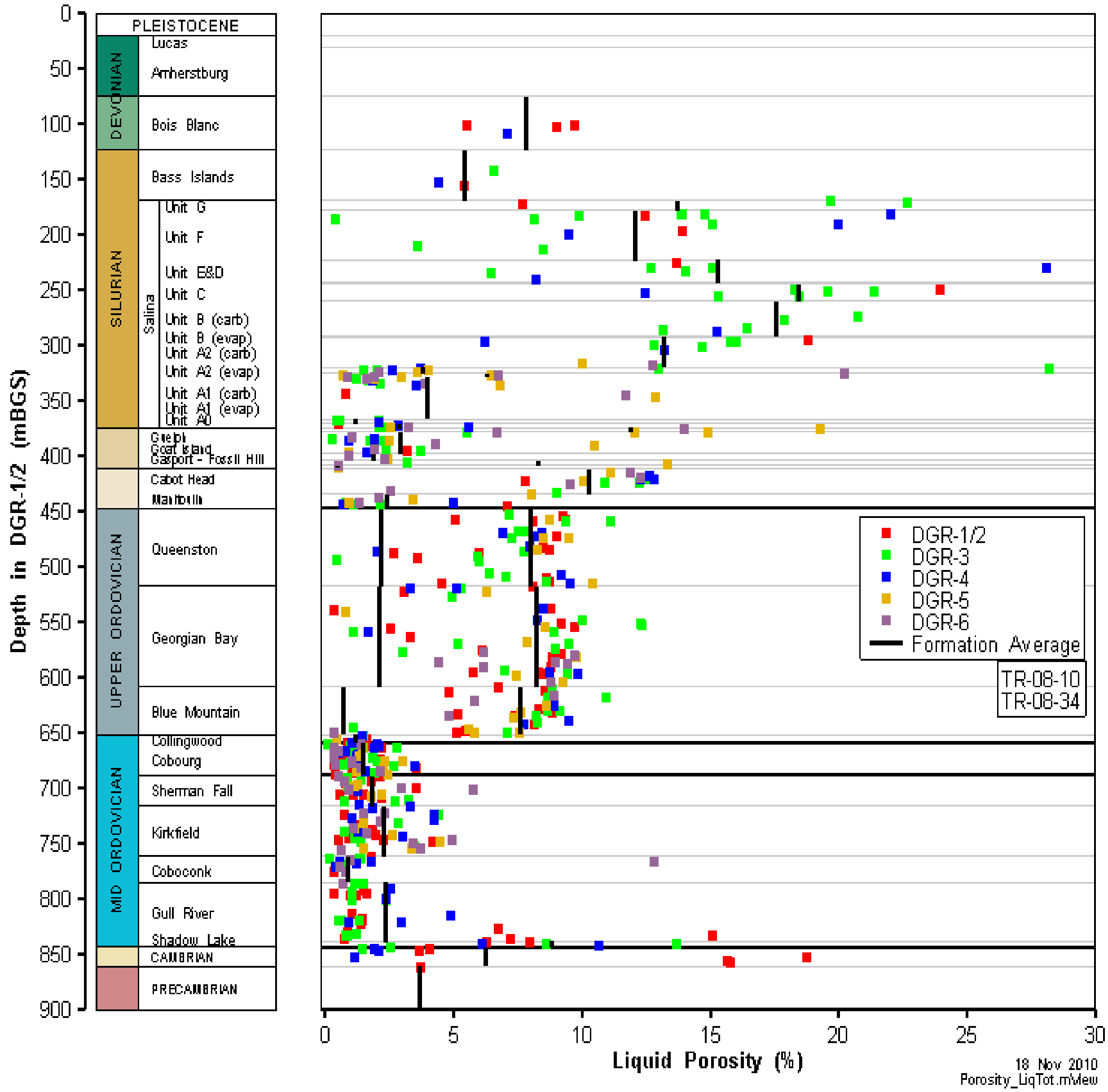
The total and liquid porosity measurements in the uppermost Silurian Salina F through A2 Units, as shown in Figures 5.6.1-8 and 5.6.1-9, range from 5 to 30%, often exceeding 10%. The highest measurements of liquid porosity occur in the Salina C Unit dolomitic shale and a shaly dolostone sample found in the Salina A2 Unit, with values of 14 to 30%. The mean liquid porosities reported for the Devonian and Silurian Units and formations range from 0.7% for the Salina A1 Unit Evaporite to 20.5% for the Salina C Unit dolostone. Silurian argillaceous dolostone and shale sequences as represented by the Salina G and F Units and Cabot Head Formation show liquid porosities of 17, 13 and 12%, respectively. Other Silurian dolostone sequences including the Bass Islands, Goat Island and Manitoulin formations, and Salina A1

Unit, show variable liquid porosity ranging from 1.9 to 7.7%. For many of the core samples collected from the Salina Formation, where gypsum ($CaSO_4 \cdot 2H_2O$) may be present as secondary mineralogy (e.g., G Unit to A2 Unit Carbonate), the liquid porosities are likely overestimations attributed to release of the hydration water during heating.

The total and liquid porosity profiles display a very pronounced reduction in porosity in the Lower Silurian formations and immediately above the Ordovician shales. This reduction in porosity is generally to below 5% and is consistent with the porosity values observed in the Ordovician limestones and also the limestone/siltstone “hard beds” found in the Ordovician shales.

Figures 5.6.1-8 and 5.6.1-9 show that the total and liquid porosities for the Ordovician shale formations are clustered by two groupings and that the liquid porosities are slightly larger than the total porosities. The two groupings of porosity data reflect the different mineralogy of samples tested within the Ordovician shale formations. The more massive shale samples show formation mean total porosity of 7.1 to 7.5%, and liquid porosity of 7.8 to 8.5%. The lower porosity data (mean formation total porosity 1.1 to 2.9%, mean formation liquid porosity 1.1 to 3.2%) are for ‘hard beds’ within these shale formations that are primarily limestone and/or siltstone.

The total and liquid porosity data for the Ordovician limestones are very similar with overall mean values of 1.9 and 1.7%, although some high values (6 to 15%) at the base of the Ordovician limestones (i.e., bottom of Gull River Formation) were also reported. Porosity data for the Shadow Lake and Cambrian sandstone are similar for total porosity (mean 9.5%) and liquid porosity (mean 8.1%).



Source: [11]

Figure 5.6.1-8: Liquid Porosity Profile for DGR Cores Showing Point Data and Arithmetic Formation Averages

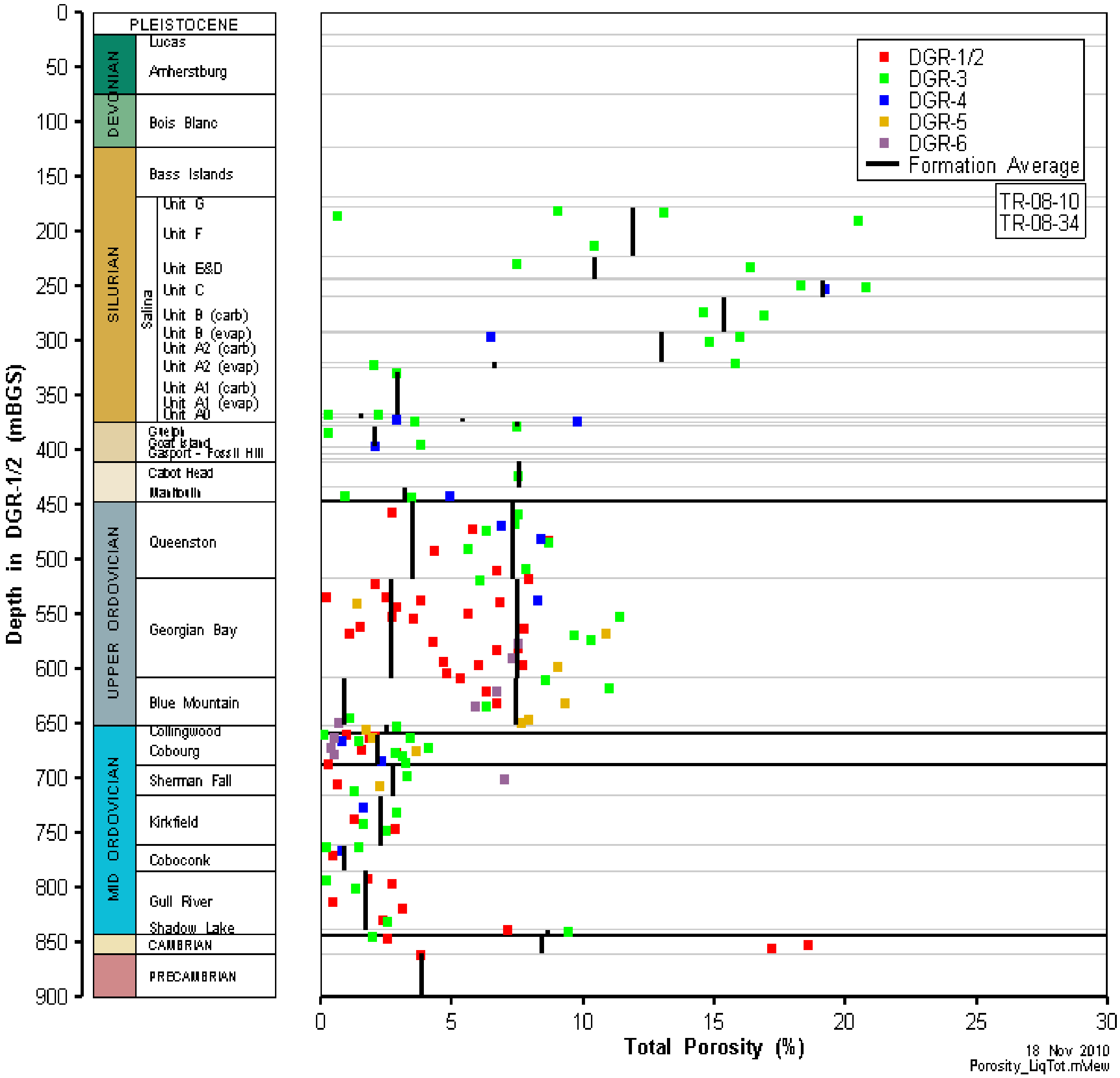


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Figure 5.6.1-9: Total Porosity Profile for DGR Cores Showing Point Values and Arithmetic Formation Averages

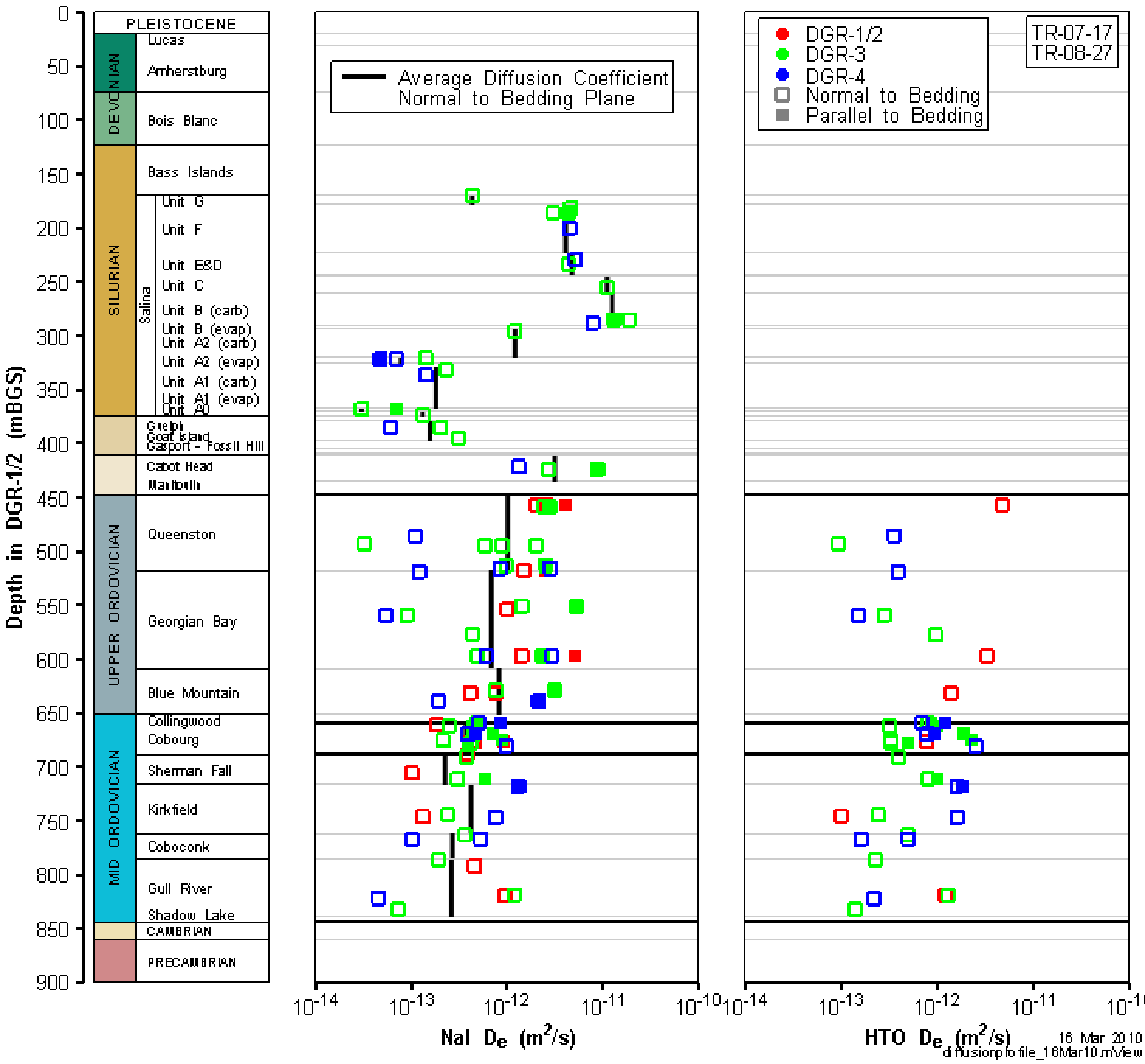
Diffusion

The low values of hydraulic conductivity reported above, particularly at stratigraphic levels within the Ordovician, suggest that solute transport is dominated by diffusion. In support of efforts to assess diffusive solute transport, site characterization activities included plans to determine distributions of aqueous species (e.g., $\delta^{18}O$, $\delta^{2}H$, Cl, Br) that could be expected to behave as natural tracers and thereby provide a basis for quantifying rates and mechanisms of solute transport in a manner similar to previous studies [126;127;128].

In order to provide complimentary data that can be used to evaluate the natural tracer profiles, laboratory-scale diffusion measurements were undertaken to determine effective diffusion coefficients (D_e) for rock samples from the Silurian and Ordovician sections of the stratigraphy (Figure 5.6.1-10).

The D_e measurements were conducted with sodium iodide and tritiated water (HTO) tracers, using radiography and through-diffusion methods. The details of each method are provided in the associated technical reports: Laboratory Diffusion Testing of DGR-2 Core, and Laboratory Diffusion Testing of DGR-3 and DGR-4 Core [125]. The through-diffusion technique is well established and data acquired with this method have been published by numerous authors [129;130]. The radiography technique was pioneered by Tidwell et al [131]; the radiography technique was modified for application to samples from the DGR project and was benchmarked against results from the through-diffusion method [125].

With the exception of just a few samples from the Upper Silurian, the D_e values measured from DGR drill cores are all less than 1×10^{-12} m²/s (Figure 5.6.1-10). The highest values occur in the Upper Silurian Salina B, C, E and F units, with values greater than 1×10^{-11} m²/s in the silty shale of the Salina B. The lowest D_e values, on the order of 3×10^{-14} to 5×10^{-14} m²/s, are obtained in the gypsum-anhydrite layers of the Salina A0-A2 units, in the carbonate “hardbeds” within the Georgian Bay Formation, and in several limestone samples from the Gull River Formation. These extremely low values may be the lowest measured for sedimentary rocks anywhere. The majority of the D_e values are in the range 1×10^{-13} to 1×10^{-11} m²/s, with Lower Silurian and Upper Ordovician shale samples representing the higher end of this range because of their relatively high porosity (approximately 10%). Fifteen diffusion measurements have been made on samples of the Lower Member of the Cobourg Formation, which is the proposed DGR host rock; the results indicate consistently low D_e values of 1×10^{-13} to 1×10^{-12} m²/s.



Note: The D_e values were determined by x-ray radiography using and/or through-diffusion*
Source: [11]

Figure 5.6.1-10: Effective Diffusion Coefficient (D_e) Profile of DGR Cores Showing Point Measurements and Formation Averages

The D_e data display systematic variability as a function of the tracer used to make the measurements, and D_e values obtained with HTO tracer are on average 1.9 times greater (range of 0.8 to 4.9) than D_e values obtained with iodide tracer. This difference is attributed to the influence of anion exclusion in lowering the tracer-accessible porosity for iodide. There is also a systematic difference in D_e values as a function of the orientation of the measurements with respect to the bedding direction. With only two exceptions in the Upper Silurian (Figure 5.6.1-10), the D_e values are greatest for diffusion in the orientation parallel to bedding. The anisotropy ratio (D_e parallel/D_e normal) ranges from 1 to 4 for measurements made with the iodide tracer, and from 1 to 7 for measurements made with HTO [132].

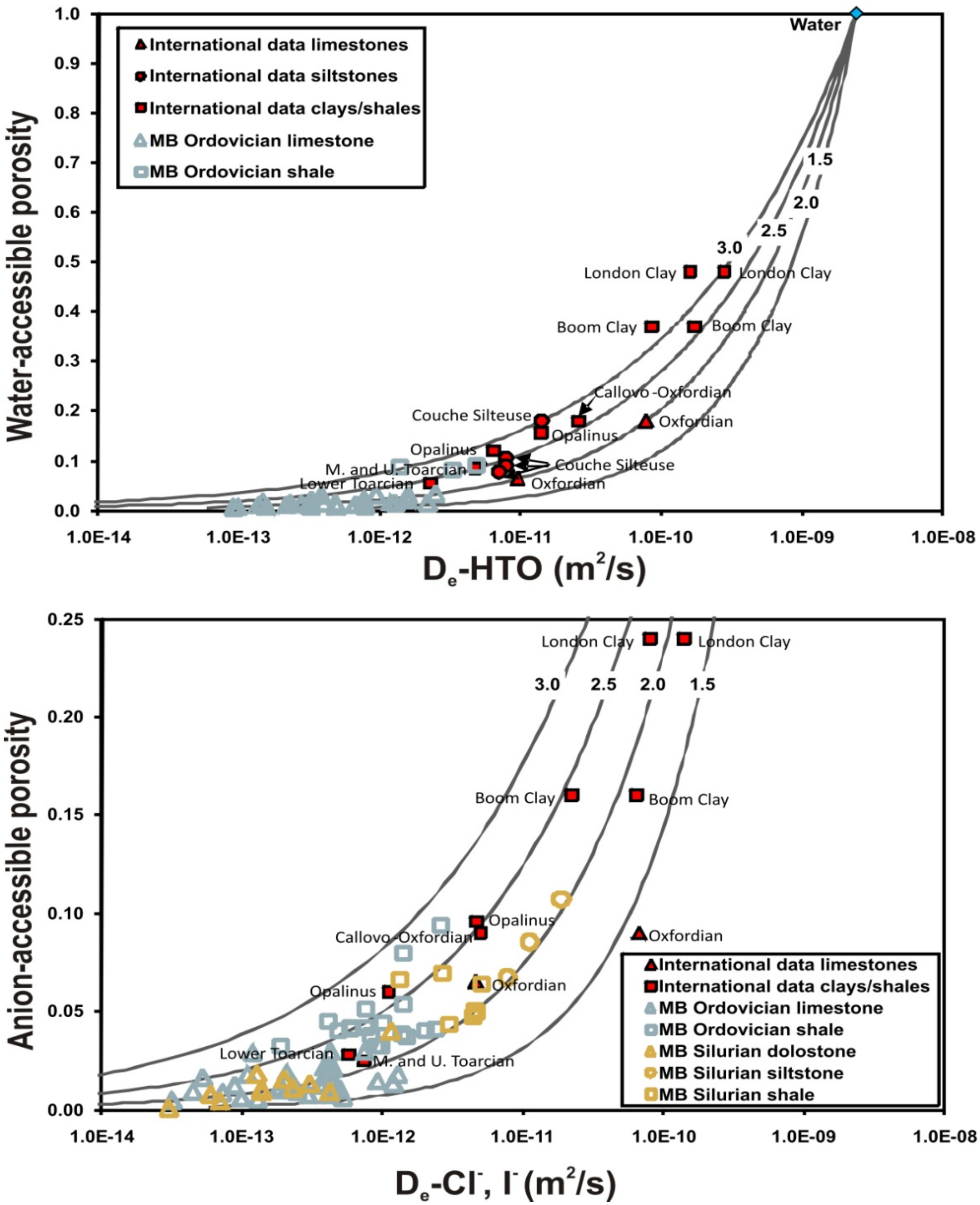
The D_e data display systematic variability as a function of the tracer used to make the measurements. D_e values obtained from through-diffusion testing with HTO tracer are on average 1.9 times greater (range 0.8 to 4.9) than D_e values measured with the iodide tracer. This difference is primarily attributed by UNB [133] to anion exclusion in lowering the tracer-accessible porosity, although 20% of the differences in D_e values are due to a 20% larger value of free-water diffusion coefficient for iodide over HTO. Anion exclusion effects in porous media are commonly attributed to charge interactions between ions in solution and the electric double layer (EDL) present in clay-rich media. Some simple calculations of EDL thickness and comparison to pore throat sizes determined from high-pressure mercury injection testing provide insight to this exclusion process.

Figure 5.6.1-11 shows a comparison of the site-specific D_e data with values measured from international programs involving argillaceous sedimentary rock. The figure shows that the D_e values measured at the Bruce nuclear site are very comparable to the international data, and in fact, are typically lower than the international values by a factor of approximately ten.

5.6.1.6 Fluid Density

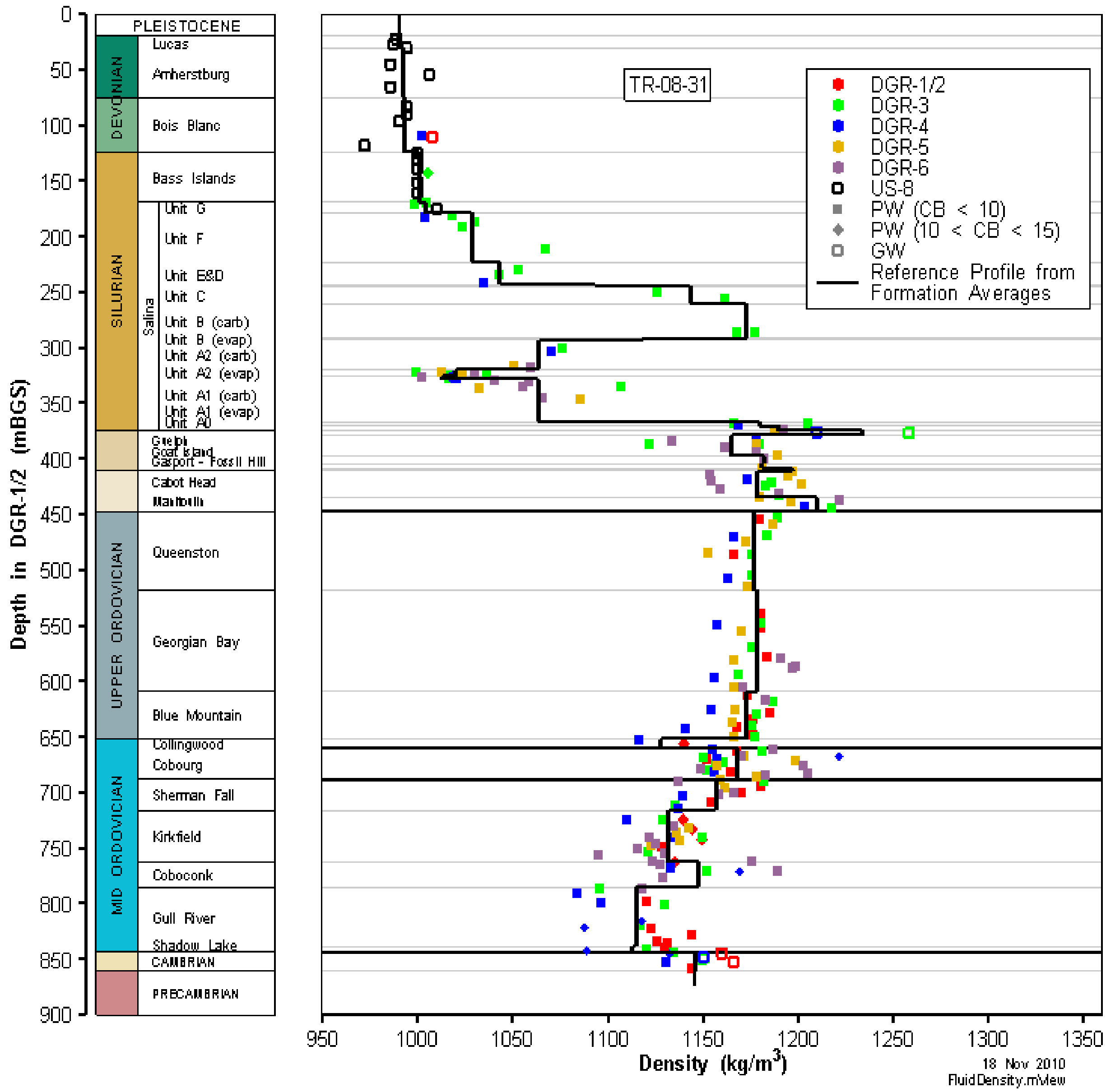
Groundwater (GW) and porewater (PW) chemistry data and field and laboratory fluid density measurements were used to generate a profile of formation fluid density for the Paleozoic bedrock column at the Bruce nuclear site [134]. Figure 5.6.1-12 shows the fluid density versus depth and formation data, the recommended or reference density profile selected for the DGR bedrock sequence, and arithmetic formation averages. A reference density profile is required to calculate environmental water heads from fresh water heads in variable density fluid systems as exist at the Bruce nuclear site.

The density profile transitions from fresh water (ρ=990 to 1,000 kg/m^3) in the upper dolostone units (Lucas, Amherstburg, Bois Blanc and Bass Islands formations) though brackish water (ρ=1,010 kg/m^3) in the Salina F Unit to brine (ρ=1,070 kg/m^3) in Salina Formation B Unit. From the Salina B Unit down to the upper A1 Unit aquifer the water density decreases to the saline water that characterizes the upper A1 Unit aquifer (ρ=1,018 kg/m^3). There is then a significant increase in water density from the upper A1 Unit aquifer to the brine found within the Guelph Formation (ρ=1,234 kg/m^3), which is the highest TDS and fluid density measured at the DGR Project site. From the Guelph downward the water density decreases to 1,180 kg/m^3 in the Goat Island and Manitoulin formations. Through the Ordovician shales the fluid density decreases from 1,180 kg/m^3 in the upper Queenston Formation to 1,160 kg/m^3 at the bottom of the Collingwood Member. Further reductions in porewater density occur down through the Ordovician limestones to the top of the Gull River Formation with fluid density of 1,105 kg/m^3. Fluid density then increases through the Gull River and Shadow Lake formations to an average groundwater density of 1,156 kg/m^3 within the Cambrian sandstone.



Note:
International data compiled by Mazurek [128]. The Solid Lines Represent the Exponential Term, *m*, in the Archie's Law Relationship between Diffusivity and Porosity

Figure 5.6.1-11: Comparison of Diffusion Data Collected from DGR Drill Cores from the Michigan Basin (MB) With Diffusion Data for International Programs Involving Argillaceous Sedimentary Rocks



Note: GW – groundwater, PW – porewater
Source: [11]

Figure 5.6.1-12: Reference Fluid Density Profile and Formation Averages based on US-8 and DGR Borehole Groundwater and Porewater Data

5.6.2 Local Study Area

Groundwater flow within the surficial deposits and bedrock of the Local Study Area is directed northwestward toward Lake Huron, generally sub-parallel to the well established surface drainage pattern (see Figure 5.6.2-1). Shallow groundwater discharges within the streams running off of this area, while a component of deeper groundwater flow discharges within the swampy areas below the Algonquin Bluff.

Above the Algonquin Bluff, groundwater hydraulic gradients are downward from surface toward the bedrock. Upward hydraulic gradients are observed adjacent to Lake Huron, where groundwater in the bedrock, recharged over time from locations above the bluff, discharges into the lake. Lake Huron is the ultimate receptor of groundwater within the Local Study Area.

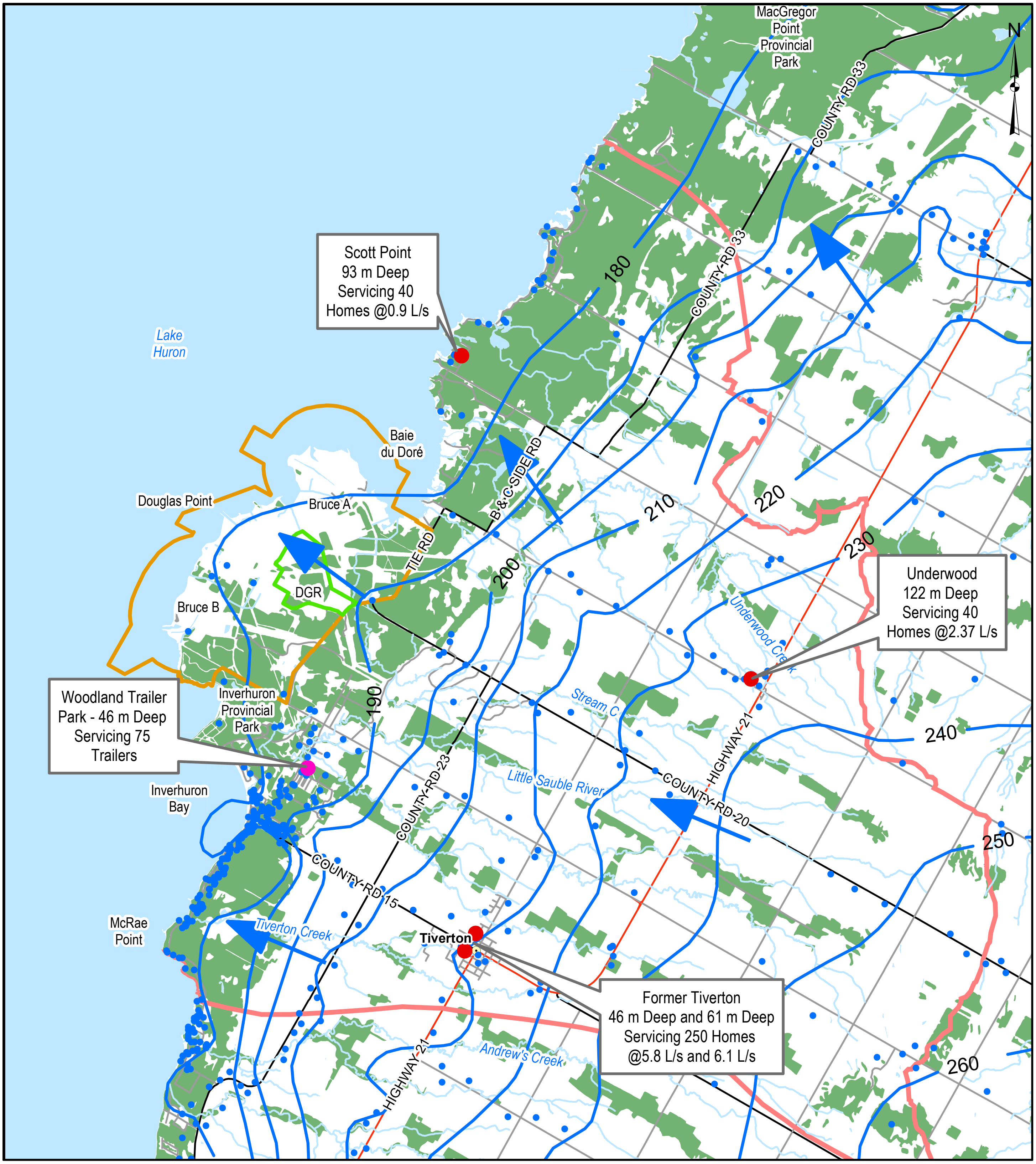
Fresh groundwater is available within the Local Study Area from sand and gravel lenses within the clayey glacial deposits and from the bedrock. These horizons provide water supplies for domestic and municipal services throughout the Local Study Area. Ontario Hydro Nuclear carried out a survey of water well use in 1997 and 1998 [18], which encompassed the Local Study Area and points beyond. The report summarized water supplies obtained from deep wells and from shallow wells. For example, the Town of Underwood was served by a 122 m deep municipal well supplying 40 households within an average pumping rate of 2.37 L/s while Tiverton was served by two wells 46 and 61 m deep, supplying 250 households at an average pumping rate of 5.8 and 6.1 L/s, respectively. There are also several communal wells in the Local Study Area (e.g., Woodland Trailer Park is served by a 46 m deep well supplying up to 75 trailers). Shallow wells typically 3 to 6 m deep are largely associated with lakeshore cottages and farms. The locations of municipal and communal wells within the Local Study Area are shown in Figure 5.6.2-1. The 93 m deep Scott Point well serves 40 homes and provides approximately 9 L/s. Recently, the communal wells for Inverhuron Provincial Park were taken off-line, as the Park switched from a well water supply to surface water from the Kincardine Water Supply Plant. Kincardine and Tiverton now obtain their water supply directly from Lake Huron and are no longer supplied by municipal wells.

MOE water well records indicate that there are approximately 1,000 domestic wells in the Municipality of Kincardine (see Figure 5.6.2-1). All of these wells were completed within either the surficial deposits or within the underlying bedrock. Approximately 80% of the wells are completed in bedrock, typically to depths of 30 to 100 m into the upper bedrock of the Lucas, Amherstburg and Bois Blanc formations. Over 95% of all wells were reported in the MOE records as having encountered fresh water. Shallow wells typically 3 to 6 m deep are largely associated with lakeshore cottages and farms. There may also be additional dry wells completed in the surficial deposits for which records may not exist.

An understanding of groundwater levels and directions of groundwater flow within the Local Study Area has been acquired through a review of available Ministry of the Environment (MOE) water well records for the Municipality of Kincardine (formerly Kincardine and Bruce Townships), and from observations of monitoring wells located within the Bruce nuclear site. The locations of domestic and municipal wells obtained from the records and the associated water levels are shown in Figure 5.6.2-1. The water levels in these wells indicated that the direction of groundwater flow is northwestward from the Tiverton and Underwood (220 to 240 mASL) areas towards the Bruce nuclear site and Lake Huron (176 mASL). The Bruce nuclear site is down-gradient (downstream) from neighbouring groundwater users in the Municipality of Kincardine and the Regional Study Area.

5.6.3 Hydrogeological Modelling Summary

The hydrogeologic characteristics of the Bruce nuclear site and surrounding region were explored through the development of a three-dimensional numerical model of groundwater and solute migration within the Paleozoic sedimentary sequence [29]. This three-dimensional model provided a structured framework on which to integrate regional and site-specific information governing hydrostratigraphy, hydrogeochemistry and boundary conditions.



LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Local Study Area
- Communal Well
- Domestic Well
- Municipal Well
- Inferred Direction of Flow

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007. Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

GROUNDWATER LEVELS & DIRECTION OF GROUNDWATER FLOW-LOCAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct 2007	**FIGURE 5.6.2-1**	
GIS	ASB	5 May. 2010		
CHECK	AKB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

[PAGE LEFT INTENTIONALLY BLANK]

The performance measure used in the analysis of the regional scale groundwater model is Mean Life Expectancy (MLE). This is an estimate of the time required for a water particle at a specific position in a groundwater system to reach a potential outflow point, considering both advective and dispersive transport processes. The results of the analyses provide a reasoned basis to understand the evolution of the regional and site-specific groundwater systems as they relate to implementation of the DGR concept at the Bruce nuclear site. Results from the simulations include the following:

- Base case and sensitivity simulations indicated that diffusion was the dominant transport mechanism in the Ordovician rocks. MLEs from the repository horizon to the surface were typically greater than several millions of years.
- Base case and sensitivity analyses demonstrate the effectiveness of near-horizontally layered Silurian and Ordovician aquitards/aquicludes to maintain a stable hydrogeologic setting at the proposed DGR horizon.
- Simulation of anomalous vertical hydraulic head distributions within the Ordovician and Cambrian rocks indicate that groundwater movement is converging on the Ordovician formations. Depending on the assumed hydraulic conductivity anisotropy (i.e., 10:1 to 1,000:1) re-equilibration of these heads to present day boundary conditions may require 1 million years (Ma) or longer.
- The origin of the anomalously low hydraulic heads observed in the Ordovician rocks is unlikely to be attributed to glacial events as a consequence of the predicted loading-unloading cycle.
- Extensive low permeability strata overlying the Cambrian Formation are required for the maintenance of the observed hydraulic over-pressures. Analyses indicate that to preserve the hydraulic over-pressure for 1 Ma vertical hydraulic conductivities of 1×10^{-14} m or less are required.

Paleohydrogeologic simulations for a glaciation scenario indicate that basal meltwaters would not penetrate below the Salina Formation. Simulations further indicate that while ice-loading will influence hydraulic head distributions and gradients, mass transport processes within the Ordovician rocks hosting and enclosing the proposed DGR will remain diffusion dominant [29].

5.6.4 Hydrogeological Summary

The hydrogeological site model describes the hydrogeologic properties and three-dimensional spatial distribution of all important hydrogeologic units and features within the Paleozoic bedrock units at the Bruce nuclear site. The descriptive hydrogeologic model provides a basis for understanding groundwater flow and radionuclide transport properties of the Paleozoic bedrock that will contain and isolate the proposed Bruce DGR. The hydrogeologic site model focuses on description of the physical properties of the bedrock, and the geochemical and isotopic properties of the groundwater and porewater.

The regional scale groundwater domain has been subdivided into a shallow of overburden and Devonian and Upper Silurian dolostones (hydraulic conductivity of 8×10^{-8} to 2×10^{-6} m/s) an intermediate zone of Silurian shales and dolostones (hydraulic conductivity of 5×10^{-14} to 3×10^{-10} m/s) and a deep zone of Ordovician shales and limestones (hydraulic conductivity of 2×10^{-14} to 5×10^{-14} m/s). At the Bruce nuclear site this has been further subdivided into nine hydrostratigraphic units. The groundwater is commonly encountered at 8 to 10 m below the ground surface. A system of surface water drainage is well established at the site.

Measured horizontal hydraulic conductivities ranged from 1×10^{-15} m/s in the Kirkfield Formation to 3×10^{-6} m/s in the Cambrian sandstone. The average estimates of horizontal hydraulic conductivity of the Ordovician shale and Trenton Group limestone formations range from 8×10^{-15} to 5×10^{-14} m/s, with vertical hydraulic conductivity estimated as a factor of 10 less than horizontal hydraulic conductivity. The average estimates of horizontal hydraulic conductivity in the Black River limestones are greater ranging from 7×10^{-13} to 4×10^{-12} m/s, with vertical hydraulic conductivity potentially being a factor of 10 to 1,000 less than horizontal hydraulic conductivity.

Monitoring of formation pressures in packer-isolated intervals in DGR boreholes over monitoring periods of months to a year shows the presence of moderate over-pressures in Salina A1 and A0 Units, Goat Island, Gasport and Fossil Hill formations, significant stable over-pressure in the Cambrian sandstone, and significant transient under-pressures throughout most of the Ordovician shale and limestone, as well as moderate under-pressures in the Salina B and C units. Environmental water heads calculated from formation pressures and the porewater/groundwater fluid density profile range from 165 m above ground surface (350 mASL) for the Cambrian sandstone to less than 300 mBGS (-115 mASL) in the Blue Mountain shale. The occurrence of such significant under-pressures implies that the formations in which they are measured must be of extremely low permeability in order for them to persist.

Measurements of formation pressures in DGR boreholes were used to determine horizontal groundwater flow directions. Groundwater flow directions in the Upper A1 Unit aquifer are the same as those in the shallow dolostones, being to the northwest toward Lake Huron. In contrast, the calculated groundwater flow directions for the Guelph Formation and the Cambrian sandstone are outward from the middle of the Michigan Basin toward the northeast (Guelph Formation) and to the east (Cambrian sandstone). Calculated hydraulic gradients in all three deep permeable aquifers are in the range of 2×10^{-3} to 9×10^{-3} m/m.

The mean total and liquid porosities ranged from: 8.9 and 9.8%, respectively, in the Silurian and Devonian strata; 1.9 and 1.7% in Ordovician limestones; 1.7 and 1.0%, for limestone/siltstone hard beds within Ordovician shales; 7.3 and 8.0% for Ordovician shales; and 9.5 and 8.1% in the Shadow Lake siltstone and Cambrian sandstone.

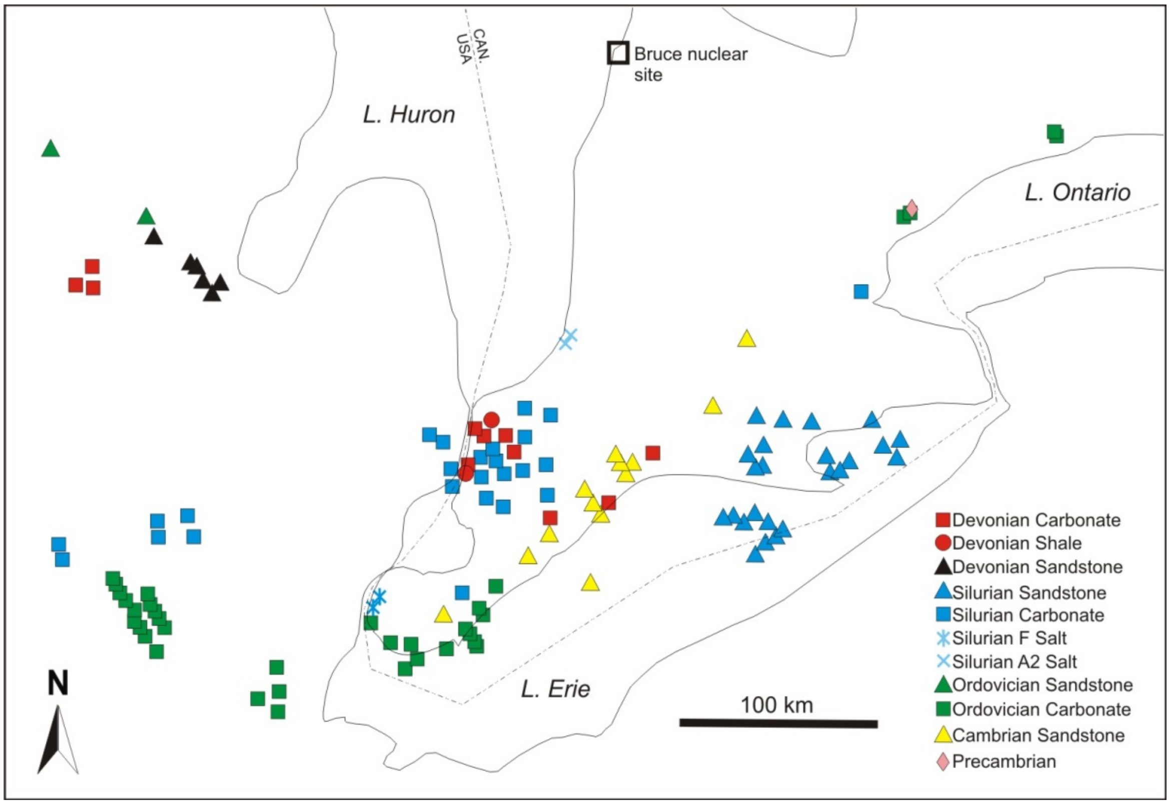
The iodide effective diffusion coefficients for the Ordovician shales and limestones were found to be proportional to the porosity of the formations with values of about 1×10^{-12} m^2/s for Queenston and Georgian Bay Formation shales and 4×10^{-13} m^2/s for the Cobourg Formation limestone.

5.7 HYDROGEOCHEMISTRY

The information presented below is based on a comprehensive examination and integration of the regional hydrogeochemistry of southern Ontario [26] and detailed site characterization activities specifically related to understanding the hydrogeochemical evolution at the Bruce nuclear site (see Chapter 4 of [11]).

Section 5.7.1 provides a summary of the hydrogeochemical framework of the Michigan Basin at the regional-scale in terms of the age (i.e., residence time) and origin of the porewater and groundwater, the mechanisms controlling solute transport, and the processes responsible for the observed evolution in porewater and groundwater chemistry. The purpose of this integration is to develop an understanding of the hydrogeochemical evolution of the Bruce nuclear site, discussed in Section 5.7.2.

An important data source for the regional hydrogeochemical setting described below is a compilation of research undertaken at the University of Waterloo, hereafter referred to as the UW database. The UW database includes information regarding characterization of formation fluids from within the Paleozoic sedimentary succession underlying southwestern Ontario. The UW database is included as an appendix in the Regional Hydrogeochemistry – Southern Ontario report [26], and sampling locations for the database are shown on Figure 5.7-1.



Source: Modified from Figure 2.5 of [26].

Figure 5.7-1: Formation Fluid Sampling Locations for the UW Database

5.7.1 Regional Hydrogeochemical Framework of the Michigan Basin

Saline fluids occur at all levels in the Michigan Basin, and although the associated sedimentary rocks were deposited in a marine environment, the salinity of the Michigan Basin fluids (TDS commonly greater than 200 g/L) is generally much higher than that of seawater (TDS approximately 35 g/L). Salinity is often classified based on the TDS load of the fluid (as in [100]: freshwater (TDS less than 1,000 mg/L); brackish water (TDS between 1,000 and 10,000 mg/L); saline water (TDS between 10,000 and 100,000 mg/L); and brine (TDS greater than 100,000 mg/L).

At the regional-scale, the geochemistry of waters in the sedimentary sequence is characterized by a two-layer system [26].

- A shallow groundwater system occurring at depths of up to approximately 200 m below ground surface (mBGS) and containing fresh through brackish waters. Waters in the shallow zone have $\delta^{18}O$ and $\delta^{2}H$ isotopic compositions suggesting that they are mixtures of dilute, recent, or cold-climate waters with more saline waters.

- An intermediate to deep system at depths greater than 200 mBGS. These waters are brines, as indicated by characteristically elevated TDS values (200 to 400 g/L), and these brines have stable isotopic signatures that are enriched in $\delta^{18}O$ (-6 and +3 ‰) and $\delta^{2}H$ (-55 and +20 ‰) relative to the Global Meteoric Water Line (GMWL). The information for this system is based predominantly on waters sampled from hydrocarbon reservoirs.

5.7.1.1 Origin and Evolution of Sedimentary Brines

The brines in the Michigan Basin are considered to have originated by evaporation of ancient seawater [135;136;26]. For a full discussion of the origin of the sedimentary brines within the Michigan Basin, the reader is referred to Chapter 3 of the Regional Hydrogeochemistry – Southern Ontario report [26]. The regional and site-specific data for chloride (Cl) versus bromide (Br), and $\delta^{18}O$ versus $\delta^{2}H$, are presented in Figure 5.7.1-1 (a and b) and Figure 5.7.1-2 (a and b), respectively. The trends observed at the regional and site-scale are similar, suggesting both a common origin for the brines and a common evolution.

Deviations from the sea water evaporation curve on a plot of Cl versus Br can aid in interpretation of processes that have influenced the evolution of the brine composition through time [137] , such as mixing of fluids from different sources. The Cl-Br plot in Figure 5.7.1-1a from the UW database [26], displays trends that indicate: i) dilution of brines by lower salinity water, and ii) dissolution of halite. Dilution is indicated for samples that plot below the sea water evaporation curve on a trend toward the origin, and dissolution of halite is indicated for samples that plot above the sea water evaporation trend. Infiltration of lower salinity water, such as meteoric water, glacial melt water, normal sea water, or water of hydrothermal origin, could contribute to the observed dilution trends. Figure 5.7.1-1b shows the Cl and Br data from groundwater and porewater collected during site characterization activities at the Bruce nuclear site. The trends in the data are very similar to the regional data, suggesting an evaporated seawater origin for the brine, with subsequent modification by processes such as dilution, halite dissolution, and water-rock interaction.

The $\delta^{18}O$ and $\delta^{2}H$ data presented in Figure 5.7.1-2a are consistent with the Cl-Br data presented in Figure 5.7.1-1a in that they indicate mixing has occurred in the shallow formations between saline brines and more dilute water(s). Most of the samples that display evidence of mixing with meteoric water are from Devonian and Silurian formations, which, in southern Ontario, occur at shallow depths and are commonly overlain by unconsolidated glacial overburden. The deep sedimentary formations of Ordovician and Cambrian age plot primarily to the right of, and below, the GMWL, indicative of long time periods of water-rock interaction. Similar trends are evident in the data from the Bruce nuclear site shown in Figure 5.7.1-2b.

When compared to the regional data, the shallow sedimentary formations (Devonian and Silurian) at the Bruce nuclear site may show more influence of mixing with glacial and/or meteoric water(s) (Figure 5.7.1-2b) due to their shallower depth relative to samples taken from the same sedimentary formations nearer to the Chatham Sag in southern Ontario (refer to Figures 5.5-1 and 5.7-1).

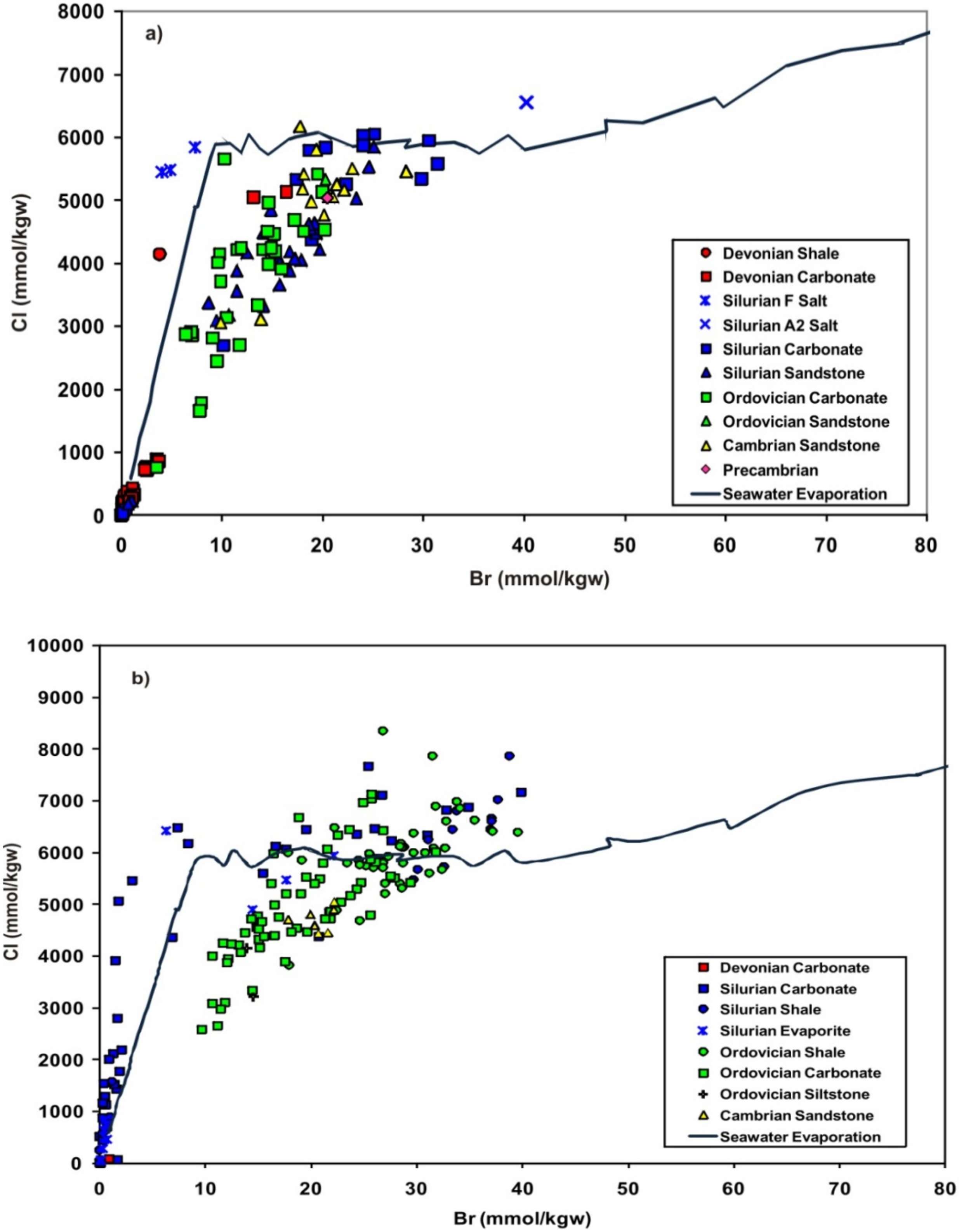
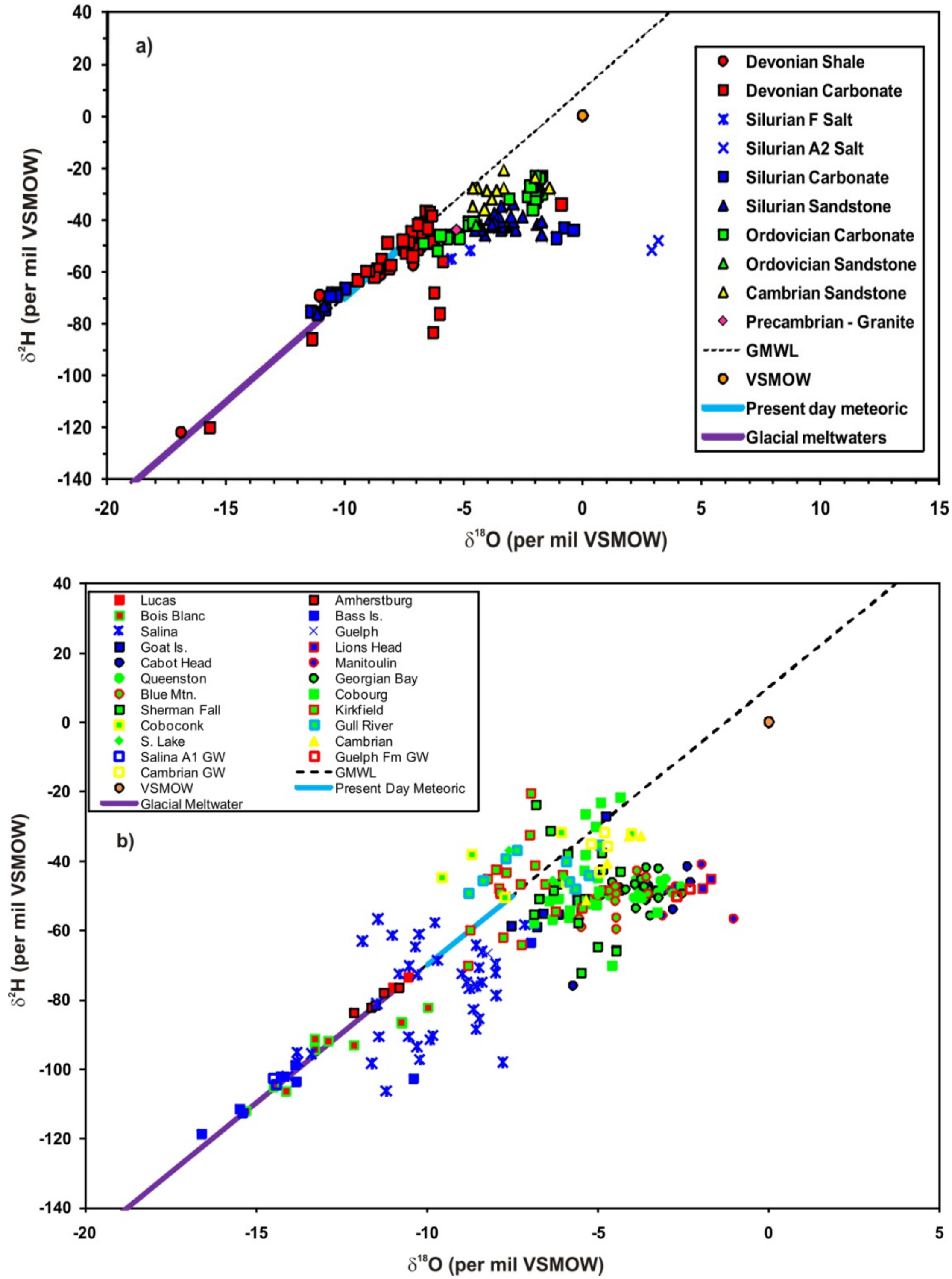


Figure 5.7.1-1: Chloride Versus Bromide Concentrations Measured for a) Groundwaters in Southwestern Ontario (UW Database) and b) the Bruce Nuclear Site



Notes:
(a) represents all fluids within the UW database (from Figure 6.5 of [26]).
(b) represents groundwater and porewater samples collected at the Bruce nuclear site
Source: modified from Figure 4.59 of [11]).

Figure 5.7.1-2: Hydrogen Versus Oxygen Isotopic Signatures

Fluid Migration and Solute Transport Mechanisms

The presence of hypersaline brines in sediments should result in a gravitationally stable system, and fluid flow would not be expected without a large pressure perturbation to the system. Fluids in sedimentary basins also do not flow without changes to hydraulic gradients [138]. Possible driving forces for these changes, which can prompt groundwater flow and solute transport within the context of the geologic history of the Michigan Basin, include orogenesis, evaporation, and glaciation (e.g., Figure 5.5.1-6). The results of studies that have examined fluid migration and solute transport associated with orogenesis, evaporation, and glaciation are summarized below. A more complete discussion of fluid migration and solute transport associated with orogenesis is provided in Sections 5.5.1.3 through 5.5.1.5 and in the Geosynthesis [3].

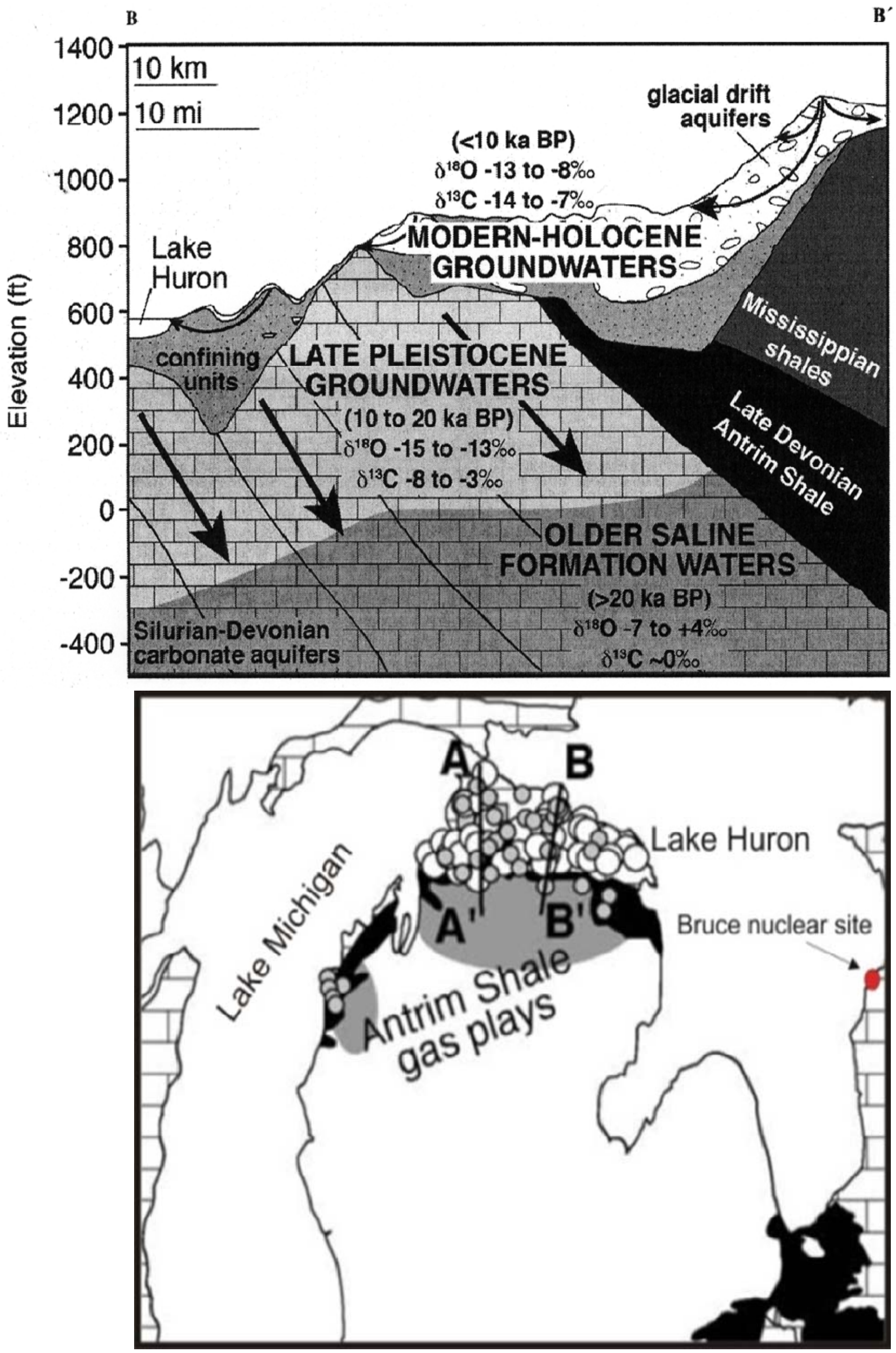
- Fluid migration would likely have occurred within permeable sedimentary units, for example the Cambrian sandstones and dolomitized Ordovician carbonates, in response to hydraulic gradients and crustal motion related to Taconic, Acadian, and Appalachian orogenesis.
- Restricted marine conditions during the Silurian and Devonian periods led to periods of sea water evaporation, which would have created unstable high salinity brine layers in the upper stratigraphic levels of the basin, leading to the formation of hypersaline brines. Overturn by density-driven advection [98;139] and diffusion are possible solute transport mechanism under such conditions. Although the Silurian sedimentary rocks are underlain by low-permeability Upper Ordovician shale, localized fracture and fault systems may have provided the opportunity for dense brine to migrate downward into the underlying Ordovician, Cambrian and Precambrian rocks [98;140]. In the absence of localized fracturing, the resulting concentration gradients between the underlying sedimentary porewaters and the hypersaline fluids would have resulted in downward diffusion of solutes.
- Barker and Pollock [141] noted that the natural gas chemistries in samples from the Michigan Basin were distinct from the natural gas chemistries within the Appalachian Basin, indicating that there has been no significant migration of gases between the basins. This interpretation is consistent with isotopic analyses of Ordovician brines [142;143;144], which indicate that groundwater from Ordovician formations within the Michigan Basin have a different evolution than fluids in the Appalachian Basin.
- Oil-field brines obtained near the eastern edge of the Michigan Basin in Ontario have strontium (Sr) isotopic compositions that are very similar to samples from deeper within the Michigan Basin suggesting intra-basin fluid migration over distances of hundreds of kilometres [145].
- Sherwood Lollar et al. [146], using isotopic and compositional indicators, concluded that hydrocarbons to the southeast of the Algonquin Arch display elevated thermal maturities consistent with migration from the Appalachian Basin. Conversely, gas hydrocarbons from northwest of the Algonquin Arch do not display elevated maturities and are therefore not likely sourced from the Appalachian Basin, indicating the lack of detectable migration (mixing) between the basins [146].
- Pb isotope ratios ($^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$) for galena northwest of the Algonquin Arch in the Michigan Basin indicate a crustal source that is distinct from the Pb in galena samples from the Appalachian Basin [147] southeast of the arch, and lends support to the interpretation of intra-basin, but not inter-basin, fluid migration for the Michigan and Appalachian basins.
- Sedimentary basin fluid migration is also evidenced by the existence of hydrothermal dolomite:

  - Hydrothermal-dolomite-hosted oil and gas reservoirs in the Black River and Trenton groups within southern Ontario and Michigan are presumed to have also formed as a result of brine migration during the Taconic Orogeny [140]. Middleton et al. [148] measured homogenization temperatures ranging between 100 and 220 °C in primary fluid inclusions from the fracture-related dolomite in oil and gas fields in the Chatham Sag region of southern Ontario (see Figure 5.5-1 for location). These temperatures are substantially higher than those likely to be generated during peak burial of the sedimentary sequence suggesting the influence of these dolomitizing hydrothermal fluids [98].
  - On the basis of carbon and strontium isotope data, sea water-derived fluids are thought to be responsible for regional-scale dolomitization in the Middle Silurian Guelph Formation [149]. Primary fluid inclusions temperatures of between 65 and 130 °C indicate that the fluids were hydrothermal in nature [149] after [150].
  - Several authors suggest that fracture-related dolomitization and hydrocarbon migration in the Michigan Basin likely occurred during the Late Paleozoic to Early Mesozoic [151;152;97].
- High fluid pressures at the base of glacial ice sheets are also potentially able to drive fluid migration. Although glacial events are recognized periodically throughout geologic history, there are no known events that would have affected the Michigan Basin between Upper Silurian and Pleistocene time [153]. Fluid migration could also occur in response to pressure gradients formed by tilting of the basin during differential isostatic rebound following deglaciation.

Isotopic Evidence for Pleistocene and Post-Pleistocene Infiltration Events

The widespread occurrence of ancient brines in the Michigan Basin demonstrates that, under conditions prevalent since the Paleozoic, it has not been possible for hydraulic heads generated in freshwater aquifers at the top boundary of the basin to displace the deep basin brines.

- Glacial melt water can be pressurized beneath continental ice sheets during interglacial periods to levels in excess of ambient heads, and has been driven to depths of several hundred metres in Paleozoic aquifers around the periphery of the Illinois and Michigan basins (see [154;155;156] and references therein). The conceptual model developed by McIntosh and Walter [155] for Pleistocene infiltration around the margins of the Michigan Basin is presented in Figure 5.7.1-3. Their research suggests that glacial melt water has penetrated to depths up to 200 to 300 m in Silurian-Devonian carbonate aquifers in northern Michigan on the northern margin of the Michigan Basin.
- Stable O isotope data provide the best evidence for infiltration and cross-formational mixing of glacial melt water, which displays strongly depleted $\delta^{18}O$ values (between -25 and -11 ‰), and this cold-climate water can be distinguished from: i) hypersaline basinal brines which have $\delta^{18}O$ values ranging between -6 and +5 ‰ [135] and ii) modern recharge in southwestern Ontario which has $\delta^{18}O$ values typically ranging between -11 and -7.5 ‰.
- Although stable O and H isotopic data demonstrate that fresh glacial melt water has infiltrated around the periphery of the Michigan Basin, the composition of the water has been significantly altered by mixing with ancient hypersaline brines and by dissolution of evaporite minerals (refer to Figures 5.7.1-2a and b). Evidence for these changes in water chemistry is reviewed in detail by McIntosh and Walter [154;155].



Source: Lower figure (modified from [155]) indicating position of section line B-B’ used in upper figure (modified from Figure 4.2 of [3]).

Figure 5.7.1-3: Conceptual Model Showing Ancient Brine at Depth, Cold-Climate Water Infiltrated to Mid-Depths, and Modern Meteoric Water near Surface

5.7.2 Hydrogeochemical Data from the Bruce Nuclear Site

In a similar manner as the regional discussion above, hydrogeochemical site characterization activities at the Bruce nuclear site have focused on the collection of data that will assist in identifying the residence time and origin of the porewaters and groundwaters underlying the Bruce nuclear site (e.g., [11]). In particular, these results provide evidence regarding the extent of meteoric water and/or glacial melt water infiltration, allow for estimation of the redox conditions present, and provide constraints on the processes and timing of solute transport, in the key host (Cobourg Formation) and bounding Ordovician rocks for the proposed DGR. As in Section 5.5.2.1, all mention of the Cobourg Formation below refers only to the lower argillaceous limestone member of this formation. The results are considered below in terms of the distinguishable shallow, and intermediate to deep, groundwater systems. The Cambrian unit is also discussed separately. The discussion is based primarily on results from natural tracer, major ion, and gas characterization analyses undertaken as part of the site characterization activities [11]. Following this, the conceptual model and numerical modelling results for the hydrogeochemical evolution of the Bruce nuclear site is provided.

It should also be noted that the hydrogeochemical characteristics of the porewaters and groundwaters, described below, are obtained by direct sampling in the case of groundwater [124;157], and by use of leaching/extraction techniques for estimation of porewater composition in low-permeability rocks [158;159;118]. The six deep boreholes, DGR-1 through DGR-6, as well as the two existing shallow bedrock monitoring wells (US-3 and US-7) and an additional shallow monitoring well (US-8), were instrumented with MP38 multi-level casings manufactured by Westbay Instruments Inc., which allow groundwater samples to be obtained from packer-isolated intervals.

5.7.2.1 Phase II ESA

In 1998–99, OPG undertook a project to identify all potential sources of contamination at sites within the Bruce nuclear site [14]. There were nine potential areas of contamination that may be hydrogeologically relevant to the Project Area. They are all located within the Site Study Area, and within or proximal to the Project Area, as shown in Figure 5.7.2-1. All nine potential areas of contamination were determined to require further evaluation (i.e., Phase II ESAs).

The nine potential areas of contamination considered relevant to the Project Area are:

- Bunker C Oil ASTs and Oil Delivery System (BCOA) (site 1);
- Former Bruce Nuclear Standby Generators (BNSG) (site 2);
- Former Spent Solvent Treatment Facility (SSTF) (site 3);
- Distribution Station #2 and #4 (DS#2 and DS#4) (site 4);
- Former Construction Landfill #1 (CL1) (site 5);
- Former Construction Landfill #4 (CL1) (site 6);
- Fire Training Facility (FTF) (site 7);
- RWOS/WWMF (site 8); and
- Former Bruce Heavy Water Plant (BHWP) (site 9).

These nine areas are considered to be up-gradient to cross-gradient of the Project Area.

LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- 1, Bunker C Oil ASTs and Oil Delivery System
- 2, Bruce Nuclear (Steam Plant) Standby Generators
- 3, Former Spent Solvent Treatment Facility
- 4, Distribution Station #2 and #4
- 5, Former Construction Landfill #1
- 6, Former Construction Landfill #4
- 7, Fire Training Facility
- 8, WWMF
- 9, Former Bruce Heavy Water Plant

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007. Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

GEOLOGY TECHNICAL SUPPORT DOCUMENT

TITLE

AREAS OF POTENTIAL CONTAMINATION IN THE SITE STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	**FIGURE 5.7.2-1**	
GIS	BC	16 Jun. 2010		
CHECK	CK	16 Jun. 2010		
REVIEW	MAR	16 Jun. 2010		

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Supplementary Phase II ESAs were conducted in 2001 to 2002 at the nine sites listed above [14;17;16] (among other sites within the Site Study Area). These sites represent a legacy from past construction and operations activities. Investigation, management, and remediation of these areas constitute part of the Bruce nuclear site's Contaminated Lands Program.

In addition, there are two potential sources of groundwater quality effects in the WWMF portion of the Project Area, as a result of two low and intermediate level radioactive waste facilities which are referred to as Radioactive Waste Operation Site 1 (RWOS 1) and Radioactive Waste Operation Site 2 (RWOS 2, currently known as the WWMF) (site 8). OPG manages both RWOS 1 and RWOS 2, which are geographically and functionally separate from Bruce Power's operations on the Bruce nuclear site.

RWOS 1 received solid radioactive wastes from the early 1960s to November 1976. The WWMF has received wastes from 1974 to present. The WWMF stores LLW and ILW in both above ground and underground storage units.

There are two general types of storage facilities in the WWMF, above ground and in ground storage facilities. The above ground storage units known as Low Level Storage Buildings (LLSB) are used to store LLW and some ILW. Some of the LLSBs have supplementary shielding depending on the waste being stored. The approximate total capacity of the LLSBs as of 1999 is 53,960 m^3 (including a reserve of 1,000 m^3). There are two types of in-ground containers (IC), IC-HX and IC-18. The IC-HXs store LLW heat exchangers. The IC-18s are generally used for ILW. The approximate total capacity of the IC-18s as of 1999 is 2,590 m^3 (including a reserve of 50 m^3).

There are 16 monitoring well locations around the WWMF in both the overburden and the bedrock. They are used to monitor long-term changes in groundwater quality in order to determine whether there is a release of radioactive waste from the storage compound.

There have been many geologic and hydrogeologic studies completed at both the RWOS 1 and RWOS 2 (WWMF) sites. These sites have been fully engineered to maintain hydraulic containment. As a precaution, monitoring wells have been installed around both of these sites and routine water quality monitoring is carried out. The wells act as an early warning system to any potential groundwater impacts from the sites. A Phase II ESA was completed at RWOS 1 in 1998 and the only radioactivity detected in groundwater was tritium. The leading edge of a tritium "plume" extends to the adjacent spruce swamp at activities much lower than the allowable limit, presumably as a result of dilution. The groundwater discharges to the swamp, which in turn discharges to Lake Huron.

A summary of the status of Phase II ESA and subsequent monitoring activities for the nine areas of interest noted above is presented in the following subsections.

Bunker C Oil ASTs and Oil Delivery System (BCOA) (site 1)

The BCOA area was the subject of Phase II ESA activities from 1999 to 2001 which comprised the advancement of nine boreholes completed as monitoring wells (Figure 5.7.2-1; also Figure 5.2.1-1). There were no soil-related impacts identified during the Phase II ESA.

Several polycyclic aromatic hydrocarbon (PAH) compounds were measured in exceedance of the MOE Table B (now Table 3) groundwater standards in one well (BCOA-7) in 2001 [160;161].

The BCOA well network is monitored on an annual basis. In 2006, there were no groundwater exceedances of the MOE Table 3 Site Condition Standards (SCS) [8] recorded in any of the BCOA wells, for any of the analyzed parameters (metals, volatile organic compounds (VOCs), Petroleum Hydrocarbons (PHCs), or PAHs).

Former Bruce Nuclear Standby Generators (BNSG) (site 2)

The BNSG area was the subject of Phase II ESA activities from 1999 to 2001. There are currently six monitoring wells installed in the vicinity of the BNSG (Figure 5.7.2-1; also Figure 5.3.1-1).

The BNSG well network is monitored on an annual basis. In 2006, there were slight exceedances of the MOE Table 3 SCS in one monitoring well (BNSG-13) for two PAH parameters: indeno (1,2,3,cd) pyrene and benzo(ghi)peryline. All of the other parameters that were analyzed were measured below their pertinent SCS.

Former Spent Solvent Treatment Facility (SSTF) (site 3)

The SSTF (Figure 5.7.2-1) was the subject of Phase II ESA activities in 1999 to 2001 which comprised the advancement of four boreholes completed as monitoring wells. Metals in exceedance of the Table 3 SCS were measured in samples from SSF9 in 2001 (copper, lead and zinc). Zinc and phosphorous were measured at concentrations greater than their respective Provincial Water Quality Objectives (PWQO) [162] in a surface water sample obtained from a local ditch.

There was no analytical data available for review from the SSTF area after 2001.

Distribution Station #2 and #4 (DS#2 and DS#4) (site 4)

Soil and groundwater sampling was conducted in the vicinity of DS#2 and DS#4 (Figure 5.7.2-1) during the 1999 Phase II ESA activities [14]. There were no concentrations greater than their respective SCS measured in any of the samples, and further assessment was not undertaken.

Former Construction Landfill #1 (CL1) (site 5)

Soil and groundwater sampling was conducted in the vicinity of CL#1 during the 1999 to 2001 Phase II ESA activities [14]. A total of eight groundwater monitors were sampled at the site in 2001. MOE Table 3 SCS exceedances that were measured in one well nest (CL1 WD40A and WD40B) for trichloroethylene and vinyl chloride by Kinectrics in 2000 were not replicated during the 2001 supplementary ESA. There were no soil or groundwater exceedances of the SCS measured for any parameters that were analyzed in 2001. Elevated chloride was measured in groundwater down-gradient of the landfill footprint.

There was no analytical data available for review from the CL#1 area since 2001.

Former Construction Landfill #4 (CL#4) (site 6)

Soil and groundwater sampling was conducted in the vicinity of CL#4 during the 1999 to 2001 Phase II ESA activities [14]. Results from the soil sampling program in 1999 indicated a need for further assessment.

Nine boreholes were advanced by CH2M Hill in 2001 with four boreholes completed as monitoring wells. Metals impacts were measured in a sample from one borehole (CL4 – copper and zinc). An exceedance of the Table 3 SCS for vinyl chloride was measured in one groundwater sample (CL4-16). Metals exceedances were measured in sediment from the ornamental pond (copper and zinc) [16].

The CL#4 well network is monitored on an annual basis [163;24]. In 2006, there were no groundwater exceedances of the MOE Table 3 SCS recorded in any of the CL#4 wells, for any of the analyzed parameters (metals, volatile organic compounds (VOCs), Petroleum Hydrocarbons (PHCs), or PAHs). There was a single exceedance of the Ontario Drinking Water Standards (ODWS) for sulphate measured in CL4-16.

Fire Training Facility (FTF) (site 7)

Soil sampling was undertaken at twenty sites in and around the FTF during the 1999 Phase II activities (Figure 5.7.2-1). PHC contamination in the gas/diesel range was identified in the FTF soils [14].

A total of 19 monitoring wells were installed in 2000 [14] and 2001. Elevated concentrations of PHCs (gas/diesel) in soil were measured at locations throughout the FTF display areas. The volume of PHC impacts greater than the Table 3 SCS was estimated to be 47,500 m^3 [16].

VOC and BTEX compounds in groundwater were recorded below the Table 3 SCS in 2001. Elevated concentrations of PHCs (gas/diesel) were measured at the majority of the groundwater monitoring locations. Free product of light non-aqueous phase liquids (LNAPLs) was measured at six locations in 2001, ranging in thickness from 0.1 cm to 36 cm.

The FTF well network is monitored on an annual basis [163;24]. In 2006, there were no groundwater exceedances of the MOE Table 3 SCS recorded in any of the FTF wells for metals, VOCs, or BTEX. Exceedances of the Table 3 SCS for PHCs in the Fraction 2 to Fraction 4 range (F2 to F4) were measured at 10 locations, while PAHs greater than the Table 3 SCS were recorded at two wells. The 2006 analytical results are generally similar to those reported in 2005.

In 2006, free product was measured at two locations; FTF-30 (3 mm thickness) and FTF-38 (42 mm thickness), with a sheen observed in seven wells. In 2005, free product was measured at one well (FTF-30 18 mm), with a sheen observed at eight wells (including the same seven 2006 locations). A comparison of the PHC F3 contaminant plume extent from 2005 to 2006 suggests a diminishing strength of the hydrocarbon contamination, except in the immediate vicinity of FTF-38 in the northwest corner of the site [24].

5.7.2.2 WWMF Portion of the Project Area

In September 2000, an EA was completed at the WWMF (former RWOS 2) for the expansion of the facility [35]. The WWMF has 18 monitoring wells located around the site, both in overburden and in bedrock. The only parameter of concern identified was tritium in groundwater.

WWMF Groundwater Monitoring

Since 1978 a groundwater monitoring system has been in place at the WWMF portion of the Project Area in support of its regulatory operating licence. Groundwater samples are collected routinely on a quarterly basis as a minimum. These wells are primarily used to sample radiological constituents; tritium and gross beta concentrations are measured in water from 18 wells, and carbon-14 (C-14) is measured in water from three groundwater monitoring wells at the WWMF. A summary of the radiological results from groundwater monitoring is provided in the Radiation and Radioactivity TSD. The primary intent of the program is to identify any gradual changes in groundwater quality that may indicate a likely subsurface release of radioactive waste from the WWMF.

The 18 monitoring wells are purposely positioned within the uppermost aquifers adjacent to the above-ground and below-ground concrete LLW storage structures. These aquifers include the laterally discontinuous Middle Sand aquifer and the underlying semi-confined carbonate bedrock aquifer. The locations of the monitoring wells intersecting these aquifers are shown in Figure 5.3.1-1. The majority of the monitoring wells are located down-gradient of the WWMF at or near the WWMF perimeter.

The groundwater in the WWMF area is characterized as a hard, mineralized calcium and magnesium bicarbonate dominated water with varying amounts of sulphate as the major ion chemistry. This chemistry is typical of the overburden soils and carbonate mineralogy of the region [12]. The water is hard to very hard and has good buffering capacity to neutralize acidic leachates. Transport of metals (e.g., strontium and cesium) is controlled in neutral to alkaline groundwaters by adsorption and precipitation reactions, resulting in very little potential for movement [122].

The Middle Sand aquifer is not laterally extensive and does not extend beyond the perimeter of the Bruce nuclear site. Immediately beneath the WWMF portion of the Project Area, as discussed above, there are local downward connections with the underlying bedrock aquifer. At these points of contact the bedrock acts as a sink and a point of discharge for the Middle Sand aquifer. Once within the bedrock aquifer, groundwater flow is sub-horizontal in a westward direction toward a point of shallow nearshore discharge into Lake Huron.

It should be noted that drinking water at the Bruce nuclear site and the WWMF site is not obtained from groundwater. The supply is taken from the Bruce nuclear site Domestic Water System, operated by Bruce Power, which takes water from Lake Huron.

5.7.2.3 Heavy Water Plant Down-gradient of the Project Area

Soil Quality

Soil quality beneath the Project Area within the former Bruce Heavy Water Plant (BHWP) area was evaluated through Phase I and Phase II Environmental Site Assessments (ESAs), which were conducted in 1998 [15].

The Phase I ESA identified 41 different areas that were assessed as being either potentially or actually contaminated (a 1999 Addendum to the Report indicated there were 39 areas). A review of the Phase I ESA identified 19 areas of actual or potential contamination that are located within the BHWP footprint and vicinity. Of these, a total of 13 areas are in close proximity to the Project Area.

The contaminants identified in these areas included seal oil, lube oil, insulating oil and/or PCB-contaminated insulating oil, diethylamine/methyldiethylamine (DEA/MDEA), iron, manganese, phosphorus and sulphur.

A Phase II ESA was undertaken to identify, confirm and delineate, or demonstrate the absence of contamination at the locations identified in the Phase I ESA [15]. The field-sampling program for the former BHWP area included a series of eight boreholes, 47 test pits and 45 hand-dug, or hand-augered, holes. A total of 31 nested monitoring wells were installed at 16 locations.

More than 200 soil samples were collected and analyzed. The locations of the sampling sites are shown in Figure 5.7.2-2. Parameters that were included in the analysis can be categorized into several groups including metals; oils and grease; benzene, toluene, ethylbenzene, xylene (BTEX); PCBs; O.Reg. 347; and VOCs. Not all parameter groups were analyzed for each sample.

The data were compared to surface soil guidelines for industrial/commercial use with a potable and a non-potable groundwater condition (Tables A and B respectively, 1997 MOE Guideline for Use at Contaminated Sites in Ontario (GUCSO)). The GUCSO criteria were superseded in October 2004 by the Ontario Regulation 153/04 Soil, Groundwater, and Sediment Standards for Use Under Part XV.1 of the *Environmental Protection Act* (the Site Condition Standards). The Site Condition Standards (SCS) are the same as the GUCSO criteria for all of the pertinent chemical parameters except for petroleum hydrocarbons (PHCs), which are subject to a different analytical protocol for their SCS. In light of this, the PHC values will be compared to the GUCSO criteria that prevailed at the time of the 1998 ESA.

The results of the ESA soil sampling program are summarized below:

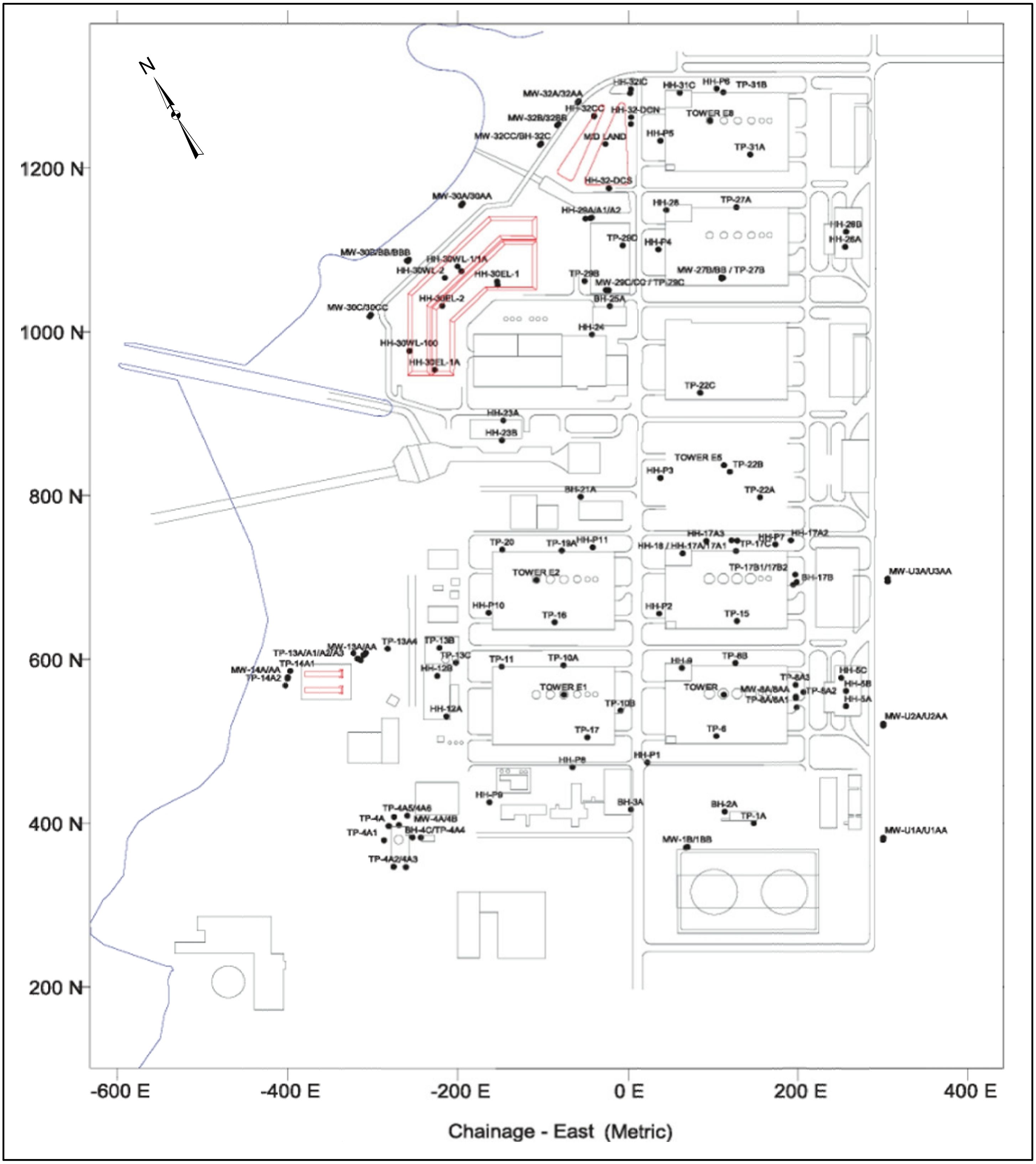
Metals

Of the 154 samples analyzed, the MOE guidelines for one or more parameters were exceeded in 15 samples (including one duplicate) from 10 different locations within the former Heavy Water Plant area. A total of six samples from six locations were in close proximity to the Project Area (Table 5.7.2-1) [15]. Copper, nickel and zinc were the metals most commonly reported to exceed the guidelines. The majority of samples exceeding the guidelines were collected at the ground surface and likely reflect the presence of metallic scale and rust particles that are accompanied by rust colour staining observed at the surface.

Table 5.7.2-1: Metal Parameters Exceeding MOE Guidelines

Sample	Depth (m)	Location	Parameter	Value (µg/g)	MOE Guideline[a] (µg/g)
HH-P4	Surface	Pipe Racks E7	Copper	240	(300) 225
			Zinc	839	(800) 600
HH-P5	Surface	Pipe Racks W. of E8 Pad	Copper	228	(300) 225
			Nickel	204	(200) 150
HH-P6	Surface	Pipe Racks N. of E8	Nickel	167	(200) 150
			Zinc	2033	(800) 600
BH-2A	Surface	Flammable Stores	Arsenic	68	(50) 40
			Chromium	808	(1,000) 750
			Copper	298	(300) 225
			Molybdenum	104	40
			Nickel	723	(200) 150
			Zinc	1290	(800) 600
HH-17A1	0.05	E4-North Side	Copper	231	(300) 225
			Zinc	786	(800) 600
HH-17A1	Surface	E4-North Side	Nickel	176	(200) 150
			Zinc	747	(800) 600

Note:
a Site Condition Standards from [161] Ministry of the Environment. Soil, Groundwater and Sediment Standards Under Part XV. 1 of the Environmental Protection Act (2004), formerly the Guideline for Use at Contaminated Sites in Ontario (1996) [160].



LEGEND

● Wardrop Engineering Sample

REFERENCE

Figure from Bruce Heavy Water Plant Decomissioning Environmental Assessment Study Report, Dated December 2002.

PROJECT	GEOLOGY TECHNICAL SUPPORT DOCUMENT
TITLE	**LOCATIONS OF SOIL SAMPLES HEAVY WATER PLANT**

Golder Associates
Mississauga, Ontario

PROJECT No. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct 2007	**FIGURE 5.7.2-2**	
GIS	BC	5 May. 2010		
CHECK	AB	5 May. 2010		
REVIEW	MAR	5 May. 2010		

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Petroleum Hydrocarbons (PHCs)

More than 180 soil samples were analyzed for total petroleum hydrocarbons (TPH), heavy oil, extractable petroleum hydrocarbons (EPH), and purgeable petroleum hydrocarbons (PPH) within the BHWP (Figure 5.7.2-2). Both the potable and the non-potable groundwater guidelines for TPH were exceeded in numerous samples. Overall, values exceeding the guidelines are limited to several specific locations where high concentrations of TPH are located at surface and at shallow depths. Five of these locations were in close proximity to the Project Area:

- E7 Substation;
- Main Substation D;
- NE corner of E4 Pad;
- Substation B; and
- East of the E3 Pad.

Concentrations were found to decrease with increasing depth at individual sampling locations.

PCBs

None of the 91 soil samples analyzed exceeded the pertinent GUSCO potable or non-potable PCB criterion.

BTEX

The MOE GUSCO criteria for benzene, toluene, ethylbenzene and xylene (BTEX) were not exceeded for the twenty-four samples analyzed within the BHWP. Values were reported as Not Detected in all twenty-four samples.

EPA 624

The MOE GUSCO criteria for the constituents listed within the EPA 624 scan for VOCs [99] were not exceeded for the eighty-one samples analyzed within the BHWP. The vast majority of values were reported as Not Detected.

VOC

The MOE GUSCO criteria for VOC parameters were not exceeded for the eight samples analyzed within the BHWP. Forty-seven parameters were included in the VOC parameter list. Results for all parameters, in all samples, were reported as Not Detected.

Groundwater Quality

Detailed site-specific information is available from the Phase II ESA which was undertaken in 1998 [15].

The groundwater monitoring network established during the Phase II ESA comprised the following: seven upgradient monitoring wells (upgradient relative to groundwater flow and the enriching towers), 16 down-gradient monitoring wells (down-gradient relative to groundwater flow, along the shoreline of Lake Huron) and eight monitoring wells within the former BHWP site. The location classifications of these wells are as follows:

- Upgradient Monitoring Wells - MW-U1AA, U2A, U2AA, U3A, U3AA, 8A, 8AA;
- Centre of Site Monitoring Wells - MW-1B, 1BB, 4A, 4B, 27B, 27BB, 29C, 29CC; and
- Down-gradient Monitoring Wells - MW-13A, MW-13AA, MW-14A, MW-14AA, MW-30A, MW-30AA, MW-30B, MW-30BB, MW-30BBB, MW-30C, MW-30CC, MW-32A, MW-32AA, MW-32B, MW-32BB, MW-32CC.

Of the seven wells installed upstream, four have well screens located in the upper bedrock aquifer (upper carbonate bedrock) and three have well screens in the unconsolidated overburden material (sand and gravel, silt till, construction fill). With respect to the 16 down-gradient monitoring wells, eight are screened in the upper bedrock aquifer and eight are screened in the unconsolidated overburden.

A comparison of the 1998-99 groundwater chemistry to the then applicable MOE Table B criteria (current MOE Table 3 SCS) indicated that there was no significant impact to the environment, as none of the analytes measured in the down-gradient monitoring wells showed appreciably higher concentration levels than those measured in the wells located upgradient of the former BHWP. None of the analytes measured from monitoring wells located in the interior of the former BHWP site exceeded the MOE GUSCO criteria for non-potable groundwater, although one parameter (selenium) in one well was at the SCS for that parameter (50 µg/L).

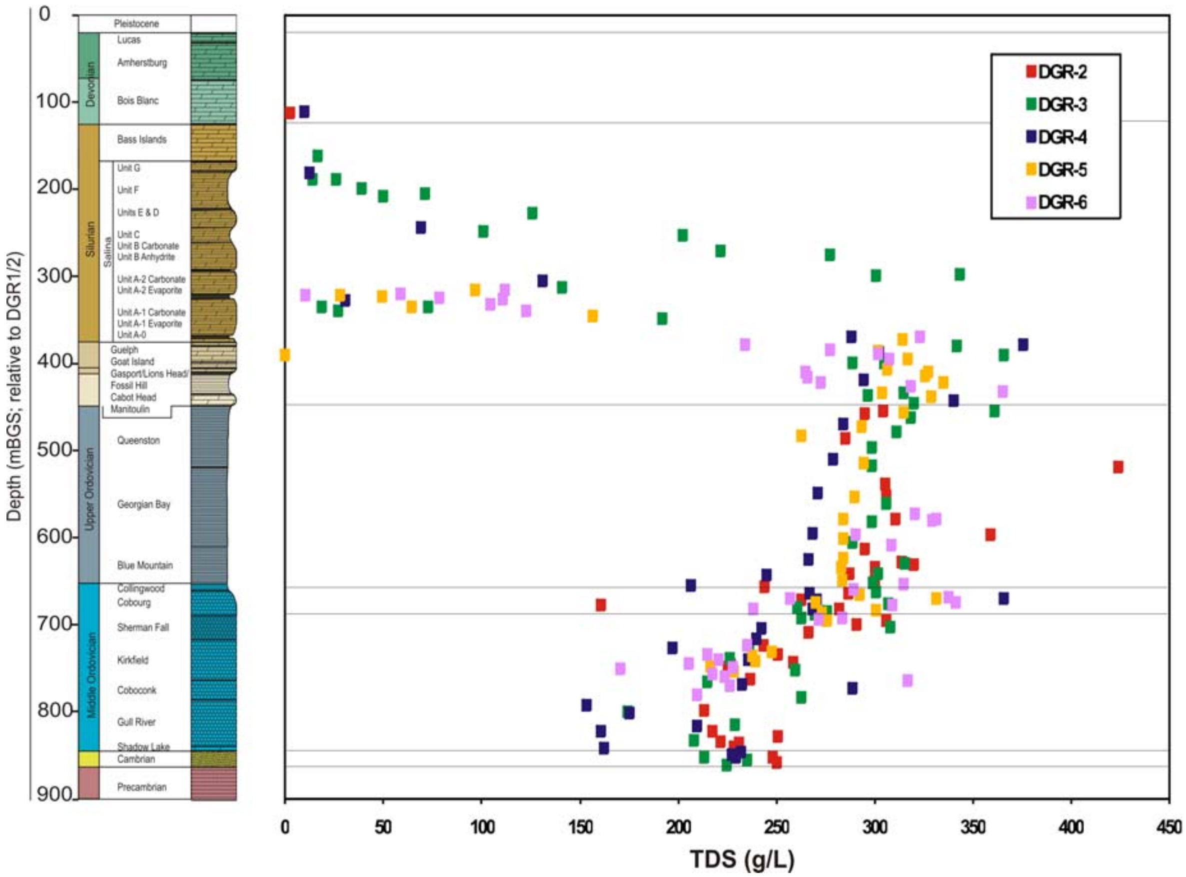
The monitoring well network was re-sampled in 2005 as part of the follow-up monitoring program for the BHWP Demolition Phase. The results were compared to the current applicable standards, the MOE Table 3 SCS, and may be summarized as follows:

- A comparison of the groundwater chemistry to MOE Table 3 SCS for non-potable groundwater [161] indicates no exceedances of contaminants of concern were identified during the 1998 Phase II ESA. Concentrations of all parameters that were measured in all of the BHWP monitoring wells were below the MOE Table 3 SCS during 2005.
- Upstream Monitoring Wells:
    - Contaminants of concern antimony, arsenic, selenium, phenols, PCBs or BTEX were all measured below the Table 3 SCS.
    - Measurable hydrocarbon concentrations were detected in June 2005 at MW-8A (2,540 µg/L and 100 µg/L for the F3 (C16-C34) and F4 (>C34) fractions, respectively). An oily sheen was noted in groundwater from MW-8A during the June 2005 sampling event. Free product was then measured at MW-8A (2.2 cm), using an oil/water interface probe, in September 2005.

- Centre of Site Monitoring Wells:
    - Contaminants of concern antimony, arsenic, selenium, phenols, PCBs or BTEX were all measured below the Table 3 SCS.
    - Petroleum hydrocarbons were measured at detectable concentrations for MW-4A and MW-4B. Hydrocarbon odours and/or oily sheens were detected at MW-4A, and MW-4B. Measurable free-product levels (9.1 cm and 12.2 cm in June and September 2005, respectively) were measured at MW-4B.
- Downstream Monitoring Wells:
    - Contaminants of concern antimony, arsenic, selenium, phenols, PCBs or BTEX were all measured below the Table 3 SCS.
    - Oil sheen was detected at MW-13A in June 2005 but was not observed during the September 2005 sampling event. Measurable hydrocarbon levels were detected at MW-13A in June 2005 but were not detected in September 2005.

5.7.2.4 Groundwater Characterization at the Bruce Nuclear Site

The distribution of total dissolved solids (TDS) with depth beneath the Bruce nuclear site, presented in Figure 5.7.2-3, allows for the distinction of groundwater systems relevant to the following discussion. In a similar manner as the regional two-layer system, a shallow system of fresh to brackish groundwater (0.5 to 5.0 g/L TDS) is defined for the overburden unit and the bedrock interval from the Lucas and Amherstburg formations to the top of the Salina G Unit, to a depth of approximately 170 mBGS. The porewaters within the interval of 110 to 170 mBGS have TDS values that range from 2.0 to 16.0 g/L. These TDS concentrations are relatively low compared to groundwater and porewater samples from the underlying intermediate to deep system. As Figure 5.7.2-3 indicates, the TDS values increase with depth from within the Salina F unit to the base of the Silurian (Guelph to Manitoulin formations). In the Ordovician rocks, TDS values are relatively high (most fluids have TDS greater than 200 g/L). TDS values are stable from the Queenston Formation to the Collingwood Member, and then decrease with depth, but typically maintain concentrations greater than 200 g/L, in the carbonate-rich Cobourg to Gull River formations. At the base of the profile, within the Shadow Lake and Cambrian formations, TDS values increase slightly, but are still lower than the values measured within the Ordovician shales.



Source: Modified from Figure 4.54 of [11].

Figure 5.7.2-3: Total Dissolved Solids versus Depth for DGR Boreholes

5.7.2.5 Shallow Groundwater System Characterization

The shallow groundwater system is characterized by two different water types. Within the overburden aquifer, the water is classified as Ca:Na-HCO_3. In the upper bedrock (above 170 mBGS), the dominant cations yield Ca:Mg-HCO_3 porewaters.

Generally, major ion concentrations in groundwater from US-3 are slightly greater than US-7 and US-8, but the molal ratios are similar in each borehole, and groundwater concentrations increase with depth in each borehole.

Major Ions

Ferrous iron, or reduced iron (Fe^{2+}), concentrations in the US-series samples were between 0 and 1.3 mg/L. Where there was dissolved ferrous iron in the groundwater, the reduction-oxidation state may be classified as iron-reducing. This classification is supported by the core logs for DGR-1, DGR-3 and DGR-4, which note the presence of pyrite near the base of the Amherstburg Formation. Pyrite is indicative of ferrous iron in solution, resulting in precipitation of FeS_2. Pyrite is inconsistently observed through the Bois Blanc and Bass Islands formations in

DGR-1, DGR-3 and DGR-4. Although pyrite was identified in the cores, sulphide was not detected in the groundwater samples.

Colorimetric and potentiometric measurement of Dissolved Oxygen (DO) showed concentrations were below 2 mg/L in most groundwaters sampled from US-series wells, except for one measurement of 6.3 mg/L in US-8 at a depth of 170.2 mBGS. These low oxygen levels indicate dissolved oxygen is limited in the shallow groundwater. Iron staining is observed in rocks of the Lucas, Amherstburg and Bois Blanc formations, however, and is likely due to ferric iron, or oxidized iron (Fe^{3+}), which is commonly associated with relatively oxidizing conditions. Isolated oxidized zones may occur in the upper flow system (Lucas, Amherstburg and Bois Blanc formations) based on the presence of iron staining within these rocks [11].

The observed low ferrous iron concentrations and low DO contents (less than 2 mg/L) in the groundwater, combined with the presence of iron and pyrite in the cores, suggests oxygen is almost absent in the shallow groundwater, and that the redox conditions are in a transition from near-anaerobic to iron-reducing [11].

Alkalinities measured in the field range between 100 and 330 mg/L as $CaCO_3$, with pH ranging between 6.8 and 8.5. The alkalinity in the samples is derived from HCO_3^-, which is the dominant anion in the groundwater due to carbonate dissolution. The major ion chemistry profile for the shallow groundwater system (US-8 data) is shown in Figure 4.44 of the Descriptive Geosphere Site Model (DGSM) [11].

Oxygen and Hydrogen ($\delta^{18}O$, $\delta^{2}H$, ^{3}H)

The stable water isotope data ($\delta^{18}O$ and $\delta^{2}H$) for shallow bedrock groundwaters collected from US-series wells, as well as drill waters, are plotted in Figure 5.7.2-4 and compared to the Global Meteoric Water Line (GMWL). Figure 5.7.2-4 shows the shallow bedrock groundwaters grouped by Middle to Lower Devonian dolostones (Lucas, Amherstburg and Bois Blanc formations) and Upper Silurian dolostones (Bass Islands and Salina G Unit). For comparison purposes the groundwater samples collected from the Salina A1 Unit carbonate aquifer, the Guelph Formation, and the Cambrian sandstone in DGR boreholes are also shown. The following features can be observed in Figure 5.7.2-4.

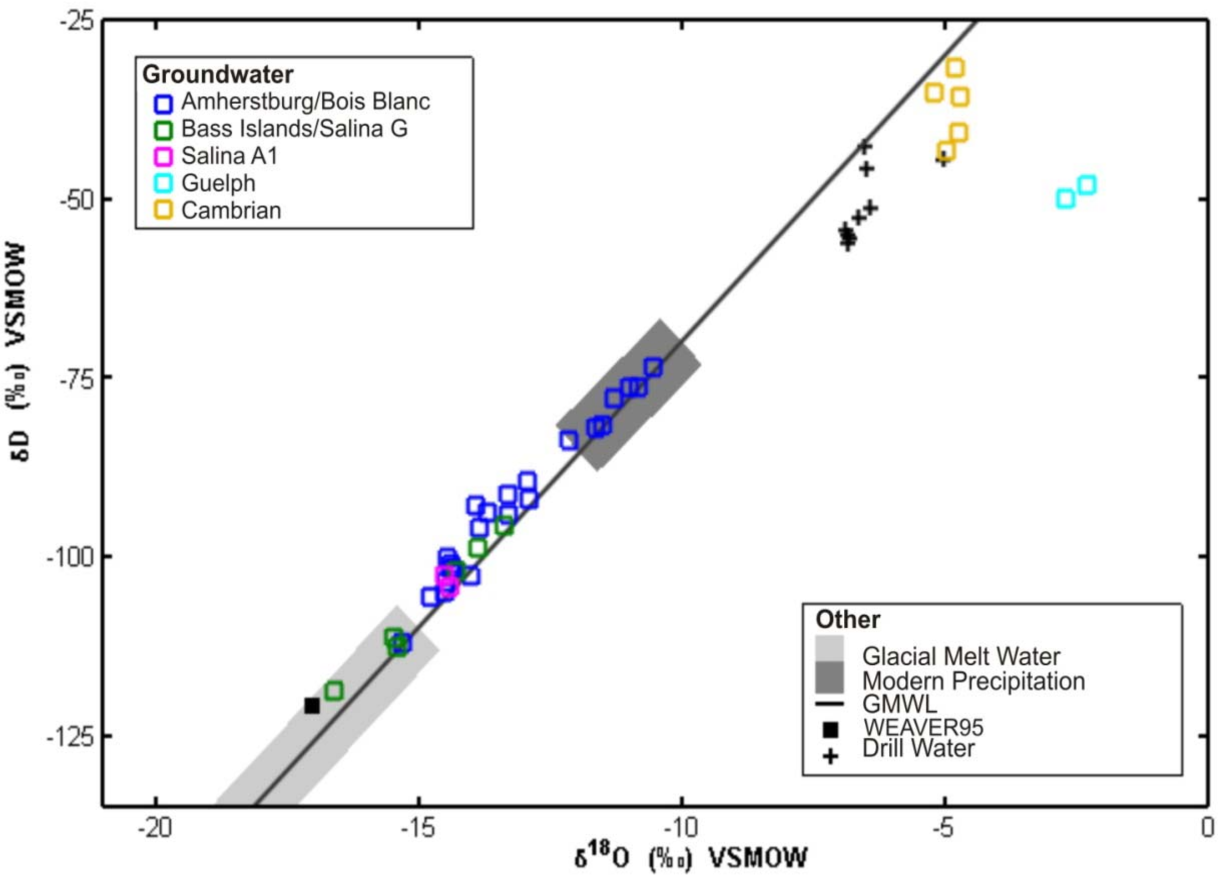
- Lake Huron water used for drilling has a characteristic evaporative enrichment signature. As well, the Cambrian groundwater is significantly enriched and plots close to the GMWL. Both of these waters plot remotely from the Devonian and Upper Silurian dolostone groundwaters, suggesting that the shallow bedrock groundwaters are not influenced by drill water, casing installation water, or Cambrian sandstone water.
- The groundwater values in the Devonian and Silurian aquifers plot between modern precipitation (mean approximately -12 ‰ for $\delta^{18}O$) and glacial meltwater (i.e., -20 to -15 ‰ for $\delta^{18}O$), indicating that these groundwaters are mixtures containing both glacial melt water and modern precipitation [26].

Tritium units (TU) are a measure of the concentration of ^{3}H in a given sample. One tritium unit (1 TU) is equal to one ^{3}H atom per 10^{18} hydrogen atoms. Most groundwater samples from the US-series wells had <35 TU (<4.13 Bq/L), and 14 out of 29 samples had tritium counts below the detection limit for direct counting analysis (<6 TU, or 0.708 Bq/L). Tritium in precipitation at the Bruce nuclear site is elevated and averaged 1,700 TU (200.6 Bq/L) during 2005-2006

(BP08). Although the $\delta^{18}O$ and $\delta^{2}H$ ratios indicate the groundwater is of atmospheric origin (Figure 5.7.2-4), the low tritium counts suggest the groundwater does not contain recent atmospheric water that is affected by activities at the Bruce nuclear site.

Chloride

The trend toward low solute concentrations toward the surface, as indicated by low Cl and Br concentrations (refer to Figure 5.7.2-6), likely results from diffusive or advective mixing of surface-derived meteoric water with the shallow formational fluids. This interpretation is supported by $\delta^{18}O$ and $\delta^{2}H$ data for groundwater and porewater from the Bruce nuclear site (Figure 5.7.2-4).



Notes: Also shown is the range of modern precipitation [164] and the range and best estimate of glacial meltwater for Southern Ontario [165;166].
Source: Modified from Figure 4.47 of [11].

Figure 5.7.2-4: Cross-plot of $\delta^{2}H$ (δD) Versus $\delta^{18}O$ for Drill Waters and Groundwater Samples from US-3, US-7, US-8, and DGR Boreholes

5.7.2.6 Intermediate to Deep System Groundwater and Porewater Characterization

The following section focuses primarily on the intermediate to deep groundwater system from deep boreholes DGR-1 through DGR-6, with reference to the shallow groundwater system when relevant.

The intermediate to deep groundwater system is characterized by a transition from the brackish Ca-SO_4 water observed in the Silurian G Unit, to an increasingly concentrated Na-Cl type (saline) brine from the Silurian C Unit down to the base of the Cambrian (244.6 to 860.7 m BGS). The underlying Precambrian fluid chemistries have not been characterized at the Bruce nuclear site, but the chemistries of shield brines have been the subject of extensive study across southern Ontario and are discussed briefly in Section 5.7.3.

Natural Tracers

Analysis of natural environmental tracer profiles (such as chloride, bromide, and the stable isotopes of oxygen and hydrogen) in the porewaters of low-permeability sedimentary rocks can be a powerful approach for assessing the transport properties of potential host rock formations for nuclear waste management at time and spatial scales relevant to a DGR.

Profiles of the stable water isotopic data below the Bruce nuclear site are presented in Figure 5.7.2-5 and the Cl and Br profiles are presented in Figure 5.7.2-6.

Trends in the data should be considered in terms of deviations from some initial baseline condition. For these tracers, that condition could be considered to be their respective concentrations in the ancient evaporated sea water from which the Michigan Basin brines are presumed to have been derived [136;135]. The baseline $\delta^{18}O$ is best represented by a value of -2‰ for all of the sedimentary formations [167;143;136;135]. An initial Cl concentration of 6 to 7 mol/kgw is proposed for the Silurian and Devonian fluids to represent evaporated sea water, and an initial Cl concentration of 0.6 mol/kgw is suggested for the Ordovician and Cambrian formation fluids as a representation of normal marine sea water. These baseline values are assigned to maintain consistency with the evolutionary history of the Michigan Basin.

The following features are observed in the natural tracer data.

- There is a decrease for all tracers from the Guelph Formation upward through the Silurian. The presence of high horizontal hydraulic conductivity (K_h) zones in the Silurian (see Figure 5.6.1-2) and the corresponding abrupt variations in tracer profiles with depth through the Silurian sediments, suggest that dilution may have occurred by a combination of advective mixing and diffusion.
- There is a less pronounced but persistent trend toward depleted $\delta^{18}O$ values, reduced Cl and Br concentrations, and enriched $\delta^{2}H$ values below the Ordovician shale.
- The trends toward depleted $\delta^{18}O$ values, and reduced Cl and Br concentrations, below the Ordovician shale, are interrupted at the Cambrian where the tracer values become more enriched.

Little is known about the timing of exposure of the Devonian rocks in southern Ontario to infiltration. If something close to the present-day erosion level was exposed during the

Pleistocene, then the cyclic nature of glacial-interglacial periods in the past 1 to 2 Ma would have resulted in repeated infiltration events in the Devonian (and possibly Silurian) stratigraphy of southern Ontario, with subsequent diffusive equilibration of the formation waters in the low-K_h sediments with fresh water during interglacial periods. These processes may explain the trends toward depleted $\delta^{18}O$ and $\delta^{2}H$ (Figure 5.7.2-5) and decreased Cl and Br concentrations (Figure 5.7.2-6) that are observed above the Silurian Guelph Formation and discussed in Section 5.7.2.2. The most depleted $\delta^{18}O$- and $\delta^{2}H$-depleted signatures (-14.5 and -110‰, respectively) are measured in a thin aquifer at 325.5 to 328.5 m depth in the Salina A1 Unit carbonate (Figure 5.7.2-5) and indicate the presence of glacial melt water. This represents the maximum depth of glacial melt water infiltration observed at the Bruce nuclear site.

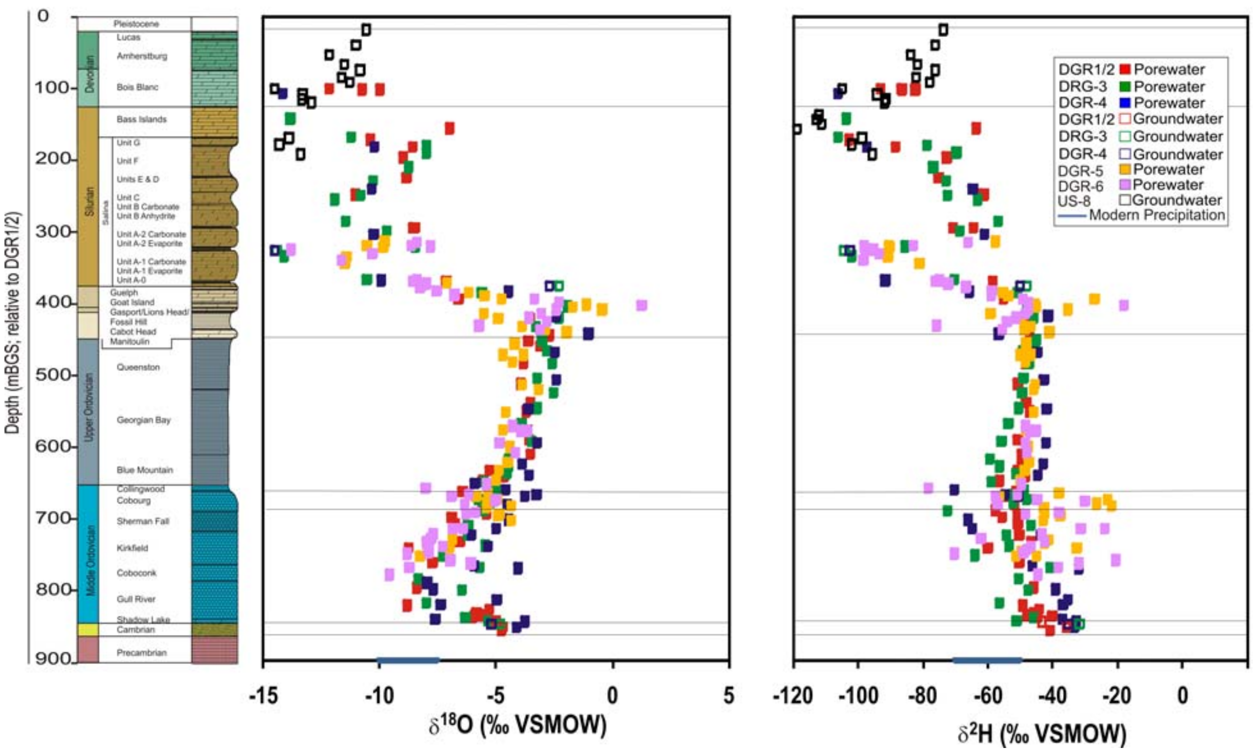
With increasing depth, the general trend in the data in the Middle Ordovician is toward a gradual depletion in $\delta^{18}O$ and decreasing salinity. Coincident with the depletion of $\delta^{18}O$, there is minor enrichment in $\delta^{2}H$ (Figure 5.7.2-5). In contrast with the natural tracer profiles in the Silurian, the very low K_h values in the Ordovician limestone (see Figure 5.6.1-2), and the smooth nature of the downward depletion trends, suggest that solute transport is dominated by diffusion in the Ordovician. The time period required to form such trends in the profiles by diffusion is expected to be on the order of tens to hundreds of millions of years, and is discussed in more detail in Section 5.7.3.2.

The groundwater and porewater profiles change within the Cambrian sandstone, where tracer concentrations shift back toward values representative of Cambrian groundwater sampled from southwestern Ontario oilfields (Figures 5.7.1-1 and 5.7.1-2). The Cambrian chemistry at the Bruce nuclear site is discussed in Section 5.7.4.

Water-rock Interaction

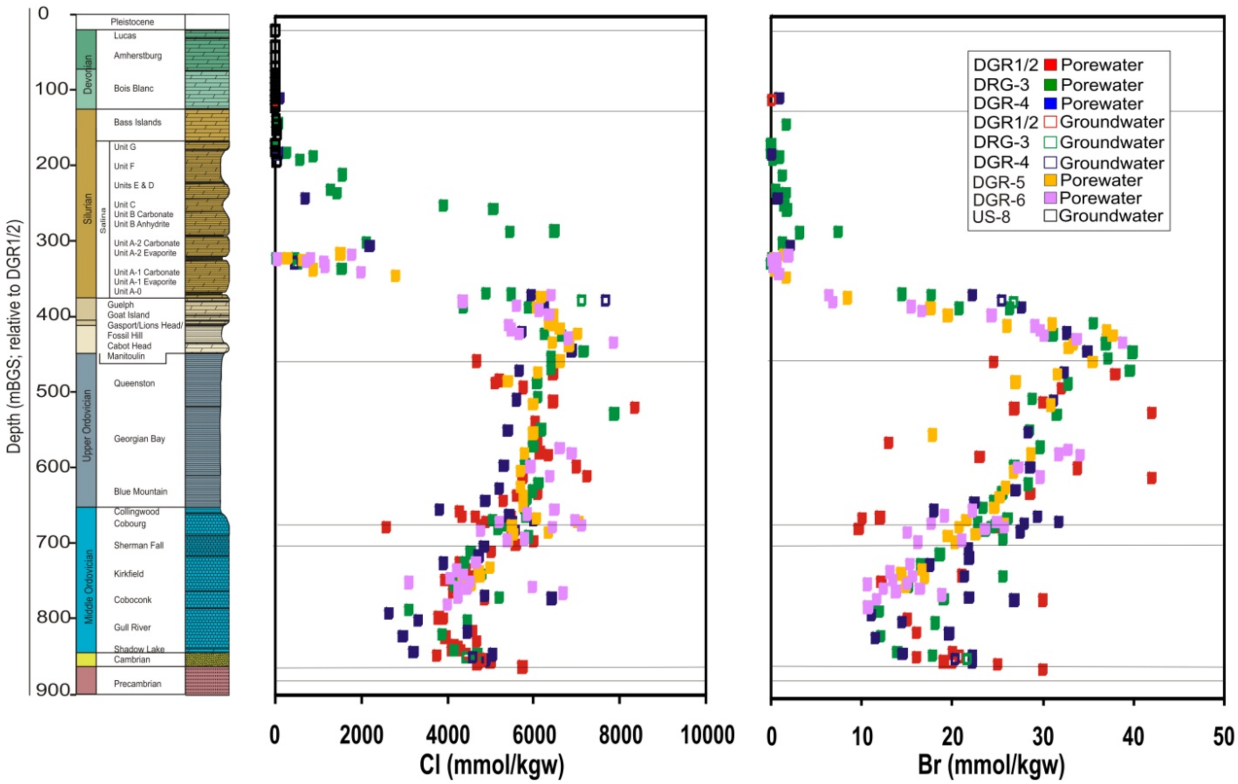
Water-rock interaction must be considered as a possible explanation for the observed $\delta^{18}O$ and $\delta^{2}H$ profiles with depth. At elevated temperatures, reactions with calcite and illite-smectite clays could lead to an increase in $\delta^{18}O$ values (as is commonly observed in sedimentary basin brines), but such reactions cannot easily explain the decrease in $\delta^{18}O$ to values as low as -8.78‰ in the Middle Ordovician carbonates. The dolomite content in the Middle Ordovician limestone increases versus depth (Figure 3.5 of [11]), coincident with the decrease in $\delta^{18}O$ values versus depth. If it is assumed that the porewater in the system is static, a very long porewater residence time is available and it may be possible that the observed $\delta^{18}O$ profiles have evolved in response to isotopic equilibration with dolomite. Using $\delta^{18}O$ values for Middle Ordovician dolomite from Coniglio and Williams-Jones [90] and dolomite-water fractionation factors from Vasconcelos et al. [168] and Chacko and Deines [169], the isotopic composition of pore water in equilibrium with dolomite can be calculated over a reasonable temperature range (25 to 45 °C). Results of these calculations indicate that equilibration with dolomite could result in porewater $\delta^{18}O$ values from -13.1 to -2.7‰. These results suggest that isotopic equilibration with dolomite might explain the observed decrease in $\delta^{18}O$ values with depth.

Although water-rock interaction might provide an explanation for the $\delta^{18}O$ profile, it is not apparent that water-rock interactions could explain the observed $\delta^{2}H$ enrichment versus depth in the Middle Ordovician. It is well known that $\delta^{2}H$ partitions preferentially to the fluid during mineral hydration reactions (e.g., feldspar to clay transformations) [170] and this fractionation may have operated throughout the Ordovician units as detrital feldspars were altered to clay minerals. However, mass-balance requirements suggest that any resulting δ^2H enrichment of the porewater should be proportional to the ratio of sheet-silicate content to porosity. Regarding illite and chlorite content (Figure 3.7 of [11]), there is no significant increase versus depth in the Middle Ordovician as would be expected if mineral hydration reactions were responsible for the observed δ^2H enrichment in the porewater.



Source:
Oxygen profile (left) is modified from Figure 4.61 of [11]. Deuterium profile (right) is modified from Figure 4.62 of [11].

Figure 5.7.2-5: Vertical Depth Profiles for Natural Tracers δ^{18}O and δ^2H Determined in Porewater and Groundwater



Note: Chloride profile (left) is modified from Figure 4.53 of [11]. Bromide profile (right) is modified from Figure 4.55 of [11].

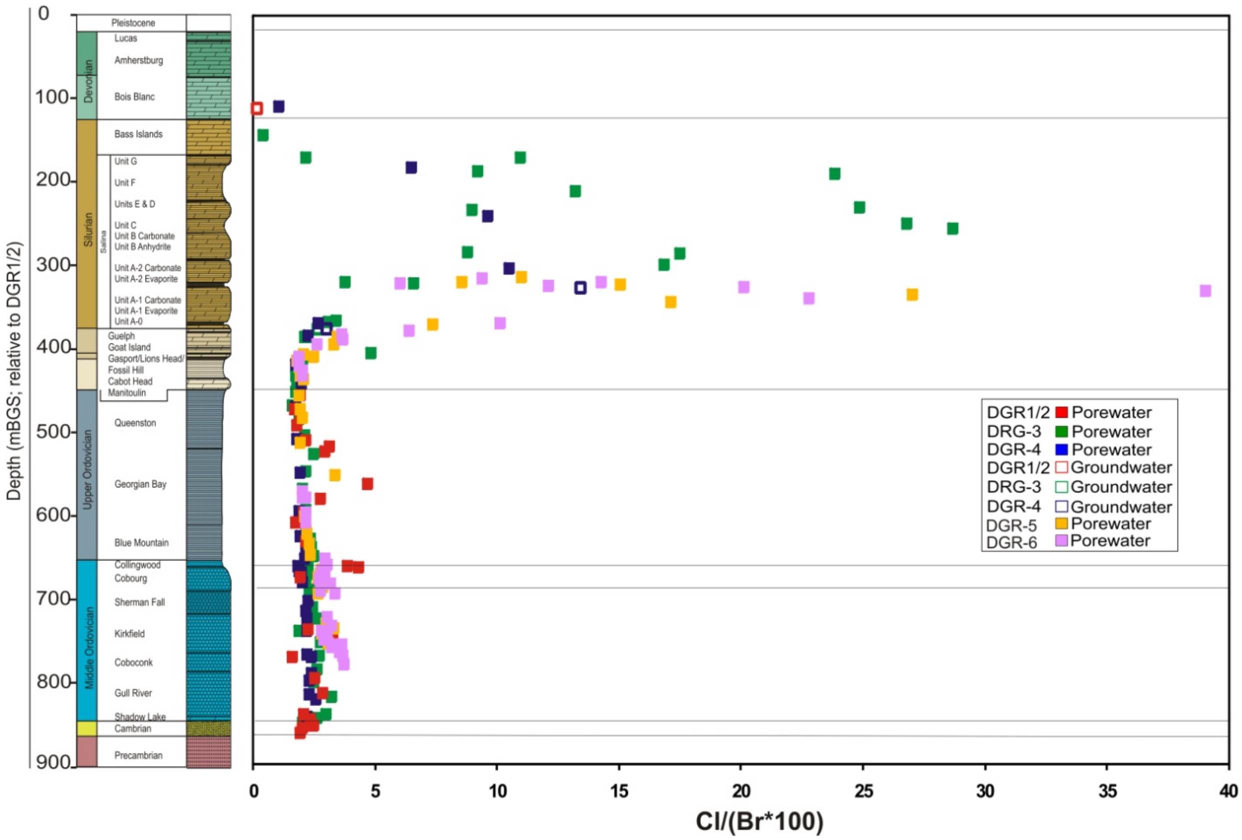
Figure 5.7.2-6: Vertical Depth Profiles for Natural Tracers Cl and Br Determined in Porewater and Groundwater

Fluid Mixing

In contrast to water-rock interaction, the Middle Ordovician trends for all tracer profiles could result from one or more mixing events with water at depth that is relatively depleted in $\delta^{18}O$, has lower Cl and Br concentrations, and is enriched in δ^2H. This could not be the brine that is currently contained in the Cambrian sandstone because it has a higher salinity and more enriched isotopic composition than the porewater in the Middle Ordovician carbonates (Figures 5.7.2-5 and Figure 5.7.2-6). However, the relatively high permeability in the Cambrian sandstone could have allowed changes in the groundwater composition at some point in the geologic past, provided the appropriate driving mechanism(s) for fluid migration were present. The question arises as to whether groundwater in the Cambrian aquifer, or groundwater in the underlying shield, could have provided a suitable end member to generate these mixing trends. The current state of knowledge regarding groundwater in the Precambrian shield and in the Cambrian is discussed in Sections 5.7.3 and 5.7.4, respectively.

The relatively constant Cl/Br ratios in the Ordovician and Cambrian rocks suggest that halite dissolution does not have a significant influence on the Cl concentration in the porewater (Figure 5.7.2-7). The elevated Cl/Br ratios in the Salina Formation suggest that these porewaters have been influenced by halite dissolution. The occurrence of halite within the

Ordovician units, as shown in Figure 5.5.2-8 suggests that hypersaline brine was present at depth within the Middle Ordovician at some time in the geologic past.



Source: Modified from Figure 4.58 of [11].

Figure 5.7.2-7: Cl/Br Ratios versus Depth for DGR Boreholes

Gas Characterization

Methane (CH_4), carbon dioxide (CO_2) and helium (He) were extracted from samples of groundwater and core [158;159]. The isotopic compositions $\delta^{13}C$ (CH_4 and CO_2), $\delta^{2}H$ (CH_4) and $^{3}He/^{4}He$ were determined for the gases. The approach of normalizing the total mass of extracted gas (CH_4 and CO_2) to the porewater content was adopted. This approach does not provide an accurate measure of dissolved gas content in cases where gas occurs in other forms, such as in a separate gas phase, dissolved in liquid hydrocarbons, or sorbed to solid forms of organic carbon; however, as measured (mass of gas per mass of rock normalized to water content), the concentrations can be compared to the solubility limits for the gases in brine. Values in excess of the solubility limits provide evidence for the presence of either a separate gas phase or gas in association with solid organic carbon or liquid hydrocarbons.

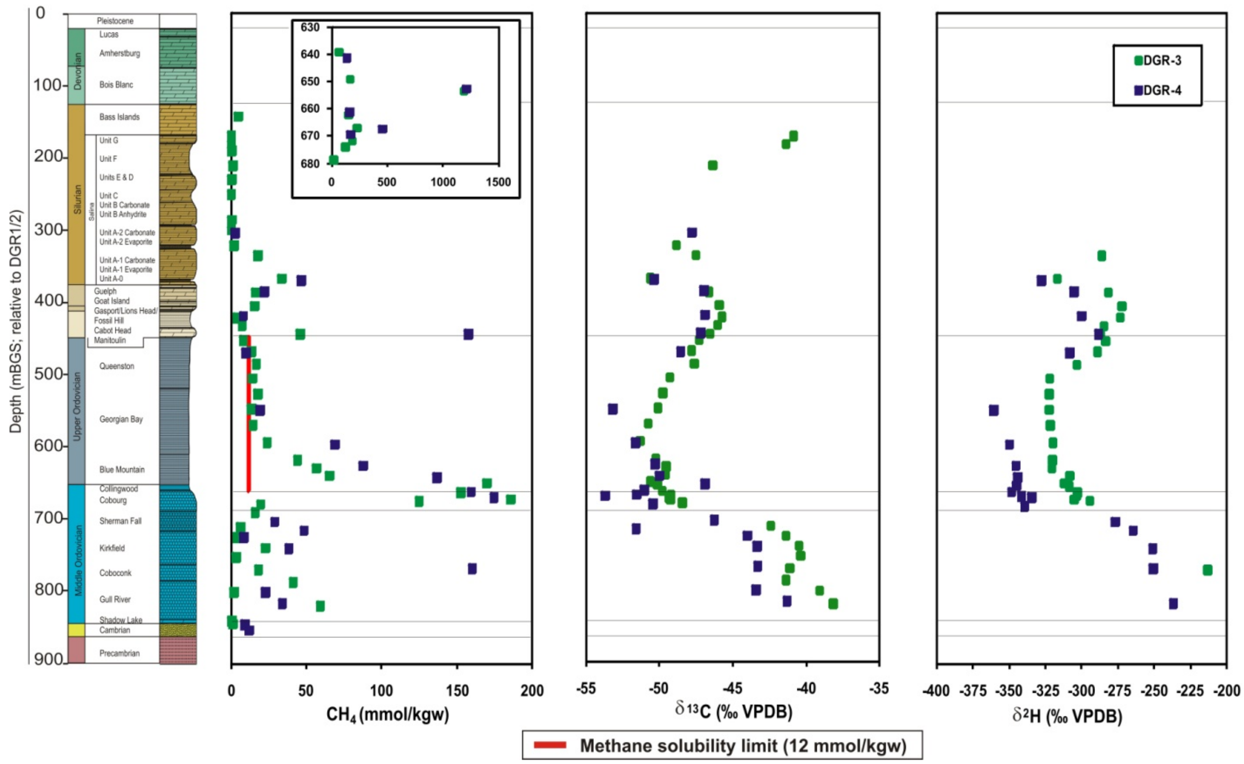
Methane and Carbon Dioxide

The CH_4 and CO_2 data are reported in units of mmol/kgw but, as discussed above, they should not be considered to be exactly equivalent to porewater aqueous concentrations. The concentrations of CH_4 and CO_2, and the respective stable isotopic data, are presented in Figures 5.7.2-8 and 5.7.2-9. There are a number of features observed consistently in the CH_4 and CO_2 data from the DGR drill cores.

- Low CH_4 concentrations are observed near the surface and down to a depth of approximately 300 mBGS, which corresponds to the top of the Upper Silurian Salina A2 Unit.
- Elevated CH_4 concentrations occur in proximity to the hydrocarbon-containing Guelph Formation (375 to 410 mBGS; [171]). The overlying Salina A1 and A2 units may represent a low-permeability barrier to gas transport upward from the Guelph Formation.
- The CH_4 concentration increases gradually downward through the Ordovician Queenston Formation shale and then remains at a near constant value through the Georgian Bay Formation shale.
- There is a pronounced increase in the CH_4 concentration in the interval represented by the Blue Mountain Formation shale and the Collingwood Member (617 to 660 mBGS).
- The CH_4 concentration in the Middle Ordovician limestones and the underlying Cambrian sandstone is low relative to the overlying Blue Mountain shale and the Collingwood calcareous shale.
- The CO_2 data (Figure 5.7.2-9) display a step-wise increase, with the lowest concentrations occurring from surface downward to the Guelph Formation, intermediate concentrations from the top of the Guelph Formation down to the bottom of the Blue Mountain Formation shale, and highest concentrations in the Middle Ordovician carbonates.

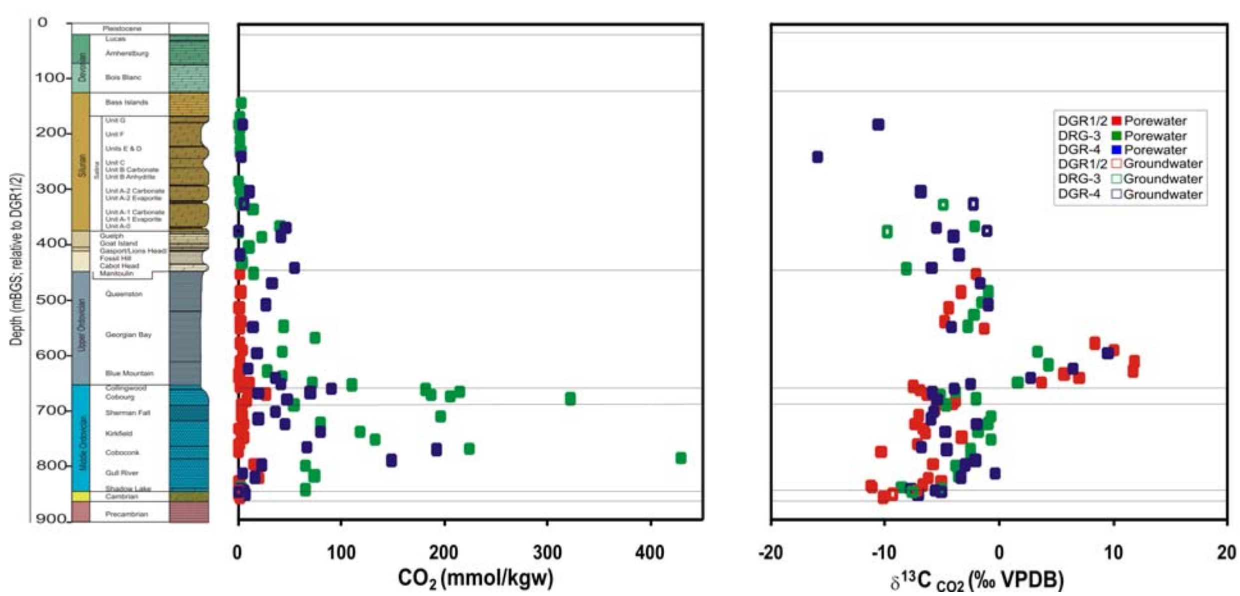
The stable isotope data provide important insight into the origin of the CH_4.

- The $\delta^{13}C$ and $\delta^{2}H$ data for CH_4 display a clear separation between the Upper Ordovician shales and the Middle Ordovician carbonates (Figure 5.7.2-8).
- The stable isotope data from CH_4 have been plotted on the variation diagram from Whiticar [172] and they define two fields: one field represents CH_4 of biogenic origin in the Upper Ordovician shales, and a second field represents CH_4 of thermogenic origin in the Middle Ordovician carbonates (Figure 5.7.2-10).



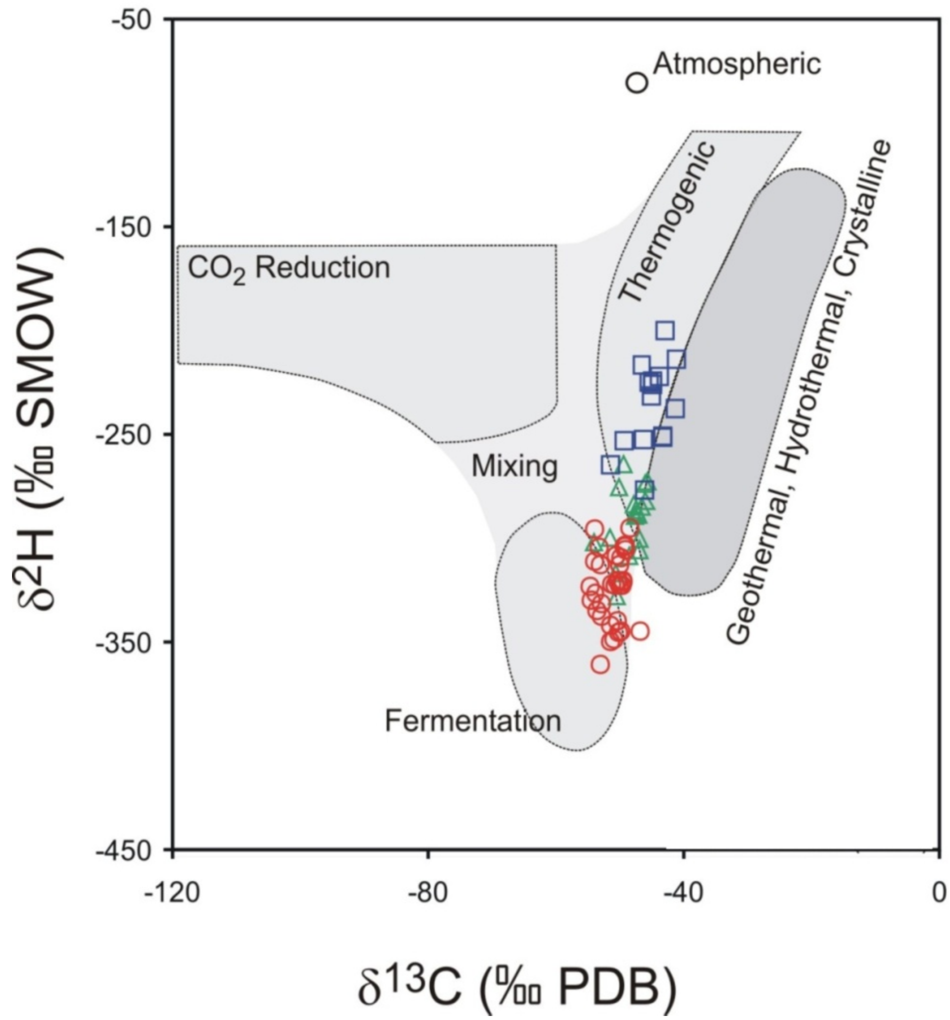
Note: Upper dataset (DGR-3) and lower dataset (DGR-4).
Source: Modified from Figure 4.67 of [11]

Figure 5.7.2-8: Concentration Distributions for CH_4 and $\delta^{13}C$ and $\delta^{2}H$ in CH_4



Source: Modified from Figure 4.69 of [11].

Figure 5.7.2-9: Concentration Distribution for CO_2 Versus Depth (left), and Corresponding Distributions of $\delta^{13}C$ in CO_2 (right)



Note:
Green triangles represent data from the Queenston Formation and above, red circles from the Cobourg, Blue Mountain and Georgian Bay formations, and the blue squares from below the Cobourg Formation.
Source: Modified from [172].

Figure 5.7.2-10: Discrimination Diagram Indicating Fields for CH_4 of Biogenic (CO_2 Reduction and Fermentation) and Thermogenic Origin

The generation of thermogenic gas requires temperatures in excess of approximately 70 °C [2], a condition that has probably not prevailed since maximum burial in the Carboniferous (see discussion in Section 5.5.2.10). It is therefore likely that the thermogenic gas is very old. The age of the biogenic CH_4 contained in the Ordovician rocks is unknown, but some insight can be gained by considering the following:

- If the biogenic gas is young, or perhaps even accumulating via methanogenesis at the present time, then there should be viable and active methanogens in the Blue Mountain shale. The presence of active methanogens is highly unlikely due to the high salinities and low water activities (0.6 to 0.7) measured in the Ordovician sediments. A preliminary microbiological investigation did not find evidence of active methanogens within the Ordovician sediments [173], suggesting that microbes, if present within the sediments at depth, are most likely in a dormant state.

- The alternative interpretation is that the biogenic gas is relatively old and immobile. This is possible if the aqueous CH_4 concentrations are at saturation in the porewater and sections of the profiles with elevated CH_4 content can be explained either by the presence of a discrete gas phase, or by the partitioning of CH_4 into solid organic carbon or liquid hydrocarbons. The CH_4 concentrations exceed presumed solubility limits in the Collingwood Member, the Blue Mountain Formation shale, and, in most samples obtained from the Georgian Bay Formation shale and the lower portion of the Queenston Formation shale (Figure 5.7.2-8), suggesting that CH_4 may occur in a separate gas phase or in associated with organic carbon or liquid hydrocarbons in these zones.

In addition, there appears to be a lack of solute migration in response to the existence of isotopic gradients. There are at least two possible explanations for the apparent retardation of diffusive transport and the full discussion can be found in Section 4.4.3.1 of the Geosynthesis [3].

- Sorption and dissolution/exsolution reactions between CH_4 and solid organic carbon, or liquid hydrocarbons, respectively, cause a decrease in apparent diffusion coefficients.
- Infill or occlusion of porosity in the Cobourg Formation by precipitation of secondary minerals would also act to inhibit solute transport.

The observed separation of biogenic gas above, from thermogenic gas below, provides evidence that there has been little or no cross-formational mixing by advection while the gas has been resident in the system. It appears that neither the biogenic nor the thermogenic gas is mobile, at least in the vertical direction, and this immobility may reflect slow accumulation over a very long period of time. Given that high salinities and low water activities appear to inhibit microbial activity within these sediments, it may be that the biogenic gas is of Paleozoic age.

Helium

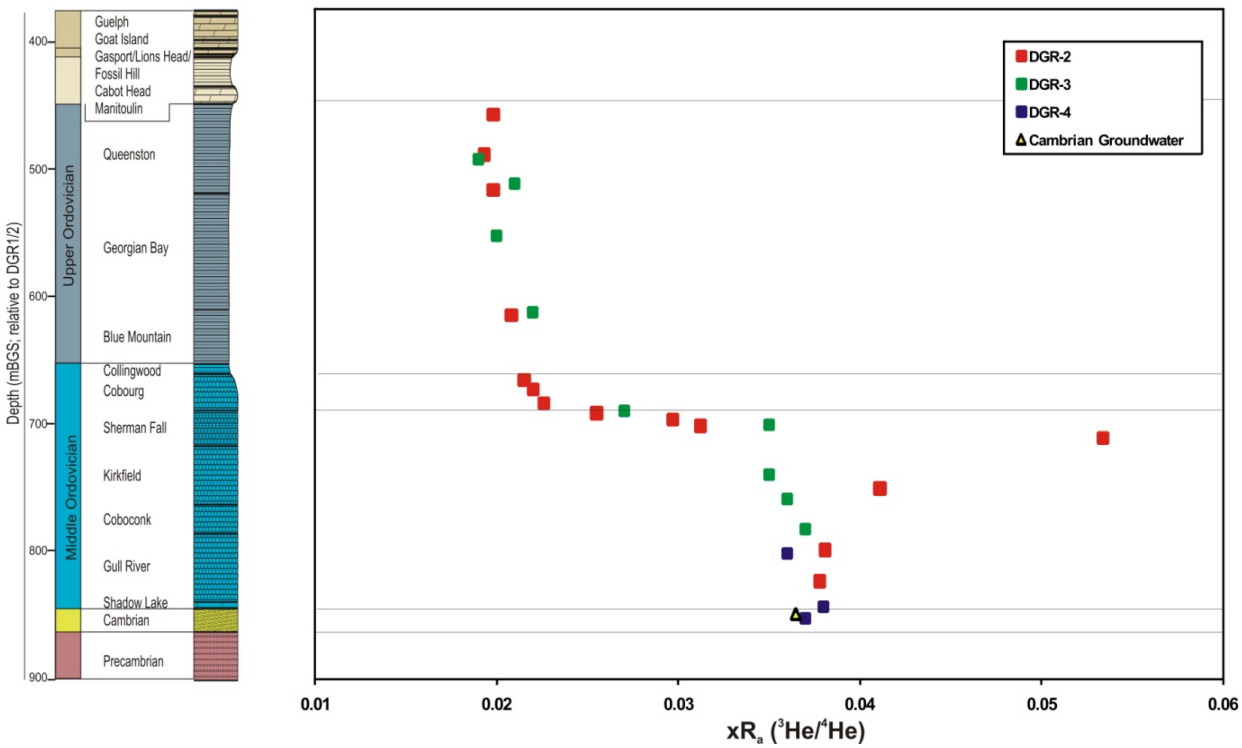
Profiles of $^3He/^4He$ for DGR-2, DGR-3 and DGR-4 are presented in Figure 5.7.2-11. The data are presented as the isotope ratio in the sample (R_s) normalized to the isotope ratio in air (R_a) such that $xR_a = R_s/R_a$. The data are remarkably consistent among the three drill cores, and they define two distinct regions of differing isotope ratio separated at the base of the Cobourg Formation, with xR_a of approximately 0.02 within and above the Cobourg Formation, and xR_a of approximately 0.035 below. Consistent with observations from the CH_4 data, the clear separation between regions of differing He isotope composition indicates that there has been very little cross-formational mixing of helium between the Middle Ordovician limestones and the Upper Ordovician shales, and suggests that there is a barrier to solute migration within the Cobourg Formation.

<u>Redox Conditions in the Ordovician Shale and Carbonate</u>

Redox conditions can be defined in terms of the principal redox couples that reflect the oxidation state at a given depth (e.g., Fe^{3+}/Fe^{2+}; SO_4^{2-}/S^{2-}; CO_2/CH_4). It is commonly possible to determine the dominant redox couple by analysis of dissolved gases, stable carbon isotope ratios, and the distribution of redox-sensitive minerals. Mineralogical and geochemical evidence

[174;175] indicates that sulphide minerals (predominantly pyrite) and organic carbon are common throughout the stratigraphic sequence, particularly below the Silurian. The presence of these materials suggests that redox conditions range from sulphate reducing to methanogenic.

The presence of CH_4 suggests that the redox conditions are strongly reducing throughout most of the Ordovician. The redox conditions are in the range of iron- or sulphate reduction to methanogenesis, with Eh values estimated at -150 mV for the whole of the Ordovician sedimentary sequence [11].



Source: Modified from Figure 4.75 of [11].

Figure 5.7.2-11: Vertical Profiles of Helium Isotopic Ratios ($^3He/^4He$) from DGR-2, DGR-3 and DGR-4

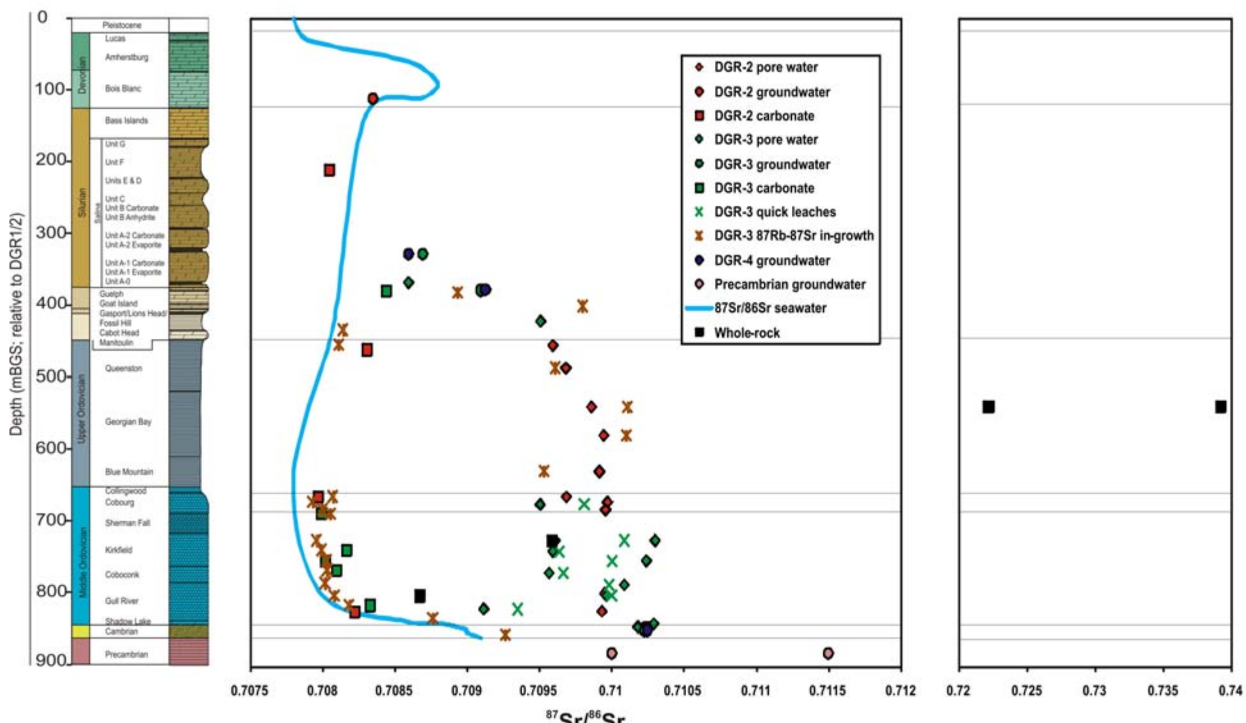
Strontium Isotopes

The $^{87}Sr/^{86}Sr$ ratios in the porewater and the host rocks were determined by Clark et al. [158;159]. Consistent with the results for strontium (Sr) isotopic analysis of oilfield groundwater from the Michigan Basin reported by McNutt et al. [145], the $^{87}Sr/^{86}Sr$ ratios from Cambrian groundwaters and from the Ordovician and Silurian porewaters at the Bruce nuclear site are more radiogenic than the Paleozoic seawater curve (Figure 5.7.2-12). With the exception of the Ordovician shale units, the $^{87}Sr/^{86}Sr$ signatures of the porewater are more radiogenic than those of the host rocks. There are three possible explanations for the ^{87}Sr enrichment in the porewater.

These include:

- ingrowth of ^{87}Sr from ^{87}Rubidium (Rb) decay since the Ordovician;
- leaching of ^{87}Sr from old shield-derived siliciclastic material in the shales and the argillaceous component of the limestones; and
- transport of Sr upward from an ^{87}Sr-enriched brine source in the underlying Precambrian shield.

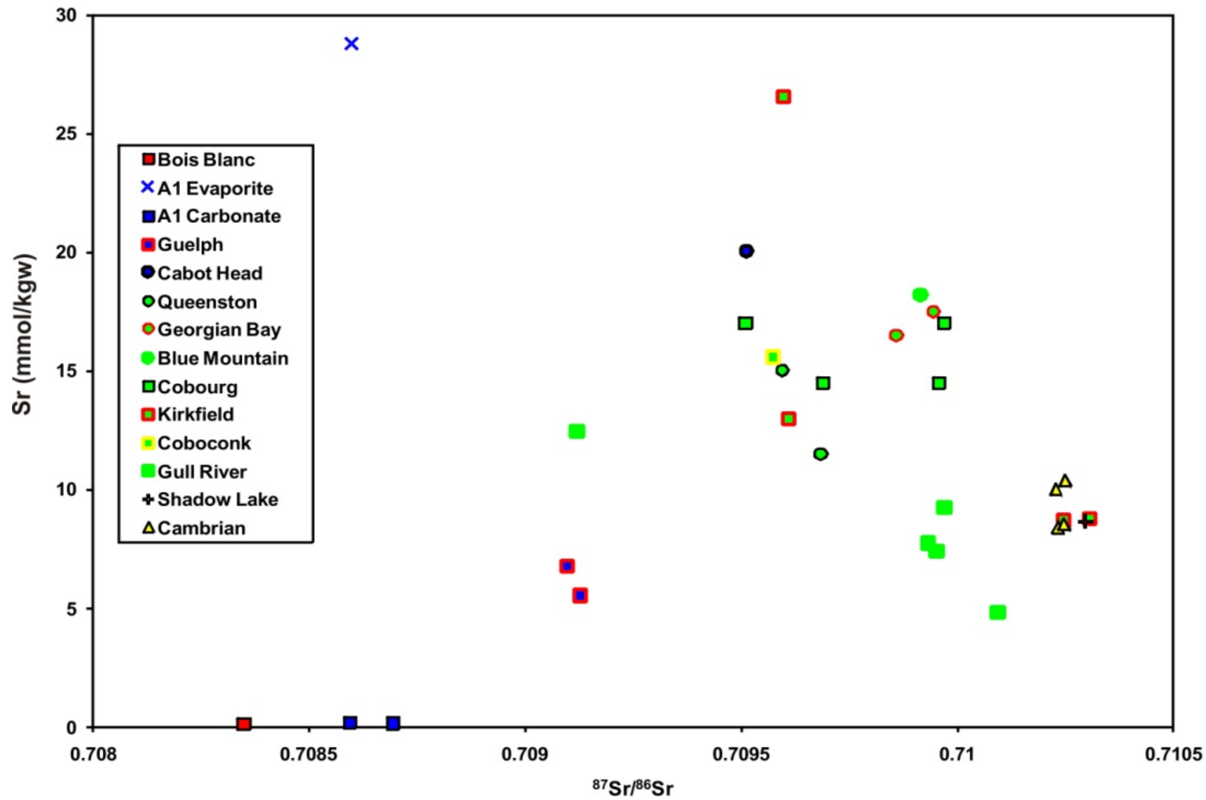
The observed ^{87}Sr enrichment in the Ordovician must have resulted from some combination of the three processes described above, but the respective contributions cannot be resolved quantitatively. In any case, the presence of radiogenic Sr throughout the Ordovician indicates extremely long time periods for water-rock interaction and/or diffusive transport of radiogenic Sr upward from the shield.



Source: Seawater $^{87}Sr/^{86}Sr$ curve from [176] is shown for reference Modified from Figure 4.65 of [11].

Figure 5.7.2-12: Depth Profiles for $^{87}Sr/^{86}Sr$ in Groundwater, Porewater and Host Rocks at DGR-2, DGR-3 and DGR-4

Above the Guelph Formation aquifer, the $^{87}Sr/^{86}Sr$ ratios for Silurian porewater and groundwater at the Bruce nuclear site approach the values of the enclosing host rock and the seawater curve. The convergence demonstrates the dominance of the Silurian sea water $^{87}Sr/^{86}Sr$ signature in the evaporite minerals (anhydrite) and non-argillaceous limestones of the Salina formations. A significant decrease in Sr concentrations in the Upper Silurian and Devonian formations (Bois Blanc, A1 carbonate) is also observed (Figure 5.7.2-13), further demonstrating that the shallow groundwaters have been diluted, most likely due to the influx of glacial melt water and/or meteoric water in these relatively high permeability zones.



Source: Modified from Figure 4.16 of [3].

Figure 5.7.2-13: $^{87}Sr/^{86}Sr$ versus Sr Concentration for DGR Groundwaters and Porewaters

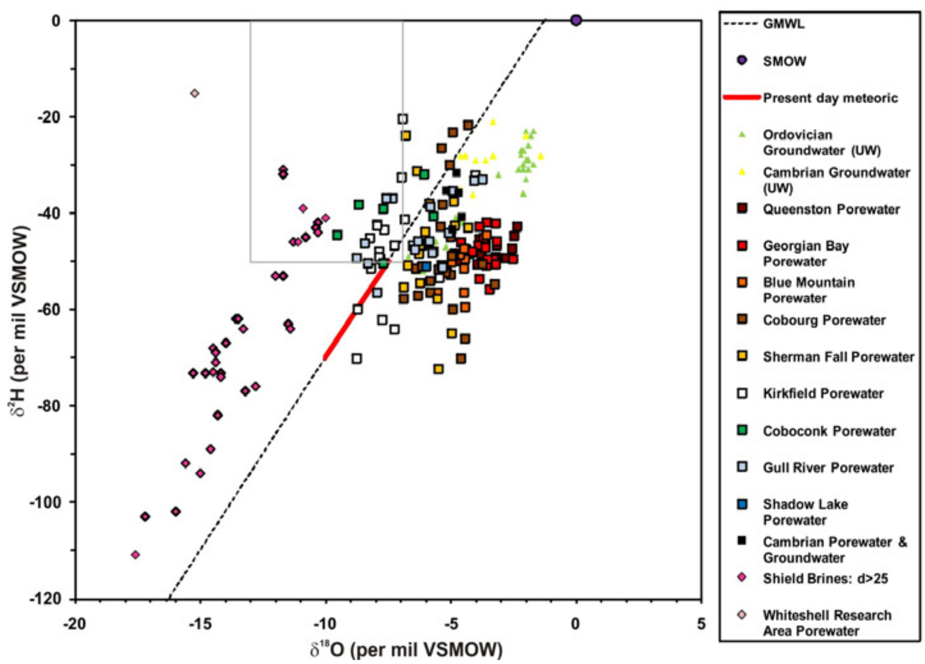
5.7.3 Illustrative Modelling of the Bruce Nuclear Site Geochemistry

In this section, a conceptual model is presented to describe the hydrogeochemical evolution at the Bruce nuclear site. This model is consistent with the regional-scale information presented in Section 5.7.1 and provides insight into the natural tracer profiles for the site described above in Section 5.7.2.6, including:

- the large decrease in concentration for all tracers from the top of the Guelph Formation upward through the Silurian; and
- a less pronounced, but persistent, trend toward depleted $\delta^{18}O$ values, decreased Cl and Br concentrations, and enriched $\delta^{2}H$ values occurs in the Middle Ordovician limestone.

The conceptual model has been adopted because of its ability to describe the observed geochemical profile trends for almost all of the data collected at the Bruce nuclear site. The conceptual model is tested with numerical modelling, described in Section 5.7.3.2. One feature of the natural tracer profiles that the model cannot simulate is the current Cambrian fluid chemistry, suggesting that its fluid evolution may be more complex. The Cambrian chemistry is discussed in Section 5.7.4.

In order to model the fluid evolution, the composition of potential end members for mixing must be established. Because the composition of groundwater in the Precambrian shield below the Michigan Basin and below the Bruce nuclear site is not known, a potential end member composition for the Precambrian was assumed. The δ^2H-enrichment, coupled with $\delta^{18}O$-depletion relative to the GMWL, are consistent characteristics of old groundwater in a shield setting. Various authors have proposed isotopic compositions for a hypothetical shield groundwater end member based on mixing trends observed at various locations across Canada where the shield is shallow or exposed (Sudbury, Yellowknife and Manitoba; [164;177;178;179;180;181;182;183;184;185]). The typical compositions range from δ^2H = -50 to -20 ‰ and $\delta^{18}O$ = -13 to -7 ‰ ([164;177;179;180]). Given that the porewater and groundwater in the shield underlying the Michigan Basin is likely to be at least as old as, and perhaps several hundred million years older than, shield groundwater studied in exposed regions of the Canadian Shield, it is expected that the isotopic composition of shield brines underlying the basin would be characterized by strong δ^2H enrichment and depleted $\delta^{18}O$ values and this assumption is the basis for the Precambrian fluid composition utilized in the hydrogeochemical modelling (see Table 4.3 in [3]). The proposed shield-brine end member responsible for the observed mixing trends (shown in Figure 5.7.3-1 along with data from the UW database, the Bruce nuclear site, and various shield locations across Canada) plots to the left of the GMWL, and the δ^2H enrichment that is required to cause this shift is thought to occur as a result of water-rock interactions over long periods of geologic time.



Notes:
The grey box indicates proposed range in composition for a shield end member. Also shows groundwater brine samples from Ordovician carbonates and Cambrian sandstone from the UW database.
Source: Modified from Figure 4.19 of [3].

Figure 5.7.3-1: $\delta^{18}O$ versus δ^2H for Ordovician and Cambrian Porewater from DGR-2, DGR-3 and DGR-4

5.7.3.1 Conceptual Model

The Ordovician Tracer Profiles: Diffusion from Above

Diffusion downward from a Silurian source could provide an explanation for the salinity profile because the original porewater in the Ordovician would be expected to be close to normal seawater, and the high-salinity porewater in the overlying Silurian evaporites would create a strong downward gradient for diffusive transport. In support of this hypothesis, numerical modelling of diffusive transport downward from the Silurian suggests that the observed natural tracer profiles in the Ordovician could be generated over a period of approximately 300 Ma (see discussion in Section 5.7.3.2 below).

The presence of halite in the Middle Ordovician carbonates [119] can be explained by asserting that localized halite occurrences were formed by concentration mechanisms, such as hydration reactions [186] or hyperfiltration [187;188].

The "diffusion from above" conceptual model is summarized below.

- Deposition of the Cambro-Ordovician sequence under normal marine conditions, followed by deposition of the Silurian and Devonian, created a condition with high-TDS porewater overlying porewater of normal marine composition. This established a natural concentration gradient that promoted a downward mass flux of salts by diffusion.
- A very long period (approximately 300 Ma) of diffusive transport followed, during which the high-salinity profile propagated downward into the Upper and Middle Ordovician by diffusion. During the same period, water-rock reactions in the underlying shield and Cambrian sediments caused the deep groundwater isotopic characteristics to evolve toward a shield signature with enriched δ^2H and depleted $\delta^{18}O$ values.

The very long period of diffusion-dominated transport and water-rock reaction required to justify the interpretations presented in the diffusion from above conceptual model is supported by multiple lines of hydrogeochemical evidence.

- The enriched $\delta^{18}O$ signatures of most of the Ordovician fluids relative to the GMWL are indicative of long time periods for water-rock interaction (i.e., long residence times).
- Separation between biogenic CH_4 in the Upper Ordovician shales and thermogenic CH_4 in the Middle Ordovician carbonates (Section 5.7.2.6), and between He with different $^3He/^4He$ ratios in the Upper Ordovician shales and the Middle Ordovician carbonates (Section 5.7.2.6), suggests that advective mixing has not occurred and diffusive transport is extremely slow.
- The presence of radiogenic Sr in the Upper Ordovician shale and the Middle Ordovician carbonate porewaters suggests that the radiogenic Sr must have been derived either from in-growth from ^{87}Rb decay, leaching from the siliciclastic sediments, or diffusion upward from a ^{87}Sr-enriched end member in the shield (Section 5.7.2.6). All of these possibilities require extremely long time periods.

Devonian and Silurian Tracer Profiles: Glacial Melt Water Infiltration

In addition to the diffusion from above model, a glacial melt water infiltration scenario is also proposed to explain the natural tracer profiles observed for the Devonian and Silurian porewaters and groundwaters at the Bruce nuclear site. The observed decrease in salinity and the depleted $\delta^{18}O$ values that are apparent from the top of the Guelph Formation to ground surface suggest that a combination of glacial melt water and recent meteoric water have contributed to the shallow fluid chemistries. Based on the geologic history of the site, these signatures are best explained by episodic infiltration of meteoric and/or glacial melt water during the Pleistocene.

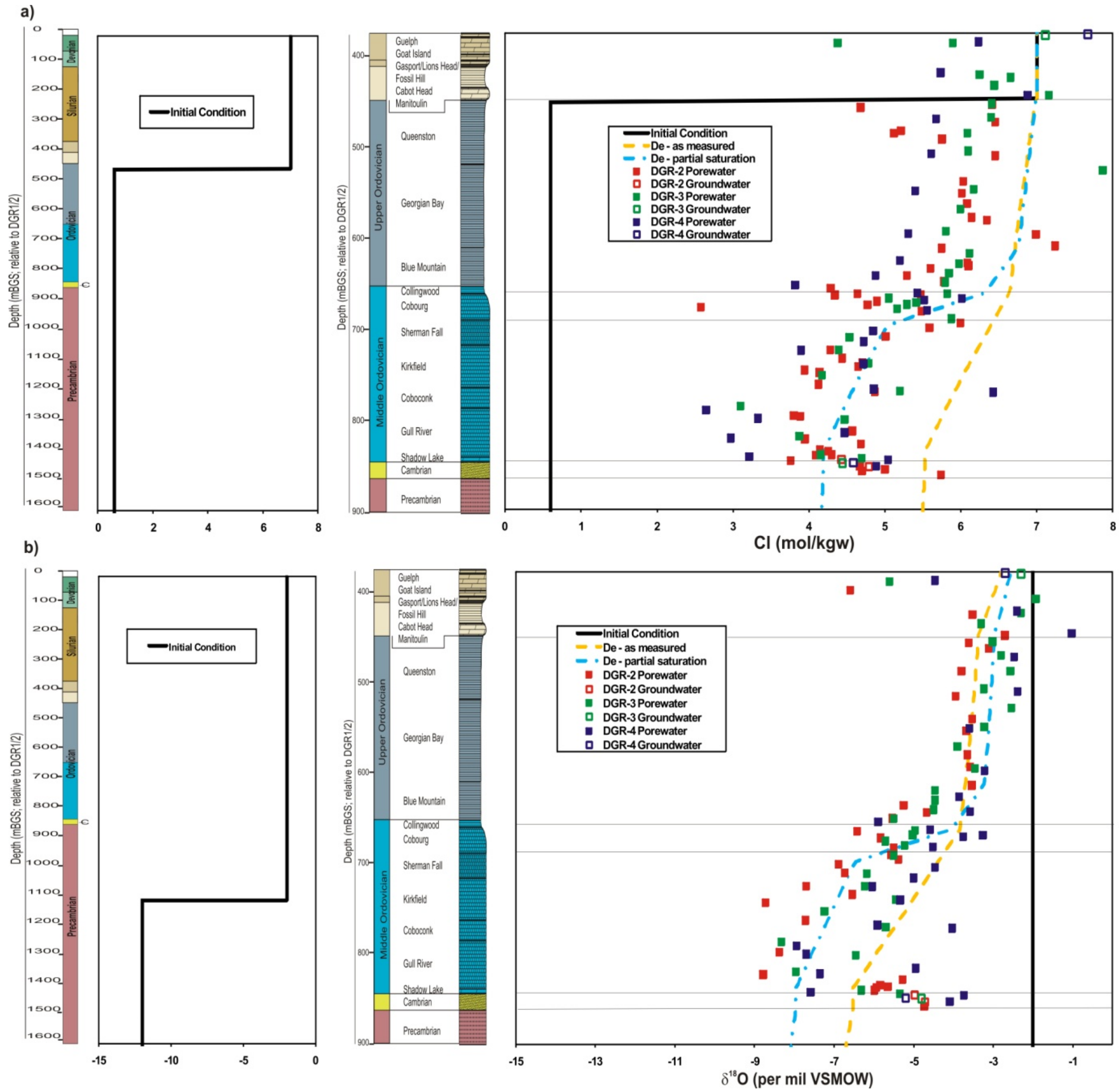
5.7.3.2 Numerical Modelling Results

Details on the model justification and the modelling parameters can be found in Section 4.5.2 of the Geosynthesis [3].

Diffusion From Above Conceptual Model – Tracer Profiles in the Ordovician

The numerical modelling presented in Figure 5.7.3-2 is not intended to be unique, but rather is intended to provide a test, through reasoned illustrative modelling, of various elements of the conceptual model described. The key results that can be drawn from the hydrogeochemical modelling are indicated below:

- The principal controls on the shape of the simulated profiles are the boundary conditions, the contrast in D_e between the Upper and Middle Ordovician, and the effect of partial saturation in lowering the D_e values at the boundary between the Upper and Middle Ordovician.
- The diffusion from above conceptual model is able to explain the observed natural tracer profiles of the Ordovician fluids. The numerical simulations are able to reproduce the measured Cl and $\delta^{18}O$ profiles, and the data are particularly well matched under the partial saturation case, indicating that partially saturated conditions (or conditions that result in a decrease in D_e; e.g., secondary mineral precipitation) may exist within the Ordovician shales and carbonates.
- The profiles are best matched for both Cl and $\delta^{18}O$ under partially saturated conditions for a time period of 300 Ma, assuming diffusive transport only. The simulated profiles are consistent with the site-specific data, supporting the hypothesis that solute transport in the Ordovician sediments is diffusion dominated.



Notes:

(a) Salinity (Cl) tracer profile develops as a result of salt diffusion downward from the Silurian.

(b) δ^{18}O profile results from diffusive mixing with shield brine at the base of the profile.

X-axis for left side plot in (a) and (b) is same as right side (δ^{18}O per mil VSMOW).

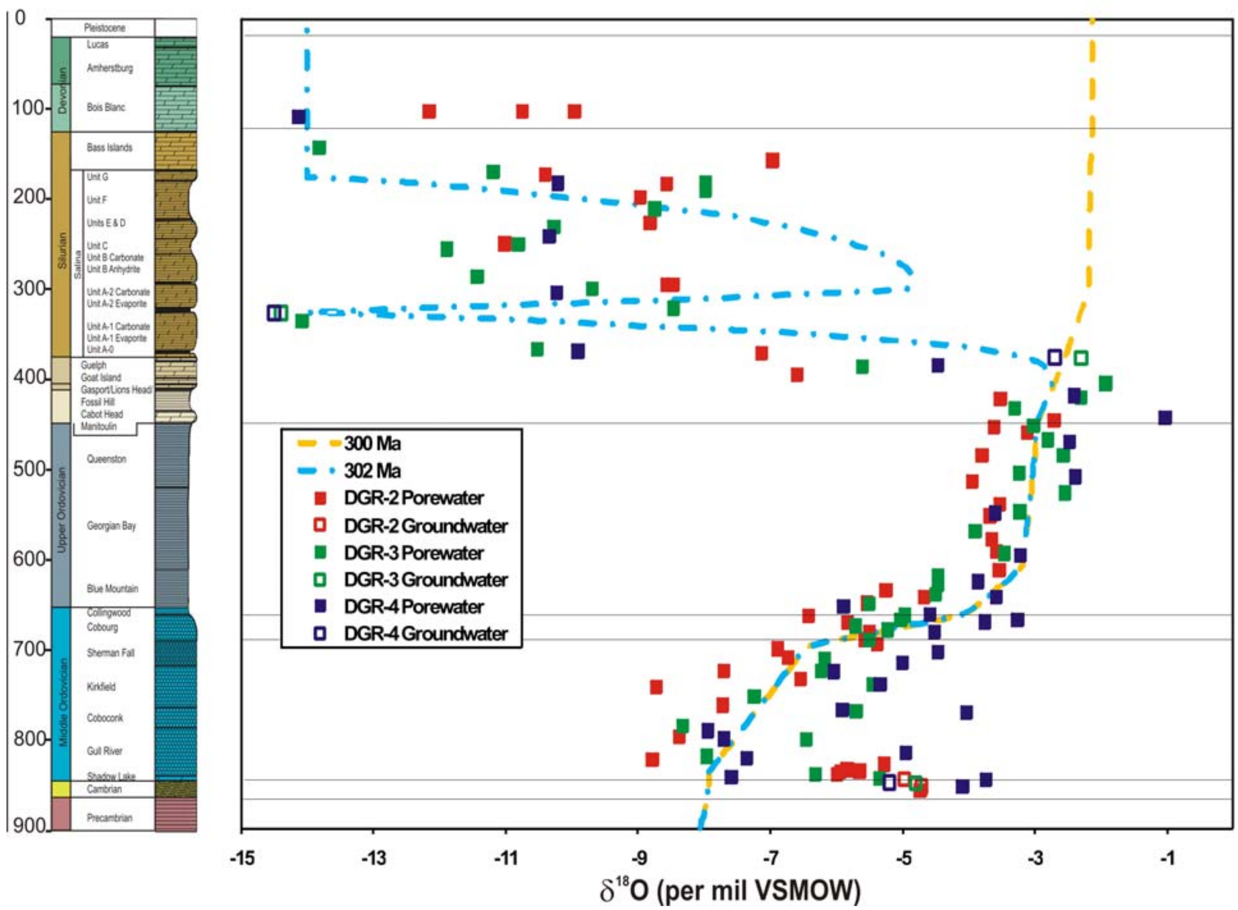
Source: Modified from Figure 4.21 of [3].

Figure 5.7.3-2: Results of the “Diffusion from Above” Modelling Scenario

Glacial Infiltration – Tracer Profiles in the Silurian and Devonian

There is considerable uncertainty in attempting to translate the conceptual model into a numerical model to describe advective and diffusive mixing between basin water and infiltrating glacial and/or meteoric water. The most important issues include: 1) when did these units “open up" to glacial and meteoric water infiltration; 2) did they open up sequentially, or all at once; and 3) what was the volume and duration of glacial melt water infiltration?

The model results in Figure 5.7.2-3 describe a general depletion in $\delta^{18}O$ values upward through the Silurian and Devonian that is generally consistent with the site data. Therefore, in support of the conceptual model, it is suggested that there is a glacial melt water component in many of the shallow system (Devonian and Silurian) fluids and in the Salina A1 Unit carbonate aquifer. A relatively poor fit in the upper units of the Salina Formation, however, suggests that the hydrogeochemical history of these rocks is more complex than has been represented in the model.



Source: Modified from Figure 4.22 of [3].

Figure 5.7.3-3: Results of $\delta^{18}O$ Diffusion Simulation (dashed lines) Compared to Measured Porewater $\delta^{18}O$ Data

5.7.4 Cambrian Fluid Chemistry

The Cambrian chemistry displays a distinct rebound in the natural tracer profiles relative to the overlying Ordovician carbonates. The rebound in the profiles, as shown in Figures 5.7.2-5 and 5.7.2-6, is abrupt compared to the gradual decline in concentrations and isotope ratios observed with depth through the Ordovician carbonates. The composition of the Cambrian groundwater below the Bruce nuclear site is very similar to Cambrian groundwater samples from elsewhere in southern Ontario (refer to Section 4.5.4 in [3]). The similarity between the present-day brine in the Cambrian below the Bruce nuclear site and Cambrian and deep Ordovician brines elsewhere in the Appalachian and Michigan basins, respectively, suggests that the Cambrian fluid underlying the Bruce nuclear site originated at depth within the Michigan Basin.

The hydraulic conductivity of the Cambrian aquifer is approximately six orders of magnitude higher than that of the overlying Middle Ordovician limestones (see Figure 5.6.1-2). The groundwater in the Cambrian sandstone would be more susceptible than porewater in the Ordovician carbonates to advection-driven changes in composition through geologic time.

Under the influence of diffusion, it is expected that such an abrupt concentration gradient would be attenuated over time. Conventional hydrogeologic rationale would suggest that this feature of the profiles could represent a geologically recent movement of groundwater in the permeable Cambrian formation, thereby disrupting the mixing relationship that had developed previously between basin and shield end members. Assuming that the Cambrian fluid composition represents a recent change, the mechanism responsible for the re-supply of basin water is not known. Based on the evolutionary history of the Michigan Basin, the possible driver(s) for fluid migration from basin centre in the recent geologic past are rather limited. These drivers include: 1) fluid migration in response to the anomalous pressures deep in the Michigan Basin [189] and/or 2) fluid migration in response to differential uplift of the basin due to repeated isostatic adjustments related to glaciation and deglaciation.

Irrespective of the mechanism(s) responsible for the current Cambrian fluid chemistry beneath the Bruce nuclear site, the fundamental hypothesis that solute migration with the Ordovician sediments is diffusion dominated is well supported by the geochemical and hydrogeological data (presented in Section 5.6); the data also support the assertion that solute residence times in the Ordovician shales and carbonates are long.

5.7.5 Hydrogeochemistry Summary

The following points may be made in support of the hydrogeochemical suitability of the Bruce nuclear site for the proposed DGR:

- The current understanding regarding the origin of brines from the Michigan Basin indicates that they were formed by evaporation of sea water and subsequently modified by dilution, halite dissolution, and water-rock interaction processes. The regional data (Cl-Br, $\delta^{18}O$-$\delta^{2}H$) and the data from the Bruce nuclear site are very similar, indicating that the brines at both the regional scale and the site scale are of similar origin and evolution.
- The widespread occurrence of ancient brines in the basin demonstrates that, under most conditions prevalent since the Paleozoic, it has not been possible for hydraulic heads generated in freshwater aquifers to drive infiltration events capable of displacing the brines. Glacial melt water infiltration has been identified to maximum depths of 200 to 300 mBGS along the northern margins of the Michigan Basin. Consistent with regional observations, glacial melt water infiltration is identified to a maximum depth of 328.5 mBGS at the Bruce nuclear site within the permeable Salina A1 Unit carbonate aquifer.

- At the Bruce nuclear site, concentrated brines occur at all depths below the top of the Silurian Guelph Formation.
- $\delta^{18}O$ enrichment with respect to the GMWL in the majority of the Ordovician porewaters suggests long periods of water rock interaction (i.e., long residence times in the sedimentary system).
- Separation between biogenic CH_4 in the Upper Ordovician shales and thermogenic CH_4 in the Middle Ordovician carbonates, as well as the separation between He with different $^3He/^4He$ ratios in the Upper Ordovician shales and the Middle Ordovician carbonates, suggests that diffusion is extremely slow and that there is a barrier to vertical solute migration within the Cobourg Formation.
- Radiogenic $^{87}Sr/^{86}Sr$ ratios in the Middle and Upper Ordovician porewater are interpreted to result from a combination of water-rock interaction, in situ ^{87}Rb decay, and diffusion of ^{87}Sr upward from an enriched end member in the shield. All of these mechanisms indicate a very long residence time, on the order of tens to hundreds of millions of years.
- The redox conditions in the Ordovician and Cambrian formations are strongly reducing, in the range of iron- and/or sulphate reduction and methanogenesis.
- Illustrative modelling suggests that the time frames required for the development of the salinity and $\delta^{18}O$ profiles within the Ordovician sediments are on the order of 300 Ma; the results are consistent with the assertion that solute transport in the Ordovician is diffusion dominated.

5.8 SOIL QUALITY

For convenience, soil quality in the Project Area and Site Study Area has been discussed collectively with the groundwater quality analysis as part of the Phase II Environmental Site Assessments completed (see Section 5.7.2.1).

5.9 GEOMECHANICS

5.9.1 Introduction

The purpose of this section is to present an understanding of the properties of the deep sedimentary formations at and surrounding the Bruce nuclear site. This includes establishing the existing geomechanical knowledge as it relates to site material strength properties, ground stress distribution, and seismicity. Site specific data available from site characterization work, when combined with regional data, provide quantitative “best estimates” of the physical properties that will control the geomechanical behaviour of the rock mass beneath the Bruce nuclear site during and after the construction of the DGR.

In the following sections, a summary of the above studies is presented, and conclusions, based on the available outcomes of the site characterization activities and the geomechanics geosynthesis study at site and regional scale, are compared.

5.9.2 Geomechanical Properties: Rock Strength and Deformation

A good understanding of the geomechanical properties of rock is necessary to allow the prediction of the current and long-term behaviour of the proposed facility. The geoscientific site-characterisation work included an investigation of the geomechanical properties of the

Paleozoic sedimentary formations at the Bruce nuclear site [11]. The aim of the site-characterization multi-phase geomechanical testing of samples from DGR-1 through DGR-6 was to provide a comprehensive suite of site specific geomechanical data of the rock material. A detailed summary of the types of testing and results are presented in the Descriptive Geosphere Site Model (DGSM) and the Geosynthesis [11;3]. Figure 5.9.2-1 shows the distributions of general geomechanical properties of all rock units with depth. In addition to the peak intact rock strength obtained from uniaxial compressive test, Figure 5.9.2-1 also presents elastic modulus and Poisson’s ratio. Results from other geomechanical tests, including triaxial compression, cross anisotropic, free and semi-confined swelling, and long-term strength degradation tests, are documented in the DGSM report [11].

The following sections are mainly focused on the DGR host rock — the Cobourg Formation of middle Ordovician age (Trenton Group) — and the caprock (Queenston and Georgian Bay formations) of upper Ordovician age. Only brief descriptions of the overlying rocks are included.

To determine the intact strength of the caprock, uniaxial compression testing was carried out on a total of 14 Queenston and 11 Georgian Bay samples from DGR-2 through DGR-4. From these tests, key parameters such as the unconfined compressive strength (UCS), elastic modulus, and Poisson’s ratio were measured. Results plotted in Figure 5.9.2-2 show that the shales have a moderate strength with estimated mean values of 48 and 32 MPa for the Queenston and Georgian Bay Formations, respectively. Regional UCS data of both rock formations are also presented, and it is clear that both data sets lie within the same range [3].

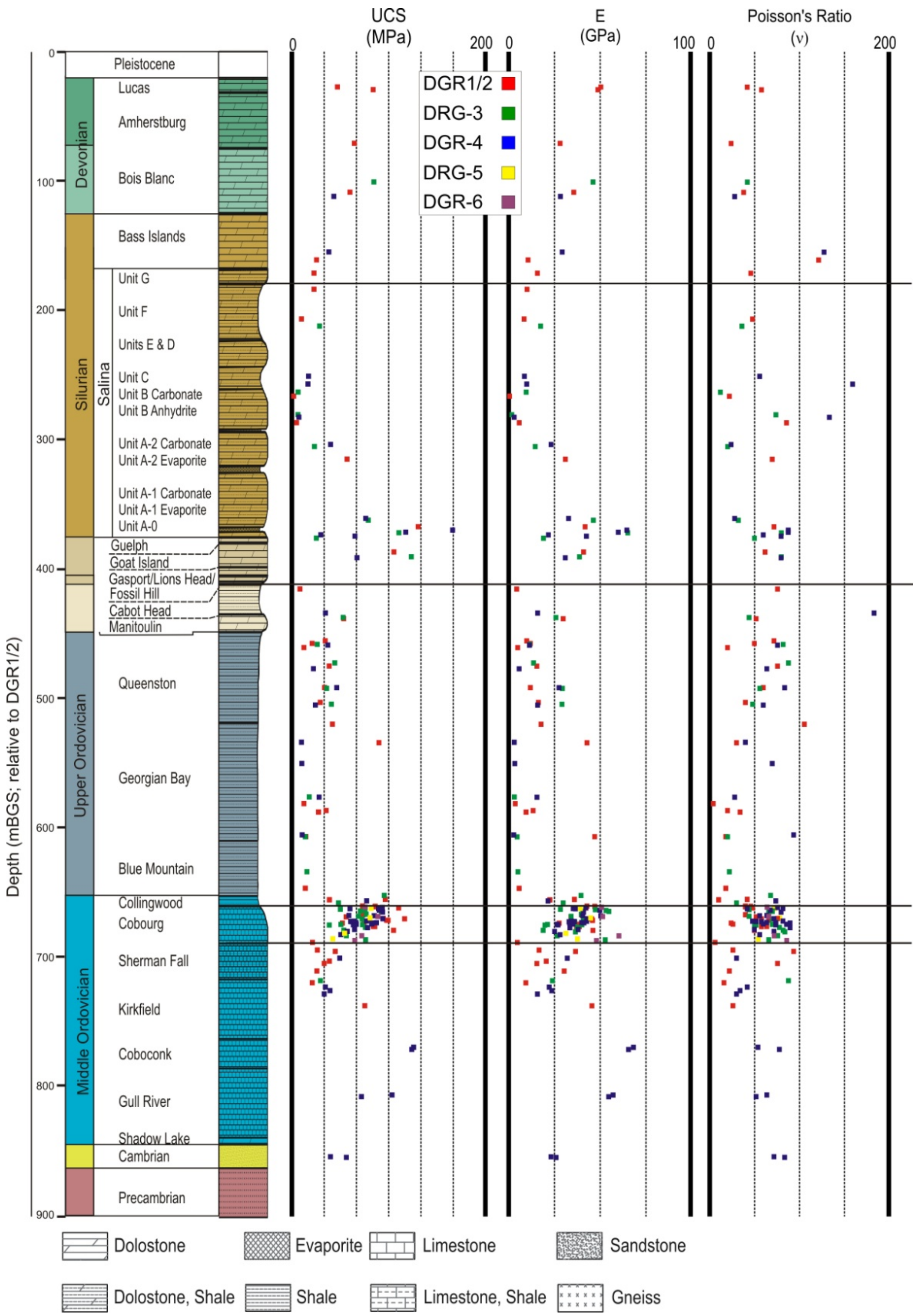
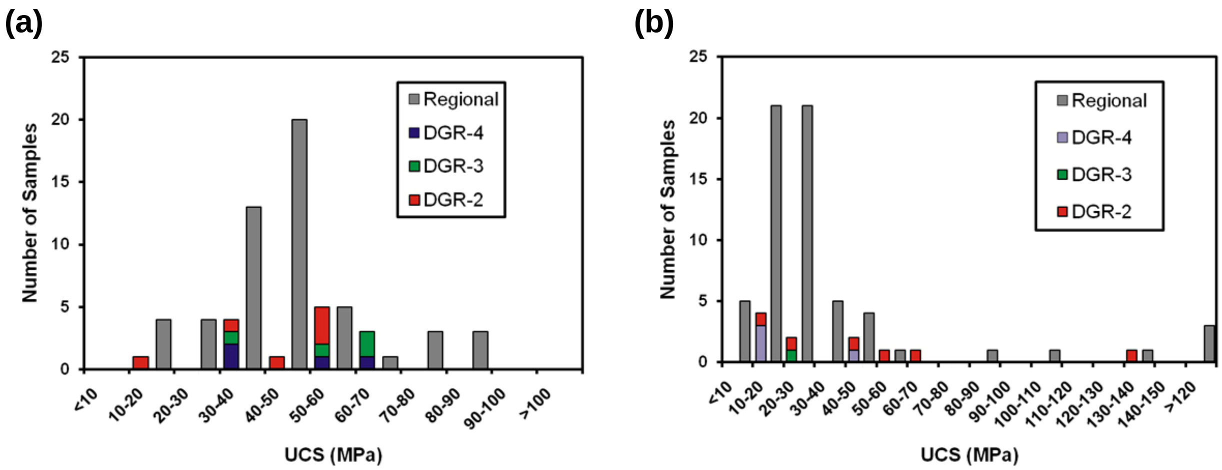


Figure 5.9.2-1: Stratigraphic Column showing Uniaxial Compression Test Results at the Bruce Nuclear Site for Boreholes DGR-1 to DGR-6



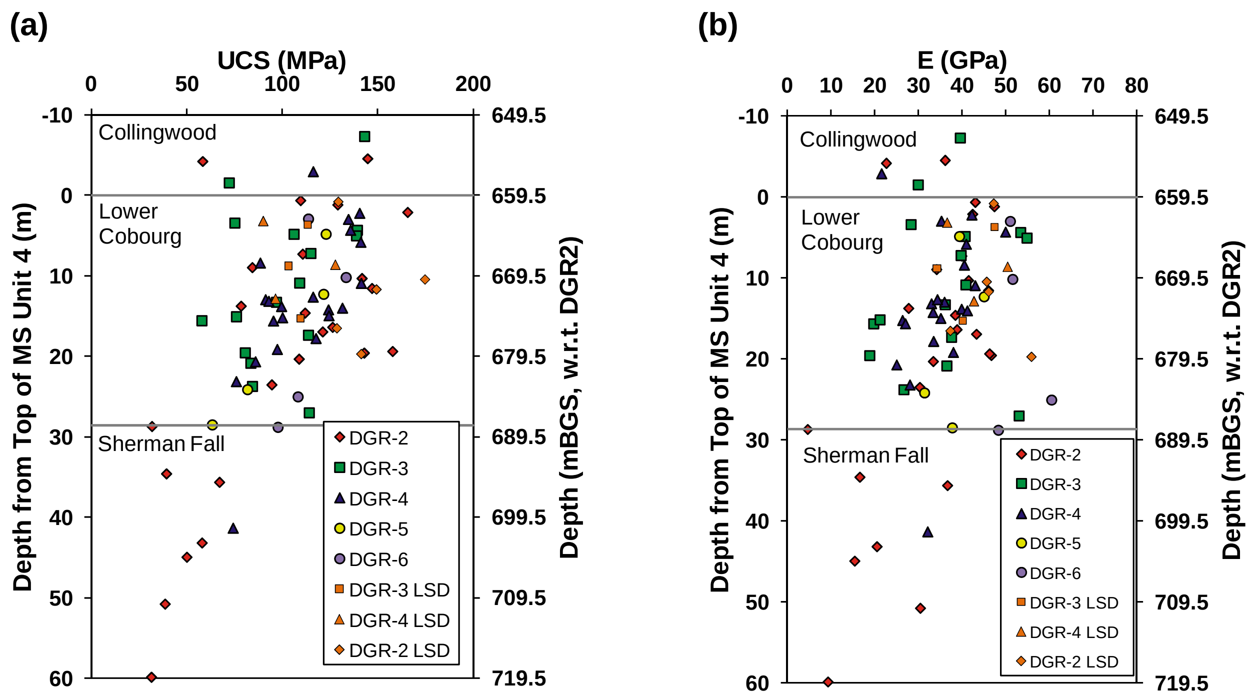
Note: Data is from regional compilation and boreholes DGR-2, DGR-3 and DGR-4.

Figure 5.9.2-2: Unconfined Compressive Strength of the Queenston Formation (a) and Georgian Bay Formation Shales (b)

For the Cobourg argillaceous limestone, the peak uniaxial compressive strength, as determined from the results of 67 samples, ranges from 58 to 175 MPa (Figure 5.9.2-3a) with an arithmetic mean of 113 MPa and a standard deviation of 25 MPa. The corresponding elastic modulus has a mean value of 39 GPa (Figure 5.9.2-3b). The Cobourg limestones can be classified as high strength rock with an average modulus ratio [190] that is considerably stronger when compared with other sedimentary formations studied in the framework of waste disposal around the globe [191]. This greater strength favors the stability of deep underground excavations at the DGR horizon.

A comparison of DGR versus regional UCS results for the Cobourg Formation reveals that the former have a considerably higher average peak strength value (Figure 5.9.2-4). This strength increase is likely attributed to different sampling depths, mineralogical variation (i.e., clay fraction), improved sample preservation methods, and/or the quality of the laboratory testing.

The UCS results from DGR-2 through DGR-6 show a consistent distribution and range within the formation when they are plotted versus depth (Figure 5.9.2-1). The variation in strength noted in the UCS test results is due to the variation in material properties within the formation, induced damage while drilling — as a result of sampling (unloading) from great depth, and local platen interference and/or other boundary effects during laboratory testing.



Note: LSD – Long-Term Strength Degradation.

Figure 5.9.2-3: Unconfined Compression Test Data for Collingwood, Lower Cobourg and Sherman Fall: (a) UCS and (b) Elastic Modulus from Boreholes DGR-2 to DGR-6

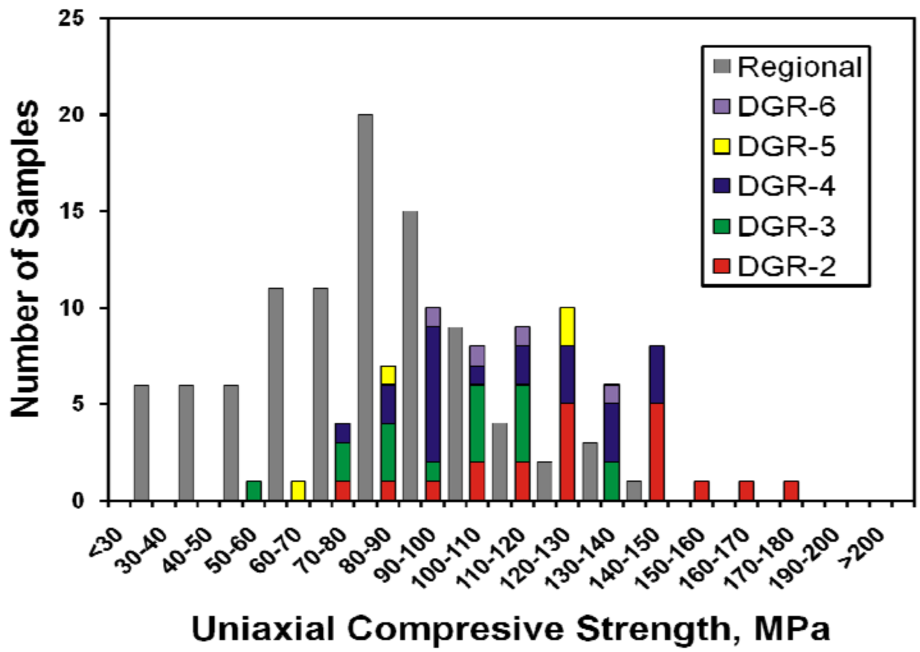


Figure 5.9.2-4: Uniaxial Compression Strength of the Lower Cobourg – Site Specific and Regional Test Data

The discontinuity data from the DGR series of deep boreholes also provides an opportunity to further characterize the rock mass. Competent rock formations, illustrated by their high RQD values and low fracture frequencies, were encountered in formations below 200 m in boreholes DGR-1 through DGR-6 (Figure 5.9.2-5). The upper 200 m of rock consists mostly of dolostones which contain highly fractured and permeable zones with highly variable RQD values. Based on RQD, the Cobourg Formation is classified as an excellent quality rock, has a very low fracture frequency and few inclined to vertical joints (none were encountered in the DGR series of boreholes). Rock joint orientation measurements and spacing were obtained from the two inclined boreholes (DGR-5 and DGR-6) in Silurian and Ordovician rocks. Fractures at depth are tight and usually cemented with gypsum, anhydrite and/or calcite.

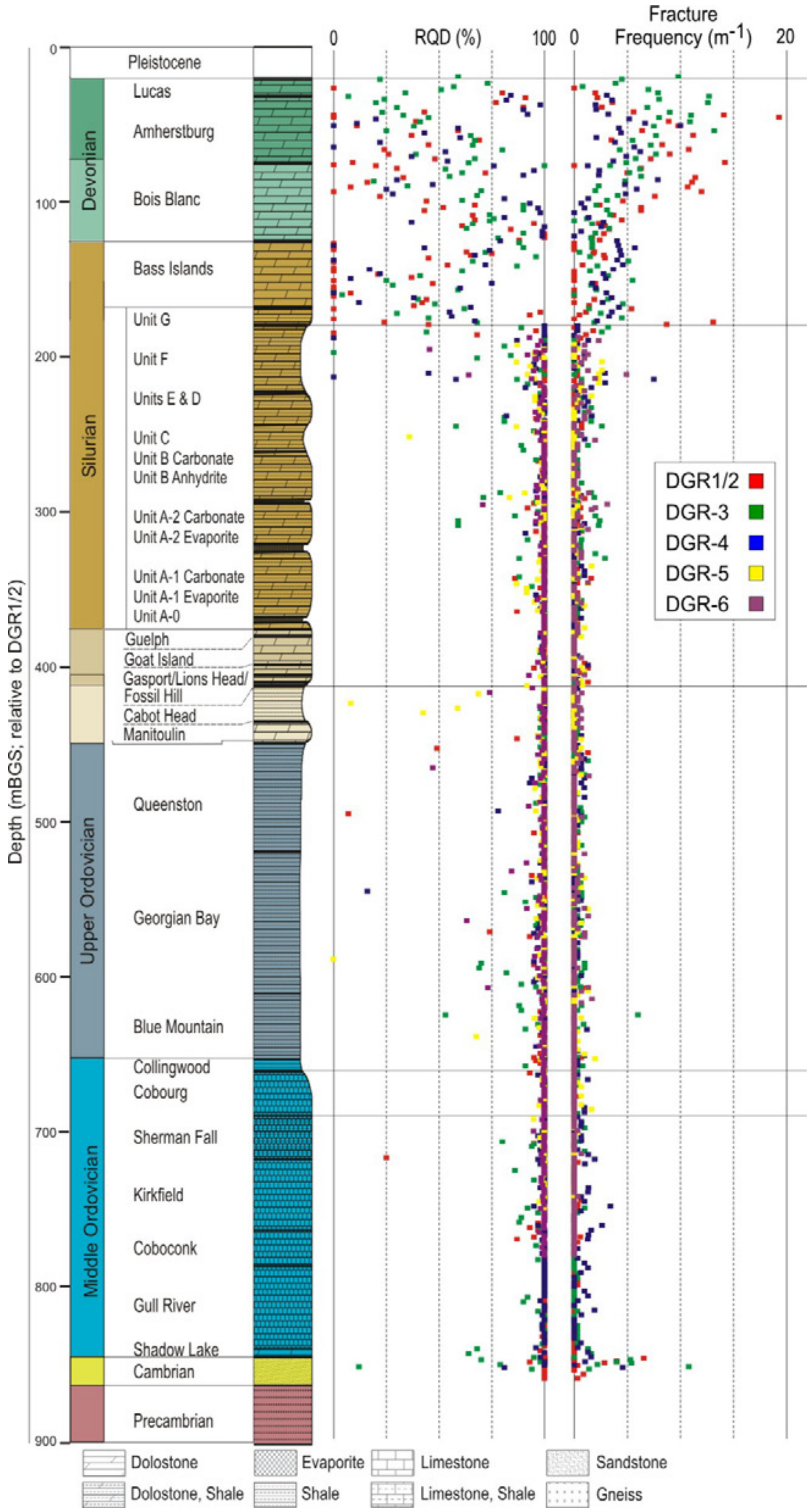
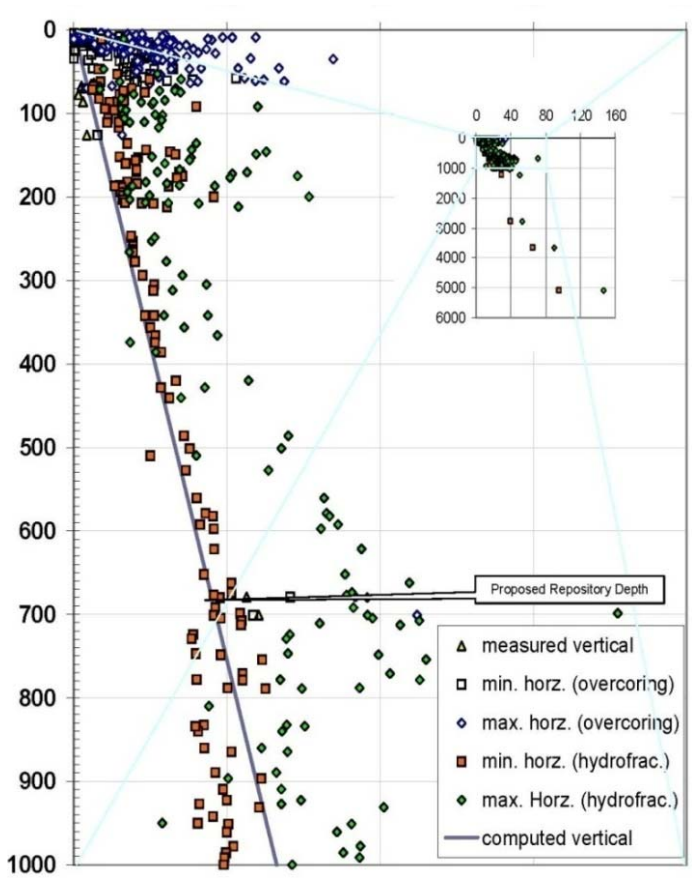


Figure 5.9.2-5: Stratigraphic Column Showing RQDs and Fracture Frequency from DGR-1 and DGR-6 at the Bruce Nuclear Site

5.9.3 In Situ Stresses

5.9.3.1 In Situ Stress Magnitude

The regional in situ stress data in Paleozoic rock from over 20 sites in the Great Lakes region indicates the presence of relatively high horizontal compressive stresses and is characterized as that of a thrust fault regime ($\sigma_v < \sigma_h < \sigma_H$). Figure 5.9.3-1 shows a plot of the maximum and minimum horizontal stresses (σ_H and σ_h) as a function of depth. The diamond symbol indicates the magnitude of the maximum stress at a given horizon and the square symbol corresponds to the minimum horizontal stress. The coloured symbols represent measurements from hydraulic fracturing tests, whereas the open symbols represent results obtained from over-coring tests. The stress measurements for shallow bedrock were made using the over-coring method while virtually all of the deeper measurements were conducted using the hydrofracture technique. Except for Norton Mine in Ohio, providing measurements at approximately the 670 mBGS level, the over-coring stress measurements are limited to the upper 100 m depth. There is a large scatter in both hydraulic fracture and over-coring measurements particularly in the shallow zone above 200 mBGS and in the deeper zone below 700 mBGS from these many sites.



Note: Included are both hydro-fracturing and over-coring results.
Source: [27]

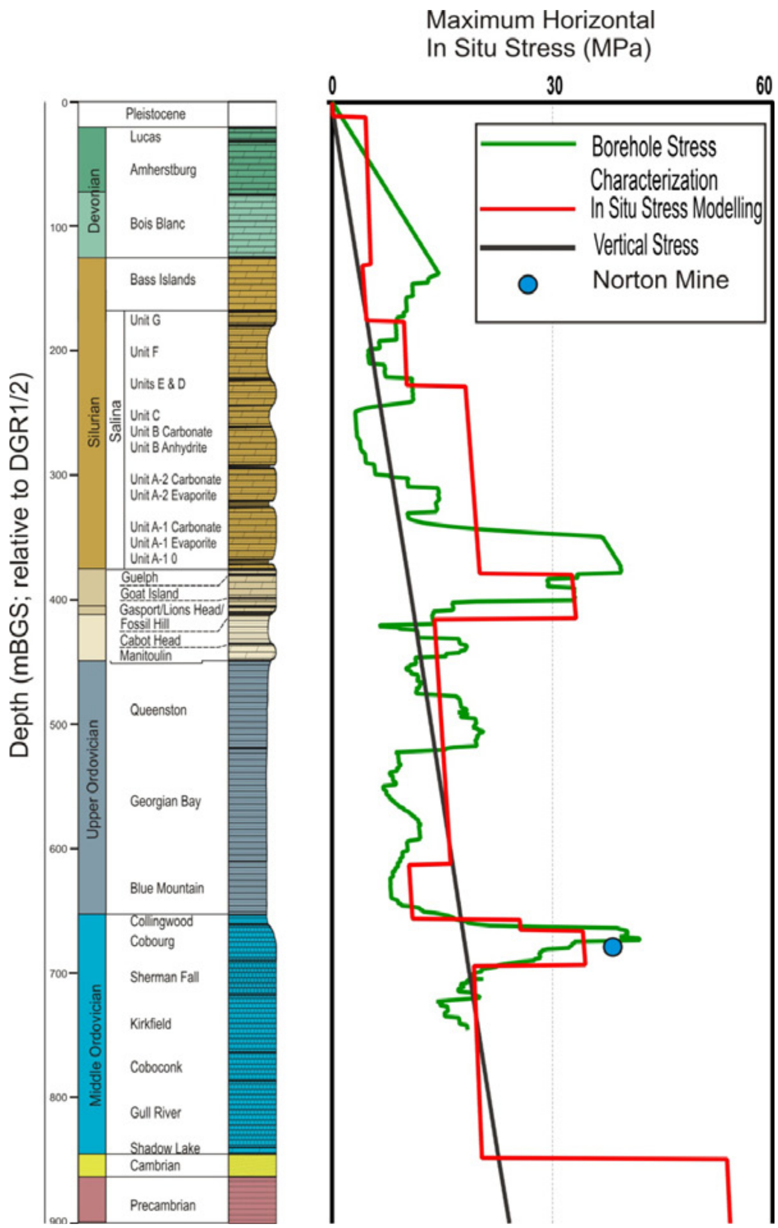
Figure 5.9.3-1: Distribution of Principal Stress with Depth in the Appalachian and Michigan Basin

There are great challenges in obtaining, with confidence, the in situ stress magnitude and orientations at the depths of interest from a surface-based exploratory borehole. This is particularly true in horizontally bedded formations where the vertical stress is less than the horizontal stresses, as hydrofracture techniques cannot be used with confidence in this situation [192]. While traditional strain-relief methods (e.g., overcoring) are suitable for relatively shallow measurements, such testing from within an exploration borehole at the approximately 680 m depth of the DGR has not been successfully demonstrated. Consequently, no measurements of the in situ stresses at the depth of the proposed repository at the Bruce nuclear site were undertaken during the site characterization investigations. Borehole core and televiewer data from DGR-1 to DGR-4 were analyzed to determine the physical response of these deep boreholes to the surrounding stress field. The objective of such review was to back-calculate the in situ stress magnitudes at the site scale that were consistent with the measured stability of the borehole wall. Valley and Maloney [193] assessed the possible range of the maximum in situ stress magnitudes that could exist without inducing failure of the borehole wall. Assessing the lack of borehole-wall failure must assume a strength value for the borehole wall strength. Strength and stiffness profiles were created by averaging UCS strength and elasticity modulus over a 30 m moving window along the borehole. Assuming a 100% of UCS threshold rock strength with the characteristic of no failure observation along borehole walls, the maximum allowable horizontal stress could be estimated for each section of the borehole and the results are summarized in Figure 5.9.3-2. The 100% UCS threshold, which represents no failure, is shown on the figure by a green line.

During the site-scale investigations, replacement of the Westbay casings in DGR-2 and DGR-3 provided two opportunities to re-inspect their borehole walls. ATV inspection detected no evidence of borehole breakouts or drilling-induced tension fractures over an 18-month period for DGR-2 and a 6-month period for DGR-3. This supplements previous observations that found no evidence of drilling-induced tension fracturing or borehole breakouts in these holes.

A model of the DGR stratigraphy was also constructed using FLAC3D to further evaluate the vertical distribution of in situ stress within the sedimentary succession in the subsurface below the Bruce nuclear site [194]. The model simulates the stiffness variability of individual rock formations oriented in the direction of the maximum horizontal principal stress. The model was strained horizontally in both directions to simulate tectonic strains observed at the Norton mine, in Ohio, which has a similar depth horizon and stratigraphy. The results indicate that stiffness contrasts in adjacent rock units play a significant role governing formation-specific in situ stress distributions. A comparison of the estimated maximum horizontal in situ stress from the modelling and the constraints deduced from the anlaysis based on lack of borehole breakout observation using 100% UCS as borehole wall strength (Figure 5.9.3-2).

At the repository horizon (about 680 mBGS) with σv assumed equal to the approximate gravity load of superincumbent materials, $\sigma_H/\sigma v$ is estimated to range from 1.5 to 2.0 and σ_H/σ_h from 1 to 1.2 [11].



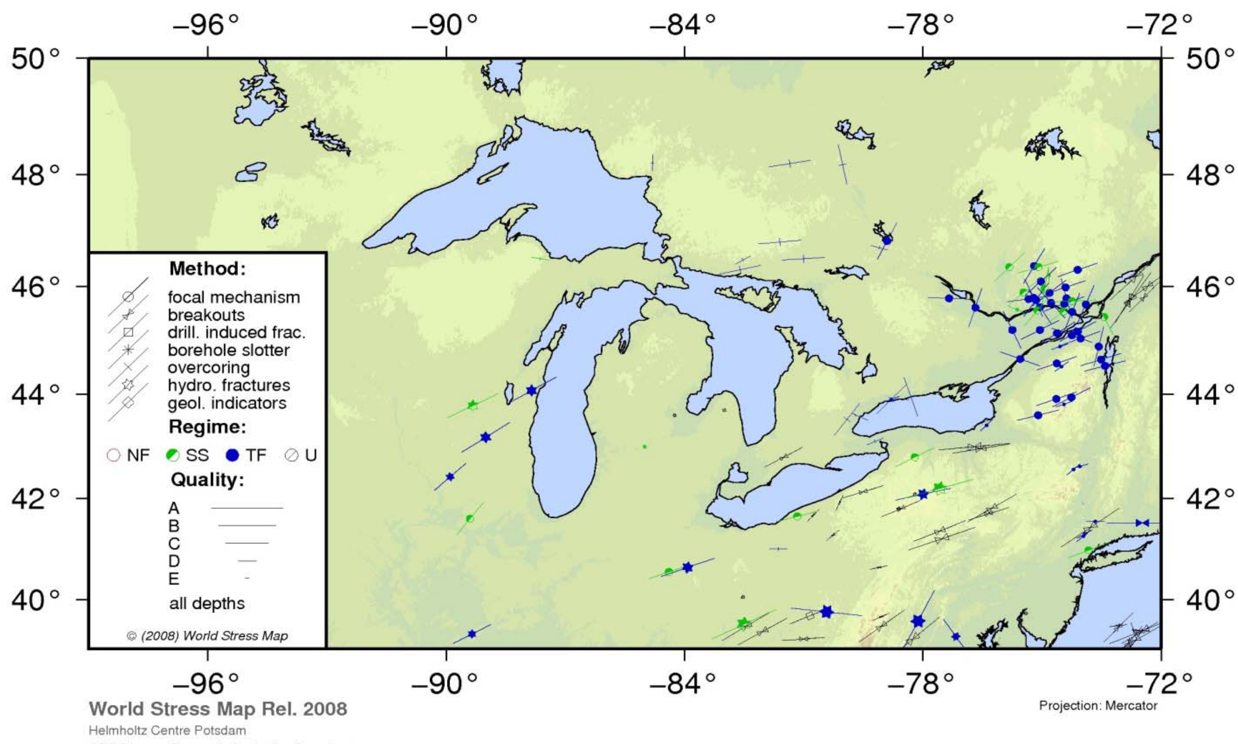
Note: Numerical modelling results (red line) plotted against vertical stress profile (black line) and the absence of borehole failure constraint based on borehole wall strength of 100% UCS (green line). Figure is based on data from Itasca [194] and Valley and Maloney [193].

Figure 5.9.3-2: Comparison of Calculated Maximum Horizontal In Situ Stress Profiles

5.9.3.2 Orientation

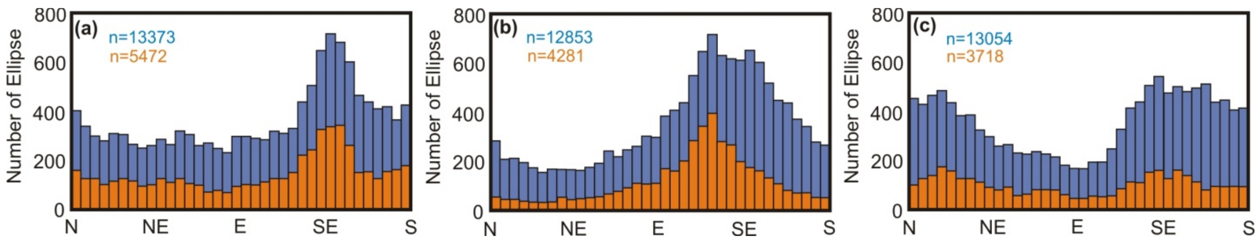
The principal sources for estimating regional in situ stress orientations are the database compiled for the World Stress Map project (Figure 5.9.3-3; [195]) and the regional in situ stress database as described in the Regional Geomechanics report [27]. In brief, the regional principal horizontal in situ stress is consistently oriented in a northeasterly to east-northeasterly direction throughout north-eastern North America, including Southwestern Ontario and the Bruce nuclear site in particular. This data is reliably constrained by numerous surface and borehole measurements including shallow (<100 m) over-coring measurements and deep (up to about 5 km) hydrofracturing measurements [27].

Acoustic televiewer (ATV) logs from DGR-1 to DGR-4 utilized ellipticity detection analyses to fit ellipses on borehole sections measured from the acoustic travel time logs over 10 cm intervals. From the analysis, the lengths of the ellipse's long and short axes, as well as their orientations, were determined. The results reveal the length difference between the ellipse axes is typically less than 0.5%. The orientations of the long axis of the ellipses are erratic for most of the borehole length in DGR-1, DGR-2 and DGR-4, except in the (Lower) Cobourg, Sherman Fall and Kirkfield formations (660 to 760 mBGS) where the orientations are systematic in a SE (138^o in DGR-1 and DGR-2, and 131^o in DGR-4) direction. The same systematic southeast (141°) borehole elongation in the Ordovician limestones was observed in borehole DGR-3. Figure 5.9.3-4 shows the histograms of the orientation of the ellipse long axis for all boreholes. It appears that the systematic southeast borehole elongation could possibility be stress related (i.e., the direction of the maximum horizontal stress is northeast). This orientation is consistent with the regional trend.



Note: NF = normal-fault regime, SS = strike-slip regime, TF = thrust fault regime, and U= regime unknown.
Source: [195]

Figure 5.9.3-3: Stress Map of Greater Study Area



Note: (a) DGR-1 and DGR-2, (b) DGR-3, and (c) DGR-4. Peak values are interpreted to indicate the orientation of the minimum horizontal in situ stress for all orientations (blue) and for axis ratios greater than 1.0025 (orange).

Figure 5.9.3-4: DGR Borehole Long Axis Orientation Histograms for Middle Ordovician Formations

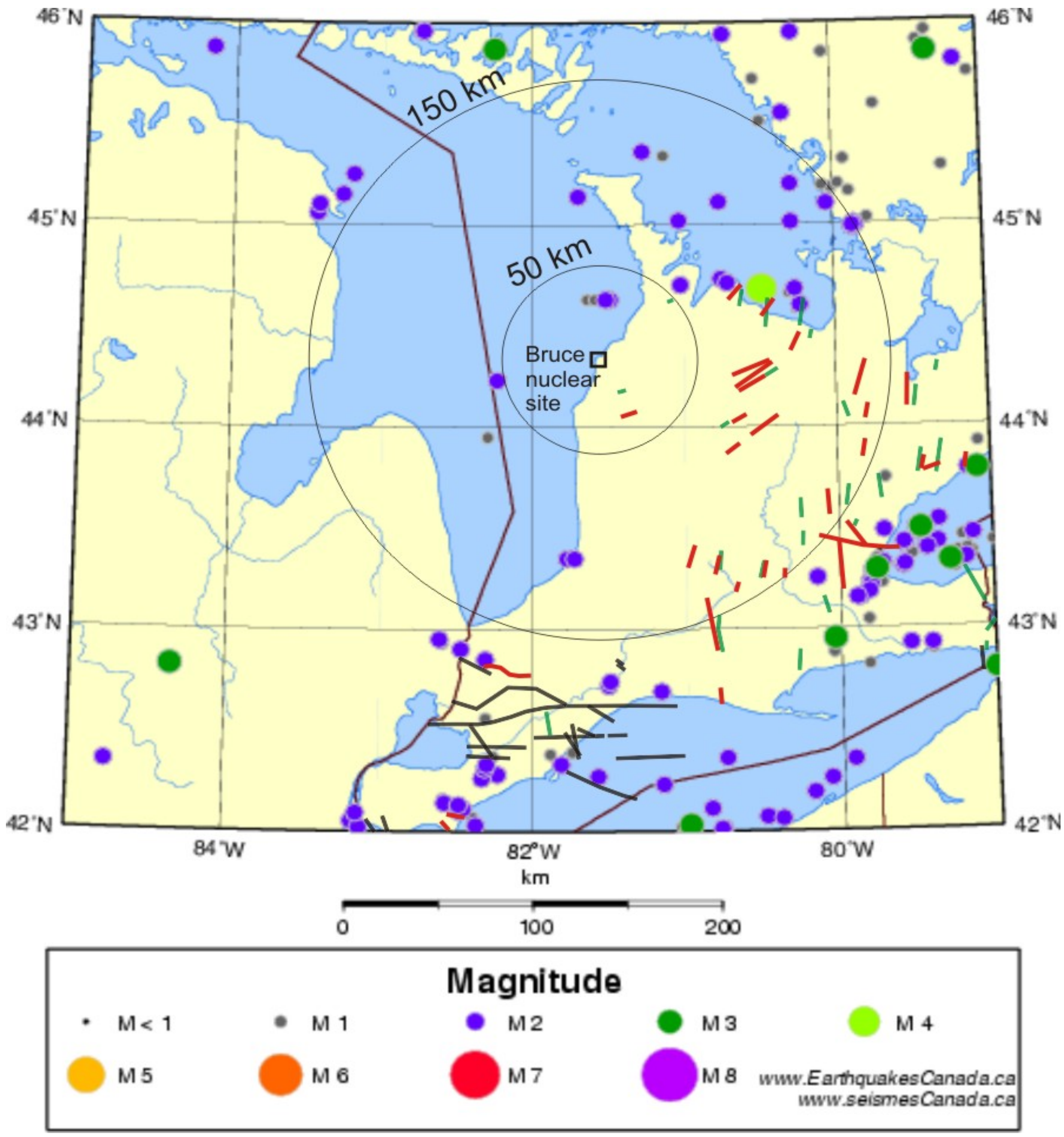
5.10 REGIONAL SEISMICITY

Southwestern Ontario and the Regional Study Area lie within the tectonically stable interior of the North American continent. This stable interior region of North America is characterized by low rates of seismicity. Figure 5.10-1 shows all known earthquakes in the region up to December 2010 [196] based on historical records since the late 1800s and the monitoring results from the seismograph stations around the Bruce nuclear site. Most recorded events have a magnitude of less than M3, with rare occurrences of larger events within a 150 km radius from the Bruce nuclear site. The local magnitude scale is the Nutti magnitude (m_N), which is an extension of the Richter Scale, and is the magnitude scale used for reporting of seismic activity in regions of North America to the east of the Rocky Mountains. Twenty-six events have been detected in this region since 1952 with a maximum magnitude of 4.2 measured 15 km north of Meaford near Owen Sound. The historical record is considered to be relatively complete for events of about M > 3.5. It has become more complete for lower magnitude events over the last 10 years owing to the increased station density in the region.

To improve the detection of the local pattern of low-level seismicity, three highly sensitive borehole seismometer stations were installed within an approximate 40 km radius of the Bruce nuclear site during the summer of 2007. The threshold for detection was further lowered to M1.0. The objectives of this new array are to capture microseismic events in the immediate area and to determine if they delineate seismogenic features deep in the bedrock. The data collected since the station installation suggest that, in general, the Regional Study Area experiences sparse seismic activity and there are no major seismogenic features or active faults of concern. This is confirmed by a recently completed remote-sensing and field-based study [81] that looked at landforms and sediments within 50 km of the Bruce nuclear site and found no evidence for neotectonic activity associated with the most recent glacial cycle within the Regional Study Area.

Currently, Canadian Hazards Information Services (CHIS) of the Geological Survey of Canada (GSC) monitors and reports on seismic activity in the immediate region of the Bruce nuclear site on an annual basis [197;196;198]. CHIS [197] reviewed historical seismicity for the Bruce area and noted that only three earthquakes have historically been detected within 50 km of the Bruce nuclear site prior to 2007. These three events occurred in Lake Huron about 20 km northwest of Southampton, with M1.7 to M2.1. The current and historical monitoring data confirm that the Bruce nuclear site is located in a seismically quiet area with only one minor event in each of 2008 and 2009, and none in 2010.

A probabilistic seismic hazard analysis (PSHA) was performed for the Bruce region to estimate bedrock ground motions that are expected for probabilities of 1×10^{-3} to 1×10^{-6} per annum [80]. Figure 5.10-2 shows the seismic hazard spectra developed from the PSHA. Selected peak ground accelerations obtained from the PSHA are tabulated in Table 5.10-1. The table also presents the results of a 4×10^{-4} probability event determined from this study and that is defined in the National Building Code of Canada [199].



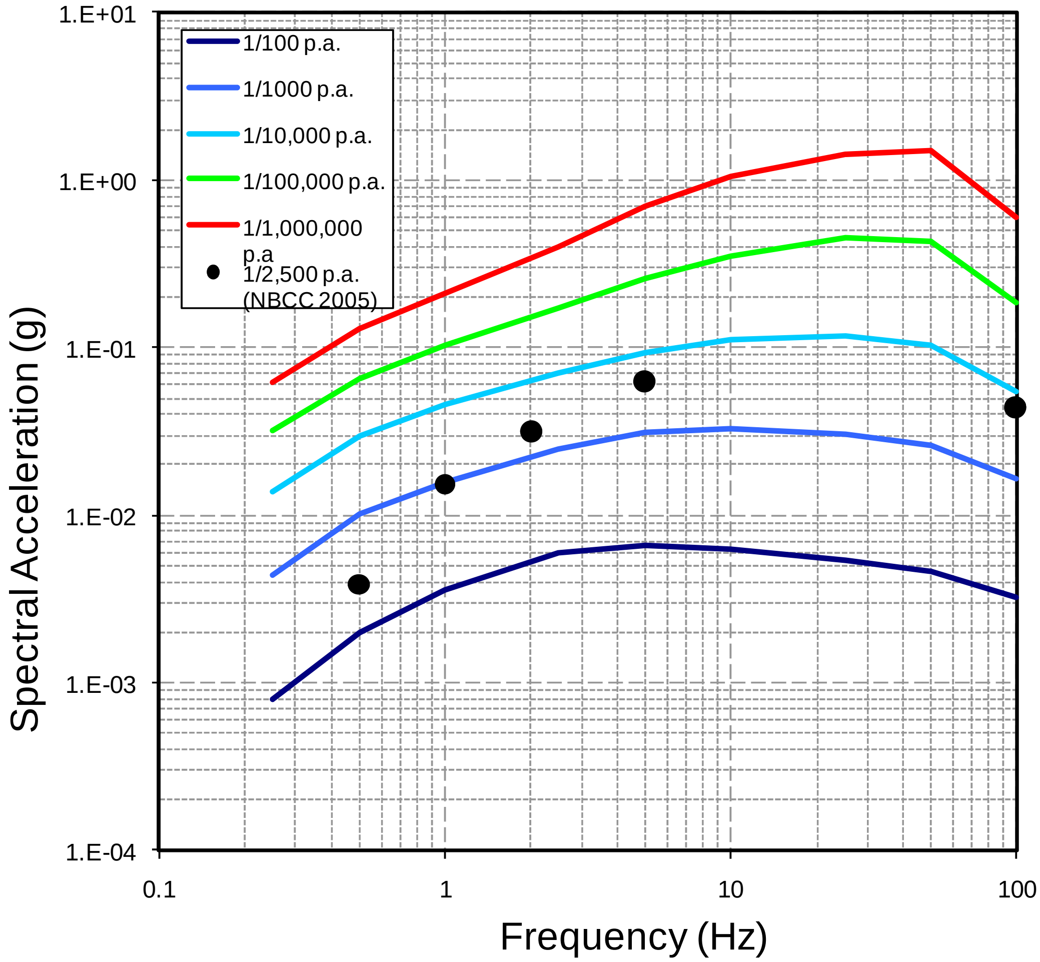
Note: All events plotted in local magnitude ($M=m_N$)
Source: [196]

Figure 5.10-1: Seismicity in the Bruce Region from 1985 to 2010 Overlain with Mapped Faults in Southern Ontario

Table 5.10-1: Summary of Seismic Hazard Analysis Result

Event (probability of exceedance per annum)	Peak Ground Acceleration	
	(cm/s²)	(%g)
1/1,000	17	1.7
1/2,500 (NBCC 2005)	43	4.4
1/100,000	183	18.7
1/1,000,000	589	60.1

Source: [200]



Source: [80]

Figure 5.10-2: Uniform Seismic Spectra for Surface Ground Motions on Hard Rock at the Bruce Nuclear Site for Probabilities of 1/100 to 1/100M p.a. (black dots show NBCC05 model results at 1/2,500 p.a.)

Ground shaking hazard is one of the greatest threats to surface facilities, and forms the basis for seismic design. For underground facilities, it is generally known that earthquake damage to underground workings is rare. Dowding and Rozen [201], and Blackblom and Munier [202] demonstrated, using case histories of the extent of tunnel damage during earthquakes, that there is a strong dependence of damage to peak ground acceleration and peak ground velocity. Based on the results of the preliminary PSHA, no damage is likely in the repository even under 1×10^{-5} annual probability events because the peak ground accelerations and peak ground velocities of the ground motion generated are well below the damage threshold [80]. This was further confirmed by numerical analysis of a cavern subjected to seismic ground motions of the same probability level [80].

5.10.1 Regional Seismicity Summary

The recently completed Geoscientific Site Characterization work presents an understanding of the properties of the deep sedimentary formations at and surrounding the Bruce nuclear site. This report presents a summary of the geomechanical knowledge that was gained, as it relates to site material strength properties, ground stress distribution and seismicity on a site-specific and regional basis for southern Ontario and bordering U.S. states. Information contained in the study provides an insight on the site and regional systems and on the long-term stability of the DGR. High in situ stresses provide a tight rock environment and estimates of stress magnitudes and orientations are predictable with depth; however, these will require confirmation from in situ measurements. The following is a summary of the main findings of this geomechanics study:

- Based on the current site characterization data, the rock of the Cobourg Formation at the Bruce nuclear site is found to be very competent and massive with high RQD and UCS values.
- The values of geomechanical parameters for the Cobourg Formation determined from site specific testing agree favorably with the regional database assembled, with the exception of the uniaxial compressive strength, which is significantly higher than the regional values for the rock unit. The laboratory testing of the Cobourg Formation for the site gave an average UCS value of 113 MPa compared to 72 MPa from the regional database.
- Based on the observation from the deep DGR boreholes, the orientation of maximum horizontal stress at the Bruce nuclear site appears to be similar to the stress orientation in the Michigan Basin, a NE to ENE direction. This conforms to the general trend of in situ stresses in Eastern North America.
- Stress analyses to evaluate estimated horizontal magnitudes were carried out, assuming that one principal stress is vertical. The absence of breakouts observed in the deep DGR boreholes permits the setting of an upper bound on the allowable maximum horizontal stress magnitude. At the repository horizon, the range of stress ratios is estimated to be: σ_H/σ_V from 1.5 to 2.0; σ_h/σ_v from 1.0 to 1.2.
- Earthquakes in the region are sparse based on historic seismicity. A new microseismic monitoring network installed in August 2007 has confirmed the low seismicity rate.
- No seismic events >M5 have been recorded in the past 180 years. Earthquakes measured in the region generally have deep epicentres originating in the Precambrian beneath the Paleozoic sediments.
- There are no known seismogenic features that could trigger a significant earthquake.
- The likelihood of a large seismic event in the region is very low with a seismic rate comparable to the Stable Cratonic Region of North America.

- A Probabilistic Seismic Hazard Assessment (PSHA) was conducted for the Bruce nuclear site. The PSHA conducted for the DGR explicitly incorporated uncertainties in the probabilistic models and model parameters that affect seismic hazard at the site. The results of the PSHA are generally consistent with values published in the 2005 National Building Code of Canada when corrected to a common site condition and accounting for the differences in the selected ground motion models used in the two studies.
- The results of the PSHA indicate that the estimated ground motions at the surface on hard rock are expected to be less than 1.0 g for annual exceedance frequencies of 10^{-5}, the reference case, and 10^{-6}, the extreme case.

5.11 SUMMARY OF EXISTING ENVIRONMENT

The existing environment is summarized as follows:

- Predictable: horizontally layered, undeformed sedimentary shale and limestone formations of large lateral extent.
    - Comparing the Paleozoic bedrock stratigraphy encountered in the deep DGR boreholes to that derived from an assessment of historic oil and gas well records demonstrates that the occurrence of individual bedrock formations and facies assemblages is predictable and traceable at the local scale and consistent with the regional stratigraphic framework of [48;47].
    - The thickness and orientation of bedrock formations encountered beneath the Bruce nuclear site are highly consistent [11]. Within an area of approximately 1.5 km^2 enclosing the DGR footprint, information derived from the deep drilling and cor[i]ng program confirms that Ordovician formation thickness variations are on the order of Metres only. No published evidence exists to demonstrate that fault structures within the Huron domain penetrate sediments younger than Ordovician age [48]. This contradicts the notion that the Paleozoic sequences within the Huron domain possess similar fracture frameworks as observed within the Niagara block of the Appalachian basin [50], and is consistent with the results of detailed structural mapping studies [203;204;43;205;28].
- Seismically Quiet: comparable to stable Canadian Shield setting.
    - The Bruce nuclear site is located within the tectonically stable interior of the North American continent, which is characterized by low rates of seismicity. No earthquake exceeding magnitude 5 has been observed in the Regional Monitoring Area in 180 years of record. The maximum earthquake within the 150 km radius study area is a M4.3 event at 99 km from the site with a focal depth of 11 km. This is consistent with the seismic hazard information provided in the 2005 National Building code of Canada. Field-based neotectonic and geologic investigations in the DGR area, including outcrop and Quaternary paleoseismic mapping and deep drilling have found no evidence for the presence of structural features that would indicate a higher seismic hazard near the Bruce nuclear site than that estimated from the regional rate of earthquake occurrence. The micro-seismic monitoring network installed and commissioned in August 2007 confirms the lack of low level seismicity (>M1.0) within the vicinity of the Bruce nuclear site implying no seismogenic structures or faults within or in close proximity to the DGR footprint.
- Multiple Natural Barriers: multiple low-permeability bedrock formations enclose and overlie the DGR (need to ensure permeability.

  - The sedimentary sequence underlying the Bruce nuclear site is comprised of 34 near horizontally layered, laterally continuous bedrock formations. Based on formation properties, and hydraulic head conditions, the hydrostratigraphy of the site has been sub-divided into nine units. Within the Ordovician sediments that host and enclose the proposed DGR are numerous units characterized as aquicludes that posses extremely low rock mass permeabilities. The host Cobourg Formation has a hydraulic conductivity ($K \approx 1\times10^{-14}$ m/s). The overlying 200 m of Ordovician shales (3 formations) possess rock mass hydraulic conductivities $<1\times10^{-13}$ m/s. The underlying 150 m of Ordovician carbonates (5 formations) possess K ranging from 1×10^{-14} to 1×10^{-11} m/s. Above the Ordovician sediments, within the Silurian age sediments, 10 formations possess K's $<1\times10^{-11}$ m/s.
  - The long-term barrier integrity of the Ordovician shale cap rock is, in part, demonstrated by a analogue with hydrocarbon cap rock seals located in the Appalachian and Michigan basins [28], and with observations from the Bruce nuclear site. These observations include: the occurrence of paleo-under-pressures, sealed fractures, low formation permeabilities, and a low degree of thermal maturation, all of which have beenmaintained since the late Paleozoic (250 Ma) [11]. These factors combine to significantly limit, if not render immobile, vertical fluid migration and solute transport through the cap rock.
  - No geochemical evidence has been found for the ingress of glacial or recent meteoric recharge water into the host or bounding formations. The stable water isotopes ($\delta^{18}O$ and $\delta^{2}H$) indicate that the maximum depth of glacial meltwater penetration is within the Salina A1 carbonate aquifer, approximately 330 mBGS. Further, the results of numerical simulations — paleohydrogeology — provide insight into long-term groundwater system performance, and indicate that glacial perturbations do not significantly alter the governing groundwater transport mechanisms within the deep groundwater system.
- Shallow Groundwater Resources are Isolated: near-surface groundwater aquifers are isolated from the deep saline groundwater system.
  - Regionally, the hydrogeochemistry of the Michigan Basin defines two distinct groundwater regimes: i) a shallow bedrock system containing potable groundwater at depths above 200 m; and ii) an intermediate to deep saline system characterized by elevated TDS (>200 g/L) and distinct isotopic signatures.
  - Groundwater resources in the vicinity of the Bruce nuclear site are obtained from shallow overburden or bedrock wells extending to depths of ca. 100 m into the permeable Devonian carbonates. At increasing depth groundwater becomes brackish then saline and yields decrease which would prevent or discourage deep drilling for potable water.
  - Observed abnormal hydraulic heads in the Ordovician and Cambrian rocks and high vertical hydraulic gradients strongly suggest that vertical connectivity across bedrock aquitards/ aquicludes does not exist.
- Geomechanically Stable: selected DGR limestone formation will provide stable, virtually dry openings.
  - The laboratory testing of the Cobourg Formation core rock samples reveals a high strength argillaceous limestone with an average uniaxial compressive strength (UCS) value of 113 MPa. These rock strength conditions compare favorably with other sedimentary formations considered internationally for long-term radioactive waste management purposes.

    - No borehole breakouts were observed in the deep DGR boreholes, which provides a constraint on the possible range of the in situ stress magnitudes. Observed borehole deformation over time frames to 16 months strongly suggests that the orientation of maximum horizontal stress is similar to that of the Michigan Basin, a northeast to east-northeast direction.
- Contaminant Transport is Diffusion Dominated: deep groundwater regime is ancient showing no evidence of glacial perturbation or cross-formational flow.
    - Hydraulic conductivity (K) testing of the Lower Member of the Cobourg Formation (DGR host rock), the overlying Ordovician shales (Georgian Bay, Blue Mountain and Queenston formations and the Collingwood Member of the Cobourg Formation), and underlying Ordovician limestones and dolostones (Sherman Fall, Kirkfield, Coboconk, Gull River, and Shadow Lake formations) confirm low hydraulic conductivity in all formations, such that transport would be diffusion-dominated. The K values in the Ordovician shales range between 1×10^{-13} m/s and 1×10^{-14} m/s. The Trenton Group carbonate values average 1×10^{-14} m/s. The Black River Group carbonate values range between 1×10^{-11} and 1×10^{-13} m/s.
    - The effective diffusion coefficients (D_e) measured in the laboratory for samples from the DGR cores are generally lower by a factor of ten than diffusion coefficients measured for samples of argillaceous sedimentary rocks considered for radioactive waste isolation in other international programs. The D_e values in the Ordovician shales are on the order of 1×10^{-12} m²/s, and in the carbonates are on the order of 1×10^{-12} to 1×10^{-13} m²/s. The low D_e values, coupled with the low permeabilities (1×10^{-20} to 1×10^{-21} m²) and the low hydraulic conductivities of the Ordovician carbonates, indicate that solute migration is diffusion dominated in the deep groundwater system. Further, the persistence of low hydraulic heads in the Ordovician compared to the underlying over-pressured Cambrian can only be maintained in the presence of low-permeability bounding rocks.
    - The occurrence of isotopically distinct types of methane and helium in separate zones (one zone in the Upper Ordovician shale and another zone in the Middle Ordovician carbonates) demonstrates that there has been little to no cross-formational mixing (advective or diffusive) while these gases were resident in the system. The occurrence of radiogenic $^{87}Sr/^{86}Sr$ ratios in the Middle and Upper Ordovician porewater are interpreted to result from a combination of water-rock interaction, in situ ^{87}Rb decay, and diffusive transport upward.
    - The chemistries of the deep brines indicate that they were formed by evaporation of seawater, which was subsequently modified by fluid-rock interaction processes. The Cl, Br and stable water isotope data, suggest that the deep groundwater system contains evolved ancient sedimentary brines at, or near, halite saturation. The nature of the brines, in particular the high salinities and the enriched $\delta^{18}O$ values (enriched in $\delta^{18}O$ with respect to the GMWL) in the porewaters, indicate that the deep system is isolated from the shallow groundwater system and that the porewaters have resided in the system for a very long time.
- Natural Resource Potential is Low: commercially viable oil and gas reserves are not present.
    - The likelihood of encountering commercial shale gas at the Bruce nuclear site is extremely low due to a combination of low thermal maturity wherein sediments barely reached the oil window, and low measured TOC of < 2.5% within the most prospective Collingwood Member and lower Blue Mountain Formation shales [28]. Lateral continuity between the Bruce nuclear site boreholes and other

proximal dry wells (Union Gas #1, Texaco #4 and Texaco #6), demonstrates that locally around the Bruce nuclear site (approximately 7km radius), no pockets of gas shale exist [28;11].

- A transition from fresh to saline groundwater is recorded through the shallow and intermediate hydrogeological systems with saline groundwater dominating from ca. 170 m depth within the Silurian Salina F Unit [11]. A transition into more permeable rock occurs in the lower Ordovician and the underlying Cambrian sandstone (ca. 830 mBGS). The porewater at the repository depth (nominally 680 mBGS) is not potable (TDS >200 g/L) and this extremely low permeability bedrock formation (hydraulic conductivities $<1\times10^{-13}$ m/s) cannot yield groundwater. This combination of extremely high salinities and low hydraulic conductivities in the rock surrounding the proposed repository depth would discourage deep drilling for groundwater resources.

Given all the information summarized above that supports the key hypotheses, the geological setting at the Bruce nuclear site is suitable to support the development of a DGR for L&ILW in the Cobourg Formation.

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6. INITIAL SCREENING OF PROJECT-ENVIRONMENT INTERACTIONS

The first screening considers whether there is a potential for the DGR Project to interact with the geology VECs.

6.1 INITIAL SCREENING METHODS

Following the description of the DGR Project, identification of VECs, and description of the existing environment, the project works and activities are screened to determine those with the potential to interact with the geology VECs. The screening was conducted based on the general description of the existing environmental conditions. This allowed the EA to focus on issues of key importance where potential interactions between the DGR Project and geology are likely. The analyses are based on the experience of the technical specialists supported by information collected from field studies and information from earlier EAs carried out for projects on the Bruce nuclear site. This screening is conducted by VEC for each project phase. As the mechanism of the interactions between the DGR Project and some VECs (e.g., intermediate bedrock solute transport and deep bedrock solute transport) are similar, the discussion is grouped where appropriate to facilitate readability.

Geology VECs interact with the DGR Project directly (e.g., change in overburden groundwater transport as a result of dewatering) and indirectly (e.g., effects on overburden groundwater quality attributed to changes in surface water quality [a VEC in Hydrology and Surface Water Quality TSD]). Both direct and indirect interactions are carried forward through this assessment. Where a mechanism for interaction is identified, the individual project work or activity is advanced for further consideration of measurable changes. Where no potential interaction is identified, no further screening is conducted. The analyses at this stage are based on qualitative information, including the professional judgement and experience of the EA team with regard to the physical and operational features of the project and their potential interactions with the environment.

The results of the screening are documented in an interaction matrix. A potential project-VEC interaction is marked with a '•' on Matrix 1 (Section 6.3).

If, following the evaluation of project-environment interactions, there are no potential interactions between a VEC and a project work and activity or other VEC, the VEC is not considered further.

6.2 IDENTIFICATION OF DGR PROJECT-ENVIRONMENT INTERACTIONS

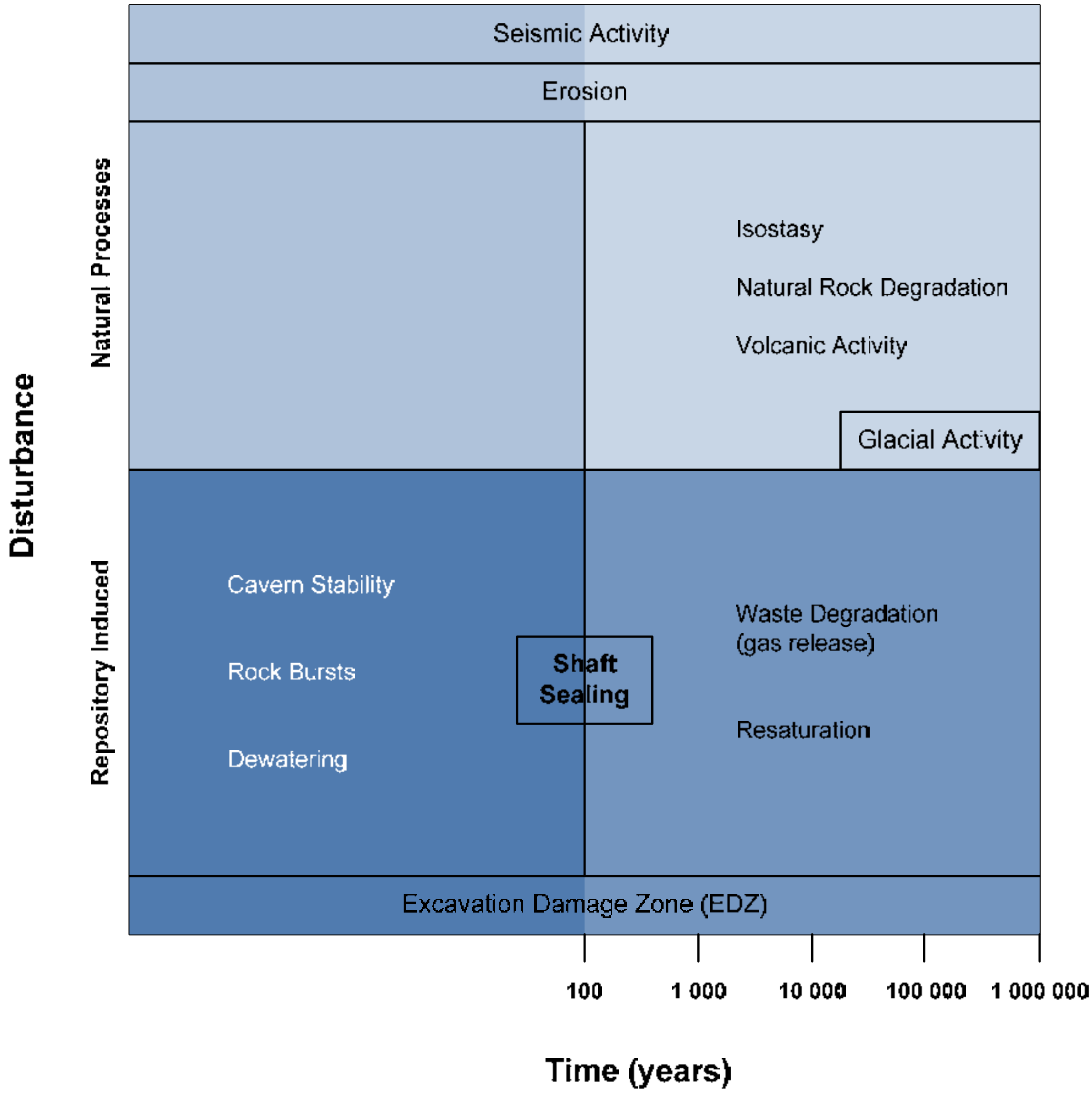
In the initial screening, all works and activities associated with the DGR Project are identified and analyzed for possible interactions with the geology VECs. As shown in the Basis for the EA (Appendix B), the DGR Project includes the following project works and activities:

- site preparation;
- construction of surface facilities;
- excavation and construction of underground facilities;
- above-ground transfer of waste;
- underground transfer of waste;
- decommissioning of the DGR Project;

- abandonment of the DGR facility;
- presence of the DGR Project;
- waste management;
- support and monitoring of DGR life cycle; and
- workers, payroll and purchasing.

The abandonment of the DGR facility work and activity occurs immediately following decommissioning and does not encompass the entirety of the abandonment and long-term performance phase. This TSD considers normal operations and non-radiological effects only. For a consideration of the effects of malfunctions and accidents (e.g., a spill) on geology, refer to the Malfunctions, Accidents and Malevolent Acts TSD. Radiological effects are considered in the Radiation and Radioactivity TSD.

In the following sections, each work and activity is evaluated for potential direct and indirect interactions with the VECs. Potential interactions between the DGR Project and the geology VECs occur on two broad timescales, the near-term (i.e., when activities are occurring on-site during the site preparation and construction, operations, and decommissioning phases) and in the long-term (i.e., following abandonment of the DGR). As illustrated in Figure 6.2-1, the former occurs over approximately 65 years, and the latter occurs over millions of years. The long-term performance interactions are discussed collectively in Section 6.2.3.



Source: [3]

Figure 6.2-1: Factors Influencing the Future Evolution of the DGR

6.2.1 Direct Interactions

The key mechanisms for the DGR Project directly interacting with the geology VECs are through a physical activity intersecting the VECs (e.g., excavation of the shaft through the sedimentary sequence). Many of the project works and activities occur on the surface; therefore, most of the sections below focus on the near surface VECs (i.e., soil quality, overburden groundwater quality, overburden groundwater transport). Indirect mechanisms on how the units relate to each other are considered in Section 6.2.2.

6.2.1.1 Site Preparation

The site preparation will involve activities for the initial preparation of the site for future construction activities. This preparation would encompass all land area associated with the DGR Project, including construction and operations areas such as construction laydown areas, Waste Rock Management Area (WRMA), a stormwater management system, and road network construction.

The expected site preparation activities will include earth-moving activities and conventional urban construction activities. Therefore, site preparation activities can only interact with the shallow geologic/hydrogeologic regime through the following key mechanisms:

- The removal of soils during grading. Based on the near-surface geology in the vicinity of the Project Area, excavation of bedrock is not expected during this surface work of the DGR Project. A potential reduction in the area for local recharge may also affect groundwater quality.
- The alteration of the surface permeabilities during the installation/construction of impervious surfaces (roads, buildings) which can potentially reduce the groundwater recharge area.

Therefore, site preparation works and activities may interact with the following VECs:

- soil quality;
- overburden groundwater quality; and
- overburden groundwater transport.

These are advanced for further consideration in Section 7.

6.2.1.2 Construction of Surface Facilities

Surface structures for the DGR Project will be constructed during the site preparation work and activities, as well as during construction. In preparation for shaft sinking (see Section 6.2.1.3), the two permanent headframes will be constructed, complete with the permanent ventilation shaft hoist house. Temporary facilities will include engineering, procurement and construction management trailers, a construction laydown area, a construction parking area, construction trailers, and a truck lane for the removal of excavated material to the WRMA. After completion of shaft sinking, the temporary structures will be removed and the operations phase structures will be constructed. Surface construction methods will be consistent with those used for typical light industrial buildings. The proposed layout of surface facilities is shown in Figure 3.2.1-1.

The WRMA will dominate the surface features of the site. This area is further described and assessed under the project work and activity ‘Waste Management’ in Section 6.2.1.9.

The main mechanisms for interaction with the VECs identified for geology during the construction of surface facilities include:

- The installation/construction of impervious surfaces (roads, buildings), which can potentially reduce the area for groundwater recharge due to precipitation. A potential reduction in the area for local recharge may also affect groundwater quality.
- The potential pumping of groundwater for dewatering during construction of foundations and other shallow underground structures.

Therefore, surface facility construction works and activities may interact with the following VECs:

- overburden groundwater quality;
- overburden groundwater transport; and
- shallow bedrock groundwater and solute transport.

These are advanced for further consideration in Section 7.

6.2.1.3 Excavation and Construction of Underground Facilities

The underground facilities will comprise the main and ventilation shaft access-ways, emplacement rooms and tunnels. The main and ventilation shafts will be advanced using excavation through the overburden, and drill and blast techniques for all of the bedrock excavation. Ground treatment of the upper 150 to 200 m of rock will be performed to create safe excavation conditions. Throughout these operations, dewatering will be undertaken, as necessary, to maintain these conditions[2].

Therefore, underground excavation and construction works and activities may have interactions with the following VECs:

- overburden groundwater transport;
- shallow bedrock groundwater and solute transport;
- intermediate bedrock solute transport; and
- deep bedrock solute transport.

These are advanced for further consideration in Section 7.

6.2.1.4 Above-ground Transfer of Waste

The above-ground transfer of waste will include truck transfer of waste from the WWMF fenceline, and receipt of L&ILW from the WWMF at the DGR Project Waste Package Receiving Building. All waste packages will be inspected at the WWMF prior to transfer to the main shaft station. There are no potential mechanisms for the above-ground transfer of waste to interact with the geology VECs. Accordingly, this project work and activity is not considered further.

[2] For purposes of the assessment, it was conservatively assumed that the maximum design dewatering flow rates would occur continuously. In reality, the contribution from dewatering is expected to be lower. During excavation, inflows will need to be on the order of 1 L/s to facilitate construction.

6.2.1.5 Underground Transfer of Waste

The main shaft will be used to transfer waste packages to the underground repository. The packages will be off-loaded to a staging area. At the underground shaft station, all packages will be off-loaded from the cage compartment in the centre of the shaft. Wastes are inspected prior to transfer and are fully contained during underground transfer activities. There are no potential mechanisms for the underground transfer of waste to interact with the geology VECs. Accordingly, this project work and activity is not considered further.

6.2.1.6 Decommissioning of the DGR Project

Work will begin to dismantle the facility, and seal the repository, after waste emplacement operations have ended and regulatory approval has been received to decommission the DGR Project. The scope of decommissioning work for the repository would include preparation and approval of decommissioning plans, decommissioning of underground facilities, sealing of shafts, and demolition of all surface facilities.

The function of the seals will be to:

- maintain the long-term integrity of the overlying low permeability geologic formations above the Cobourg Lower Member Formation; and
- minimize the potential for migration of contaminants associated with the waste material.

The main mechanisms for interaction with the VECs identified for geology during the decommissioning of the DGR include:

- The removal of impervious surfaces (roads, buildings), which can potentially change the area for groundwater recharge from precipitation. A potential change in the area for local recharge may also affect groundwater quality.
- The placement of seal materials, which may influence the groundwater system in the immediate vicinity of the shaft.

Therefore, decommissioning works and activities may have interactions with the following VECs:

- soil quality;
- overburden groundwater quality;
- overburden groundwater transport;
- shallow bedrock groundwater quality;
- shallow bedrock groundwater and solute transport;
- intermediate bedrock water quality;
- intermediate bedrock solute transport;
- deep bedrock water quality; and
- deep bedrock solute transport.

These are advanced for further consideration in Section 7.

6.2.1.7 Abandonment of the DGR Facility

The abandonment activities may include removal of access controls. There are no potential mechanisms for abandonment of the DGR facility to interact with the geology VECs. Accordingly, this project work and activity is not considered further.

6.2.1.8 Presence of the DGR Project

The “presence of the DGR Project” represents the meaning people may attach to the existence of a L&ILW management facility in their community and the influence normal operations of the DGR Project may have on their sense of health, safety and personal security.

There are no potential mechanisms for the presence of the DGR facility to interact with the geology VECs during the site preparation and construction, operations, and decommissioning phases. The potential interactions between geology VECs and the sealed shafts during the abandonment and long-term performance phase are considered as part of the “Long-term Performance of the DGR Project” in Section 6.2.3.

6.2.1.9 Waste Management

Waste management activities for the project are classified as follows:

- conventional waste management;
- toxic/hazardous waste management;
- radiological waste management; and
- waste rock management.

Conventional waste produced by the construction activities will be reused or recycled if possible, or transported to a licensed facility for disposal. Types of conventional waste will include non-reusable/recyclable construction materials, and other regular waste generated at an industrial work site.

During decommissioning of the DGR Project, any waste that was in contact with radioactive material will be treated separately. Radioactive waste management is described in the Radiation and Radioactivity TSD.

Therefore, the only mechanism for interaction with the geology VECs is with the waste rock management area. The rock materials that will be excavated during the construction of the DGR Project will be stored on-site and will be re-used for future uses on-site, as applicable. In order to provide temporary management of these materials, and long-term management of argillacious limestones, a total of 11 ha is required as shown in Figure 3.2.1-1. It is anticipated that overburden materials will be reused in less than a year.

If the temporary storage of shales is required for more than one year, the shale pile will be covered to minimize the potential for erosion of these materials, while also limiting infiltration into the pile. Covering the limestone pile will not occur until decommissioning as erosion is not expected to be significant.

The waste rock pile will be constructed upon graded topsoil/overburden. Lining of the ground surface underneath the rock piles is not planned. Surface runoff from precipitation events within the WRMA will be directed to the perimeter drainage ditches which form part of the stormwater management system for the project, and will ultimately flow to the stormwater management pond (SWMP, Figure 3.2.1-1). Potential interactions with stormwater runoff are screened in Section 6.2.1.10. Some runoff is expected to infiltrate through the rock pile into the subsurface.

Therefore, waste management works and activities may interact with the following VECs:

- soil quality;
- overburden groundwater quality; and
- overburden groundwater transport.

These are advanced for further consideration in Section 7.

6.2.1.10 Support and Monitoring of DGR Life Cycle

Site support and monitoring services during the operation of the DGR Project include the following works and activities:

- provision of potable water from surface for underground workers, washrooms, and refuge stations;
- provision of compressed air and ventilation for sustenance;
- provision of electricity, lighting and heating;
- management and operation of communications systems;
- management and operation of fire protection systems;
- management and operation of emergency response systems;
- the development of “zones” that define procedures and practices that are mandatory in order to move from one area to the other;
- implementation of a security system to control access to the DGR;
- dewatering from a sump at the bottom of each shaft to capture any water generated within the repository;
- management of water from the shaft sumps and the WRMA; and
- implementation of a variety of monitoring systems, including the monitoring of underground water quality.

Only the dewatering from the sumps and the management of sump and WRMA water could result in a potential interaction with the soil quality, groundwater quality, and groundwater flow VECs. The groundwater monitoring program is not considered to have a potential interaction with the VECs; it is a tool for assessing the potential interaction of the DGR Project with the VECs.

Water requiring management will be generated from the following sources:

- infiltration through the rock during construction and operations;
- water collected in the shaft sumps from wash-down water and condensation in the ventilation shaft;
- water from repository level development mining; and

- surface runoff from the DGR Project site, including the WRMA.

During excavation of the shafts and emplacement rooms, a groundwater inflow collection system will collect and direct groundwater inflows. Dewatering during excavation and construction was the subject of the screening in Section 6.2.1.3 and is not considered further in this section.

During operations, a sump at the bottom of each shaft, just off the shaft barrel, will capture any water generated within the repository, including water from infiltration through the rock[3], fire system maintenance and wash water for cleaning equipment. Water inflow volumes are expected to be small. The water will be pumped up the shaft column and discharged to the stormwater management system via a stormceptor to treat sump water for suspended solids, oil and grease. After treatment, the water will be directed to the perimeter ditch network.

The stormwater management pond, shown in Figure 3.2.1-1, will ultimately receive water pumped from the excavation during construction and from the sumps during operations. As described in the Hydrology and Surface Water Quality TSD, stormwater runoff from the site surface facilities and WRMA will also be collected in the stormwater management system (see Figure 3.2.1-1). The stormwater management pond and the perimeter drainage network will not be lined. Therefore, there is some potential for stormwater and discharged sump water to infiltrate into the subsurface soils and interact with the following geology VECs:

- soil quality;
- overburden groundwater quality; and
- overburden groundwater transport.

Therefore, the dewatering from the sumps, the management of sump and WRMA water, and the presence and operation of the stormwater management pond could result in a potential interaction with the soil quality, groundwater quality, and groundwater transport VECs.

6.2.1.11 Workers, Payroll and Purchasing

The workers, payroll and purchasing project works or activities encompass the activities that relate to the administration of the project. These activities do not affect the physical environment except for changes to the ground surface for transportation routes and parking. These aspects of the project are considered under the construction of surface facilities project works and activities (Section 6.2.1.2). Therefore, there are no potential interactions between the workers, payroll and purchasing project work and activity and the VECs for geology. Accordingly, this project work or activity is not considered further.

6.2.2 Indirect Interactions

Indirect interactions consider how changes to a given VEC during the project (e.g., soil quality) can cause changes in another VEC on the Project (e.g., shallow bedrock quality). In essence a physical activity from the project directly interacts with a VEC, which can then indirectly interact with another VEC.

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3 The DGR will be designed with the objective of operating largely as a dry facility with only relatively small amounts of water collecting in shaft pumps.

6.2.2.1 Changes in Air Quality

Construction activities during site preparation and decommissioning and to a lesser degree, during the operations phase could potentially indirectly affect soils via the deposition of airborne dust and associated contaminants. The deposited dust could include residues from the blasting agents. As a result, changes in air quality could cause indirect interactions with soil quality. Accordingly, the soil quality VEC is advanced for further consideration in Section 7.

There are no potential indirect interactions attributable to changes in air quality with any of the remaining VECs.

6.2.2.2 Changes in Surface Water Quantity and Flow

Changes in surface water quantity and flow have the potential to interact with overburden groundwater transport through the groundwater/surface water interface. The creation or removal of impervious surfaces may affect the localized groundwater recharge. In addition, redirection of surface water runoff may also affect the localized groundwater recharge characteristics. Accordingly, the overburden groundwater transport VEC is advanced for further consideration in Section 7.

There are no potential indirect interactions attributable to changes in surface water quantity and flow with any of the other VECs.

6.2.2.3 Changes in Surface Water Quality

Potential indirect interactions with groundwater quality attributable to changes in surface water quality are possible. Infiltration of precipitation or surface water has the potential to transport some portion of dissolved minerals into the underlying overburden groundwater resource. This mineral transport could alter the mineralization of the overburden groundwater resource. Accordingly, the overburden groundwater quality VEC is advanced for further consideration in relation to indirect interactions from changes in surface water quality (Section 7).

There are no potential indirect interactions attributable to changes in surface water quality with any of the remaining VECs.

6.2.2.4 Changes in Soil Quality

Changes in soil quality could affect groundwater quality through interaction between the soil and groundwater. As a result, changes in soil quality could cause an indirect effect to overburden groundwater quality, and is advanced for further consideration in Section 7. There are no potential indirect interactions attributable to changes in soil quality with any of the remaining VECs.

6.2.2.5 Changes in Overburden Groundwater Quality

Changes in overburden groundwater quality could affect soil quality through interaction between the soil and groundwater. Changes in overburden groundwater quality could also interact with shallow bedrock groundwater quality through leakage of overburden groundwater into the shallow bedrock groundwater. As a result, potential indirect interactions between changes in overburden groundwater quality and soil quality and shallow bedrock groundwater quality are advanced for further consideration in Section 7.

There are no potential indirect interactions attributable to changes in overburden groundwater quality with any of the remaining VECs.

6.2.2.6 Changes in Overburden Groundwater Transport

Changes in overburden groundwater transport could interact with overburden groundwater quality through concentration or dilution of parameters. As a result, changes in groundwater transport could interact with overburden groundwater quality, and therefore this interaction is carried forward for further consideration in Section 7.

There are no potential indirect interactions attributable to changes in overburden groundwater transport with any of the remaining VECs.

6.2.2.7 Changes in Shallow Bedrock Groundwater Quality

Changes in shallow bedrock groundwater quality could conceivably interact with the intermediate bedrock water quality, through the leakage of shallow bedrock groundwater into the intermediate bedrock. As a result, changes in shallow bedrock groundwater quality could interact with intermediate bedrock water quality, and are advanced for further consideration in Section 7.

There are no potential indirect interactions attributable to changes in shallow bedrock groundwater quality with any of the remaining VECs. The potential for transport in the long-term is described in Section 6.2.3.

6.2.2.8 Changes in Shallow Bedrock Groundwater and Solute Transport

Changes in shallow bedrock groundwater and solute transport could interact with shallow bedrock groundwater quality through concentration or dilution of parameters. As a result, changes in shallow bedrock groundwater and solute transport could cause an indirect interaction with shallow bedrock groundwater quality, and therefore this interaction is carried forward for further consideration in Section 7.

Changes in shallow bedrock groundwater and solute transport may also interact with intermediate bedrock solute transport. Therefore, changes in the shallow bedrock groundwater and solute transport because of the DGR Project are advanced for further consideration in Section 7.

There are no potential indirect interactions attributable to changes in shallow bedrock groundwater and solute transport with any of the remaining VECs.

6.2.2.9 Changes in Intermediate Bedrock Water Quality

Changes in intermediate bedrock water quality could potentially interact with shallow bedrock groundwater quality through diffusive transfers. As a result, changes in intermediate water quality could cause an indirect interaction with shallow bedrock groundwater quality, and therefore this interaction is carried forward for further consideration in Section 7. There are no potential indirect interactions with any of the remaining VECs.

6.2.2.10 Changes in Intermediate Bedrock Solute Transport

Changes in intermediate bedrock solute transport could potentially interact with intermediate bedrock water quality through concentration or dilution of parameters. As a result, changes in intermediate solute transport could cause an indirect interaction with intermediate bedrock water quality, and therefore this interaction is carried forward for further consideration in Section 7. There are no potential indirect interactions with any of the remaining VECs.

6.2.2.11 Changes in Deep Bedrock Water Quality

Changes in deep bedrock water quality could potentially interact with intermediate bedrock water quality and are advanced for further consideration in Section 7. The postclosure safety assessment describes a potential transport pathway from deep bedrock all the way to surface, through the sealed shaft. This interaction is described further in Section 6.2.3. There are no potential indirect interactions with any of the remaining VECs.

6.2.2.12 Changes in Deep Bedrock Solute Transport

The hydraulic gradients in the deep bedrock zone are upward. Therefore, the potential interaction between changes in deep bedrock solute transport and intermediate bedrock solute transport are advanced for further assessment in Section 7. There are no potential indirect interactions with any of the remaining VECs.

6.2.3 Long-term Performance of the DGR

The DGR will remain in place upon completion of decommissioning and abandonment activities. The future evolution of the DGR system was postulated in the postclosure safety assessment [2]. Although effects from the DGR are expected to be extremely small, in keeping with the precautionary approach for this EA, these potential interactions are advanced for a second screening. Within the EA context, these potential interactions are identified as follows:

- direct interaction between the shaft (presence of the DGR Project) and each of the solute transport and water quality VECs; and
- indirect interactions between the geological groupings:
    - soil quality may interact with overburden groundwater quality;
    - overburden groundwater quality may interact with soil quality and shallow bedrock quality;
    - shallow bedrock quality may interact with intermediate water quality;
    - intermediate bedrock water quality may interact with shallow bedrock water quality; and

- deep bedrock water quality may interact with intermediate bedrock water quality.

These interactions are advanced to Section 7 for further consideration.

6.3 SUMMARY OF FIRST SCREENING

Table 6.3-1 provides a summary of the initial screening for the DGR Project. Small dots (•) on this matrix represent possible DGR Project-environment interactions involving VECs. These interactions are advanced to Section 7 for a second screening to determine those interactions that may result in a potential measurable change to the geology VECs.

Table 6.3-1: Matrix 1 – Summary of the First Screening for Potential Interactions with VECs

Project Work and Activity	Soil Quality				Overburden Groundwater Quality				Overburden Groundwater Transport			
	C	O	D	LT	C	O	D	LT	C	O	D	LT
Direct Effects												
Site Preparation	•	—	—	—	•	—	—	—	•	—	—	—
Construction of Surface Facilities		—	—	—	•	—	—	—	•	—	—	—
Excavation and Construction of Underground Facilities		—	—	—		—	—	—	•	—	—	—
Above-ground Transfer of Waste	—		—	—	—		—	—	—		—	—
Underground Transfer of Waste	—		—	—	—		—	—	—		—	—
Decommissioning of the DGR Project	—	—	•	—	—	—	•	—	—	—	•	—
Abandonment of the DGR Facility	—	—		—	—	—		—	—	—		—
Presence of the DGR Project				•				•				•
Waste Management	•	•	•	—	•	•	•	—	•	•	•	—
Support and Monitoring of DGR Life Cycle	•	•	•	—	•	•	•	—	•	•	•	—
Workers, Payroll, and Purchasing				—				—				—
Indirect Effects												
Changes in Air Quality	•	•	•	—				—				—
Changes in Surface Water Quantity and Flow									•	•	•	•
Changes in Surface Water Quality					•	•	•	•				
Changes in Soil Quality	—	—	—	—	•	•	•	•				
Changes in Overburden Groundwater Quality	•	•	•	•	—	—	—	—				
Changes in Overburden Groundwater Transport					•	•	•	•	—	—	—	—
Changes in Shallow Bedrock Groundwater Quality												
Changes in Shallow Bedrock Groundwater and Solute Transport												
Changes in Intermediate Bedrock Water Quality												
Changes in Intermediate Bedrock Solute Transport												
Changes in Deep Bedrock Water Quality												
Changes in Deep Bedrock Solute Transport												

Notes:
C = Site Preparation and Construction Phase;
O = Operations Phase;
D = Decommissioning Phase
LT = Abandonment and Long-term Performance Phase

The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

• Potential project-environment interaction
— Activity does not occur during this phase
Blank No potential project-environment interaction

Table 6.3-1: Matrix 1 – Summary of the First Screening for Potential Interactions with VECs (continued)

Project Work and Activity	Shallow Bedrock Groundwater Quality				Shallow Bedrock Groundwater and Solute Transport				Intermediate Bedrock Water Quality			
	C	O	D	LT	C	O	D	LT	C	O	D	LT
Direct Effects												
Site Preparation		—	—	—		—	—	—		—	—	—
Construction of Surface Facilities		—	—	—	•	—	—	—		—	—	—
Excavation and Construction of Underground Facilities		—	—	—	•	—	—	—		—	—	—
Above-ground Transfer of Waste	—		—	—	—		—	—	—		—	—
Underground Transfer of Waste	—		—	—	—		—	—	—		—	—
Decommissioning of the DGR Project	—	—	•	—	—	—	•	—	—	—	•	—
Abandonment of the DGR Facility	—	—		—	—	—		—	—	—		—
Presence of the DGR Project				•				•				•
Waste Management				—				—				—
Support and Monitoring of DGR Life Cycle				—				—				—
Workers, Payroll and Purchasing				—				—				—
Indirect Effects												
Changes in Air Quality				—				—				—
Changes in Surface Water Quantity and Flow												
Changes in Surface Water Quality												
Changes in Soil Quality												
Changes in Overburden Groundwater Quality	•	•	•	•								
Changes in Overburden Groundwater Transport												
Changes in Shallow Bedrock Groundwater Quality	—	—	—	—					•	•	•	•
Changes in Shallow Bedrock Groundwater and Solute Transport	•	•	•	•	—	—	—	—				
Changes in Intermediate Bedrock Water Quality	•	•	•	•					—	—	—	—
Changes in Intermediate Bedrock Solute Transport									•	•	•	•
Changes in Deep Bedrock Water Quality									•	•	•	•
Changes in Deep Bedrock Solute Transport												

Notes:
C = Site Preparation and Construction Phase;
O = Operations Phase;
D = Decommissioning Phase
LT = Abandonment and Long-term Performance Phase

The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

• Potential project-environment interaction
— Activity does not occur during this phase
Blank No potential project-environment interaction

Table 6.3-1: Matrix 1 – Summary of the First Screening for Potential Interactions with VECs (continued)

Project Work and Activity	Intermediate Bedrock Solute Transport				Deep Bedrock Water Quality				Deep Bedrock Solute Transport			
	C	O	D	LT	C	O	D	LT	C	O	D	LT
Direct Effects												
Site Preparation		—	—	—		—	—	—		—	—	—
Construction of Surface Facilities		—	—	—		—	—	—		—	—	—
Excavation and Construction of Underground Facilities	•	—	—	—		—	—	—	•	—	—	—
Above-ground Transfer of Waste	—		—	—	—		—	—	—		—	—
Underground Transfer of Waste	—		—	—	—	—	—	—	—		—	—
Decommissioning of the DGR Project	—	—	•	—	—	—	•	—	—	—	•	—
Abandonment of the DGR Facility	—	—		—	—	—		—	—	—		—
Presence of the DGR Project				•				•				•
Waste Management				—				—				—
Support and Monitoring of DGR Life Cycle				—				—				—
Workers, Payroll and Purchasing				—				—				—
Indirect Effects												
Changes in Air Quality				—				—				—
Changes in Surface Water Quantity and Flow												
Changes in Surface Water Quality												
Changes in Soil Quality												
Changes in Overburden Groundwater Quality												
Changes in Overburden Groundwater Transport												
Changes in Shallow Bedrock Groundwater Quality												
Changes in Shallow Bedrock Groundwater and Solute Transport	•	•	•	•								
Changes in Intermediate Bedrock Water Quality												
Changes in Intermediate Bedrock Solute Transport	—	—	—	—								
Changes in Deep Bedrock Water Quality					—	—	—	—				
Changes in Deep Bedrock Solute Transport	•	•	•	•					—	—	—	—

Notes:
C = Site Preparation and Construction Phase;
O = Operations Phase;
D = Decommissioning Phase
LT = Abandonment and Long-term Performance Phase

The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

• Potential project-environment interaction
— Activity does not occur during this phase
Blank No potential project-environment interaction

Following the assessment of potential project-environment interactions, all VECs have a potential interaction with the DGR Project. Therefore, all of the VECs listed in Table 6.3-2 will be carried forward for further assessment. Indirect interactions between geology VECs, where identified, are also carried forward for further assessment.

Table 6.3-2: Re-evaluation of VECs for Geology

VEC	Retained?	Rationale
Soil Quality	Yes	• Potential interaction with site preparation, decommissioning, waste rock management and stormwater management system • Potential indirect interaction with changes in overburden groundwater quality • Potential interaction with changes in air quality • Potential interaction with abandonment and long-term performance phase
Overburden Groundwater Quality	Yes	• Potential interaction with site preparation, construction of surface facilities, decommissioning, waste rock management and stormwater management system • Potential indirect interactions with changes in surface water quality, soil quality and overburden groundwater transport • Potential interaction with abandonment and long-term performance phase
Overburden Groundwater Transport	Yes	• Potential interaction with site preparation, construction of surface facilities, excavation and construction of underground facilities (dewatering), decommissioning, waste rock management and stormwater management system • Potential indirect interaction with changes in surface water quantity and flow • Potential interaction with abandonment and long-term performance phase
Shallow Bedrock Groundwater Quality	Yes	• Potential interaction with decommissioning (shaft sealing) • Potential indirect interactions with changes in overburden groundwater quality, shallow bedrock groundwater and solute transport and intermediate bedrock water quality • Potential interaction with abandonment and long-term performance phase
Shallow Bedrock Groundwater and Solute Transport	Yes	• Potential interaction with construction of surface facilities, excavation and construction of underground facilities (dewatering) and decommissioning • Potential interaction with abandonment and long-term performance phase

Table 6.3-2: Re-evaluation of VECs for Geology (continued)

VEC	Retained?	Rationale
Intermediate Bedrock Water Quality	Yes	• Potential interaction with decommissioning (shaft sealing) • Potential indirect interactions with changes in shallow bedrock groundwater quality, intermediate bedrock solute transport and deep bedrock water quality • Potential interaction with abandonment and long-term performance phase
Intermediate Bedrock Solute Transport	Yes	• Potential interaction with excavation and construction of surface facilities, and decommissioning (shaft sealing) • Potential indirect interactions with changes in shallow bedrock groundwater and solute transport and deep bedrock solute transport • Potential interaction with abandonment and long-term performance phase
Deep Bedrock Water Quality	Yes	• Potential interaction with decommissioning (shaft sealing) • Potential interaction with abandonment and long-term performance phase
Deep Bedrock Solute Transport	Yes	• Potential interaction with excavation and construction of underground facilities, and decommissioning (shaft sealing) • Potential interaction with abandonment and long-term performance phase

7. SECOND SCREENING OF PROJECT-ENVIRONMENT INTERACTIONS

The second screening considers the DGR Project works and activities advanced from Section 6 to determine if the identified interactions are likely to cause a measurable change on the geology VECs.

7.1 SECOND SCREENING METHODS

Each of the potential interactions identified in the first screening is evaluated to determine those likely to result in a measurable change in the environment. For the purposes of the assessment, a measurable change in the environment is defined as a change that is real, observable or detectable compared with existing conditions. To determine likely direct measurable changes, a judgement is made using qualitative and quantitative information, as available.

For potential indirect changes, a measurable change is considered possible if there is a likely adverse effect identified on the other VEC in question (e.g., there could be a measurable change on overburden groundwater transport if there is a likely adverse effect on surface water quantity and flow).

A predicted change that is trivial, negligible or indistinguishable from background conditions will not be considered measurable. A measurable change on a VEC is marked with a '■' on Matrix 2 (Section 7.6).

All of the DGR Project works and activities found to have potential interactions with geology VECs, are further screened for each of the DGR Project phases. Where likely measurable changes as a result of the DGR Project works and activities are identified, these are advanced for assessment in Section 8. Table 7.1-1 presents definitions for measurable change for geology VECs.

Table 7.1-1: Definition of Measurable Change for Geology VECs

VEC	Indicator	Measurable Change Definition
Soil Quality	• Soil chemistry indicators (see Section 4.2.1)	• Change is measurable relative to baseline conditions
Overburden Groundwater Quality	• Groundwater chemistry indicators (see Section 4.2.2)	• Change is measurable relative to baseline conditions
Overburden Groundwater Transport	• Advective transport • Diffusive transport	• Change is measurable relative to baseline conditions
Shallow Bedrock Groundwater Quality	• Groundwater chemistry indicators (see Section 4.2.2)	• Change is measurable relative to baseline conditions
Shallow Bedrock Groundwater and Solute Transport	• Advective transport • Diffusive transport	• Change is measurable relative to baseline conditions

Table 7.1-1: Definition of Measurable Change for Geology VECs (continued)

VEC	Indicator	Measurable Change Definition
Intermediate Bedrock Water Quality	• Groundwater/porewater solute concentrations	• Change is measurable relative to baseline conditions
Intermediate Bedrock Solute Transport	• Advective transport • Diffusive transport	• Change is measurable relative to baseline conditions
Deep Bedrock Water Quality	• Groundwater/porewater solute concentrations	• Change is measurable relative to baseline conditions
Deep Bedrock Solute Transport	• Advective transport • Diffusive transport	• Change is measurable relative to baseline conditions

Likely measurable changes between the DGR Project and the geology VECs occur on two broad timescales, the near-term (i.e., when activities are occurring on-site during the site preparation and construction, operations, and decommissioning phases) and in the long-term (i.e., following abandonment of the DGR). As illustrated in Figure 6.1-1, the former occurs over approximately 65 years, and the latter occurs over millions of years. The long-term performance interactions are discussed collectively in Section 7.5.

7.2 SOIL QUALITY

7.2.1 Direct Changes

The following project works and activities have a potential interaction with soil quality:

- site preparation – grading of soils on-site;
- decommissioning of the DGR Project – interaction with shaft sealing materials;
- waste management – specifically, the waste rock management area; and
- support and monitoring of the DGR life cycle – specifically, the operation of the stormwater management system.

The second screening for these activities is presented below. Additionally, a direct interaction was identified for soil quality during the abandonment and long-term performance phase of the DGR Project. This interaction is considered in Section 7.5.

7.2.1.1 Site Preparation

Soils will be removed, graded and stockpiled during the site preparation work and activity. No non-native materials will be brought in during this phase. Therefore, it is unlikely that site grading activities will measurably change soil quality. This interaction is not considered further.

7.2.1.2 Decommissioning (Shaft Sealing)

During decommissioning, materials such as sand, bentonite, concrete and asphalt will be emplaced into the subsurface during the sealing of the shafts. These materials are designed to be permanent emplacements which will be in direct contact with the surrounding native overburden and bedrock formations, and will eventually be in contact with migrating groundwater.

The shaft sealing materials near surface (0 to 187 mBGS) will be engineered fill comprising native earth/rock materials that are crushed and screened prior to placement [4]. Overburden groundwater moving through these materials may dissolve ions in the sealing materials, and transport them into the surrounding native soils, where some ions could be adsorbed onto soil.

Overburden groundwater quality and soil quality in the area are similar, being relatively elevated in calcium, sulphate, and magnesium, and low in sodium and chloride. Metal concentrations are generally low [17;16]. The fill materials in the upper shaft seals are a mixture of the native soils and some crushed rock. Some of this rock may be elevated in chloride, sulphate and sodium. These parameters, however, will be largely in porewater trapped within the rock, and will not be readily released for ion exchange by groundwater migrating through the upper seal materials. In addition, the volume of material that will be emplaced in the shaft within the soil horizon (approximately 550 m^3 per shaft) is relatively small when compared to the volume of soil and bedrock down-gradient from the shafts (approximately 120,000 m^3). Groundwater will subsequently migrate through down-gradient soils, potentially exchanging ions with the down-gradient soil. This groundwater will not exchange enough ions with shaft seal materials to result in a measurable change in the soil quality down-gradient of the shafts (i.e., between the shafts and Lake Huron).

Accordingly, the presence of the shaft seal will not constitute a direct measurable change to the soil quality VEC. This project-environment interaction is not considered further.

7.2.1.3 Waste Management

For the waste rock management areas, the infiltration of precipitation through the waste rock piles has the potential to transport cations and anions into the soil subsurface. Physicochemical processes can then lead to their adsorption onto soil particles.

There are three different types of waste rock that will be stockpiled within the vicinity of the DGR: dolostones, shales and argillaceous limestones. Based on a review of the available soil stratigraphy, the surficial soils in this area are expected to be largely unweathered till, as the Middle Sand aquifer is thin to absent north and west of the WWMF, and the surficial sands are largely absent west of the stockpile areas, towards the former BHWP (see Figure 5.4.1-1). Groundwater recharge into the till is very low, conservatively estimated at 5 to 10 cm/a [21].

The dissolved elements that would be introduced into the subsurface by precipitation percolating through the rock piles would be similar to the dominant elements in the underlying surficial silt tills: calcium, magnesium, potassium and iron. Other dissolved species that would be expected to be present in the shale rock pile (e.g., sulphides, chlorides, sodium, arsenic, bromine, and boron), will not be a concern because these parameters will be largely in the porewater trapped within the shale rock, and will not be readily released by water percolating through the waste rock piles. Also, the shale pile will be covered with overburden excavated from the shafts or other clean fill from on-site projects, should the shale pile remain on-site for more than one year. This will tend to promote runoff towards the drainage network, as opposed to percolation down through the piles.

The porewater in the dolostones and argillaceous limestones is highly saline; however, as noted above, this water will be released very slowly from the low-permeability rock, and will be highly diluted with much greater volumes of precipitation. In addition, analysis of the sandy silt till underlying the rock pile indicates that it is dominated by calcite, dolomite and quartz (silica) mineral grains. The mineral composition of the till has a low capacity for adsorption of additional dissolved minerals, in contrast to more adsorptive clay mineral soils. The native till soil also has a very low potential for infiltration (conservatively estimated at 5 to 10 cm/a); therefore, precipitation that percolates through the rock pile is more likely to flow from the base of the rock pile to the stormwater management system than it is to infiltrate to the subsurface. Leachate testing indicated that certain formations represented in the waste rock itself could generate concentrations of some parameters above their respective PWQOs; however, water infiltrating from the waste rock is a small percentage of an already limited infiltration potential [206]. In conclusion, direct changes to the soil quality VEC as a result of waste management are not considered to be measurable, and are not considered further.

7.2.1.4 Support and Monitoring of DGR Life Cycle (Stormwater Management System)

The perimeter drainage network and stormwater management pond will not be lined; therefore, it is likely that a component of stormwater runoff from the WRMA will infiltrate the subsurface soils, transporting some chemical parameters into the near-surface soils. The ions that would be adsorbed by soils would be minor amounts of chloride, bromine, sulphate, sodium, and possibly boron and potassium. However, only a very small proportion of water in the stormwater management system would infiltrate into the subsurface soils, because of the low permeability of the native till soils (infiltration ±5 cm/a). The vast majority of precipitation that reaches the native soil in the drainage ditches or from sheet runoff towards the management pond will migrate along the till surface, as opposed to infiltrating into the till. Further, the surface area of the drainage ditch and stormwater pond that is available for potential infiltration is a small percentage of the area of the DGR Project site.

Dilution by horizontally migrating groundwater will be on the order of 10 times the volume of vertically infiltrating groundwater. Therefore, the operation of the stormwater management system will not constitute a direct measurable change on the soil quality VEC. Accordingly, this project-environment interaction is not considered further.

7.2.2 Indirect Changes

Two potential indirect interaction pathways were identified for the soil quality VEC in the first screening of project-environment interactions:

- changes in air quality; and
- changes in overburden groundwater quality.

The second screening for these pathways is presented below.

7.2.2.1 Changes in Air Quality

As described in Section 6, changes in air quality were considered to have a potential interaction with the soil quality VEC during the site preparation and construction phase of the DGR Project.

Section 6.2.2 identifies an indirect interaction between changes in air quality and the soil quality VEC. As discussed in the Atmospheric Environment TSD, changes in air quality are predicted due to airborne dust and associated contaminants during construction and operation activities. This dust deposits itself on the surface of the shallow soil and it will be subjected to wind dispersion and entrainment due to surface water runoff from precipitation. It is not expected that dust will persist on the surface long enough to impart measurable concentrations to the subsurface. In addition, as noted above, this will be a temporary condition due to construction and operations. Therefore, there is no measurable indirect change to the soil quality VEC and this indirect interaction is not considered further.

7.2.2.2 Changes in Overburden Groundwater Quality

As described in Section 6, changes in overburden groundwater quality were considered to have a potential interaction with the soil quality VEC during all phases of the DGR Project.

No measurable changes in overburden groundwater quality are identified (see Section 7.3). Therefore, no measurable changes to soil quality from changes in overburden groundwater quality during site preparation and construction, operations, and decommissioning phases are likely. Changes in the abandonment and long-term performance phase are described in Section 7.5. Accordingly, this indirect interaction is not considered further.

7.3 OVERBURDEN, SHALLOW BEDROCK, INTERMEDIATE BEDROCK, AND DEEP BEDROCK SOLUTE TRANSPORT

The solute transport VECs are considered together in order to provide some conciseness to the assessment. Some of these VECs interact with each other readily (e.g., overburden and shallow bedrock, shallow bedrock and upper reaches of intermediate bedrock), while others generally do not interact with each other (e.g., deep bedrock and shallow bedrock). In addition, many of the project works and activites (e.g., site preparation) will never interact with certain VECs (e.g., intermediate bedrock). By focussing on the interaction of works and activities with specific VECs, and isolating indirect actions that occur between certain VECs, the evaluation of the potential for measurable changes due to the DGR Project can be presented in a more clear, concise manner.

7.3.1 Direct Changes

Seven project works and activities were identified that have direct interactions with the overburden groundwater and the shallow, intermediate, and deep bedrock solute transport VEC as described below.

- Site preparation – the installation/construction of impervious surfaces (roads, buildings, storage areas) can potentially reduce the area for groundwater recharge from precipitation (overburden groundwater transport VEC).
- Construction of surface facilities – the installation/construction of impervious surfaces (roads, buildings) may potentially reduce the area for groundwater recharge from precipitation and pumping during excavation of building foundations may affect the local flow regime (overburden groundwater and shallow bedrock groundwater and solute transport VECs).

- Excavation and construction of underground facilities – dewatering would be used to provide safe and manageable conditions during underground excavation and construction. Dewatering of the shallow and intermediate systems could temporarily alter hydraulic gradients and groundwater flow conditions (overburden groundwater and shallow groundwater and solute transport and intermediate and deep bedrock solute transport VECs).
- Decommissioning of the DGR Project – shaft sealing materials could potentially create changes to the localized flow patterns in the vicinity of the shafts (overburden groundwater transport, shallow bedrock groundwater and solute transport, and intermediate and deep bedrock solute transport VECs).
- Waste management – the presence of the waste rock piles could potentially alter the localized recharge characteristics within the Project Area (overburden groundwater transport VEC).
- Support and monitoring of DGR life cycle – some stormwater may infiltrate into the subsurface soils, locally altering the groundwater recharge regime (overburden groundwater transport VEC).

The second screening for these activities is presented below. Site preparation, construction of surface facilities and waste management are discussed collectively as they have the same effect (i.e., change in recharge areas). Additionally, direct interactions were identified for groundwater flow VECs during the abandonment and long-term performance phase of the DGR Project. This interaction is considered in Section 7.5.

7.3.1.1 Changes in Recharge Areas

The installation/construction of impervious surfaces (roads, buildings, storage areas) during the site preparation, surface facility construction, and waste management works and activities can potentially reduce the area for groundwater recharge from precipitation. The decrease in the recharge area can affect the overburden groundwater flow regime.

As described in Section 6.3, for the construction laydown areas, the sites will be cleared of brush, and graded, but will not be made impervious, with the exception of some impervious surfaces created by resting equipment. However, run-off from these areas is expected to flow to the surrounding ground surface during precipitation events. The construction of buildings and paved roads will result in an additional 9% of impervious surface area on the DGR Project site.

The un-covered dolostone and argillaceous limestone piles will allow infiltration of precipitation through the piles into the shallow subsurface. Potential infiltration may even be enhanced, as water percolates through the piles and is not lost as readily to surface runoff or evaporation. Assuming that the shale pile will be on-site for greater than one year and will be covered, the shale pile will then allow very little infiltration of precipitation. However, covering the shale pile will promote runoff from the pile surface onto the surrounding ground surface, which will eventually drain to the perimeter drainage ditches. The shale pile is expected to be 0.6 ha in area, which is approximately 2% of the DGR Project site and less than 1% of the Project Area.

This scale of potential recharge reduction would be well within the seasonal variation in precipitation [207], and therefore this direct interaction is considered to be negligible. Accordingly, these project-environment interactions are not advanced for further consideration.

7.3.1.2 Dewatering During Excavation

Dewatering may be used to lower the water table in the vicinity of a given building, and to provide dry conditions during excavation of the shafts and underground facility. Dewatering activities directly affect the groundwater flow regime through the lowering of the water table during pumping and the creation of a Zone of Influence (ZOI), which is a region with a lowered water table.

Construction of Surface Facilities

A conservative estimate for the potential depth of surface facility foundations is 4 mBGS for the shaft buildings, which are the largest surface structures on the DGR Project Area. The water table is expected to be near ground surface within the glacial tills underlying the Project Area. The soils are expected to be the relatively low permeability Unweathered Till. The amount of dewatering that will be required will be very low, and will be directed to the drainage ditch network, where some of this water may re-infiltrate into the subsurface. The expected ZOI from this dewatering will be very localized, and will be of ephemeral duration (i.e., days to weeks).

Although this ZOI can theoretically be measured during dewatering (through water level monitoring of nearby monitoring wells), it is not likely that it will extend beyond several metres in radius from a given foundation trench(es). There will not be a measurable long-term effect from this dewatering, and the influence on the overburden or shallow bedrock groundwater flow regimes within the Project Area will be restricted to the immediate vicinity of the foundation trenches.

Therefore, the surface facility construction will not constitute a measurable change on the overburden groundwater transport VEC, and will not constitute a measurable change to the shallow bedrock groundwater and solute transport VEC. Accordingly, this project-environment interaction will not be considered further.

Excavation and Construction of Underground Facilities

Ground treatment in advance of shaft sinking through the overburden and shallow bedrock may not negate the requirement for dewatering; however, it will reduce the effective hydraulic conductivity of the surrounding soils and bedrock, greatly reducing the pumping requirements for dewatering.

For the purposes of dewatering estimation, the advance grouting is assumed to conservatively result in a bulk hydraulic conductivity (K) of 1×10^{-7} to 1×10^{-8} m/s over the upper 170 m of each shaft (i.e., overburden and shallow bedrock). This is likely to result in a measurable zone of influence, and is advanced for assessment in Section 8.

For the intermediate and deep bedrock strata, where K values are generally 1×10^{-12} m/s or lower, the inflow estimates are on the order of litres per day over the entire reach under consideration and the radius of influence was not quantifiable. Therefore, there is no measurable change on the intermediate and deep bedrock solute transport VECs because of excavation and construction.

7.3.1.3 Decommissioning (Shaft Sealing)

There is a potential for changes to local solute transport patterns of the overburden and various stratigraphic formations as a result of emplacement of sealing materials in the main and ventilation shafts during decommissioning.

The main shaft will have a finished internal diameter of approximately 6.5 m and the ventilation shaft will have a finished internal diameter of approximately 5.0 m. The excavation diameters will vary, depending upon ground reach, initial support types and excavation methods. The sealing materials will be of similar or higher permeability than the surrounding soils and shallow bedrock (0 to 170 mBGS). Groundwater in close proximity of the shafts will tend to flow towards the sealed shafts in the horizontal plane. This perturbation of very localized solute transport direction is expected to only extend several metres from the sealed shaft walls, and will not be noticeable within the scale of the Project Area or Site Study Area.

In the intermediate and deep bedrock groupings, the hydraulic conductivity in the rock (1×10^{-12} to 1×10^{-15} m/s) will be much lower than any seal can provide (10^{-10} m/s in the seal below 170 mBGS). The rate of migration of porewater into the shaft seals will be so low that there will not be a discernible effect on the solute transport patterns. Long-term performance of the seal is considered in Section 7.5.

Therefore, the direct interaction of the decommissioning (i.e., shaft sealing) of the DGR Project on the solute transport VECs is considered to be negligible, and will not constitute a measurable change to the groundwater flow VECs.

7.3.1.4 Support and Monitoring of DGR Life Cycle (Stormwater Management System)

There is potential for a component of runoff water collected in the stormwater management system to infiltrate into the subsurface soils, locally altering the groundwater recharge regime. Infiltration of stormwater through the drainage ditches and stormwater pond to the subsurface is constrained by the infiltration capacity of the receiving Unweathered Till soils, which is considered to be low, conservatively estimated to be in the range of 5 to 10 cm/a [21]. As the ditches and stormwater pond are not hydraulically lined, the infiltration rates of the water into the till overburden will remain unchanged. Therefore, the potential recharge of water through the stormwater management system within the Project Area will not constitute a measurable change to the overburden groundwater transport VEC. Accordingly, this interaction is not considered further.

7.3.2 Indirect Changes

7.3.2.1 Overburden Groundwater Transport

As described in Section 6.2.2, an indirect interaction was identified between the overburden groundwater transport VEC and changes in surface water quantity and flow by affecting recharge characteristics. Changes in surface water quantity and flow are predicted in the Hydrology and Surface Water Quality TSD. Some of the surface flow to the North Railway Ditch will be redirected to the stormwater management system and drainage ditch at Interconnecting Road.

Some of the water in the North Railway Ditch may contribute to the recharge of the overburden groundwater system. A small portion of water may be redirected to the stormwater management system and drainage ditch. It is likely that the small portion of redirected water flow will now recharge through the stormwater management system and drainage ditch floor. Therefore, overall redirection of surface flows is unlikely to affect current groundwater recharge characteristics. Therefore, there is no measurable indirect change to the overburden groundwater transport and this indirect interaction is not considered further.

Indirect measurable changes on surface water quantity and flow attributed to groundwater discharge are discussed in the Hydrology and Surface Water Quality TSD.

7.3.2.2 Shallow Bedrock Groundwater and Solute Transport

No potential indirect interaction pathways were identified for the shallow bedrock groundwater and solute transport VEC in the first screening of project-environment interactions.

7.3.2.3 Intermediate Bedrock Solute Transport

Two potential indirect interaction pathways were identified for the intermediate bedrock solute transport VEC in the first screening of project-environment interactions:

- changes in shallow bedrock groundwater and solute transport; and
- changes in deep bedrock solute transport.

The second screening for these pathways is presented below.

<u>Changes in Shallow Bedrock Groundwater and Solute Transport</u>

The interaction between the shallow bedrock and the intermediate bedrock is predominantly through diffusion and gas transfer (i.e., <1 mm/year). Therefore, it is unlikely that a change in shallow bedrock groundwater and solute transport would cause a measurable change downward in the near term (i.e., <65 years). Accordingly, this potential indirect interaction is not considered further. Measurable changes during the long-term performance of the DGR are considered in Section 7.5.

<u>Changes in Deep Bedrock Solute Transport</u>

The interaction between the deep bedrock and the intermediate bedrock is through diffusion and gas transfer only, within rock with very low hydraulic conductivites ($<1\times10^{-12}$ m/s). Therefore, it is unlikely that a change in deep bedrock groundwater transport would cause a measurable change in the intermediate bedrock in the near term (i.e., <65 years). Therefore, this interaction is not considered further.

7.3.2.4 Deep Bedrock Solute Transport

No potential indirect interaction pathways were identified for the deep bedrock solute transport VEC in the first screening of project-environment interactions.

7.4 OVERBURDEN, SHALLOW BEDROCK, INTERMEDIATE BEDROCK AND DEEP BEDROCK WATER QUALITY

7.4.1 Direct Changes

The following project works and activities have a direct interaction with the groundwater quality VECs:

- site preparation – reduction in recharge attributed to creation of impervious surfaces (overburden groundwater quality);
- construction of surface facilities – reduction in recharge attributed to creation of impervious surfaces (overburden groundwater quality);
- decommissioning of the DGR Project – interaction with the shaft sealing materials (overburden and shallow bedrock groundwater quality, intermediate and deep bedrock water quality);
- waste management – specifically, the waste rock management activity, which includes the establishment and maintenance of the WRMA (overburden groundwater quality); and
- support and monitoring of DGR life cycle – specifically, the operation of the stormwater management system (overburden groundwater quality).

The second screening for these activities is presented below. The screenings are grouped by type of measurable change. Additionally, direct interactions were identified for overburden groundwater quality during the abandonment and long-term performance phase of the DGR Project. These are considered in Section 7.5.

7.4.1.1 Changes in Recharge Areas

The installation/construction of impervious surfaces (roads, buildings, storage areas) during the site preparation, surface facility construction, and waste management works and activities can potentially reduce the area for groundwater recharge from precipitation. A potential reduction in the area for local recharge may affect groundwater quality through a potential reduction in the mixing of infiltrating surface water within the Project Area with the underlying, migrating shallow groundwater.

For the construction laydown areas, the sites will be cleared of brush, and graded, but will not be made impervious. Some impervious surfaces will be created by resting equipment, but much of this will runoff onto the ground during precipitation events.

The approximate area of surface buildings at the DGR is 4,800 m^2 [4]. The area of impervious surfaces is conservatively estimated to be 20,000 m^2, largely based on the area of the access road to be constructed to the north of the facility. The area of the DGR Project site is approximately 270,000 m^2 (see Figure 3.2.1-1). This results in an approximate ratio of impervious to pervious surfaces of 9% (24,800/270,000 m^2) as a result of buildings and new impervious surface area.

The reduction in areas for recharge is lower than the variation in precipitation from year to year [207]. Therefore, there is no foreseen measurable change in overburden groundwater quality through a potential reduction in the mixing of infiltrating surface water within the Project Area with the underlying, migrating shallow groundwater. In addition, stormwater runoff from roads will be directed to the stormwater management system. This water will eventually discharge to Lake Huron, which is the same outlet as the current groundwater system. Based on this, no measurable difference is expected in the total discharge of water to Lake Huron.

Accordingly, these project-environment interactions are not considered further.

7.4.1.2 Decommissioning (Shaft Sealing)

Shaft sealing materials include bentonite, sand, concrete and asphalt. After sealing of the shafts during decommissioning, migrating groundwater will interact with the various sealing materials. The seal materials that are selected for the shallow reaches of the shaft (i.e., overburden and shallow bedrock) are engineered fill comprising native soil and crushed rock. The quality of the fill materials will therefore be broadly similar to the surrounding native soils. In addition, as with the interaction with soil quality (see Section 7.2.1.2), only a minimal amount of groundwater will migrate through the seals relative to the surrounding materials.

In the case of the intermediate and deep bedrock groundwater interacting with the shaft seal material, the quality of the water (including porewater) ranges from fresh to brine. The materials that will be emplaced in shaft sealing are largely bentonite, sand and concrete with a minor component of asphalt. This material is largely considered inert, except for the asphalt, which was selected for its compatibility with the hydrocarbon-bearing layers of the Georgian Bay Formation [4]. The groundwater passing through the shaft seal is likely to change in quality in the immediate vicinity of the shaft, albeit on a very local scale (a few metres or less) and over very long time frames (thousands of years), because of the low hydraulic conductivities in the geologic formations and shaft seal.

Therefore, the presence of the shaft seal will not constitute a direct measurable change on the groundwater quality VECs. Accordingly, these project-environment interactions are not considered further.

7.4.1.3 Waste Management

As described in Section 7.2.1.3, infiltration of precipitation through the WRMA has the potential to uptake minerals from the rock and transport some portion to the underlying shallow groundwater resource. This could potentially alter the mineralization of the overburden groundwater resource. For the same rationale as described in Section 7.2.1.3, this project-environment change is not likely to be measurable and is not considered further.

7.4.1.4 Support and Monitoring of the DGR Life Cycle (Stormwater Management System)

As described in Section 7.2.1.4, the infiltration of stormwater into the shallow subsurface has the potential to transport dissolved chemical parameters into the underlying shallow groundwater resource. This could potentially alter the quality of the groundwater resource. Applying the same rationale as in Section 7.2.1.4, it is unlikely that the operation of the stormwater management system on the groundwater quality VEC will constitute a measurable change to the groundwater quality VEC and is not considered further.

7.4.2 Indirect Changes

7.4.2.1 Overburden Groundwater Quality

There were three potential indirect interactions identified for the overburden groundwater quality VEC in the first screening:

- changes in surface water quality;
- changes in soil quality; and
- changes in overburden groundwater transport.

The second screening for this activity is presented below.

Changes in Surface Water Quality

In Section 6.2.2.3, changes in surface water quality were identified that could affect overburden groundwater quality. The Hydrology and Surface Water Quality TSD evaluated potential effects on surface water quality. No adverse effects on surface water quality were identified. Stormwater will ultimately discharge via a controlled output into the existing drainage ditch along the Interconnecting Road. The discharge will be monitored to confirm it meets water quality permitting requirements. Therefore, this indirect interaction is not carried forward for assessment.

Changes in Soil Quality

Changes in soil quality could potentially affect overburden groundwater quality. No measurable changes in soil quality are identified (see Section 7.2). Therefore, this indirect interaction is not forwarded for assessment.

Changes in Overburden Groundwater Transport

Changes in groundwater flow could potentially affect overburden groundwater quality. Since changes in overburden groundwater flow may be measurable during the site preparation and construction phase (see Secton 7.3), this indirect change to overburden groundwater quality is forwarded for further consideration in Section 8.

7.4.2.2 Shallow Bedrock Groundwater Quality

Three potential indirect interactions were identified for the shallow bedrock groundwater quality VEC in the first screening of project-environment interactions:

- changes in overburden groundwater quality;
- changes in shallow bedrock groundwater and solute transport; and
- changes in intermediate bedrock water quality.

The second screening for these pathways is presented below.

Changes in Overburden Groundwater Quality

Changes in overburden groundwater quality could indirectly affect shallow bedrock groundwater quality through leakage of overburden groundwater into the shallow bedrock groundwater. In Section 7.4.2.1, a likely measurable change in overburden groundwater quality is identified during the site preparation and construction, operations, and decommissioning phases. Accordingly, this indirect interaction is advanced to the assessment of the likely environmental effects.

Changes in Shallow Bedrock Groundwater and Solute Transport

Changes in shallow bedrock groundwater flow were identified as having the potential to interact with shallow bedrock groundwater quality through concentration or dilution of parameters. In Section 7.3.1.2, a measurable change in shallow bedrock groundwater and solute transport is identified during the site preparation and construction phase. Accordingly, this indirect interaction is advanced for further consideration in Section 8.

Changes in Intermediate Bedrock Water Quality

Changes in intermediate bedrock water quality could indirectly affect shallow bedrock groundwater quality through diffusion of intermediate bedrock groundwater into the shallow bedrock groundwater. Although there is some potential for upward diffusion, the proportion of groundwater diffusing upward from the intermediate into the shallow bedrock will be largely masked due to the greater quantity and movement of water within the shallow formations. No measurable change in shallow bedrock groundwater quality is identified. Therefore, this indirect interaction is not forwarded for assessment.

7.4.2.3 Intermediate Bedrock Water Quality

The following indirect interactions were identified for the intermediate bedrock water quality VEC:

- changes in shallow bedrock groundwater quality;
- changes in intermediate bedrock solute transport; and
- changes in deep bedrock water quality.

The second screening for this pathway is presented below.

Changes in Shallow Bedrock Groundwater Quality

Transport between the shallow bedrock and the intermediate bedrock is predominantly through diffusion and gas transfer. Therefore, it is unlikely that a change in shallow bedrock groundwater quality would cause a measurable change in intermediate bedrock water quality in the near term (i.e., <65 years). Accordingly, this potential indirect interaction is not considered further.

Changes in Intermediate Bedrock Solute Transport

Changes in intermediate bedrock groundwater flow could interact with intermediate bedrock water quality through concentration or dilution of parameters. As described in Section 7.3.2.4, no measurable changes in intermediate solute transport are likely. Therefore, this indirect interaction is not considered further.

Changes in Deep Bedrock Water Quality

Transport between the deep bedrock and the intermediate bedrock is through diffusion and gas transfer within these very low permeability materials. Therefore, it is unlikely that a change in deep bedrock water quality would cause a measurable change in intermediate bedrock water quality in the near term (i.e., <65 years). Accordingly, this potential indirect interaction is not considered further.

7.4.2.4 Deep Bedrock Water Quality

No indirect interactions were identified with deep bedrock water quality.

7.5 ABANDONMENT AND LONG-TERM PERFORMANCE PHASE

The long-term movement of water and gas from the from the repository has been modelled as part of the postclosure safety assessment [2]. The assessment considered several pathways for movement of groundwater and gas through the geosphere, including diffusion-dominated solute transport, advective solute transport, and gas migration. These transport mechanisms can occur within the geosphere surrounding the shafts and through the sealed shafts themselves. The routes of potential transfer are illustrated schematically on Figure 7.5-1. The mechanism for each type of transfer is described in detail in Section 8 of the Preliminary Safety Report [4] and in the postclosure safety assessment [2].

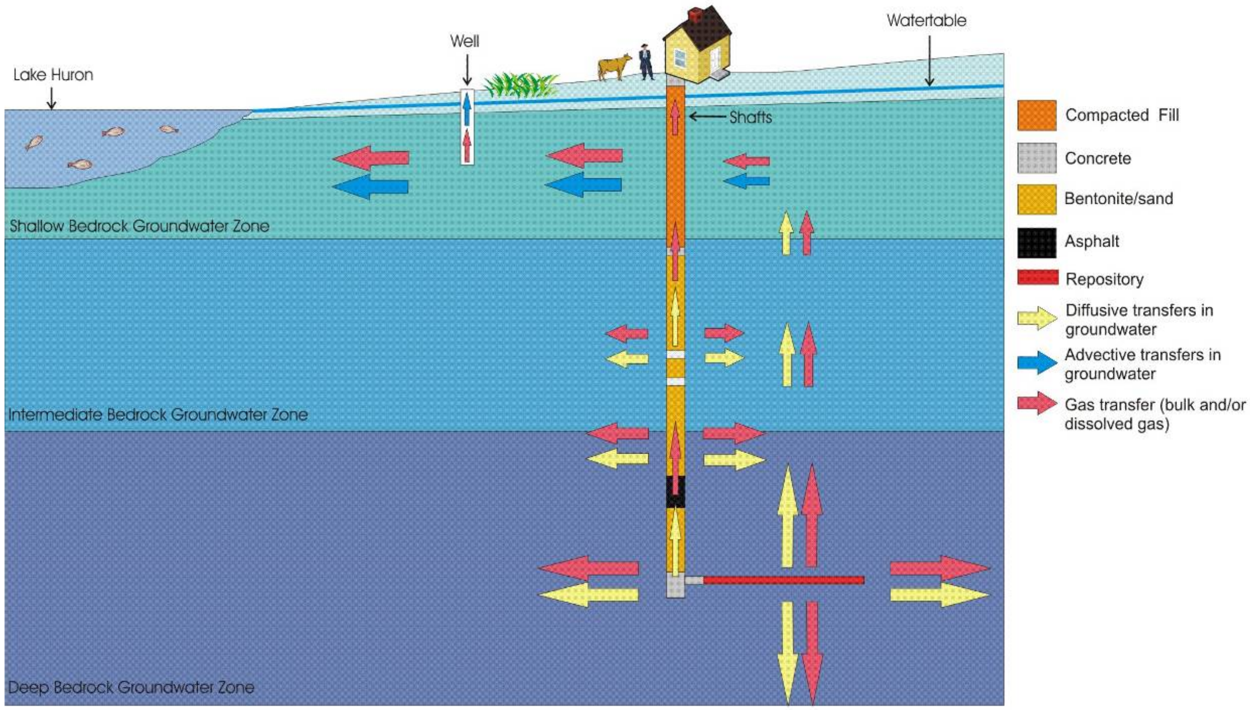

Figure 7.5-1: Schematic Representation of Potential Transport Pathways for the Normal Evolution Scenario

The predicted changes in flow and quality are not expected to be measurable in the long-term. However, in keeping with a precautionary approach, all potential interactions in the abandonment and long-term performance phase have been assumed to be measurable and are advanced to Section 8 for an assessment of likely effects.

7.6 SUMMARY OF SECOND SCREENING

Table 7.6-1 provides a summary of the second screening for the DGR Project. Squares (■) on this matrix represent likely DGR Project-environment interactions resulting in a measurable change in VECs. These interactions are advanced to Section 8 for an assessment of likely effects on geology VECs.

Table 7.6-1: Matrix 2 – Summary of the Second Screening for Measurable Change to VECs

Project Work and Activity	Soil Quality				Overburden Groundwater Quality				Overburden Groundwater Transport			
	C	O	D	LT	C	O	D	LT	C	O	D	LT
Direct Changes												
Site Preparation	•	—	—	—	•	—	—	—	•	—	—	—
Construction of Surface Facilities		—	—	—	•	—	—	—	•	—	—	—
Excavation and Construction of Underground Facilities		—	—	—		—	—	—	■	—	—	—
Above-ground Transfer of Waste	—		—	—	—		—	—	—		—	—
Underground Transfer of Waste	—		—	—	—		—	—	—		—	—
Decommissioning of the DGR Project	—	—	•	—	—	—	•	—	—	—	•	—
Abandonment of the DGR Facility	—	—		—	—	—		—	—	—		—
Presence of the DGR Project				■				■				■
Waste Management	•	•	•	—	•	•	•	—	•	•	•	—
Support and Monitoring of DGR Life Cycle	•	•	•	—	•	•	•	—	•	•	•	—
Workers, Payroll, and Purchasing				—				—				—
Indirect Changes												
Changes in Air Quality	•	•	•	—				—				—
Changes in Surface Water Quantity and Flow									•	•	•	■
Changes in Surface Water Quality					•	•	•	■				
Changes in Soil Quality	—	—	—	—	•	•	•	■				
Changes in Overburden Groundwater Quality	•	•	•	■	—	—	—	—				
Changes in Overburden Groundwater Transport					■	•	•	■	—	—	—	—
Changes in Shallow Bedrock Groundwater Quality												
Changes in Shallow Bedrock Groundwater and Solute Transport												
Changes in Intermediate Bedrock Water Quality												
Changes in Intermediate Bedrock Solute Transport												
Changes in Deep Bedrock Water Quality												
Changes in Deep Bedrock Solute Transport												

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
LT = Abandonment and Long-term Performance Phase

The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential project-environment interaction

Table 7.6-1: Matrix 2 – Summary of the Second Screening for Measurable Change to VECs (continued)

Project Work and Activity	Shallow Bedrock Groundwater Quality				Shallow Bedrock Groundwater and Solute Transport				Intermediate Bedrock Water Quality			
	C	O	D	LT	C	O	D	LT	C	O	D	LT
Direct Changes												
Site Preparation		—	—	—		—	—	—		—	—	—
Construction of Surface Facilities		—	—	—	•	—	—	—		—	—	—
Excavation and Construction of Underground Facilities		—	—	—	■	—	—	—		—	—	—
Above-ground Transfer of Waste	—		—	—	—		—	—	—		—	—
Underground Transfer of Waste	—		—	—	—		—	—	—		—	—
Decommissioning of the DGR Project	—	—	•	—	—	—	•	—	—	—	•	—
Abandonment of the DGR Facility	—	—		—	—	—		—	—	—		—
Presence of the DGR Project				■				■				■
Waste Management				—				—				—
Support and Monitoring of DGR Life Cycle				—				—				—
Workers, Payroll and Purchasing				—				—				—
Indirect Changes												
Changes in Air Quality				—				—				—
Changes in Surface Water Quantity and Flow												
Changes in Surface Water Quality												
Changes in Soil Quality												
Changes in Overburden Groundwater Quality	■	■	■	■								
Changes in Overburden Groundwater Transport												
Changes in Shallow Bedrock Groundwater Quality	—	—	—	—					•	•	•	■
Changes in Shallow Bedrock Groundwater and Solute Transport	■	•	•	■	—	—	—	—				
Changes in Intermediate Bedrock Water Quality	•	•	•	■					—	—	—	—
Changes in Intermediate Bedrock Solute Transport									•	•	•	■
Changes in Deep Bedrock Water Quality									•	•	•	■
Changes in Deep Bedrock Solute Transport												

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
LT = Abandonment and Long-term Performance Phase

The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential project-environment interaction

Table 7.6-1: Matrix 2 – Summary of the Second Screening for Measurable Change to VECs (continued)

Project Work and Activity	Intermediate Bedrock Solute Transport				Deep Bedrock Water Quality				Deep Bedrock Solute Transport			
	C	O	D	LT	C	O	D	LT	C	O	D	LT
Direct Changes												
Site Preparation		—	—	—		—	—	—		—	—	—
Construction of Surface Facilities		—	—	—		—	—	—		—	—	—
Excavation and Construction of Underground Facilities	•	—	—	—		—	—	—	•	—	—	—
Above-ground Transfer of Waste	—		—	—	—		—	—	—		—	—
Underground Transfer of Waste	—		—	—	—	—	—	—	—		—	—
Decommissioning of the DGR Project	—	—	•	—	—	—	•	—	—	—	•	—
Abandonment of the DGR Facility	—	—		—	—	—		—	—	—		—
Presence of the DGR Project				■				■				■
Waste Management				—				—				—
Support and Monitoring of DGR Life Cycle				—				—				—
Workers, Payroll and Purchasing				—				—				—
Indirect Changes												
Change in Air Quality				—				—				—
Changes in Surface Water Quantity and Flow												
Changes in Surface Water Quality												
Changes in Soil Quality												
Changes in Overburden Groundwater Quality												
Changes in Overburden Groundwater Transport												
Changes in Shallow Bedrock Groundwater Quality												
Changes in Shallow Bedrock Groundwater and Solute Transport	•	•	•	■								
Changes in Intermediate Bedrock Water Quality												
Changes in Intermediate Bedrock Solute Transport	—	—	—	—								
Changes in Deep Bedrock Water Quality					—	—	—	—				
Changes in Deep Bedrock Solute Transport	•	•	•	■					—	—	—	—

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
LT = Abandonment and Long-term Performance Phase

The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

- • Potential project-environment interaction
- ■ Measurable change
- — Activity does not occur during this phase
- Blank No potential project-environment interaction

8. IDENTIFICATION AND ASSESSMENT OF ENVIRONMENTAL EFFECTS

The assessment of effects predicts and describes the likely environmental effects, mitigation measures and residual adverse effects on the geology VECs that could reasonably be expected as a result of the DGR Project.

8.1 ASSESSMENT METHODS

8.1.1 Identify Likely Environmental Effects

All measurable changes identified in the second screening (Section 7) are advanced for assessment within the framework of the applicable VECs. Consistent with accepted EA practice, quantitative and qualitative methods, including professional expertise and judgment, are used to predict and describe the DGR Project-specific effects.

If a likely environmental effect is identified, the effect is assessed as either beneficial or adverse. Any adverse effects on VECs attributable to the DGR Project are advanced for consideration of possible mitigation measures. Beneficial effects, if any, are marked with a ‘+’ on the matrix, but are not considered further in this TSD. The results of the assessment are recorded in Matrix 3 (Section 8.9).

A measurable increase in a soli/groundwater quality relative to baseline and greater than the MOE Table 3 Site Conditions Standard (SCS) for soil, and the MOE criteria/standards could signify an adverse effect. A high magnitude of adverse effect is defined as a change to soil or groundwater quality that likely poses a significant threat to human health or ecological health, based on a site-specific Risk Assessment under O.Reg. 153/04 [208]. The same criteria apply to the assessment of indirect adverse effects.

In terms of the solute transport regime, an adverse effect is likely the effect is measurable relative to the existing dominant transport process. This may include hydraulic heads, hydraulic gradients, and/or velocity of transport.

8.1.2 Consider Mitigation Measures

When the assessment of effects indicates that an adverse effect on one of the geology VECs is likely, technically and economically feasible mitigation measures are proposed to address the identified effect.

8.1.3 Identify Residual Effects

Once mitigation measures are proposed, the likely adverse effect is re-evaluated with the mitigation measures in place to identify any residual adverse effects. If a residual adverse effect on a VEC is identified, it is marked with a ‘◆’ on Matrix 3 (Section 8.9). Residual adverse effects are advanced to Section 11 for an assessment of significance.

8.2 SOIL QUALITY

As described in Section 7, no measurable changes in soil quality are likely during the site preparation and construction, operations, and decommissioning phases. The long-term performance of the DGR is considered in Section 8.7.

8.3 OVERBURDEN GROUNDWATER AND SHALLOW BEDROCK GROUNDWATER AND SOLUTE TRANSPORT

8.3.1 Linkage Analysis

The evaluation of the effects of the DGR Project on the overburden groundwater and shallow bedrock groundwater and solute transport VEC used changes in advective and diffusive transport characteristics to measure direct and indirect project effects.

Dewatering during excavation, which is included as part of the excavation and construction of underground facilities work and activity, was identified as having a likely measurable direct effect on the overburden and shallow bedrock transport VECs. The effects on solute transport during postclosure are evaluated in Section 8.7.

No indirect effects were identified that could affect the overburden and shallow bedrock transport VEC.

8.3.2 In-design Mitigation

Ground treatment in the upper 170 m of the two shafts is an in-design mitigation to minimize the amount of dewatering that will be required [4]. The stormwater management pond is also an in-design mitigation measure, as all pumped water will be directed to the pond, which eventually will discharge to Lake Huron.

8.3.3 Direct Effects

Dewatering will be used to provide dry, safe conditions for underground excavation and construction. As described in Section 6.2.1.3, the ground treatment in advance of shaft sinking will minimize (mitigate) shaft discharge, particularly from the intermediate aquifers. However, this will not negate the need for dewatering in the overburden and shallow bedrock. It will reduce the effective hydraulic conductivity of the surrounding soils and bedrock, greatly reducing the pumping requirements for dewatering.

For the purposes of dewatering estimation, the advance grouting of the shaft wall is assumed to conservatively result in a maximum bulk hydraulic conductivity (K) of 10^{-7} to 10^{-8} m/s over the upper 170 m (overburden and shallow bedrock) of each shaft (from ground surface to the top of the Salina Formation F Unit). The radius of influence (R_0) and inflow (Q) were estimated using generally accepted analytical equations for dewatering design [209]. A sample calculation is provided in Appendix C. The radius of influence was estimated to be approximately 54 m, with an inflow of approximately 50 L/min over the top 170 m of the shaft.

Dewatering activities directly affect the groundwater flow regime by lowering the water table/potentiometric surface during pumping, resulting in the creation of a Zone of Influence (ZOI). Within the ZOI, local shallow groundwater resources are directed towards the excavations where pumping is occurring. A ZOI is created for the duration of dewatering activities, and persists during the recovery time period when local shallow groundwater levels recover after the cessation of pumping. Based on the site preparation and construction phase timeline for the sinking of the main and ventilation shafts, the duration of pumping is estimated to be two to three years.

The estimated ZOI is 54 m, which is a small portion of the Project Area. There is no water use that can be affected by this ZOI (i.e., no nearby overburden groundwater users). This ZOI is not going to approach any surface water courses; therefore, there are no potential effects on base flow to surface water bodies (e.g., Stream C, Lake Huron). In addition, the dewatering is temporary (up to 36 months).

In conclusion, the ZOI created by the dewatering during shaft sinking through the overburden and shallow bedrock will not create an adverse effect on local groundwater resources, water levels, or discharge to Lake Huron.

8.3.4 Indirect Effects

No indirect effects on overburden groundwater and shallow bedrock groundwater and solute transport were carried forward from the second screening.

8.3.5 Mitigation Measures

No direct or indirect environmental effects were identified from solute transport-project interactions, provided that monitoring/mitigation measures that have already been incorporated into ground treatment and the conceptual design of the stormwater management system are implemented. Therefore, there are no further mitigation measures required for the potential indirect effects on the overburden and shallow bedrock transport VECs.

8.3.6 Residual Adverse Effects

No direct or indirect likely environmental effects were identified from solute transport-project interactions. Therefore, it is concluded that the DGR Project will not create residual adverse effects on the overburden groundwater and shallow bedrock groundwater and solute transport VECs.

8.4 OVERBURDEN AND SHALLOW BEDROCK GROUNDWATER QUALITY

8.4.1 Linkage Analysis

The evaluation of the effects of the DGR Project on the overburden groundwater quality VEC uses changes in groundwater quality parameters to measure direct and indirect project effects. The assessment considered chemical characteristics of the groundwater, namely:

- general chemistry (pH, anions, cations, nutrients);

- selected metals; and
- petroleum hydrocarbon indicator compounds (PHCs).

No direct measurable changes were identified that could affect the overburden groundwater quality VEC. A potential measurable indirect change in overburden and bedrock groundwater quality was identified because of changes in overburden groundwater and shallow bedrock groundwater and solute transport.

8.4.2 Indirect Effects

No effects on overburden groundwater quality were identified; therefore, there will be no likely adverse indirect effects on shallow bedrock groundwater quality. As described in Section 8.3.6, there are no likely adverse effects on overburden groundwater and shallow bedrock groundwater and solute transport. Therefore, there will be no likely adverse indirect effects on overburden and shallow bedrock groundwater quality.

8.4.3 Mitigation Measures

No direct or indirect adverse effects were identified; therefore, no mitigation measures are required for the overburden and shallow bedrock groundwater quality VECs.

8.4.4 Residual Adverse Effects

No direct or indirect environmental effects were identified for the overburden and shallow bedrock groundwater quality VECs. Therefore, it is concluded that the DGR Project will not create residual adverse effects on the overburden and shallow bedrock groundwater quality VECs.

8.5 INTERMEDIATE AND DEEP BEDROCK SOLUTE TRANSPORT

As described in Section 7.3, no measurable changes in intermediate and deep bedrock solute transport are likely during the site preparation and construction, operations, and decommissioning phases. The long-term performance of the DGR is considered in Section 8.7.

8.6 INTERMEDIATE AND DEEP BEDROCK WATER QUALITY

As described in Section 7, no measurable changes in intermediate and deep bedrock water quality are likely during the site preparation and construction, operations, and decommissioning phases. The long-term performance of the DGR is considered in Section 8.7.

8.7 ABANDONMENT AND LONG-TERM PERFORMANCE PHASE

The long-term (and near-term) movement of groundwater and gas from the repository has been modelled as part of the postclosure safety assessment of the DGR [2]. Although the migration of contaminants in groundwater and gas is considered not to create an adverse effect, this project-environment interaction was advanced to the assessment of the likely environmental effects, as this interaction is of scientific and social importance to the DGR Project.

Pathways for movement of groundwater and gas from the repository include movement up the shaft seal, and movement into the geosphere (Figure 7.5-1).

The following direct effects with the presence of the DGR Project were identified in the second screening:

- soil quality;
- overburden groundwater quality;
- overburden groundwater transport;
- shallow bedrock groundwater quality;
- shallow bedrock groundwater and solute transport;
- intermediate bedrock water quality;
- intermediate bedrock solute transport;
- deep bedrock water quality; and
- deep bedrock solute transport.

The following indirect effects were identified in the second screening:

- soil quality may affect overburden groundwater quality;
- overburden groundwater quality may affect soil quality and shallow bedrock quality;
- shallow bedrock quality may affect intermediate water quality;
- intermediate bedrock water quality may affect shallow bedrock water quality; and
- deep bedrock water quality may affect intermediate bedrock water quality.

A summary of the results of the groundwater flow and contaminant transport modelling for the postclosure evolution of the DGR is provided below, to provide context for the assessment of likely environmental effects.

8.7.1 Summary of Modelling for Postclosure Evolution of the DGR

The postclosure safety assessment considers a Normal Evolution Scenario. This is the expected long-term evolution of the repository and site following closure. Over the 1 million years assessment timescale, the scenario includes waste and packaging degradation, rockfall, earthquakes and, after about 60 ka, glacial cycles. The assessment considers both a reference case, as well as variant calculation cases which explore the importance of uncertainties associated with the normal evolution scenario. Disruptive Scenarios are also considered, which assess the consequences of unlikely events in which the key barriers are bypassed. These are discussed in the Malfunctions, Accidents and Malevolent Acts TSD.

The key results for the Normal Evolution Scenario are as follows:

- The resaturation of the repository is gradual, taking more than 1 million years, due to the low permeability of the host rock and gas generation in the repository. The majority of the water seeps into the repository from the surrounding host rock rather than the shafts.
- Contaminants are contained within the repository and host rock, thereby limiting their release into the surface environment and their subsequent impacts. Reference Case calculations estimate that less than 0.1% of the initial waste radioactivity is released into the geosphere around the repository, and much less is released into the shafts.

- Gases are contained within the repository and geosphere. The gas pressure is anticipated to equilibrate at 7-9 MPa (i.e., around the 7.4 MPa equilibrium hydrostatic pressure at the repository level, and well below the lithostatic pressure of about 17 MPa at the repository level). The gas will be primarily methane in the long term.
- The geosphere and shaft attenuate the release of contaminants, providing time for radioactive decay.
- For the Normal Evolution Scenario, essentially no radioactivity reaches the surface environment. The maximum calculated effective dose is many orders of magnitude below the public dose criterion.
- These results apply to a hypothetical family assumed to be living on the site in the future, and obtaining all of its food from the area. The potential dose would decrease rapidly with distance from the site. For example calculated doses to a “downstream” group exposed via consumption of lake fish and water from Lake Huron are more than six orders of magnitude lower than the dose to the family living on the site.

The modelling assessments concentrated on radiological parameters, which are not the subject of this TSD. Simulation of non-radiological parameters was also undertaken, and is described herein.

- Less than 3% of the non-radiological species in the wastes are released from the DGR over a one million year timeframe.
- The calculated concentrations of non-radioactive contaminants in biosphere media for the Reference Case are also much smaller than the environmental quality standards for groundwater, soils, surface water and sediments designed to protect human health and the environment.

The relevant Environmental Quality Standards that the simulated concentrations were compared to are provided in Table 8.7.1-1 below (Table 3.4 in Postclosure Safety Assessment Report [2]).

Table 8.7.1-1: Environmental Quality Standards for Non-radioactive Contaminants

Species	Groundwater (µg/L)	Note	Soil (µg/g)	Note	Surface Water (µg/L)	Note	Sediment (µg/g)	Note
Ag	0.3	A	0.5	A	0.1	H, P	0.5	A
As	13	A	11	A	5	I, P	6	A
B	1,700	A	36	A	200	I	—	B
Ba	610	A	210	A	—	B	—	B
Be	0.5	A	2.5	A	11	J	—	B
Br	—	B	—	B	1,700	T	—	B
Cd	0.5	A	1	A	0.017	Q	0.6	A
Chlorobenzene	0.01	C	0.01	C	0.0065	K	0.02	C
Chlorophenol	0.2	D	0.1	D	0.2	L	—	B
Co	3.8	A	19	A	0.9	H	50	A

Table 8.7.1-1: Environmental Quality Standards for Non-radioactive Contaminants (continued)

Species	Groundwater (µg/L)	Note	Soil (µg/g)	Note	Surface Water (µg/L)	Note	Sediment (µg/g)	Note
Cr	11	E	67	E	1	M	26	E
Cu	5	A	62	A	1	J	16	A
Dioxins/Furans	1.5×10^{-5}	F	7×10^{-6}	F	0.3	N	—	—
Gd	—	B	—	B	7.1	U	—	B
Hf	—	B	—	B	4	V	—	B
Hg	0.1	A	0.16	A	0.004	R	0.2	A
I	—	B	—	B	100	I	—	B
Li	—	B	—	B	2,500	S	—	B
Mn	—	B	—	B	200	S	—	B
Mo	23	A	2	A	40	I	—	B
Nb	—	B	—	B	600	W	—	B
Ni	14	A	37	A	25	H	16	A
PAH	0.1	G	0.05	G	0.0008	O	0.22	G
Pb	1.9	A	45	A	1	J	31	A
PCB	0.2	A	0.3	A	0.001	H	0.07	A
Sb	1.5	A	1	A	20	I	—	B
Sc	—	B	—	B	1.8	X	—	B
Se	5	A	1.2	A	1	P	—	B
Sn	—	B	—	B	73	Y	—	B
Sr	—	B	—	B	1,500	Y	—	B
Te	—	B	—	B	20	T	—	B
Tl	0.5	A	1.0	A	0.3	I	—	B
U	8.9	A	1.9	A	5	I	—	B
V	3.9	A	86	A	6	I	—	B
W	—	B	—	B	30	I	—	B
Zn	160	A	290	A	20	J	120	A
Zr	—	B	—	B	4	I	—	B

Notes:
A ‘Full depth background site condition standard’ for Ontario from MoE (2009).
B No value available.
C As note A; values for hexachlorobenzene used.
D As note A; values for trichlorophenol used.
E As note A; values for total chromium used.
F As note A; values represent standard toxic equivalents (TEQ).

Table 8.7.1-1: Environmental Quality Standards for Non-radioactive Contaminants (continued)

G As note A; values for anthracene used.
H Provincial Water Quality Objective (PWQO) for Ontario from MoEE (1994) [162].
I Interim PWQO from MoEE (1994) [162].
J Lowest PWQO/Interim PWQO conservatively adopted from MoEE (1994) [162].
K PWQO for hexachlorobenzene from MoEE (1994) [162].
L PWQO for dichlorophenols from MoEE (1994) [162].
M PWQO for Cr (VI) from MoEE (1994) [162].
N PWQO for dibenzofuran in MoEE (1994) [162].
O Interim PWQO for anthracene in MoEE (1994) [162].
P Freshwater CEQG from CCME (2007) [210].
Q Cadmium interim freshwater CEQG from CCME (2007) [210].
R Interim freshwater CEQG for methylmercury from CCME (2007) [210].
S Irrigation water value from the Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses from CCME (2007) [210].
T Calculated from minimum of Oral rate/mouse LD50s from CCOHS (2009).
U Maximum Permissible Concentration (MPC) for freshwater from Sneller et al. (2000).
V Value for Zr used.
W Lowest available from ODEQ (2001).
X Lowest available MPC for freshwater for all rare earth elements from Sneller et al. (2000).
Y Tier II secondary chronic value from Suter and Tsao (1996).
"— " No criterion.

In summary, the Normal Evolution Scenario modelling for the DGR indicates that the effects are negligible, and do not pose a threat to human or biological health.

8.7.2 Likely Effects

Based on the above, the direct effects of the postclosure behaviour of the repository will not have an adverse environmental effect on soil quality, overburden groundwater, shallow bedrock groundwater, intermediate bedrock water or deep bedrock groundwater quality VECs.

The dominant flow characteristics within the overburden, shallow bedrock, intermediate bedrock and deep bedrock regimes do not change appreciably as a result of the postclosure presence of the DGR. Dominant flow is horizontal advective flow within formations in the more permeable shallow formations. The dominant groundwater migration mechanism in the lower permeable intermediate rocks and the deep formations is diffusion; this is the principal mechanism for movement of water and contaminants within the stratigraphic column. Apart from the immediate vicinity of the repository and shafts, where movement from the repository into the geosphere will eventually occur, there is likely no measurable change in the various bedrock solute transport regimes.

8.7.3 Mitigation Measures

The principal mitigation measure for the Normal Evolution Scenario for the DGR is the site setting itself. The extensive studies from the site characterization program and the postclosure safety assessment have demonstrated that the geological/hydrogeological setting underneath the Bruce nuclear site provides excellent isolation and protection of the geosphere from the repository wastes.

8.7.4 Residual Adverse Effects

No likely environmental effects were identified during the abandonment and long-term performance phase. Therefore, it is concluded that the DGR Project will not cause a residual adverse effect on the geology VECs.

8.8 SEISMICITY

The DGR is located at the edge of the Stable Cratonic Core Region (SCC) of Canada, the most stable part of the continent. The region's seismic stability is generally manifested by a lack of detectable structural features and low seismicity. The seismic hazard assessment of a DGR relevant to operational and long-term safety has been examined through probabilistic approaches [80]. The following paragraphs describe the understanding of seismicity, natural and human induced, as it will influence operational safety and long-term performance of the DGR.

Historic monitoring of seismicity by the Geologic Survey of Canada coupled with recent micro-seismicity monitoring results from a borehole seismometer array installed in 2007 indicate that seismic activity in the region surrounding the Bruce nuclear site is low. Within a period of 180 years, major activity (>2.5M) within 150 km radius of the Bruce nuclear site has not been observed. The maximum historical event is 4.2M, which was recorded at 99 km from the site in 2005 [211]. Because of the low recurrence rate, the seismicity in the region is consistent with that of the stable Canadian Shield. Based on studies conducted as part of the DGR Geoscientific investigations structural features, such as surface faults, offset beach-ridges, and seismically disturbed and liquefaction features that would indicate a higher earthquake recurrence rate have not been observed [11;103;194;81]. Assessment of earthquake hazard examined the ability of the DGR and enclosing rock mass to withstand the effects of very rare events, including the occurrence of strong earthquake ground shaking at the site. To this end realistic ground motions from a 1/100,000 per annum event generated from probability seismic hazard assessment (PSHA) was applied for simulation of the long-term waste emplacement room and shaft stability. In addition a 1/1,000,000 per annum event was considered as an extreme event [11]. Results indicate that the integrity and barrier capacity of the enclosing rock mass remains intact and, that operational and long-term safety are not compromised.

Renewed glaciations and an ice sheet advancing over the DGR would result in a modulation of the seismicity. During this period, seismicity would be initially suppressed due to surcharge loading from the ice sheet, and later enhanced while unloading during the retreat of the ice sheet. The advance of the ice sheet would likely also result in seismicity enhancement in at least the advancing front part of the glacier. Based on the lack of evidence for neotectonic deformation, faulting and cross formational groundwater mixing at the site [11;103;81], the seismic events induced by past glacial activities at the site are interpreted to occur either deep in the Precambrian basement or of small magnitudes occurring at shallow horizons. They reveal that the impact would not be significant enough to result in fault rupture and propagation into the Paleozoic rock sequence.

The risk of human induced seismicity resulting from reservoir water filling, mining activities and deep well injection is unlikely because there is an absence of such activities in the vicinity. The closest large salt mine at Goderich is located about 65 km south of the site, which results in very low local events due to blasting as confirmed by the microseismic array [211;212]. These events, including wind generation, will not impact on the DGR. Other human induced activities associated with the DGR excavation and construction would be generally of insignificant magnitude. They can be controlled by proper engineering design and excavation sequence.

8.9 SUMMARY OF ASSESSMENT

Table 8.9-1 provides a summary of the third screening for the DGR Project. Diamonds (◆) on this matrix represent likely DGR Project-environment interactions resulting in a residual adverse effect on a VEC. If present, these interactions are advanced to Section 11 for a consideration of significance. In this case, a residual adverse effect was identified for surface water quantity and flow.

8.9.1 Application of Precautionary Approach in the Assessment

Conservatism is built into the assessment using conservative scenarios (i.e., worst-case for considering a deep geologic repository) for simulating the interaction between the DGR and the environment. The conservative range of physical parameters that have been measured and/or estimated for the geologic materials and hydrogeologic regime within and underlying the Project Area and vicinity were utilized in the various simulations or predictive assessments. Previous investigations have provided a sizeable amount of data for the near-surface geology and hydrogeology of the Project Area (e.g., [19;21;13;12]). Characterization of the regional deep geology and hydrogeology in the context of the potential for use as a deep geological repository for radioactive waste, based on then-available data, was compiled in a 2004 report for OPG [191]. Characterization of the deep geology and hydrogeology within the Project Area is the subject of a deep drilling technical work program that was conducted by OPG and NWMO from 2007 to 2009.

8.9.2 Cumulative Effects

Effects of the DGR Project have the potential to act cumulatively with those of other projects. The EIS Guidelines require that the EA consider the cumulative effects of past, present and reasonably foreseeable future projects. The description of the existing environmental conditions presented in Section 5 includes the cumulative effects of past and existing projects. The assessment completed in Section 8 considers the effects of the DGR Project in combination with those of past and present projects.

No residual adverse effects were identified during the assessment of geology. The cumulative effect of residual adverse effects identified for other environmental components is presented in Section 10 of the EIS.

Table 8.9-1: Matrix 3 – Summary of the Assessment for Likely Adverse Effects on VECs

Project Work and Activity	Soil Quality				Overburden Groundwater Quality				Overburden Groundwater Transport			
	C	O	D	LT	C	O	D	LT	C	O	D	LT
Direct Effects												
Site Preparation	•	—	—	—	•	—	—	—	•	—	—	—
Construction of Surface Facilities		—	—	—	•	—	—	—	•	—	—	—
Excavation and Construction of Underground Facilities		—	—	—		—	—	—	■	—	—	—
Above-ground Transfer of Waste	—		—	—	—		—	—	—		—	—
Underground Transfer of Waste	—		—	—	—		—	—	—		—	—
Decommissioning of the DGR Project	—	—	•	—	—	—	•	—	—	—	•	—
Abandonment of the DGR Facility	—	—		—	—	—		—	—	—		—
Presence of the DGR Project				■				■				■
Waste Management	•	•	•	—	•	•	•	—	•	•	•	—
Support and Monitoring of DGR Life Cycle	•	•	•	—	•	•	•	—	•	•	•	—
Workers, Payroll, and Purchasing				—				—				—
Indirect Effects												
Changes in Air Quality	•	•	•	—				—				—
Changes in Surface Water Quantity and Flow									•	•	•	■
Changes in Surface Water Quality					•	•	•	■				
Changes in Soil Quality	—	—	—	—	•	•	•	■				
Changes in Overburden Groundwater Quality	•	•	•	■	—	—	—	—				
Changes in Overburden Grondwater and Solute Transport					■	•	•	■	—	—	—	—
Changes in Shallow Bedrock Groundwater Quality												
Changes in Shallow Bedrock Groundwater and Solute Transport												
Changes in Intermediate Bedrock Water Quality												
Changes in Intermediate Bedrock Solute Transport												
Changes in Deep Bedrock Water Quality												
Changes in Deep Bedrock Solute Transport												

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
LT = Abandonment and Long-term Performance Phase

The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential project-environment interaction

Table 8.9-1: Matrix 3 – Summary of the Assessment for Likely Adverse Effects on VECs (continued)

Project Work and Activity	Shallow Bedrock Groundwater Quality				Shallow Bedrock Groundwater and Solute Transport				Intermediate Bedrock Water Quality			
	C	O	D	LT	C	O	D	LT	C	O	D	LT
Direct Effects												
Site Preparation		—	—	—		—	—	—		—	—	—
Construction of Surface Facilities		—	—	—	•	—	—	—		—	—	—
Excavation and Construction of Underground Facilities		—	—	—	■	—	—	—		—	—	—
Above-ground Transfer of Waste	—		—	—	—		—	—	—		—	—
Underground Transfer of Waste	—		—	—	—		—	—	—		—	—
Decommissioning of the DGR Project	—	—	•	—	—	—	•	—	—	—	•	—
Abandonment of the DGR Facility	—	—		—	—	—		—	—	—		—
Presence of the DGR Project				■				■				■
Waste Management				—				—				—
Support and Monitoring of DGR Life Cycle				—				—				—
Workers, Payroll and Purchasing				—				—				—
Indirect Effects												
Changes in Air Quality				—				—				—
Changes in Surface Water Quantity and Flow												
Changes in Surface Water Quality												
Changes in Soil Quality												
Changes in Overburden Groundwater Quality	■	■	■	■								
Changes in Overburden Groundwater Transport												
Changes in Shallow Bedrock Groundwater Quality	—	—	—	—					•	•	•	■
Changes in Shallow Bedrock Groundwater and Solute Transport	■	•	•	■	—	—	—	—				
Changes in Intermediate Bedrock Water Quality	•	•	•	■					—	—	—	—
Changes in Intermediate Bedrock Solute Transport									•	•	•	■
Changes in Deep Bedrock Water Quality									•	•	•	■
Changes in Deep Bedrock Solute Transport												

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
LT = Abandonment and Long-term Performance Phase

The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential project-environment interaction

Table 8.9-1: Matrix 3 – Summary of the Assessment for Likely Adverse Effects on VECs (continued)

Project Work and Activity	Intermediate Bedrock Solute Transport				Deep Bedrock Water Quality				Deep Bedrock Solute Transport			
	C	O	D	LT	C	O	D	LT	C	O	D	LT
Direct Effects												
Site Preparation		—	—	—		—	—	—		—	—	—
Construction of Surface Facilities		—	—	—		—	—	—		—	—	—
Excavation and Construction of Underground Facilities	•	—	—	—		—	—	—	•	—	—	—
Above-ground Transfer of Waste	—		—	—	—		—	—	—		—	—
Underground Transfer of Waste	—		—	—	—	—	—	—	—		—	—
Decommissioning of the DGR Project	—	—	•	—	—	—	•	—	—	—	•	—
Abandonment of the DGR Facility	—	—		—	—	—		—	—	—		—
Presence of the DGR Project				■				■				■
Waste Management				—				—				—
Support and Monitoring of DGR Life Cycle				—				—				—
Workers, Payroll and Purchasing				—				—				—
Indirect Effects												
Changes in Air Quality				—				—				—
Changes in Surface Water Quantity and Flow												
Changes in Surface Water Quality												
Changes in Soil Quality												
Changes in Overburden Groundwater Quality												
Changes in Overburden Groundwater Transport												
Changes in Shallow Bedrock Groundwater Quality												
Changes in Shallow Bedrock Groundwater and Solute Transport	•	•	•	■								
Changes in Intermediate Bedrock Water Quality												
Changes in Intermediate Bedrock Solute Transport	—	—	—	—								
Changes in Deep Bedrock Water Quality					—	—	—	—				
Changes in Deep Bedrock Solute Transport	•	•	•	■					—	—	—	—

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
LT = Abandonment and Long-term Performance Phase

The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential project-environment interaction

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9. EFFECTS OF THE ENVIRONMENT ON THE PROJECT

9.1 ASSESSMENT METHODS

The EA must include a consideration of how the environment could adversely affect the DGR Project. For example, the EA evaluates how hazards such as seismic events are likely to affect the DGR Project. This assessment was accomplished using the method illustrated in Figure 9.1-1. Firstly, potential conditions in the environment that may affect the project are identified. Then, the level of effect these environmental conditions could have on the DGR Project are evaluated based on past experience at the site and professional judgement of the study team. The assessment of effects of the environment on the DGR Project focuses on those conditions associated with geology (e.g., seismicity). For each environmental condition that could potentially affect the DGR Project, the mitigation measures incorporated into the project design are identified and evaluated for effectiveness. This evaluation is based on the available data, and the experience and judgement of the study team. Identified residual adverse effects, if any, are then advanced to Section 11 for an assessment of significance.

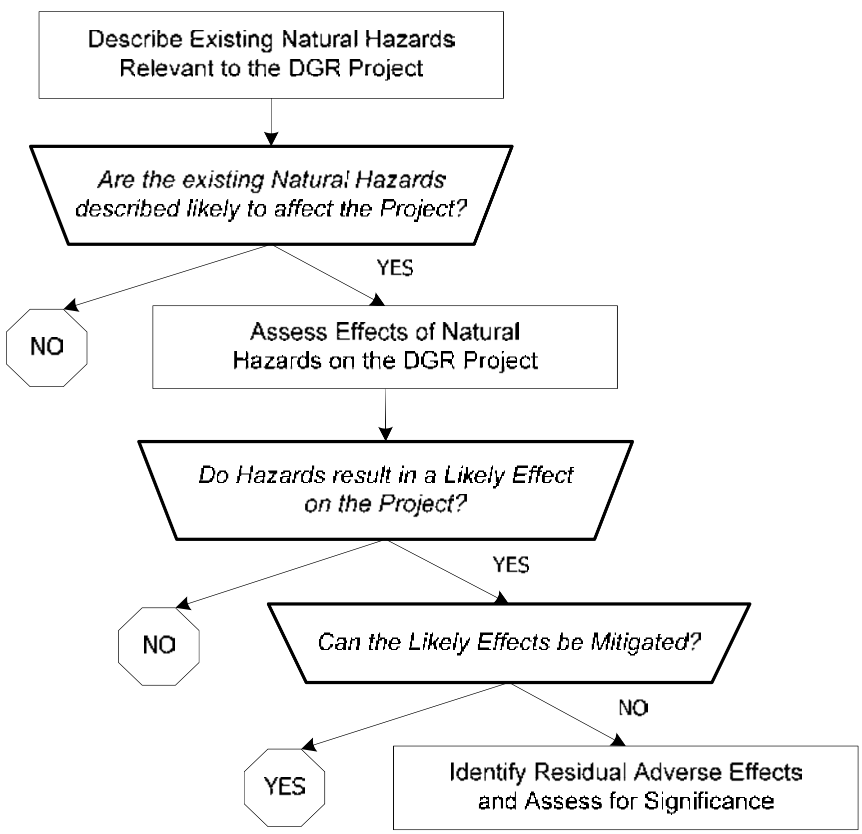

Figure 9.1-1: Method to Assess Effects of the Environment on the DGR Project

9.2 ASSESSMENT OF EFFECTS OF THE CURRENT GEOLOGY ON THE DGR PROJECT

The following existing potential natural hazards related to the current geology that may have an effect on the DGR Project are as follows:

- the seismicity of the existing environment in the vicinity of the Regional Study Area, Local Study Area, Site Study Area and Project Area.

Seismicity is defined as the frequency, intensity, and distribution of earthquakes in a given area. For the purposes of this EA, the seismicity was evaluated on a regional basis for the area shown in Figure 5.10-1. Seismicity is described in Section 5.10.

Effects of seismicity on the DGR are considered in the Preliminary Safety Report [4]. In addition, seismic events are considered in the Malfunctions, Accidents and Malevolent Acts TSD. No residual adverse effects are likely.

9.3 SUMMARY

No effects of the geology (i.e., seismicity) on the DGR Project are advanced to Section 11 for an evaluation of significance.

10. CLIMATE CHANGE CONSIDERATIONS

The DGR Project EIS Guidelines require a consideration of whether the DGR Project and EA conclusions are sensitive to changes in climatic conditions. For the purpose of this TSD, climate change is considered over the life of the DGR Project spanning the site preparation and construction, operations, and decommissioning phases only. Shifts in climate that occur from one epoch to the next have been considered as part of the postclosure safety assessment [2], and their effects on the DGR Project are described in the EIS (Section 9).

The requirement of the guidelines to consider climate change is addressed through the following considerations:

- How will the future environment affect the DGR Project?
- How will the DGR Project affect the future environment? and
- How will the DGR Project affect climate change (e.g., contribution to climate change by the emission of greenhouse gasses)?

The methods used to consider the effects of climate change are described in the following sections. Establishing how the climate may change over the life of the DGR Project is an initial requirement for addressing the first two considerations. A determination of how climate has been changing and how it might change over the DGR Project life is based on 30-year climate normals, literature review and the professional experience of the study team. The climate models used to predict high, medium and low climate change scenarios for the Regional Study Area are described in the Atmospheric Environment TSD. These predicted climate change scenarios are used by all environmental disciplines for the assessment of the consequences of climatic conditions on the first two considerations.

10.1 DESCRIPTION OF PREDICTED CHANGES IN CLIMATE

Climate represents the long-term expected values for parameters such as temperature, precipitation and winds. The climate of an area is described using normals, which are averages calculated over a 30 year period (the latest accepted normals period is from 1971 to 2000) [213]. It is now widely accepted that climate is changing; therefore, consideration of these changes needs to be incorporated in the EA conducted for the DGR Project. Traditionally, scientists looked to past weather records to provide guidance for predicting future conditions. Historic climate trends for the DGR Project are evaluated using the temperature archives observed at Wiarton Airport over the period from 1971 through 2000. While past trends have traditionally been used to provide guidance to the future, reliance is shifting to global climate models, which incorporate accepted understandings of climate mechanisms and standardized scenarios reflecting potential human development in the future.

Tables 10.1-1 and 10.1-2 provide a summary of the past and future trends for temperature and precipitation, respectively. The tables describe how climate in the region has been changing, as well as how it is projected to change over the life of the DGR Project. These data will be used to evaluate how climate change may affect the conclusions reached regarding the assessment of the effects of the DGR Project on the selected VECs. The Atmospheric Environment TSD provides further details on the predicted changes in climate.

Table 10.1-1: Historic and Future Temperature Trends

Criteria	1971-2000 Normals (°C)	1971-2000 Trend (°C/decade)	2011-2040 Forecast (°C/decade)			2041 -2070 Forecast (°C/decade)			2071 -2100 Forecast (°C/decade)		
			Low	Average	High	Low	Average	High	Low	Average	High
Annual	6.1	+0.31	+0.00	+0.41	+1.05	+0.15	+0.34	+0.66	+0.20	+0.33	+0.51
Spring	4.5	+0.50	+0.00	+0.45	+1.09	+0.14	+0.35	+0.69	+0.19	+0.34	+0.54
Summer	17.4	+0.26	+0.00	+0.43	+1.10	+0.15	+0.34	+0.69	+0.21	+0.34	+0.52
Fall	8.3	+0.05	+0.00	+0.36	+1.02	+0.12	+0.30	+0.63	+0.19	+0.32	+0.49
Winter	-5.7	+0.68	+0.00	+0.40	+0.99	+0.16	+0.33	+0.63	+0.21	+0.33	+0.50

Notes:
The low and high data correspond to the forecasts for the scenario with the smallest and largest respective changes in temperature for each forecast horizon. The average represents the arithmetic average of the available forecasts. Refer to Appendix D of the Atmospheric Environment TSD for the derivation of climate data.

Table 10.1-2: Historic and Future Precipitation Trends

Season	1971-2000 Normals (mm)	1971-2000 Trend (mm/decade)	2011-2040 Forecast (%/decade)			2041 -2070 Forecast (%/decade)			2071 -2100 Forecast (%/decade)		
			Low	Average	High	Low	Average	High	Low	Average	High
Annual	1,041.3	+0.13%	+0.00%	+1.44%	+3.57%	+0.36%	+1.11%	+2.09%	+1.39%	+1.30%	+2.25%
Spring	216.8	+3.23%	+0.00%	+2.59%	+5.39%	+0.62%	+1.51%	+2.72%	+1.88%	+2.24%	+4.05%
Summer	230.8	-0.51%	+0.00%	-1.65%	-3.40%	-0.95%	-1.13%	-0.42%	-0.68%	-0.85%	-0.61%
Fall	310.9	+4.41%	+0.00%	+2.09%	+4.35%	+2.28%	+1.67%	+2.75%	+2.11%	+1.65%	+1.85%
Winter	282.8	-4.65%	+0.00%	+2.39%	+7.30%	-0.27%	+1.82%	+3.08%	+2.05%	+1.92%	+3.32%

Notes:
The low and high data correspond to the forecasts for the scenario with the smallest and largest respective changes in temperature for each forecast horizon. The average represents the arithmetic average of the available forecasts. Refer to Appendix D of the Atmospheric Environment TSD for the derivation of climate data.

10.2 EFFECTS OF THE FUTURE ENVIRONMENT ON THE DGR PROJECT

10.2.1 Methods

Changes to the climate are predicted to occur over the lifetime of the DGR Project; therefore, it is also necessary to assess how the predicted future environment may affect the DGR Project. For example, climate change might result in new or more severe weather hazards. The method used to assess these changes is shown in Figure 10.2.1-1.

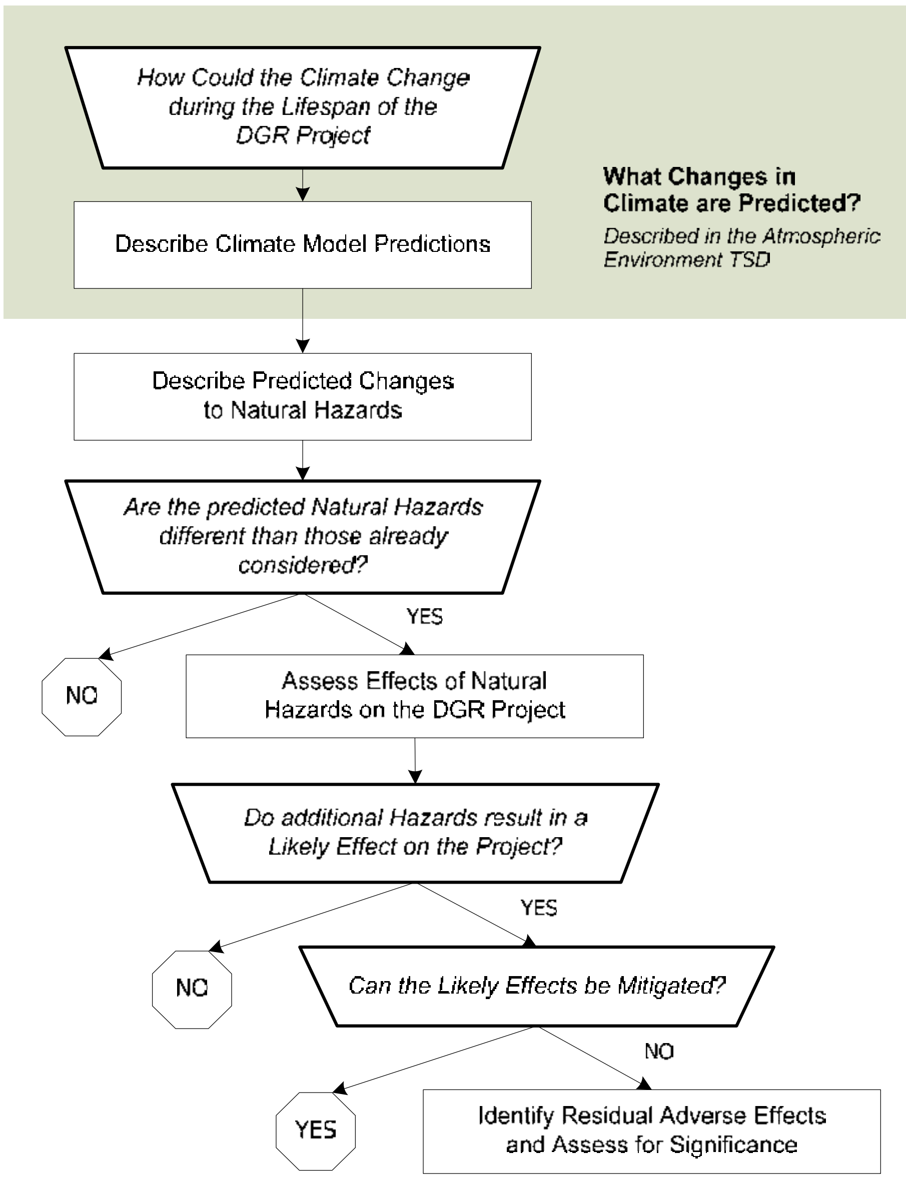

Figure 10.2.1-1: Method to Assess Effects of the Future Environment on the DGR Project

Once the future environment is established, the evaluation of changed and/or additional natural hazards on the DGR Project is conducted in a similar fashion to the assessment of effects of the current environment on the DGR Project (Section 9). The assessment addresses only predicted hazards that are different from, or in addition to, those considered in the assessment of existing natural hazards. The EA predictions of potential future hazards as a result of a changing climate relies upon both qualitative and quantitative evaluations based on available data and technical experience, with consideration for the design and contingency measures incorporated into the DGR Project to mitigate likely effects. Identified residual adverse effects are advanced to Section 11 for an assessment of significance.

10.2.2 Assessment of Effects of the Future Environment on the DGR Project

As described above in Section 9.2, the following existing potential natural hazard related to the current geology that may have an effect on the DGR Project is as follows:

- the seismicity of the existing environment in the vicinity of the Regional Study Area, Local Study Area, Site Study Area and Project Area.

Seismicity is defined as the frequency, intensity, and distribution of earthquakes in a given area. The seismicity of a region is the function of subsurface tectonic processes and forces which originate within the crust and underlying mantle of the Earth.

There are no seismic events of M>5 recorded in the past 180 years. The likelihood of a large event in the Regional Study Area is very low, exhibiting a seismicity rate comparable to that of a cratonic region. However, the rate could potentially be affected if there was a future episode of glaciation, as such events lead to in situ stress changes that may temporarily increase seismicity rates [2].

Ground shaking because of an earthquake is not normally a critical issue for an underground facility because shaking intensity decreases with depth. Case histories reveal that earthquake damage to underground structures, particularly below 500 m, is rare [2]. Damage may occur for near-surface facilities.

There is no expectation that potential climate change within the timeframe of the project will affect the seismicity of the Regional Study Area, Local Study Area, Site Study Area or Project Area in any way. No changes to the occurrence or risk of seismic events are likely as a result of climate change.

Accordingly, no effects of future geology environment on the Project (i.e., seismicity) are advanced to Section 11 for an evaluation of significance.

10.3 EFFECTS OF THE DGR PROJECT ON THE FUTURE ENVIRONMENT

10.3.1 Methods

Climate change may result in an environment that is different from the current environment as less severe winters or increased precipitation might alter the habitat or behaviour of VECs. Climate-related changes to VECs may result in changed or additional effects of the DGR Project compared with those predicted on the current environment. The method used to assess these changes is shown in Figure 10.3.1-1.

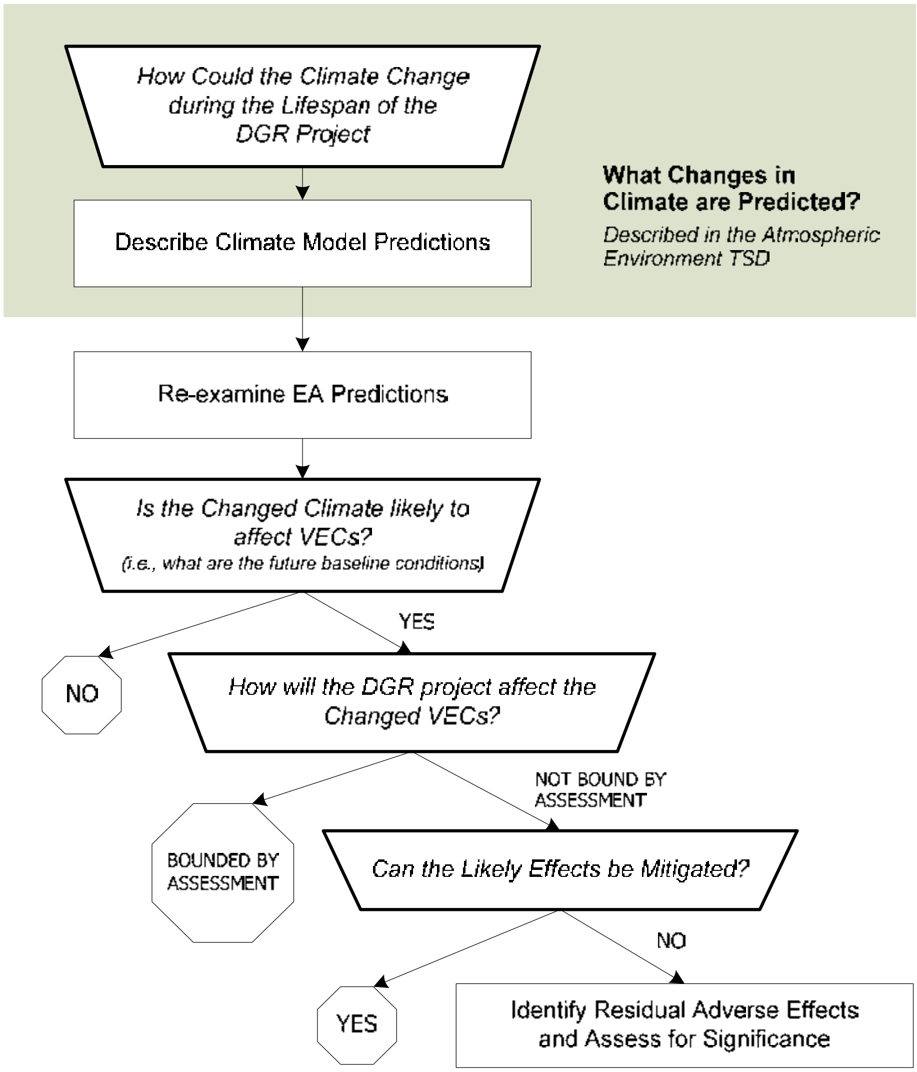

Figure 10.3.1-1: Method to Assess Effects of the DGR Project on the Future Environment

The assessment of the effects of the DGR Project on VECs in a changed future environment begins with re-examining the EA predictions for the current environment, by identifying whether or not the VECs might be altered as a result of climate change. The effects of the DGR Project on the altered VECs are then assessed to determine whether they are bounded by the predictions made for the effects assessment for the current environment (Section 8). All additional or different effects are fully assessed, using a similar method to that followed for assessing effects of the DGR Project on the current environment. Effects that cannot be fully mitigated will result in residual adverse effects, which are forwarded for an assessment of significance in Section 11.

10.3.2 Assessment of the DGR Project on the Future Geology VECs

The climate modelling results used for this project, reported in the Atmospheric TSD, predict slight increases in average annual temperature and slight increases in average annual precipitation over the life of the DGR Project.

As described above in Section 10.2, no changes to the occurrence or risk of seismic events are a likely result of climate change. Accordingly, the following discussion is limited to the effects on Geology.

The potential effects of changing climate on the assessment of effects to Geology are best indicated through the predicted changes to the regional/local groundwater transport VEC. Increases in seasonal temperatures may result in increased evaporation of precipitation, potentially reducing groundwater recharge. Conversely, increases in seasonal precipitation may result in potential increases in available groundwater recharge. For the years 2011-2100 – spring, fall, and winter modelling scenarios, both temperature and precipitation are predicted to increase over the life of the DGR Project. The potentially adverse effects to recharge because of increased temperature may be largely offset by the increases in precipitation predicted in the modelling.

For the summer modelling scenarios, an increase in average temperature is accompanied by a decrease in average precipitation. The cumulative increase in average temperature from 2011 to 2100 is 1.06°C, with a high estimate of 2.02°C. The cumulative decrease in average precipitation from 2011 to 2100 is 3.9 mm, with a maximum of 6.5 mm, though seasonal precipitation increases are expected. Compared to an average summer precipitation of 230.8 mm (1971-2000 normals), even the high reduction estimate is not considered to be significant. The potential increase in evaporative losses because of higher temperatures in summer is generally considered to be offset by the cumulative increase in precipitation predicted for the spring, winter and fall scenarios (average 11.9 mm; high 31.1 mm) over the life of the DGR Project.

The potential evaporative losses in summer because of climate change are expected to be well within the seasonal variation of evaporation. It is not expected that a net effect on recharge characteristics resulting from potential increased evaporation in summer could be accurately measured. In addition, the native soils in the vicinity of the DGR Project are dense tills which will only allow a maximum range of 5 to 10 cm/a of infiltration, regardless of the amount of precipitation.

To address the effects of the project on the future environment, Table 10.3.2-1 summarizes the potential effects of climate change on the geology VECs. The table also describes whether these changes could affect the conclusions of the assessments in Sections 6, 7 and 8, respectively.

Table 10.3.2-1: Potential Effects of Climate Change on Geology VECs

VEC	Potential Interaction of Climate Change with VEC	Likely Effect	Changes to EA Conclusion?
Soil Quality	Changes to soil quality as a result of changes in soil moisture	• Changes in climate could affect the soil moisture, and ultimately the quality of the soil	• Changes to the local soil quality are determined to be negligible • No residual adverse effects are identified for geology • No changes to the EA conclusions are warranted
Overburden Groundwater Quality	Changes to groundwater quality as a result of changes in the recharge regime	• Changes in climate could affect the surface water availability, affecting groundwater recharge and flow, and potentially groundwater quality	• Changes to the local geology are determined to be negligible • No residual adverse effects are identified geology • No changes to the EA conclusions are warranted
Overburden Groundwater Transport	Changes to solute transport (recharge) regime	• Changes in climate have the potential to affect the surface water availability, which could alter groundwater recharge	• Changes to the groundwater recharge regime are determined to be negligible • No residual adverse effects are identified for geology • No changes to the EA conclusions are warranted
Shallow Bedrock Groundwater Quality	Changes to groundwater quality as a result of changes in the recharge regime	• Changes in climate are not considered to have an effect on the transport characteristics between shallow bedrock formations	• Changes to the shallow bedrock groundwater recharge regime are considered to be negligible, therefore, changes to shallow bedrock quality are considered to be negligible • No residual adverse effects are identified for geology • No changes to the EA conclusions are warranted
Shallow Bedrock Groundwater and Solute Transport	Changes to groundwater flow (recharge) regime	• Changes in climate are not considered to have an effect on the transport characteristics between shallow bedrock formations	• Changes to the shallow bedrock groundwater recharge regime are considered to be negligible • No residual adverse effects are identified for geology • No changes to the EA conclusions are warranted

Table 10.3.2-1: Potential Effects of Climate Change on Geology VECs (continued)

VEC	Potential Interaction of Climate Change with VEC	Likely Effect	Changes to EA Conclusion?
Intermediate Bedrock Water Quality	Changes to groundwater flow (recharge) regime	• Changes in climate are not considered to have an effect on the transport characteristics between intermediate bedrock formations	• Changes to the intermediate bedrock groundwater recharge regime are considered to be negligible • No residual adverse effects are identified for geology • No changes to the EA conclusions are warranted
Intermediate Subsurface Solute Transport	Changes to groundwater flow (recharge) regime	• Changes in climate are not considered to have an effect on the transport characteristics between intermediate bedrock formations	• Changes to the intermediate bedrock groundwater recharge regime are considered to be negligible • No residual adverse effects are identified for geology • No changes to the EA conclusions are warranted
Deep Bedrock Water Quality	Changes to groundwater flow (recharge) regime	• Changes in climate are not considered to have an effect on the deep bedrock porewaters	• Changes to the deep bedrock groundwater recharge regime are not considered to be measurable therefore, changes to deep bedrock quality are considered to be negligible • No residual adverse effects are identified for geology • No changes to the EA conclusions are warranted
Deep Bedrock Solute Transport	Changes to groundwater flow (recharge) regime	• Changes in climate are not considered to have an effect on the deep bedrock porewaters	• Changes to the deep bedrock groundwater recharge regime are not considered to be measurable • No residual adverse effects are identified for geology • No changes to the EA conclusions are warranted

10.3.3 Effects of Future Glaciation Events on the DGR Project

Glacial/interglacial cycling will have an impact on the hydrogeological conditions in the overburden and shallow bedrock groundwater zones. It is very unlikely that previous glaciations had any significant impact on groundwater flow in the intermediate and deep bedrock groundwater zones. Notable responses to glaciation include; permafrost formation (which only extends tens of metres in depth), short-lived meltwater events (which may intrude into the shallow bedrock groundwater zone and have geochemical consequences) and the formation of a major proglacial lake over the site during ice-sheet retreat (see Section 6.3 of System and its Evolution Report [2]).

The future ice-sheet that is postulated will cause significant changes in the surficial physical environment and the shallow groundwater zone, in terms of permafrost, hydraulic pressures and flow rates, as well as the penetration of glacial recharge waters. Gradients within the permeable formations of the intermediate groundwater zone – Guelph, Salina A0 upper carbonate – may vary in direction and magnitude as the ice sheets advance and retreat. However, the impacts of glacial cycles on the deep groundwater zone are expected to be primarily changes in the stress and hydraulic pressure regime resulting from ice-sheet loading and unloading. This is supported by evidence from the site itself, where the deep groundwaters do not show signs of impact from past glaciations, nor are there signs of faulting or fracturing due to glaciation stresses. This is also supported by modelling of the behaviour of the groundwater and geomechanical environment around the repository, and modelling of the mechanical behaviour of the shaft seals, presented in the Geosynthesis [3]. The overall rock will remain intact, and contaminant transport remains diffusion-dominated, as in previous glacial cycles.

Geochemical studies conducted as part of the Geosynthesis program revealed that there was little likelihood that water from previous glaciations reached the intermediate or deep bedrock formations. Br and Cl profiles show very little change versus depth below the top of the Ordovician formations, suggesting that meteoric water has had no influence on the composition of the ancient brines at depth. Paleohydrogeologic simulations for a glaciation scenario indicate that basal meltwaters would not penetrate below the Salina Formation. Simulations further indicate that while ice-loading will influence hydraulic head distributions and gradients, solute transport processes within the Ordovician sediments hosting and enclosing the proposed DGR will remain diffusion dominant [29].

There was no evidence found during the deep geological site investigations of meltwater from previous glaciations penetrating the deep and intermediate bedrock groundwater zones, because of their low permeability and the relatively high permeability of the shallow bedrock groundwater zone.

Geomechanical modelling of the DGR opening in the Cobourg Formation considered several perturbation scenarios, including seismic shaking and glacial loading. The results of the work demonstrated that the maximum damage zone around the room openings was about 7.5 m under the long-term strength degradation case, and a maximum horizontal fracture propagation of 16 m under the gas generation scenario. None of the scenarios modelled created potential pathways to the biosphere [2].

In summary, the effects of future glaciation events on the DGR Project are not considered adverse.

10.4 EFFECTS OF THE DGR PROJECT ON CLIMATE CHANGE

The DGR Project may also contribute to how the climate is changing (e.g., through changes in the levels of greenhouse gas emissions). This assessment, which quantifies the direct and indirect changes in greenhouse gas emissions as a result of the DGR Project, is not relevant to geology, and is described in the Atmospheric Environment TSD.

10.5 SUMMARY

No effects of climate change related to the geology are advanced to Section 11 for an evaluation of significance.

11. SIGNIFICANCE OF RESIDUAL ADVERSE EFFECTS

Residual adverse effects of the DGR Project are assessed for a consideration of significance. Methods for the evaluation of significance are provided in Section 7 of the EIS.

No residual adverse effects of the DGR Project were identified on geology VECs in Sections 8, 9 and 10. Therefore, the assessment of the significance of the residual adverse effects is not required. Follow-up monitoring is proposed to confirm adverse effects do not occur and that in-design mitigation measures are effective. Cumulative effects are considered in Section 10 of the EIS.

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12. EFFECTS OF THE PROJECT ON RENEWABLE AND NON-RENEWABLE RESOURCES

The DGR Project EIS Guidelines (Appendix A of the EIS) require the EA to consider the effects of the DGR Project on resource sustainability. For context, non-renewable resources are also discussed in this section.

12.1 METHODS

Potential project-environment interactions (as identified for the assessment of effects of the project) are reconsidered in a context of their likelihood of affecting resource sustainability or availability through all time frames. Likely effects are predicted, described and their significance assessed by considering “renewable and non-renewable resources” as VECs. In addition, the ability of the present generation and future generations to meet their own needs was made, based on the professional judgment of the technical specialists.

One goal of the assessment is to determine whether renewable and non-renewable resources would be affected by the DGR Project to the point where they are not sustainable or appreciably depleted. Sustainability is defined in a manner consistent with the United Nation’s definition of sustainable development as “*economic development that meets the needs of the present without compromising the ability of future generations to meet their own needs*”.

Potential project-environment interactions identified in the screening matrices were reviewed to determine the likelihood of interactions between the project and resource sustainability and availbility. For the purpose of this assessment, the likely residual adverse effects of the project’s physical works and activities on the environment were considered as having the potential to adversely affect the sustainability of associated resources.

12.2 LIKELY EFFECTS

Groundwater is considered a renewable resource. Both the shallow bedrock groundwater quality VEC and solute transport VEC may be considered as distinct components of the renewable groundwater resource. In terms of the groundwater quality VEC, no potential groundwater quality-project interactions were identified which may have a direct likely environmental effect.

For the shallow bedrock groundwater and solute transport VEC, dewatering was determined to have a likely environmental effect because of pumping activities. Groundwater will be extracted through dewatering activities during the site preparation and construction phase works and activities. The groundwater is managed on-site and eventually discharges to the environment via surface water flow to Lake Huron. The duration of dewatering is short compared to the life of the Project. No adverse effect on geology has been identified because of dewatering activities. As noted in Section 8.3.3, the zone of influence resulting from dewatering activities during the site preparation and construction phase is expected to be small. No potable groundwater sources are established on-site throughout the life of the project. Therefore, there are no likely adverse effects on the sustainability of the renewable groundwater resource as a result of the DGR Project. Lake water is used as a source of water for various operations and is assessed in the Hydrology and Surface Water Quality TSD.

An assessment of Quaternary and Paleozoic geology and aggregate resources indicates that the DGR Project site is located within the Huron Fringe and Huron Slope physiographic regions, comprising Quaternary sediments, mainly till, overlying the Paleozoic basement. There are no primary sand and gravel deposits identified within 20 km of the DGR Project site.

A petroleum geology assessment based on a review of existing literature indicated that there is a very low probability of identifying economic oil and/or gas resources in the vicinity of the DGR Project site. At present, there is no petroleum/gas production within 40 km of the Project Area. In addition, the DGR boreholes confirmed the results of the Texaco #6 exploration well, some 3 km east of the Project Area, that there are no significant oil or gas shows in the Plaeozoic sequence at the Bruce nuclear site. Therefore, there are no likely adverse effects on the non-renewable aggregate and petroleum resources as a result of the DGR Project.

Aggregate resources (i.e., sand and gravel, quarried rock) are considered a non-renewable resource. There will be some concrete aggregate resources imported onto the site to complete the Project. Aggregate resources will also be created on the site through the excavation and blasting activities during the site preparation and construction phases of the project. Approximately 1,000,000 m^3 of rock will be excavated in construction of the shafts and emplacement rooms, over 90% of which is Cobourg Formation limestone and argillaceous limestone. Most of this excavated rock will be managed at the WRMA. The remainder of the soil and rock will eventually be re-used for the construction of roadways and berms. Limited aggregate will need to be imported during the beginning of the site preparation and construction phase for concrete and roadway construction. Therefore, there are not likely to be any adverse effects to the non-renewable resources in the Local and/or Regional Study Areas as a result of the DGR Project.

Many of the Paleozoic rocks identified at the Bruce nuclear site have been exploited elsewhere in Ontario for their aggregate potential, for landscaping rock, and brick manufacture. Generally, for these industries to be economic, the rock source must be close to surface (less than 8 mBGS), and be of mineable thickness. Therefore, most of the rock aggregate is extracted in quarries along the Niagara escarpment or areas of shallow overburden in Bruce County. The DGR Project site is considered to have a low potential for aggregate resource extraction.

The soil quality VEC may be considered a renewable aspect of the non-renewable soil aggregate resource, in that impacted soil quality attributed to human activities can be “renewed” (i.e., remediated) and returned to its baseline environmental quality. As described in Section 8.2, no direct or indirect likely environmental effects were identified from soil quality - project interactions. Therefore, it was concluded that the DGR Project will not create residual adverse effects on the soil quality VEC. Accordingly, soil quality-project interactions are not expected to affect the non-renewable soil resource.

13. PRELIMINARY FOLLOW-UP PROGRAM

The guidelines stipulate that the need for, and the requirements of, any follow-up program for the DGR Project be identified. A follow-up program may be required to determine that the environmental and cumulative effects of the DGR Project are consistent with predictions reported in the EIS. It can also be used to verify that mitigation measures are effective once implemented and determine whether there is a need for additional mitigation measures. A preliminary follow-up plan is provided below. The follow-up program is designed to be appropriate to the scale of the DGR Project and the effects identified through the EA process.

Follow-up monitoring programs are generally required to:

- verify the key predictions of the EA studies; or
- confirm the effectiveness of mitigation measures, and in so doing, determine if alternate mitigation strategies are required.

The CNSC will provide the regulatory oversight to ensure that NWMO has implemented all of the appropriate mitigation measures. The CNSC compliance program can be used as the mechanism for ensuring the final design and implementation of the follow-up program and for the reporting of the follow-up program results.

13.1 INITIAL SCOPE OF THE FOLLOW-UP PROGRAM

Table 13.1-1 summarizes the recommended follow-up monitoring programs for the geology assessment. The recommendations identify the general timeframe for follow-up and monitoring (site preparation and construction, operations, decommissioning and/or abandonment and long-term performance phase). These recommendations should be reviewed and incorporated, as appropriate, into the preliminary EA Follow-up Monitoring Program [214] that has been prepared and is submitted along with the EIS.

Soil Quality

As described in Section 6.1 (first screening), several of the site preparation and construction, and operations phase works and activities for the project were screened for potential interactions between the VEC and the project. In the absence of a malfunction or accident during these activities, which may introduce potential contaminants to the subsurface, it was concluded that there is no reasonable expectation that soil quality for conventional (i.e., non-radiological) chemical parameters will be affected by the DGR Project. Monitoring of soil quality for conventional (i.e., non-radiological) soil quality parameters would only be undertaken on an as-needed basis, in response to a malfunction or accident which is considered to have a potential environmental impact on soil quality within the Project Area (e.g., spill of waste to ground). In the event of such an occurrence, follow-up monitoring may include a number of activities, including surficial soil sampling, subsurface soil investigations (i.e., borehole drilling with soil sampling for analysis), and potentially, soil remediation. The purpose of these activities would be to ensure compliance with the prevailing regulatory standards, which are currently the MOE Table 3 SCS [8].

The recommended follow-up monitoring program(s) for radiological soil quality parameters are discussed in the Radiation and Radioactivity TSD.

Overburden Groundwater Quality

As described in Section 6.1 (first screening), a number of the site preparation and construction, and operations phase works and activities for the project were screened for potential interactions between the groundwater quality VEC and the DGR Project. For several of these works and activities, it was concluded that, in the absence of a malfunction or accident during these activities, which may introduce potential contaminants to the subsurface, there is no reasonable expectation that groundwater quality for conventional (i.e., non-radiological) chemical parameters will be affected by the DGR Project. Monitoring of conventional groundwater quality would only be undertaken on an as-needed basis, in response to a malfunction or accident which is considered to have a potential environmental impact on groundwater quality within the Project Area (e.g., spill of waste to ground). In the event of such an occurrence, follow-up monitoring may include a number of activities, including monitoring well installation, periodic groundwater quality monitoring, and, if necessary, groundwater remediation. The purpose of these activities would be to ensure compliance with the prevailing regulatory standards, which are currently the MOE Table 3 SCS [8].

The recommended follow-up monitoring program(s) for radiological groundwater quality parameters are discussed in the Radiation and Radioactivity TSD.

Potential effects of the project on the groundwater quality VEC were advanced for further screening for several works and activities, and it was concluded that these works and activities were not likely to have an environmental effect on the groundwater quality VEC. However, during the site preparation construction and operations phase of the project, groundwater will be discharged to the stormwater drainage system and management pond during dewatering activities. Prior to discharging this water to the drainage ditch, the water may be analyzed for a number of conventional parameters to ensure compliance with applicable discharge requirements. The frequency of sampling will be established at the detailed design stage of the project, based on the expected groundwater discharge rates and stormwater management pond sizing (which will dictate the average residence time of water prior to discharge to Lake Huron). The recommended follow-up monitoring program for the stormwater management pond is discussed in the Hydrology and Surface Water Quality TSD.

Overburden, Shallow Bedrock, Intermediate Bedrock and Deep Bedrock Solute Transport

As described in Section 6.1 (first screening), a number of the site preparation and construction, and operations phase works and activities for the project were screened for potential interactions between the groundwater flow VEC and the DGR Project. Potential effects of the DGR Project on the solute transport VECs were advanced for further screening for several works and activities, and it was concluded that these works and activities were not likely to have a residual environmental effect on the solute transport VECs.

It is expected that follow-up monitoring of the groundwater flow VECs will include monitoring well nest instrumentation and a subsequent water level monitoring program to cover the following project works and activities:

- dewatering during construction of underground facilities.

Prior to the construction of underground facilities, it is expected that a test well(s) and pumping test program will be implemented to assess the Project Area aquifer(s) properties, estimate the expected Zone of Influence (ZOI), and prepare a dewatering plan for the construction of underground facilities. This testing program would also include implementation of a water level monitoring program before, during, and after the pumping test.

Shallow, Intermediate and Deep Bedrock Groundwater Quality

A network of four deep monitoring well nests (DGR-1 to DGR-4) and three shallow monitoring well nests (US-3, US-7, and US-8) within the Project Area and outside of the underground footprint of the DGR have been installed as part of the Geosynthesis initiatives, prior to the start of the project. A monitoring program to test/confirm the findings and interpretation of the Geosynthesis regarding groundwater quality, while construction is underway will be conducted. The scope and details of this monitoring program will be established by NWMO and their consulting team at the appropriate time (i.e., upon completion of the Geosynthesis activities, and prior to site preparation).

Table 13.1-1: Recommended Follow-up Monitoring for Geology

VEC	Project Phase	Program Objective	Suggested Frequency and Location of Monitoring
Soil Quality	• Site preparation and construction • Operations • Decommissioning	Identify and monitor effects of any soil contamination to ensure compliance with regulatory standards (i.e., MOE Table 3 SCS [8]) If non-compliant, determine additional mitigation required to be compliant, as required under Ontario Environmental Protection Act	As needed and where needed in response to malfunction or accident

Table 13.1-1: Recommended Follow-up Monitoring for Geology (continued)

VEC	Project Phase	Program Objective	Suggested Frequency and Location of Monitoring
Overburden Groundwater Quality	• Site preparation and construction • Operations • Decommissioning	Identify and monitor effects of any soil contamination to ensure compliance with regulatory standards (i.e., MOE Table 3 SCS [8]) If non-compliant, determine additional mitigation required to be compliant, as required under Ontario Environmental Protection Act	As needed and where needed in response to malfunction or accident.
Overburden Groundwater Transport	• Site preparation and construction • Operations	Confirm EA predictions of no measurable change in groundwater levels beyond the Site Study Area Anticipated ZOI benchmark to be established during the pumping test for Permit to Take Water Application (regulatory requirement - Ontario Water Resources Act)	Dependent on results of pumping test program – to be established prior to excavation and site preparation and construction phase of the project
Shallow Bedrock Groundwater Quality	• Site preparation and construction • Operations • Decommissioning	Confirm predictions of Geosynthesis program	To be established in conjunction with CNSC
Shallow Bedrock Groundwater and Solute Transport	• Site preparation and construction • Operations • Decommissioning	Confirm predictions of Geosynthesis program	To be established in conjunction with CNSC
Intermediate Bedrock Water Quality	• Site preparation and construction • Operations • Decommissioning	Confirm predictions of Geosynthesis program	To be established in conjunction with CNSC
Intermediate Bedrock Solute Transport	• Site preparation and construction • Operations • Decommissioning	Confirm predictions of Geosynthesis program	To be established in conjunction with CNSC

Table 13.1-1: Recommended Follow-up Monitoring for Geology (continued)

VEC	Project Phase	Program Objective	Suggested Frequency and Location of Monitoring
Deep Bedrock Water Quality	• Site preparation and construction • Operations • Decommissioning	Confirm predictions of Geosynthesis program	To be established in conjunction with CNSC
Deep Bedrock Solute Transport	• Site preparation and construction • Operations • Decommissioning	Confirm predictions of Geosynthesis program	To be established in conjunction with CNSC

13.2 PERMITTING REQUIREMENTS

The follow-up program described in Sections 13.1 and 13.2 may be a requirement as part of the CNSC licence. In addition, it is expected that the DGR Project will be subject to a number of permitting requirements. Those permits related to geology include, but may not be limited to:

- Permit to Take Water – expected to be required for dewatering the shafts during the site preparation and construction phase of the project. This may also be required during the operations phase, depending on volume of water inflows, although the shafts are expected to be well-sealed.
- OWRA s.53 Certificate of Approval (Sewage Works) – will be required to demonstrate effective treatment of discharge water from stormwater management pond prior to release to the environment, and may be required during the operations phase.

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14. CONCLUSIONS

Based on the assessment provided in this TSD, the following major findings are provided:

- no residual adverse effects were identified on soil quality, groundwater quality or solute transport;
- climate change is not expected to have any effect on the conclusions reached regarding the effects of the DGR Project on soil quality, groundwater quality or groundwater flow; and
- the DGR Project is not expected to have any effects on renewable and non-renewable resources.

Therefore, no significant adverse effects are identified on the geology VECs.

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APPENDIX A: LIST OF ACRONYMS, UNITS AND TERMS

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LIST OF ACRONYMS

Acronym	Descriptive Term
2D	Two-dimensional
3D	Three-dimensional
ATV	Acoustic televiewer
BCOA	Bunker C Oil ASTs and Oil Delivery System
BHWP	Former Bruce Heavy Water Plant
BNSG	Bruce Nuclear Standby Generators
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CCME	Canadian Council of Ministers of the Environment
CEQG	Canadian Environmental Quality Guidelines
CEAA	Canadian Environmental Assessment Act
CL	Construction Landfill
CNSC	Canadian Nuclear Safety Commission
DEA/MDEA	Diethylamine/methyldiethylamine
DGR	Deep Geologic Repository
D_e	Effective Diffusion Coefficient
DO	Dissolved Oxygen
DS	Distribution Station
EA	Environmental Assessment
EDZ	Excavation Damage Zone
EIS	Environmental Impact Statement
EPA	Environmental Protection Act
EPH	Extractable petroleum hydrocarbons
EQS	Environmental Quality Standard
ESA	Environmental Site Assessment
Fe^{3+}	Oxidized Iron
Fe^{2+}	Reduced Iron
FEPCAT	Features, Events and Processes for Argillaceous Rocks
FTF	Fire Training Facility
GMWL	Global Meteoric Water Line
GSCP	Geoscientific Site Characteristic Plan
GUSCO	Guidelines for Use at Contaminated Sites in Ontario

LIST OF ACRONYMS (continued)

Acronym	Descriptive Term
GW	Groundwater
HS	hydrostratigraphic
HTD	Hydrothermal Dolomitization
IC	In-ground Container
ILW	Intermediate Level Waste
L&ILW	Low and Intermediate Level Waste
LLSB	Low Level Storage Building
LLW	Low Level Waste
LNAPL	Light Non-aqueous Phase Liquids
MLE	Mean Life Expectancy
MOE	Ministry of the Environment
MVT	Mississippi Valley Type
NBCC	National Building Code of Canada
NE-BC	Natural Evolution Base Case Scenario
NE-UG-BC	Natural Evolution Updated Geosphere Base Case Scenario
NWMD	Nuclear Waste Management Division
NWMO	Nuclear Waste Management Organization
ODWS	Ontario Drinking Water Standards
OPG	Ontario Power Generation Inc.
PAHs	Polycyclic Aromatic Hydrocarbons
PHCs	Petroleum Hydrocarbons
PI	Potential Index
PPH	Purgeable petroleum hydrocarbons
PSHA	Probability Seismic Hazard Assessment
PTTW	Permit to Take Water
PW	Porewater
PWQO	Provincial Water Quality Objective
QA/QC	Quality assurance/quality control
RA	Responsible Authority
R_0	Radius of Influence
RWOS	Radioactive Waste Operations Site
SCC	Stable Cratonic Core Region

LIST OF ACRONYMS (continued)

Acronym	Descriptive Term
SCS	Site Condition Standards
SSTF	Spent Solvent Treatment Facility
SWTF	Surface Water Treatment Facility
TDS	Total Dissolved Solids
TEQ	Standard Toxic Equivalent
TOC	Total Organic Carbon
TPH	Total petroleum hydrocarbons
TSD	Technical Support Document
TSS	Total Suspended Solids
UCS	Unconfined Compressive Strength
UW	University of Waterloo
VEC	Valued Ecosystem Component
VOCs	Volatile Organic Compounds
WPRB	Waste Package Receiving Building
WRMA	Waste Rock Management Area
WWMF	Western Waste Management Facility
XRD	X-ray Diffraction
ZOI	Zone of Influence

LIST OF UNITS

Symbol	Units
‰	1 part in 1,000
Bq/kg	Becquerels per Kilogram
Bq/kg-C	Becquerels per Kilogram Carbon
Bq/L	Becquerels per Litre
Bq/m^3	Becquerels per Cubic Metre
Bq/s	Becquerels per Second
°C	Degrees Celsius
Ci	Curie
Ci/kg	Curies per Kilogram
cm	Centimetre
cm/a	Centimetre per year
cm/s	Centimetres per second
cm/s^2	Centimetre per square second
dBA	Decibels
D_e	Diffusion coefficient
g	Grams
%g	Peak Ground Acceleration (percentage of gravity)
GBq	Gigabecquerel
GPa	Gigapascal
g/s	Grams per second
Gy/h	Grays per hour
ha	Hectares
Hz	Hertz
Igpd	Imperial gallons per day
Igpm	Imperial gallons per minute
in	Inch
in/a	Inch per year
K	Hydraulic conductivity
kg	Kilograms
kg/m^3	Kilogram per cubic metre
kg/s	Kilograms per second

LIST OF UNITS (continued)

Symbol	Units
km	Kilometres
km^2	Square kilometres
km/h	Kilometres per hour
kPa	Kilopascal
kV	Kilovolt
L	Litres
L/s	Litres per second
m	Metres
M	Magnitude
Ma	Mega annum (1 million years)
m_N	Local magnitude scale used in Bruce monitoring network
mg/L	Milligram per litre
mm	Millimetre
m/m	Metre per metre
mmol/kg	Millimole per kilogram
m/s	Metres per second
m^3	Cubic metres (volume)
m^3/day	Cubic metres per day
m^3/s	Cubic metres per second
MBq/kg	Megabecquerels per kilogram
mAGS	Metres above ground surface
mASL	Metres above sea level
mBGS	Metres below ground surface
mLBGS	Metres length below ground surface
µg/g	Microgram per gram
µg/L	Micrograms per litre
µg/m^3	Microgram per cubic metre
mg/L	Milligrams per litre
mGy/d	MilliGray per day, unit of dose
mk	Milli-k, a dimensionless unit of reactivity
mk/d	Milli-k per day
ML/d	Million Litres per day

LIST OF UNITS (continued)

Symbol	Units
mm	Millimetres
MPa(g)	Megapascals (gauge)
mR/h	MilliRoentgen per hour
µSv	MicroSievert
µSv/a	MicroSievert per year
mSv	MilliSievert
MVA	Million volt-amps
MW	Megawatt
MW(e)	Nominal Net Output, Megawatt (electricity)
nGy/h	NanoGray per hour
ρ	Density
pa	per annum
person-Sv	Person-Sievert
pH	A measure of the acidity or alkalinity of a solution. The pH scale spans 0 to 14, with 0 representing a strongly acidic solution, 7 representing a neutral solution, and 14 representing a strongly basic (alkaline) solution.
ppm	Parts per million
R/h	Roentgen per hour
rpm	Revolutions per minute
σ_v	Vertical Stress
σ_h	Minor Principal Horizontal Stress
σ_H	Major Principal Horizontal Stress
s	Seconds
Sv/a	Sieverts per year
t	Tonne
TBq	TeraBecquerel
TBq/kg	TeraBecquerels per kilogram
TBq-MeV	TeraBecquerel-MegaElectronvolt
TBq/a	TeraBecquerel per year
TU	Turbidity Unit
TWh	TeraWatt hours
V	Volt

GLOSSARY OF TERMS

Aboriginal traditional knowledge – Knowledge that is held by, and unique to, Aboriginal peoples. Aboriginal traditional knowledge is a body of knowledge built up by a group of people through generations of living in close contact with nature. It is cumulative and dynamic and builds upon the historic experiences of a people and adapts to social, economic, environmental, spiritual and political change.

Adaptive Management – A combination of management, research, and monitoring that allows credible information to be gained and management activities to be modified by experience.

Advection – A process by which dissolved or suspended substances (natural constituents, artificial tracers, contaminants), are transported by the bulk motion of a fluid medium (water, air).

Aerobic – Commonly used to describe the presence of air (oxygen), the term aerobic is often used interchangeably with the term *oxic*. However, aerobic can also be used more generally to describe environments in which one or more redox couples control the redox potential (Eh) at relatively positive values.

Aeromagnetic Survey – A magnetic survey measuring the earth's magnetic field, made with an airborne magnetometer.

Aftershock – An earthquake that follows a larger earthquake (main shock) and originates at or near the focus of the larger earthquake. Generally, major earthquakes are followed by many aftershocks, which decrease in frequency and magnitude with time. Such a series of aftershocks may last for many days for small earthquakes or many months for large ones.

Algonquin Arch – A northeast trending crystalline basement doming (high) that separates the *Michigan Basin* from the *Appalachian Basin*.

Alkalinity (Groundwater) – A measure of a water's capacity to neutralize an acid. It indicates the presence of carbonates, bicarbonates, hydroxides, as well as borates, silicates, phosphates and organic substances. It is expressed as an equivalent of calcium carbonate ($CaCO_3$).

Anaerobic – Commonly used to describe the absence of air (oxygen), the term anaerobic is often used interchangeably with the term *anoxic*. However, anaerobic can also be used more generally to describe environments in which one or more redox couples control the redox potential (Eh) at relatively negative values.

Analogue (Geosphere) – An investigation or quantitative analysis of the natural evolution of a repository site that conveys an understanding of long-term geologic and hydrogeologic stability relevant to demonstrating concepts of long-term waste isolation and containment.

Anhydrite – A mineral consisting of anhydrous calcium sulphate: $CaSO_4$. It represents gypsum without its water of crystallization, and it alters readily to gypsum, from which it differs in crystal form and in being harder and slightly less soluble. Anhydrite usually occurs in white or slightly colored, granular to compact masses, forming large beds or seams in sedimentary rocks or associated with gypsum or halite in evaporites.

Anion exclusion – The process by which transport of anions (negatively-charged species in solution) is confined to only part of the available pore space in a rock due to repulsion by negative charges on the surface of clay minerals.

Anisotropy – The condition of having properties that vary with direction at a given point location (e.g., a glacial till or clay, in which the hydraulic conductivities could be orders of magnitude different in the x, y, and z directions). See also *isotropy.*

Anoxic – Often used interchangeably with the term *anaerobic*, anoxic strictly means the absence of oxygen.

Appalachian Basin – An elongated *sedimentary basin* on the North American continent, with a maximum depth of 12 km. In Southern Ontario, sedimentary rocks of both the Appalachian Basin and *Michigan Basin* overlie the Precambrian crystalline basement, with a maximum thickness of approximately 1.5 km.

Aquiclude – A medium with very low values of hydraulic conductivity (permeability) which, although it may be saturated with groundwater, is almost impermeable with respect to groundwater flow. Such geologic media will act as boundaries to aquifers and may form confining strata.

Aquifer – A geological formation or structure that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells and springs. A confined aquifer is bound by low permeability formations such that it is under-pressure. An unconfined aquifer is one whose upper groundwater surface (water table) is at atmospheric pressure.

Aquifer, Fractured Bedrock – An aquifer composed of rock, but where most water flows through fractures or solution openings instead of pore spaces in the rock mass.

Aquitard – A confining bed and/or formation composed of rock or sediment that retards but does not prevent the flow of water to or from an adjacent aquifer. It does not readily yield water to wells or springs, but stores groundwater.

Archipelago – A chain or cluster of islands that are formed tectonically.

Argillaceous – Pertaining to, largely composed of, or containing clay-size particles (< 4 microns) or clay minerals*.*

Argillaceous Limestone – A limestone containing an appreciable amount (but < 50 percent) of clay*.*

Arkose – A feldspar-rich (*feldspathic*) sandstone, commonly coarse-grained and pink/reddish in color. Typically, quartz is the dominant mineral phase, and feldspars comprise ≥ 25%.

Artesian aquifer – A body of rock or sediment containing groundwater that is under greater than hydrostatic pressure; that is, a confined aquifer. When an artesian aquifer is penetrated by a well, the water level will rise above the top of the aquifer. If the water level in the well exceeds the elevation of the ground surface, it is referred to as a flowing artesian well.

Asthenosphere – The layer of the Earth below the *lithosphere* (continental plates), which is weak and plastic, in which isostatic adjustments and plate movements take place and magmas may be generated.

Backfill – An engineered material formulated and placed to fill the excavated openings in a repository as part of sealing and closure. See also *Grout.*

Barrier Reef – A long, narrow coral reef roughly parallel to the shore and separated from it by a lagoon of considerable depth and width.

Basement (rock) – **T**he crust of the Earth (Precambrian igneous and metamorphic complex) underlying the sedimentary deposits.

Bathymetry – The measurement of water depth at various locations within a body of water. Bathymetry maps enable estimates of the topography and elevation of ground surface within areas covered by bodies of water.

Bedding – The natural arrangement of sedimentary rocks into layers of varying thickness and character.

Bioclastic – Refers to rocks consisting of fragmental organic remains.

Biogenic – Pertaining to a deposit resulting from the physiological activities of organisms.

Bioherms - A mound-like or circumscribed mass of rock built up by sedentary organisms such as corals, mollusks, and algae, and enclosed in rock of different lithological character.

Biosphere – The physical media (atmosphere, soil, surface waters and associated sediments) and the living organisms (including humans) that interact with them.

Bituminous – Containing much organic or at least carbonaceous matter, mostly in the form of the tarry hydrocarbons which are routinely described as bitumen.

Brackish – Salty water, generally defined as having 15 to <30 parts per thousand salinity.

Brine - Water containing a higher concentration of dissolved salts than that of the ordinary ocean.

Borehole Breakout – The spalling at the edge of a borehole as a result of the concentration of the maximum horizontal stress. The stress concentration is so large that induced differential stress causes shear fractures within the rock next to the borehole wall. Spalling releases the fractured rock to create a deformation or elongation of the borehole wall in the direction of the least horizontal stress.

Bound Water – The sum of internally bound and externally bound water. See also *Internally Bound Water* and *Externally Bound Water.*

Bounding Assessment – An assessment designed to provide limiting estimates, based on simplification of the processes being simulated or the use of data limits (such as maximum possible precipitation, or thermodynamic solubility limits).

Brachiopod - A member of a phylum of marine shelled animals with two unequal shells (valves)each of which is normally bilaterally symmetrical. Also known as lamp shells.

Brackish Water – Water with a salinity between freshwater and seawater (i.e., water that contains between 1 and 10 g/L total dissolved solids. See also *Brine* and *Saline Water*.

Breccia – A coarse-grained clastic rock, composed of angular or broken rock fragments, and held together by a mineral cement or fine-grained matrix.

Brine – Water with a salinity greater than 100 g/L total dissolved solids. See also *Brackish Water* and *Saline Water*.

Bruce Megablock – A regional subdivision of Southern Ontario based upon characteristics of an interpreted fracture framework, developed by Sanford (1985). It extends from the top of the *Algonquin Arch* to Georgian Bay to the north.

Bruce nuclear site – The 932 hectare (9.32 km^2) parcel of land located within the administrative boundaries of the Municipality of Kincardine in Bruce County. Two operating nuclear stations are located on the site. The site is owned by OPG but has been leased to Bruce Power since May 2001. However, parts of the site, including land on which WWMF is located, have been retained by OPG. See also *OPG-retained lands*.

Bruce Power – The licensed operator of the Bruce A and Bruce B nuclear generating stations.

Calcareous – Term referring to a rock, mud, or cement is mostly or partly composed of calcium carbonate (typically >50%).

Cambrian – The earliest period of the Paleozoic era extending from 543 to 490 million years ago; also, refers to rocks formed, or sediments laid down, during this period (e.g., Cambrian sandstones).

Canadian Environmental Assessment Agency – The federal body accountable to the Minister of the Environment. The Agency works to provide Canadians with high-quality environmental assessments that contribute to informed decision making, in support of sustainable development.

Canadian Nuclear Safety Commission (CNSC) – The Canadian federal agency responsible for regulating nuclear facilities and materials, including management of all radioactive waste in Canada.

Canadian Shield – A large plateau that occupies most of eastern and central Canada and consists of exposed Precambrian basement rocks in a stable craton. It is surrounded by younger sedimentary rocks.

CANDECON Waste – CANDECON is a chemical decontamination process for nuclear heat transport systems. Wastes produced from this process are contaminated resins and filters, which contain high levels of chelating agents such as EDTA.

Capacity Factor - A dimensionless factor that accounts for retention of a solute by sorption onto the surfaces of a porous medium. The *capacity factor* α is defined by the *solute-accessible porosity* ϕ_s, the porous medium dry bulk density ρ and the porous medium distribution coefficient K_d for the specific solute as follows: $\alpha = \phi_s + \rho K_d$

Cap rock – Refers to the thick sequence of Ordovician shales that act as a barrier to fluid movement and overlie the DGR host rock.

Capillary Pressure – The difference in pressure across two immiscible fluid phases jointly occupying the interstices of a rock.

Carbonate – A salt of carbonic acid. Compound (including minerals) containing the radical CO_3^{2+}. Also refers to sedimentary rocks containing a large amount of carbonate minerals (e.g. limestone, dolostone).

Cation – An ion that bears a positive charge.

Celestite - A mineral with composition $SrSO_4$. The dominant ore for strontium.

Cenozoic – The time span covering from 65 million years to present.

Chatham Sag – A narrow topographic low within the Precambrian crystalline basement surface that separates the Algonquin and Findlay Arches; located in the vicinity of Lake St. Clair in southwestern Ontario.

Chert – 1. Mineral: A cryptocrystalline variety of quartz. Composed of interlocking grains generally not discernible under a microscope

2. Rock: A compact siliceous rock of varying colours composed of microorganisms or precipitated silica grains. Occurs as lenses, nodules, and beds in limestones and shales.

Chlorite - Family of tetrahedral sheet silicates of iron, magnesium, and aluminum, characteristic of low-grade metamorphism. Green colour, with cleavage like mica except that chlorite's small scales are not elastic.

Clastic – Refers to rock or sediment that is composed primarily of broken fragments derived from pre-existing rocks or minerals, which have been transported some distance from their place of origin and accumulated.

Closure – The administrative and technical actions directed at a repository at the end of its operating lifetime. For example covering the waste (for a near surface repository), backfilling and/or sealing of rooms, tunnels and/or shafts (for a geological repository), and termination or completion of activities in any associated structures.

Colloids – Small particles suspended in groundwater. The particles are typically 1 to 1000 nanometres in size.

Compactible Waste – Wastes which can be processed by medium force compaction, such as light metal objects, insulation materials, hoses, cables, metal fillings and turnings, with a contact dose rate less than 2 mSv/h (200 mrem/h).

Conceptual Model – A set of qualitative and/or quantitative assumptions used to describe a system or subsystem for a given purpose. At a minimum, these assumptions concern the geometry and dimensionality of the system, temporal and spatial boundary conditions, and the nature of the relevant physical and chemical processes. The assumptions should be consistent with one another and with existing information within the context of the given purpose.

Conformity – The mutual and undisturbed relationship between adjacent sedimentary strata that have been deposited in orderly sequence, with little or no evidence of time lapses.

Connate Water – Water which is entrapped in the pores at the time of sediment deposition. Term is used to describe rock porewater with long residence times, i.e., water that has been out of contact with the atmosphere for an appreciable part of a geologic period.

Containment (Safety Case) – Limiting the release of hazardous materials to the biosphere.

Controlled Area – A defined area in which specific protection measures and safety provisions are or could be required for controlling normal exposures or preventing the spread of contamination during normal working conditions, and preventing or limiting the extent of potential exposures.

Constrictivity – A geometric factor that accounts for the effects of constricted pathways or channels along a diffusive solute transport path within a porous medium. Note that constrictivity cannot be measured directly and is typically combined with *tortuosity* to yield the *tortuosity factor*.

Core Disking – Rock core recovered from vertical wells in argillaceous rocks may split into thin disks, parallel to the near horizontal bedding, due to their fissile nature. At the DGR, this does not appear to be related to relief of in situ stress. See also *Fissility (rock).*

Crack Damage Stress – Marks the onset of unstable crack growth of a brittle rock sample under loading which could be interpreted as the upper bound of the short-term in situ rock strength. Beyond this stress, the coalescence of propagating cracks in the sample will occur.

Crack Initiation Stress – Represents the threshold marking the onset of stable crack growth in brittle rock under loading, which is the lower bound for the in situ rock strength, and is identifiable as the point where the lateral strain curve of a test rock sample departs from linearity (or the initiation of acoustic emission response of the sample to loading).

Craton – A large portion of a continental plate that has remained relatively tectonically stable since the Precambrian era.

Crinoid – A type of echinoderm consisting of a cup or "head" containing the vital organisms, numerous radiating arms, an elongate, jointed stem, and roots by which it is attached to the sea bottom, while the body, stem, and arms float.

Critical Group – A group of members of the public which is reasonably homogeneous with respect to its exposure for a given contamination source and given exposure pathway, and is typical of individuals receiving the highest health impacts by the given exposure pathway from the source. See also *Exposure Group*.

Darcy Flux – Refers to the observation derived from Darcy's Law that the flux of fluid through a unit area of permeable media is directly proportional to the hydraulic gradient.

Decommissioning – Those actions taken, in the interest of health, safety, security and protection of the environment, to retire a licensed activity/facility permanently from service and render it to a predetermined end-state condition.

Deep Geologic Repository (or DGR, or Repository) – The underground portion of the deep geologic repository facility for low- and intermediate-level waste. Initially, the repository includes the access-ways (shafts, ramps and/or tunnels), underground service areas and installations, and emplacement rooms. In the postclosure phase it also includes the engineered barrier systems. The repository includes the waste emplaced within the rooms and excludes the excavation damage zone.

Deep Geologic Repository Facility (or DGR Facility, or Repository Facility) – The deep geologic repository for low- and intermediate-level waste, and the various surface and underground support facilities. The support facilities include equipment, materials and infrastructure for receiving, inspecting and handling waste packages, for transferring waste packages from the surface to the repository horizon, for handling the waste packages in the repository, for emplacing waste packages, for excavating the repository (during operations), for constructing room shield walls, and for material storage. The repository facility excludes the waste emplaced within the rooms and any zones of damaged rock around underground openings.

Deep Geologic Repository Project Site (or DGR Project Site) – The portion of the Project Area that will be affected by the site preparation and construction of surface facilities (i.e., the surface footprint).

Deep Geologic Repository System (or DGR System, or Repository System) – The deep geologic repository facility for low and intermediate-level waste, its geological setting, and the surrounding surface environment. The system includes the wastes, and the engineered and natural barriers that provide isolation and containment of the waste.

Deformation – A general term for the process of folding, faulting, shearing, or fabric development of the rocks as a result of Earth stresses; or the change in geometry of a body of rock as a consequence of stress(es).

Descriptive Geosphere Site Model – A description of the present day 3-dimensional physical and chemical characteristics of a specific site as they relate to implementation of the Deep Geologic Repository concept. The model is based on the integration of multi-disciplinary geoscientific data that, in part, relies on multiple lines of evidence to constrain uncertainty and/or non-uniqueness in interpretation. See also *Geosynthesis.*

Design Basis – Identifies specific functions to be performed by a system, structure, equipment, component or software; and the specific values or range of values chosen for controlling parameters as reference bounds for the design.

Design Constraint – A mandatory requirement to be fulfilled by the repository design. For example, must be located on OPG-retained land, must be constructed in suitable Ordovician limestone. See also *Design Limit, Functional Requirement* and *Performance Requirement.*

Design Life – The period during which a structure, system or component will perform while still meeting original design specifications, including routine maintenance but without major repair or refurbishment.

Design Limit – A limit beyond which an element or combination of repository elements is not expected to function properly. Design limits should have either “maximum” or “minimum” in the description. See also *Design Constraint, Functional Requirement* and *Performance Requirement.*

Detritus – Loose fragments or grains that have been worn away (eroded) from a rock(s) and are transported from their place of origin and accumulate elsewhere (i.e. clay is composed of numerous detrital grains that have been eroded from the primary (host) rock(s) and have been transported via mechanical forces (wind, water), resulting in the accumulation and formation of a cohesive sedimentary rock mass elsewhere).

Deuterium – Refers to ‘heavy hydrogen’, ^{2}H, the stable isotope of hydrogen that has an atomic mass of two, as opposed to the common isotope of hydrogen, ^{1}H, which has an atomic mass of one.

Devonian – The fourth period of the Paleozoic Era extending from 417 to 354 million years ago; also refers to rocks formed, or sediments laid down, during this period (e.g., Devonian shales).

Diagenesis – Process involving physical and chemical changes to sediment after deposition that converts it to consolidated rock; includes compaction, cementation, recrystallization, and replacement (e.g. dolomitization).

Diffusion – The process by which both ionic and molecular species dissolved in water move from areas of higher concentration to areas of lower concentration. Movement is random and is proportional to the gradient of concentration. The process tends to distribute the particles more uniformly. See also *Advection* and *Dispersion*.

Diffusion Coefficient – The diffusion coefficient D is the constant of proportionality relating the solute flux J_i to the solute concentration gradient in a given co-ordinate direction $\partial C/\partial x_i$ as described by Fick’s First Law: $J_i = -D \ \partial C/\partial x_i$

Apparent Diffusion Coefficient (D_a) – The diffusion coefficient for a specific solute in a porous medium that accounts for the 3-dimensional geometry of the pore space, as well as the sorption behaviour of the solute. It is related to the *effective diffusion coefficient* D_e and the porous medium *capacity factor* α as follows: $D_a = D_e / \alpha$

Effective Diffusion Coefficient (D_e) – The diffusion coefficient for a specific solute in a porous medium that accounts for the 3-dimensional geometry of the pore space, including tortuosity, constrictivity and diffusion-accessible porosity. It is the product of the *diffusion-accessible porosity* ϕ_{diff}, the *tortuosity factor* τ_f, and the *free-water diffusion coefficient* D_0 as follows: $D_e = \phi_{diff} \cdot \tau_f \cdot D_0$

Free-Water Diffusion Coefficient (D_0) – The diffusion coefficient for a specific solute in bulk aqueous solution (no porous media) at 25 °C.

Pore-Water Diffusion Coefficient (D_p) – The diffusion coefficient for a specific solute in porous medium that accounts for the 3-dimensional geometry of the pore space, including its tortuosity and constrictivity. It is the product of the *tortuosity factor* τ_f and the *free-water diffusion coefficient* D_0 as follows: $D_p = \tau_f \cdot D_0$

Digital Elevation model (DEM) – A representation of the topography of the land surface in a digital format (also digital terrain model). Data files consist of elevation data related to rectangular grid coordinates.

Dip – The maximum angle that a geological structural surface (bedding plane, fault, etc.) makes with the horizontal; measured in the vertical plane, perpendicular to the strike of the structure.

Direct Effect – A direct effect occurs when the VEC is affected by a change that results from a project work and activity.

Discontinuity – Any interruption in sedimentation (*unconformity*), for whatever cause or length of time. Typically, discontinuities represent time periods of non-deposition or erosion. May also refer to any naturally occurring fracture (break) in logging rock core samples.

Dispersion – A small scale, spreading and mixing process resulting from dissolved substances traveling at different velocities along and between flow paths through a porous or fractured medium. The spreading of the dissolved substance in the direction of bulk flow is known as longitudinal dispersion. Spreading in directions perpendicular to bulk flow is known as transverse dispersion.

Disposal – The emplacement of waste in an appropriate facility without the intention of retrieval.

Dolostone – A sedimentary rock of which more than 50 percent by weight consists of the mineral dolomite (magnesium carbonate). Dolostone is generally thought to form when magnesium ions replace some of the calcium ions in limestone by the process of dolomitization. Migrating fluids along some faults and fractures may locally dolomitize limestone, the resulting rock being more porous may become a host for oil and gas deposits.

Dose – A measure of the energy deposited by radiation in a tissue. Also referred to as absorbed dose, committed equivalent dose, committed effective dose, effective dose, equivalent dose or organ dose, depending on the context.

Drawdown – The lowering of the water level in a well or aquifer due to pumping.

Drilling Fluid – A fluid used to lubricate and cool the drill bit, to carry cuttings from the bottom, and to maintain a hydrostatic pressure in the borehole offsetting pressures of fluids that may exist in the formation. For the DGR, water from Lake Huron was employed to drill the upper rock sequence above the Salina Formation (where fresh groundwater is encountered) and a brine-based fluid was used to drill the Salina and underlying formations (where saline groundwaters are present).

Drill Fluid Tracers – Any substance that is used in a drill fluid to trace the presence of the fluid and distinguish it from the natural groundwater. It is used to determine the amount of well development required before sufficient drill fluid has been removed from the system. Naturally occurring tritium from lake water and fluorescence dye were used as tracers at the DGR.

DRL (**Derived Release Limit**) - The limit at which release of a radionuclide occurring from a nuclear station or a facility will not result in dose to individual members of the public exceeding the dose limits set by the CNSC.

Drumlin – A low, smoothly rounded, elongate oval hill, mound, or ridge, of compact glacial till or drift, built under the margin of glacial ice and shaped by fluid flow beneath the glacier. The long axis of a drumlin is oriented parallel to the direction of ice movement.

Dyke – A planar injection of magmatic or sedimentary material that cuts across the pre-existing fabric of a rock. Dykes can be formed by the filling of a crack/fissure from above, below, or laterally by forcible injection, or intrusion, under abnormal pressures.

Earthquake – A shaking or trembling of the earth resulting from subterranean movement usually along faults.

Effective Stress – The average normal force per unit area transmitted directly from particle to particle in a soil or rock mass. It is the stress that is effective in mobilizing internal friction. In a saturated soil in equilibrium, the effective stress is the difference between the *total stress* and the neutral stress of the water in the voids (porewater pressure). It attains a maximum value at complete consolidation and before shear failure. See also *Total Stress*.

Elastic Modulus – A measurement of material stiffness. The modulus represents the ratio of the stress applied to a body to the strain that results in the body in response to the stress. All moduli of elasticity determined in DGR testing are tangent Young's moduli, which are computed based on the stress-strain curve at a fixed stress level of 40% of the peak strength of the material.

Emplaced Volume (Waste) – The external volume of the *waste package* for emplacement in the DGR, which includes the waste, storage container, overpack, and/or shield.

Emplacement Room – A portion of the underground repository into which waste packages are permanently placed. Rooms are bounded by the host rock for floor, ceiling and walls on most sides, and by a wall or access tunnel on one side.

Engineered Barrier – A physical obstruction that has been constructed to prevent or delay water seepage and/or radionuclide migration and/or migration of other materials between components in the repository, or between the repository and the surface environment.

Environ – Refers to the surrounding area or surrounding environment.

Environmental Isotopes – Naturally occurring stable and radioactive *isotopes* of elements found in the environment. The principal elements of hydrogeological, geological and biological systems are hydrogen, oxygen, carbon, nitrogen and sulphur. Less abundant elements include helium, argon and krypton. Environmental isotopes permit quantitative determinations of the origin, age and flow paths of groundwaters on a regional scale.

Epicenter – The point on the Earth's surface that is directly above the focus of an earthquake.

Equivalent Sound Level (Leq) – Average weighted sound level over a specified period of time.

Era – Used to denote a long period or division of geologic time, during which the respective rocks were formed (i.e. *Paleozoic* Era, *Mesozoic* Era).

Eustasy/Eustatic – Refers to sea-level changes which occur on a global scale. Eustasy results from either a change in the volume of seawater, or a change in the size of the ocean basin that contains the water. Causes of eustatic sea level change include glaciations and deglaciation, tectonic activity, and continental drift.

Evaporites – One of the sedimentary rocks which are deposited from aqueous solution as a result of total evaporation of the solvent. Example – salt deposits.

Excavation Damaged Zone (EDZ) – The region of rock around repository openings that has been physically or chemically affected as a result of the excavation process, with significant changes in flow and transport properties (i.e., permeability of the rock increased by at least one order of magnitude). See also *Highly Damaged Zone* and *Excavation Disturbed Zone*.

Excavation Disturbed Zone (EdZ) – The region of rock surrounding the EDZ with possible stress or flow changes as a result of the excavation, but without significant changes in flow and transport properties (i.e., permeabilities with the rock materially unchanged). See also *Highly Damaged Zone* and *Excavation Damaged Zone*.

Exposure Group – A group of members of the public which is reasonably homogeneous with respect to its exposure for a given radiation source and given exposure pathway and receives a dose (radioactive contaminants) or intake (non-radioactive contaminants) by the given exposure pathway from the source. See also *Critical Group*.

Exposure Pathway – A route by which contaminants can reach humans or biota and cause exposure. An exposure pathway may be very simple, for example external exposure from airborne contaminants, or involve a more complex chain, for example internal exposure from drinking milk from cows that ate grass contaminated with deposited contaminants.

Extended Monitoring – Monitoring during the time period following completion of waste emplacement activities and prior to closure of the repository (see also *Postclosure Monitoring*). The results from extended monitoring would be used in the decision-making processes related to decommissioning and closure of the repository.

Externally Bound Water, External Layer Water – Water in close proximity (few molecular diameters) of surface areas of mineral grains or clay particles in a porous medium, influenced by electrostatic interactions with surfaces or with cations near negatively charged surfaces of clay minerals. See also *Bound Water*, *Internally Bound Water.*

Extraction Ratio – The ratio of the excavated area of the repository (at the level of emplacement rooms) to the total area occupied by the repository.

Facies Change – A lateral or vertical variation in the lithologic or paleontologic characteristics of contemporaneous sedimentary deposits. It is caused by, or reflects, a change in the depositional environment.

Fault – A discrete surface or zone of discrete surfaces separating two rock masses across which one mass has slid past the other. Any faults in the DGR region would most likely be vertical/sub-vertical with probable vertical displacements propagating from the Precambrian surface into the overlying sedimentary rocks.

Feldspars – A group of abundant rock-forming minerals, generally rich in potassium, sodium, calcium, barium, rubidium, and strontium, as well as silicon and aluminum. Feldspars constitute approximately 60% of the Earth's crust.

Feldspathic – Term to describe a rock or mineral aggregate containing feldspar.

FEPs (Features, Events and Processes) - FEPs are all relevant factors that describe the current state and possible future evolution of a system. They are used as input for scenario development and subsequent consequence analysis regarding health, safety and environment.

Filter Waste – Depending on each specific station system, filter waste may consist of disposable vessels along with the exhausted filter cartridges contained therein, or filter cartridges from systems employing permanent vessels.

Fissility (Rock) – The property possessed by some rocks of splitting easily into thin layers along closely spaced, roughly planar, and approximately parallel surfaces, such as bedding planes in shale.

Fluid Density – The mass of a fluid per unit volume.

Focal Depth – The depth at which an earthquake originates (the focal depth can be measured with respect to mean sea level, or with respect to the average ground surface elevation for all seismic stations that record a given seismic event).

Fossiliferous – Containing fossils and/or organic remains.

Fracture - A general term for any surface within a material across which there is no cohesion, including cracks, joints, faults, and bedding partings.

Free Porewater – Water in a porous medium not or only weakly influenced by mineral surfaces and cations on these surfaces. See also *Porewater*.

FSR (Final Safety Report). See *Safety Report.*

Functional Requirements – These specify what has to be done but not how it should be accomplished. A function can be described by an action verb and a measurable noun, for example, a function of the repository is to "contain waste". See also *Performance Requirements*.

Geophysics – The study of the earth by quantitative physical methods, especially by seismic reflection and refraction, gravity, magnetic, electrical, electromagnetic, and radioactivity methods.

Geosphere – The rock around the repository, and extending up to the biosphere. It can consist of both an unsaturated zone (which is above the groundwater table) and the saturated zone (which is below the groundwater table).

Geosynthesis – The assembly of all the geologically-based evidence relevant to the repository safety case; the integration of multi-disciplinary geoscientific data relevant to the development of a descriptive conceptual geosphere model; explanation of a site-specific descriptive conceptual geosphere model within a systematic and structured framework. See also *Descriptive Geosphere Site Model*.

GIS – Geographic Information System, a computer system designed to allow users to collect, manage and analyze large volumes of spatially referenced information and associated attribute data.

Glacial Perturbations – Changes in geological, hydrological or geochemical systems as a result of glacial processes that include glacial isostacy, permafrost and ice sheet history.

Glaciation – The formation, movement, and recession of glaciers or ice sheets.

Glaciolacustrine – Pertaining to lakes formed during glaciations/deglaciation or the deposits derived from such lakes.

Glauconite – A green mineral closely related to the micas, and essentially a hydrous potassium iron silicate. Commonly occurs in rocks of marine origin. Also used as the name for a rock with high glauconite content.

Gneiss – A generally coarse-grained rock in which bands rich in granular minerals alternate with bands in which schistose minerals predominate.

Graben – An elongate geological depression bounded on both sides by high-angle normal faults that dip toward one another.

Grenville Front Tectonic Zone (GFTZ) – That part of the Central Gneiss Belt (a subdivision of the Precambrian Grenville Province) that lies within 20-30 km of the Grenville Front boundary fault, consists of deformed and metamorphosed rocks, and is characterized by northeasterly trending shear zones (several kilometers wide) and foliation.

Grenville Orogeny – A major plutonic, metamorphic, and deformational event during the Precambrian era, 800 to 1,000 million years ago, which affected a broad province along the southeastern border of the Canadian Shield. The Grenville orogeny is thought to be the consequence of a Himalayan-type continental collision during the assembly of a supercontinent (Rodinia).

Groundwater – In general, water contained in geologic formations below the Earth's surface. In the context of the DGR, the term is specifically applied to water that is relatively unconstrained by low permeability media and therefore free to flow under the influence of hydraulic gradients. This includes water within the connected pore space between mineral grains in unconsolidated sediment or in a fractured or porous rock matrix, as well as water in permeable, connected structures in the subsurface. See also *Porewater.*

Grout – A fluid mixture of cementitious materials, aggregates, additives and/or clay and water that will flow without segregation of the constituents into small spaces, and will form a low-permeability fill material to resist groundwater flow. In the DGR context, grouting applies to filling of fractures within the rock, or pore spaces within waste containers. See also *Backfill*.

Gypsum – Also known as alabaster or selenite. A mineral; $CaSO_4$-$2H_2O$. Normally found in sedimentary rocks.

Halite – A mineral: NaCl. Commonly known as rock salt, and a common constituent of evaporate deposits.

Hematitie – A mineral: Fe_2O_3. The principal ore of iron.

High Pressure Permeameter – Equipment for measuring permeability using high fluid pressures. Provides measurements of the pressure and volume of unidirectional liquid flow through sample cores of rock.

Highly Damaged Zone (HDZ) – The zone of rock around an excavation where macro-scale fracturing or spalling may occur, thereby inducing changes in flow and transport through the interconnected fracture system (i.e., permeabilities within the rock increased by at least 2 orders of magnitude). See also *Excavation Damaged Zone* and *Excavation Disturbed Zone*.

Holocene – The later of two epochs comprising the Quaternary Period covering the time span between 11.5 thousand years ago and the present. See also *Pleistocene*.

Homogenous – A property of a parameter or system whose values are unchanged over space.

Horst – An elongate, topographically positive, geological block that is bounded on both sides by normal faults that dip away from one another.

Human Intrusion – Human actions that modify the performance of engineered and/or natural barriers leading to the creation of a route by which humans (potentially both the intruder(s) and public) could be exposed to radionuclides derived from the repository.

Huron Slope – An area of approximately 1,500 km^2, located on the eastern shore of Lake Huron between Point Clark and Grand Bend. The area near the shoreline consists of high clay till bluffs (primarily St. Joseph Till), which slope westward.

Hydraulic Conductivity – The capacity of a rock to transmit a fluid. It is expressed as the volume of water at a given kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic Gradient – The rate of change of pressure (pressure head) per unit of distance. Typical hydraulic gradients in natural groundwater flow systems are on the order of 0.01 to 0.001.

Hydraulic Head – Fluid mechanical energy per unit weight of fluid, which correlates to the elevation that water will rise in a well.

Elevation Head – Head caused by gravity (the elevation of the water relative to a datum elevation).

Pressure Head – Head caused by the pressure (energy) of the fluid at a given elevation.

Environmental Head – The sum of the elevation head and the pressure head calculated using the average density of the water over the entire vertical water column. This is used for calculating vertical hydraulic gradients.

Freshwater Head – The sum of the elevation head and the pressure head calculated using the density of fresh water (1,000 kg m^{-3}). This is used for calculating horizontal hydraulic gradients.

Hydrogeology – The science that deals with subsurface waters and related aspects of surface waters. Hydrogeology is the study of the law governing 1) the movement of groundwater, 2) mechanical, chemical, and thermal interaction of groundwater and the porous medium, and 3) the transport of energy and chemical constituents by flow of groundwater.

Hydrostratigraphic Unit – A subsurface zone, formation, or series of formations, which have similar hydrogeologic characteristics (hydraulic heads, gradients, and conductivities, etc.).

Hydrothermal – An adjectve applied to heated or hot aqueous-rich solutions, to the processes in which they are concerned, and to the rocks, ore deposits, and alteration products that are generated by them. Hydrothermal solutions are of diverse origin, including, magmatic, meteoric, and connate waters.

Hypersalinity – Refers to solutions that have a salt content greater than that of the oceans.

Iapetus Ocean – The ocean that existed east of North America before Europe and Africa collided with North America during the Carboniferous and Permian periods (320-250 million years ago).

IC-18 – An in-ground storage structure used for intermediate level waste, primarily ion exchange resins, with a capacity of 18 m^3. See *In-Ground Storage*.

Illite – A group of clay minerals common in sedimentary rocks and soils, intermediate in composition between muscovite mica and montmilloronite clay. Does not swell when hydrated.

Incinerable Waste – Radioactive waste materials generally consisting of paper, plastic, wood, cardboard etc. which can be incinerated. The contact dose rate of such waste is less than 0.6 mSv/h (60 mrem/hr).

Indirect Effect – An indirect effect occurs when the VEC is affected by a change in another VEC.

In-Ground Storage – Storage of waste in in-ground containers (ICs); generally used for intermediate level waste. All ICs with the exception of those used for heat exchangers (HXs) consist of steel liners fixed with concrete inside boreholes in the ground. IC-HXs use limestone gravel for the backfill.

In-Service Date – The date on which the facility is put into service or made available for operation.

In Situ Stress – The natural or virgin state of stress in a rock mass that was derived from a pervasive force field imposed by geological perturbations such as tectonic activity.

Institutional Control – Control of a deep geologic repository by an authority or institution designated under the laws of a country or state. This control may be active (monitoring, surveillance, remedial work) or passive (land use control).

Interlayer Water – Water in interlayers of expandable clays (smectites). Except for strongly expanded smectites, all interlayer water is *internally bound water*.

Intermediate-Level Waste (ILW) – Radioactive non-fuel waste, containing significant quantities of long-lived radionuclides (generally refers to half-lives greater than 30 years).

Internally Bound Water, Internal Layer Water – Water in close proximity (few molecular diameters) of internal surfaces (e.g., the surface areas of water accessible interlayers of expandable clay minerals); influenced by electrostatic interactions with internal surfaces or with cations near internal surfaces. See also *Bound Water*, *Externally Bound Water.*

Interstice – An opening or space (pore) in a rock or soil.

Intraclastic – Pertaining to components of a limestone consisting of torn-up, rounded and reworked fragments of a weakly consolidated penecontemporaneous sediment that has been re-deposited to form a new sediment.

Intracratonic Basin – A basin formed in the interior region of a continental *craton* (away from plate boundaries) due to subsidence of some part of the craton.

Intraplate – A feature, event or process (i.e. earthquake, fault) located far from any tectonic plate boundary and therefore considered unrelated to subduction or sea-floor spreading.

Ion – An atom or molecule that has an unbalanced charge (i.e. the number of protons is not equal to the number of electrons). A cation is an ion with a net positive charge (e.g. Ca^{2+}, Na^+) and an anion is an ion with a net negative charge (e.g. Cl^-, SO_4^{2-}).

Irradiated Core Components – Radioactive waste such as flux detectors and liquid zone control rods resulting from the routine replacement of core components during the operation of nuclear reactors.

Island Arc – A type of *archipelago* formed as one oceanic tectonic plate slides beneath another and produces magma at depth below the over-riding plate. Island arcs are formed by volcanic activity associated with oceanic plate subduction at convergent plate margins and are also known as volcanic arcs.

Isolation (Safety Case) – Making human encounter with the waste unlikely.

Isostacy – The condition of equilibrium, comparable to floating, of the units of the *lithosphere* above the *asthenosphere*. Crustal loading (ice, water, and/or sediment) leads to isostatic depression, and removal of load (i.e. melting of glacial ice) leads to uplift (sometimes referred to as isostatic rebound).

Isotope – An isotope is one of two or more species of the same element that have the same number of protons in the nucleus but a different number of neutrons, which results in small variations in the atomic mass (e.g., oxygen has 8 protons, but the atomic masses of naturally occurring oxygen isotopes range between ^{16}O, ^{17}O and ^{18}O). See also *radioisotope.*

Isotropy – The condition of having properties that are uniform in all directions at a given point location; the property of interest does not depend on directionality (e.g., uniform sand, in which hydraulic conductivities are the same in the x, y, and z directions). See also *anisotropy.*

IX Resin – Ion-exchange resin used to maintain the water quality in station process systems (e.g., moderator and Primary Heat Transport heavy water systems, and light water auxiliary systems such as the Active Liquid Waste Treatment System).

Joint – A planar fracture, crack, or parting in a rock, without shear displacement. Often occurs with parallel joints to form part of a joint set.

Karst – A type of topography that is formed in limestone, gypsum or other rocks, primarily by dissolution, and that is characterized by sinkholes, caves and underground drainage. The most common type of karst is associated with the dissolution of limestone by meteoric waters when the carbonate rocks are exposed to the atmosphere at the Earth's surface, forming an unconfined aquifer. This most commonly occurs when shallow-marine limestones have become exposed due to a fall in sea-level. Karst can also be formed in coastal settings where fresh and marine waters mix, or as a result of limestone dissolution by sulphuric acid during deep burial of sediments.

Kimberlite – A mantle-derived *ultramafic* igneous rock containing at least 35% olivine, does not contain leucite, and contains one or more of the following: monticellite, carbonate, serpentine, diopside, or phlogopite.

Kriging – A technique of interpolation based on a combination of known data points. Kriging is often used to interpolate geoscientific information between boreholes.

Laminae – Unit layer or sheet of a sediment in which the stratification planes are less than one centimeter apart. Laminae need not be parallel to bedding.

L&ILW – Low- and Intermediate-Level radioactive Waste.

Licensing Basis – The *Licensing Basis* for a regulated facility or activity is a set of requirements and documents comprising: (i) the regulatory requirements set out in the applicable laws and regulations; (ii) the conditions and safety and control measures described in the facility's or activity's licence and the documents directly referenced in that licence; and (iii) the safety and control measures described in the licence application and the documents needed to support that licence application.

Licensing Pre-requisites – The requirements to obtain a licence for a new facility or a licence renewal for an existing facility formally discussed and agreed with the CNSC and documented prior to applying for the licence.

Licensing Submission – A document, or set of documents, submitted to the CNSC in support of a new licence application or an application for licence renewal or amendment.

LIDAR (Laser Imaging Detection and Ranging) – A technology similar to radar technology that accurately determines distance to an object or surface using laser pulses.

Limestone – A sedimentary rock composed of the mineral calcite (calcium carbonate). Where it contains appreciable magnesium carbonate it is called dolomitic limestone. The primary source of this calcite is usually the shells of marine organisms. See also *Dolostone*.

Lineament – An extensive linear geologic or topographic surface feature. Some examples are straight stream courses, fault lines, and straight escarpments.

Lithofacies – A lateral, mappable, subdivision of a stratigraphic unit, distinguished from adjacent subdivisions on the basis of lithology (mineralogy, petrography, paleontology – appearance, composition, and texture).

Lithology – Describes the physical character of a rock, including color, grain size, and mineralogy.

Lithosphere – The outer, relatively rigid layer of the Earth that responds to the emplacement of a load by flexural bending. The lithosphere consists of the entire crust, plus the uppermost mantle. The lithosphere has been divided into about 20 plates. According to the theory of plate tectonics, motion and interaction of lithosphere plates is responsible for most geologic activity.

Low Level Storage Building (LLSB) - Refers to a series of buildings at OPG's Western Waste Management Facility for the interim storage of low-level waste.

Low-Level Waste (LLW) – Radioactive waste in which the concentration or quantity of radionuclides is above the clearance levels established by the regulatory body (CNSC), and which contains primarily short-lived radionuclides (half-lives shorter than or equal to 30-years).

Mafic – General term for igneous rocks composed primarily of ferromagnesian (iron- and magnesium-rich), dark-colored, minerals.

Marker (bed) – An easily recognized stratigraphic feature having characteristics distinctive enough for it to serve as a reference point or datum, and that is traceable over long distances, especially in the subsurface (i.e. unconformities, salt beds, etc.).

mASL – Metres above sea level.

mBGS – Metres below ground surface.

mLBGS – metres of linear core below ground surface. This measure is used to account for the inclined nature of some boreholes.

Mesozoic – An era of geologic time covering the time span from 248 to 65 million years ago, that lies above the *Paleozoic* and below the *Cenozoic*. This is the era when dinosaurs roamed on earth.

Meteoric Recharge – Surface water that has recently been a part of the atmospheric portion of the hydrologic cycle, which has infiltrated into the subsurface.

Methanogenesis – The generation of methane (CH_4) as a result of biogenic (microbial) activity.

Mean Life Expectancy (MLE) - An estimate of the time required for a water particle at a special position in a groundwater system to reach a potential outflow point, considering both advective and dispersive transport processes.

Michigan Basin – A nearly-circular intracratonic *sedimentary basin* with a diameter of between 500 and 600 km, centered in Michigan, with a maximum depth of over 4 km. In Southern Ontario, sedimentary rocks from edges of both the Michigan Basin and the *Appalachian Basin* are present. The maximum thickness of the sedimentary rocks in Southern Ontario is approximately 1.5 km.

Microcrystalline – Applied to a rock in which the individual crystals can only be seen under the microscope.

Microseismicity – Very low level seismic activity, generally considered to be seismic events of M3 or less. The three borehole seismographs installed in 2007 in the vicinity of the *Bruce nuclear site* are capable of measuring microseismic events of less than M1.

Mississippi Valley-type (MVT) deposit – A strata-bound hydrothermal deposit of lead and/or zinc minerals in carbonate rocks, together with associated minerals fluorite and barite. These deposits characteristically have relatively simple mineralogy, occur as veins and replacement bodies, are at moderate to shallow depths, show little post-ore deformation, are marginal to sedimentary basins, and are without an obvious source of mineralization.

Moderately Fractured Rock – A fractured rock domain in which groundwater flow and transport occurs through an interconnected fracture network. Fracture frequencies are typically in the range of one to five fractures per metre and effective rock mass permeability is typically 10^{-15} m^2.

Molality – Concentration of a solution expressed as mols of solute per 1,000 grams of solvent.

Moment Magnitude Scale (MMS, or M_w) – The scale used by seismologists to characterize the size of an earthquake based on the amount of energy released. The scale is logarithmic, with each increase of 1 representing a 10-fold increase in energy.

Moraine – A glacially formed accumulation of unconsolidated glacial debris (soil, rock). Moraines are deposited as sheets or piles of debris directly from the ice of the glacier on/in which the debris is carried. Various types of moraines exist and their classification is based on where they were deposited with respect to the front of the glacier.

Mylonitic Texture – A characteristic of mylonites that is produced by intense microbrecciation and shearing, giving the appearance of a ‘flowing/flow’ texture.

Near- field Rock – The rock adjacent to the repository that may have experienced changes in flow, mechanical, chemical or microbial characteristics as a consequence of the excavation, operation, decommissioning and closure of the repository. See also *Highly Damaged Zone, Excavation Damaged Zone* and *Excavation Disturbed Zone*.

Neo- – Prefix used when referring to something ‘new’ or ‘recent’.

Net Volume (Waste) – The internal volume of the container in which waste is stored.

Nodule – A small, more or less rounded body that is generally harder or softer, and of differing composition, than the enclosing sediment or rock matrix.

Non-Processible Waste – Wastes that are neither incinerable nor compactible, such as heavy gauge metal objects, glass, concrete, tools, heavy slings and cables. Maximum dose rate is 10 mSv/h (1 rem/hr) at 30 cm for storage in LLSBs. Higher dose rate wastes are stored in shielded structures, notably trenches or ICs.

OPG-retained Land – The parcels of land on the Bruce nuclear site for which control has been retained by OPG. This includes the WWMF, certain landfills, and the Heavy Water Plant Lands.

Ordovician – The second period of the *Paleozoic* Era extending from 443 to 490 million years ago; also refers to rocks formed, or sediments laid down, during this period (eg., Ordovician carbonates)..

Orogeny – A period of mountain building that lasts for several to tens of millions of years.

Orthogneiss – A gneiss that is derived from igneous rocks.

Orthophoto – A digital air photo that is like a map, with a uniform scale, after the effects of tilt and relief are removed.

Osmosis – The movement of water across a semi-permeable membrane in order to reduce the difference in solution concentration. Water moves from a volume of low solute concentration to a volume of high solute concentration - essentially diluting the fluid of high solute concentration by the addition of water, and concentrating the fluid of low solute concentration by the removal of water.

Outcrop – An exposure of bedrock at the surface of the Earth. Specifically, an outcrop is the part of a geologic (rock) formation or structure that appears at or above the surface of the surrounding land.

Overcoring – Rock coring directly over an existing smaller diameter borehole to relieve the in situ stresses present in the smaller borehole. Used to measure the magnitude and direction of in situ stresses.

Outcrop – The exposure of bedrock to ground surface through the overlying cover of detritus and soil.

Overpack – An enclosure used to provide physical and/or radiological protection or convenience in handling of a waste package, or to combine two or more waste packages.

Oxic – Often used interchangeably with the term *aerobic*, oxic strictly means the presence of oxygen.

Packer Testing – Refers to the hydraulic testing of rock formations through the isolation of discrete zones with packers. Packers use expandable membranes and air or gas to isolate the zone(s) of interest from the remainder of the bedrock column.

Packstone – A sedimentary carbonate rock in which the granular material is arranged in a self-supporting frame-work, but also contains calcareous mud.

Paleo- – Prefix used when referring to something ‘ancient’ or ‘old’ (e.g., *Paleozoic* refers to ‘ancient/old life’), or which involved ancient conditions (e.g., paleoclimate).

Paleoenvironment – An ancient environment, generally inferred by geological, paleontological, and geochemical evidence.

Paleohydrogeology – The hydrogeologic study (physical/chemical) of the evolution of a site or flow domain based on knowledge of its current state and external perturbations that have acted upon it in geologic time.

Paleozoic – The time span covering approximately 540 to 250 million years ago.

Pangaea – The supercontinent that existed during the Paleozoic and Mesozoic eras (about 300 to 200 million years ago), before the component continents were separated into their current configuration by fragmentation and continental drift.

Passive Margin – A continental boundary formed by rifting and continental rupture, without plate-boundary collisional tectonism.

Performance Requirements – The quantifiable measures of adequate performance of the deep geologic repository system. Each performance requirement should include both a measurable item or parameter and the value of that item or parameter that would identify satisfactory performance of that aspect of the deep geologic repository. See also *Functional Requirement, Design Limit* and *Design Constraint*.

Periglacial – The conditions, processes and landforms associated with non-glacial cold climate conditions. Periglacial environments are those where frost action or permafrost processes dominate.

Permafrost – Ground that has been below 0°C for at least 2 years. It is not necessarily frozen because the freezing point of any included water may be depressed by pressure or salinity, or moisture may not be present. A continuous layer of permafrost is found where the annual mean temperature is below about -5°C.

Permeability – The ease with which a porous medium can transmit water or other fluids. The intrinsic permeability [m^2] of medium is independent of the type of fluid present.

Petrography - That branch of geology dealing with the description and classification of rocks, especially igneous and metamorphic rocks, and especially by means of microscopic examination of thin sections.

Petroliferous – Containing or yielding petroleum

Petrophysics – The study of the physical and chemical properties of rocks, which relates to the distribution of the pore system and the contained water and hydrocarbons.

Phanerozoic – Includes the *Paleozoic*, *Mesozoic*, and *Cenozoic* eras, and represents the time-frame from 540 million years ago to present.

Pinnacle Reef – A small reef patch, consisting of coral growing sharply upwards (with slopes ranging from 45° to nearly vertical). In Southern Ontario, ancient, fossilized pinnacle reefs occur in the Guelph Formation and can become oil and gas traps when they are capped by anhydrite or shale.

Pleistocene – The earlier of two epochs comprising the Quaternary Period covering the time span from 1.8 million years to 11.5 thousand years before present. See also *Holocene*.

Poisson's Ratio – The ratio of the lateral strain (perpendicular to the applied load) to the axial strain (in the direction of the applied load) in a body that has been stressed longitudinally within its elastic limit.

POLARIS – (Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity) is a university-government-industry research collaboration to study earthquakes and associated ground motion in Canada.

Porewater – Water within the connected pore space between mineral grains in low-permeability sediments or rocks in which flow under the influence of hydraulic gradients is inhibited. In contrast with groundwater, which flows into or can be sampled from boreholes over time scales of days to months, laboratory techniques are generally required to extract porewaters from the sediment or rock matrix. See also *Groundwater, Free Porewater*.

Pop-ups – Are low elongated anticlinal ridges formed in response to high horizontal in situ stresses usually in horizontally bedded sedimentary rocks. They are considered as surficial deformation features, affecting only the first few meters of the bedrock surface. Some authors include quarry floor buckles as pop-ups.

Porosity – **Physical Porosity** – The volume of pores per total volume of sample. Pores are defined as everything which is not solid. Interlayer water of clays is considered as part of the pore space.

Diffusion (Accessible) Porosity – The volume of pores, per total volume, accessible for a given solute. Typically determined from diffusion experiments. Solute specific.

Liquid Porosity - the volume of voids occupied by liquid (pure water plus dissolved solutes and oil).

Transport Porosity (also Effective porosity) – The proportion of the *physical porosity* of a rock or soil in which transport of fluids (e.g., gases, water) occurs.

Water Loss Porosity – The volume of pores per total volume of sample, derived from water extraction at 105°C (additional specification if extracted e.g., under vacuum). In argillaceous rocks, water loss porosity at 105°C is usually somewhat smaller than the *physical porosity*, because the bound water is only partially released at this temperature.

Postclosure Monitoring – Monitoring during the time period following closure of the repository. See also *Extended Monitoring*.

Postclosure Phase – The period of time following closure of the deep geologic repository.

Potentiometric surface – An imaginary surface that represents the total hydraulic head in an aquifer. It represents the height above a datum plane at which the water level stands in tightly cased wells that penetrate the aquifer.

Precambrian – All geologic time before the beginning of the Paleozoic Era, preceding 543 million years ago; also refers to rocks formed, or sediments laid down, during this period (eg., Precambrian gneiss).

Precautionary Approach – The precautionary approach is ultimately guided by judgement, based on values and priorities, and it recognizes that the absence of full scientific certainty should not be used as a reason to postpone decisions in the presence of serious or irreversible harm, consistent with Principle 15 of the 1992 Rio Declaration on Environment and Development. Principle 15 of 1992 Rio Declaration on Environment and Development states that "Where there are threats of serious or irreversible damage, lack of full scientific certainty must not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Preclosure Phase – The period of time that includes all activities from siting through to decommissioning and closure of all components of the deep geologic repository.

Preliminary Design – A design product that is sufficiently developed so that management can determine the merit of completing the design based on financial, safety and regulatory criteria.

PSR – Preliminary Safety Report. See *Safety Report.*

Pyrite – A mineral: Fe S_2. Also known as Iron Pyrite or Fool's Gold. A primary ore of sulphur, and often mined for associated gold and copper.

Quadricell – An above-ground storage structure used for intermediate level waste, primarily ion exchange resins.

Quaternary – The upper time period of the *Cenozoic* era, extending from 1.8 million years ago and continuing into the present. It contains two epochs: the *Pleistocene* and the *Holocene*.

Radioactive Waste – Any material (liquid, gaseous or solid) that contains a radioactive "nuclear substance" as defined in Section 2 of Nuclear Safety and Control Act, and which the owner has declared to be waste. In addition to containing nuclear substances, radioactive waste may also contain non-radioactive "hazardous substances", as defined in Section 1 of the CNSC's General Nuclear Safety and Control Regulations.

Radioisotope – A radioactive *isotope*. See also *radionuclide.*

Radionuclide – A radionuclide is an atom with an unstable nucleus which can undergo radioactive decay by the emission of gamma ray(s) and/or subatomic particles. The resulting emission(s) is defined as radiation. See also *radioisotope.*

Ramp – An inclined excavated passageway that connects the surface with an underground workplace or connects one underground workplace to another at a different elevation. Also called inclines or declines.

Receptor – Any person or environmental entity that is exposed to radiation, or a hazardous substance, or both. A receptor is usually an organism or a population, but it could also be an abiotic entity such as surface water or sediment. See also *Exposure Group*.

Recharge – The process by which water is adsorbed and is added to the zone of saturation, either directly into a formation or indirectly by way of another formation. Also, the quantity of water that is added to the zone of saturation.

Redox – A shorthand notation used to describe chemical reduction-oxidation reactions. Such reactions involve a change in the oxidation state of the atoms or molecules involved.

Regressive – Applied to bodies of water and the sediments deposited therein during the lowering or withdrawal of the shoreline due to the contraction of a water body.

Retrieval – 1) The accessing and removal of waste containers from storage facilities for the purpose of transferring to another facility (e.g. a repository).
2) The accessing and removal of waste containers from either closed emplacement rooms (i.e., prior to decommissioning and closure of the repository), or from a sealed deep geologic repository (i.e., after the decommissioning and closure of the underground excavations).

Retrievability – The ability to remove waste packages from where they have been emplaced. Conditions may necessitate the use of different equipment and procedures from those used during emplacement of waste packages.

Retubing Waste – Radioactive waste produced from the fuel channel replacement (retubing) program i.e., pressure tubes, calandria tubes, calandria tube inserts, end fittings, yokes and studs.

Risk – A multi-attribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with actual or potential exposures. It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences.

Rock Compressibility – There are three types of rock compressibility (matrix, bulk, and pore); the fractional change in volume of the bulk volume of the rock with a unit change in pressure.

Rock-Eval Pyrolysis - Used to identify the type and maturity of organic matter and to detect petroleum potential in sediments. The method consists of a programmed temperature heating (in a pyrolysis oven) in an inert atmosphere (helium) of a small sample (~100 mg) to quantitatively and selectively determine (1) the free hydrocarbons contained in the sample and (2) the hydrocarbon- and oxygen-containing compounds (CO_2) that are volatilized during the cracking of the unextractable organic matter in the sample (kerogen).

Rock Mass – An assemblage of blocks or layers of rock material bounded by discontinuities in which groundwater may be present.

Rock Mass Rating (RMR) – A rating system for rock masses based on five parameters: 1) strength of intact rock material, 2) *Rock Quality Designation* (RQD), 3) rock discontinuity spacing, 4) rock discontinuity condition, and 5) groundwater condition. It is also adjusted for rock discontinuity orientation with respect to a tunnel or cut-slope geometry. RMR values range from 0 – 100 and indicate very poor rock (RMR≤20), poor rock (20≤RMR≤40), fair rock (40≤RMR≤60), good rock(60≤RMR≤80), and very good rock (80≤RMR≤100).

Rock Quality Designation (RQD) – The cumulative length of drilled core pieces longer than 100 mm in a run, divided by the total length of the run, expressed as a percentage. Mechanical breaks caused by the drilling process or extracting the core from the core barrel are ignored, but lost or missing core is included in the total core-run length.

Risk Quotient (RQ) – The risk quotient compares predicted exposures to radioactive or hazardous substances to the concentrations of these substances that would have to be exceeded to result in an effect. A RQ greater than one indicates that the contaminant is of concern and requires further investigation.

Safety Analysis – A calculation performed, with or without the assistance of computer software, to address a specific safety issue or as part of a safety assessment.

Safety Assessment (SA) – The process of systematically analyzing the hazards associated with the facility, and the ability of the site and design to provide the safety functions and meet technical requirements.

Safety Case – An integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the geological disposal facility.

Safety Functions – The functions that the DGR must perform to ensure that the safety objective is achieved. These functions are *Isolation* and *Containment.*

Safety Indicator – A quantity used in safety assessments as a measure of the impact of a source, or of the performance of protection and safety provisions.

Safety Objective – The safety objective of the DGR is to prevent unreasonable risk to the health and safety of the public and the workers, and the environment.

Safety Report – A key licensing document which provides an overview of the facility design and operations, summarizes the integrated results of individual safety assessments, and demonstrates that a facility can be constructed, operated, or continue to be operated, without undue risk to health and safety of the workers and the public, and the environment.

Preliminary Safety Report (PSR) is the Safety Report submitted to CNSC in support of an application for a Site Preparation/Construction Licence.

Final Safety Report (FSR) is the Safety Report submitted to CNSC in support of an application for a Licence to Operate.

Saline Water – Water with a salinity between 10 to 100 g/L total dissolved solids. See also *Brackish Water* and *Brine*.

Sandstone – A medium-grained *clastic* sedimentary rock composed of abundant sand size particles with or without a fine-grained matrix (clay or silt) and cemented (commonly silica, iron oxide or calcium carbonate), the consolidated equivalent of sand. May be deposited by water or wind.

Saturated – A state of being completely wet, or in which the rock mass has absorbed and is retaining the greatest possible amount of fluid and can hold no more.

Scenarios – A postulated or assumed set of conditions or events. They are most commonly used in analysis or assessment to represent possible future conditions or events to be modelled, such as the possible future evolution of a repository and its surroundings.

Sealing System – A low-permeability system, typically comprising clay and/or cementitious materials, placed to fill and seal rooms, tunnels, shafts and/or boreholes when they are no longer needed, in order to inhibit groundwater movement and contaminant transport.

Sedimentary Basin – A low area in the earth's crust in which sediments have accumulated over geologic time and subsequently transformed into sedimentary rock, such as the *Michigan Basin* or the *Appalachian Basin*.

Sedimentary Rock – A layered rock made of compacted and cemented sediments such as fragments of other rocks, minerals and/or organic remains (fossils), or precipitated out of solution. *Limestone*, *dolostone*, *shale* and *sandstone* are examples.

Seismicity – The frequency or magnitude of earthquake activity in a given area. See also *microseismicity*.

Seismic Reflection – A surface geophysical method recording seismic waves reflected from geologic strata, giving an estimate of their depth and thickness.

Seismograph – An instrument that detects, magnifies, and records vibrations of the Earth, either earthquake or those generated for applied seismology purposes. Also called a seismometer.

Sensitivity Analysis – A quantitative examination of how the behaviour of a simulated system (e.g., a computer model) varies with change, usually in the values of its parameters.

Shaft – A vertical or near-vertical excavated passageway that connects the surface with an underground workplace or connects two or more underground workplaces at different elevations.

Shale – A fine-grained detrital sedimentary rock, formed by the compaction and cementation of clay, silt, or mud. It may have a fine laminated structure which gives it a fissility along which the rock splits readily.

Shear Strength - The capacity to resist deformation resulting from stresses that cause contiguous parts of a body to slide relatively to each other in a direction parallel to their plane of contact.

Silurian – The third period of the *Paleozoic* Era extending from 443 to 417 million years ago, also refers to rocks formed, or sediments laid down, during this period (e.g., Silurian evaporites).

Slickenside – Term to denote lineated fault surfaces, which also may consist of grooves and/or fibrous minerals. The general definition refers to a rock surface that has been scratched or polished by the effects of friction during structural changes. The term can also refer to changes in the appearance of swelling clays that have been subject to large changes in water content, and to diagenetic features formed as a result of differential compaction of layered sediments.

Solute – A substance that is dissolved in another (e.g. dissolving salt in water: salt is the solute, water is the solvent, and the result is a saline solution).

Sonic Velocity – Acoustic velocity, related to the propagation of acoustic waves in air or water, or P-waves in the solid Earth.

Specific storage – The volume of water that a rock mass (or aquifer) releases, per unit volume of rock mass, per unit decline in pressure head, while remaining fully saturated. Essentially, the volume of water that a confined unit (or aquifer) will release due to a given change in pressure head.

Stakeholder – Any person or organization that has an interest in a particular aspect of the project.

Stored Volume (Waste) – (also As-stored waste volume) The external volume of the storage container in which the waste is currently stored. This volume does not include overpacks or concrete shields which may be required for repository emplacement. See also *Net Volume* and *Emplaced Volume*.

Straddle Packers – A straddle packer is a system of two packers separated by a fixed length into which fluid is injected, after packer inflation, to test the hydraulic properties of the bedrock in a borehole.

Strain – To alter the relations between the parts of a structure or shape by applying an external force.

Stratigraphy – The study of the age relation of rock strata, including the original succession (order of emplacement), form, distribution, composition, fossil content, geophysical and geochemical properties, and the environment of origin and geologic history, of a rock mass. The science primarily involves the description of rock bodies, and their organization into distinctive, mappable units based on their properties and features.

Strength – The ability to withstand differential stress, expressed in the units of stress. See also *stress*.

Stress – In a solid, the force per unit area, acting on any surface within it.

Strike – The direction or trend taken by a structural surface as it intersects the horizontal; measured with respect to the horizontal plane.

Strike-slip Fault – A geologic fault on which movement of the respective fault blocks is parallel to the strike of the fault.

Stylolite – A surface or contact, usually in carbonate rocks, marked by an irregular and interlocking penetration of the two sides: the columns, teeth, and pits on one side, fit into their counterparts on the other side. Stylolites resemble a suture, or 'seam', in the rock, and the 'seams' are usually parallel to bedding surfaces and consist of insoluble rock constituents (clay, iron oxides).

Subcrop – The.occurrence of strata on the undersurface of an inclusive stratigraphic unit that succeeds an important unconformity where overstepping is conspicuous, or an area within which a formation occurs directly beneath an unconformity.

Subduction – The process by which collision of the earth's crustal plates results in one plate's being drawn down or overridden by another, localized along the juncture (subduction zone) of two plates.

Subsurface characterization – All activities carried out in the shafts, tunnels and rooms of the repository and via deep boreholes in the vicinity of the repository for the purpose of gathering geoscience data for the development of a repository design and the associated safety case. Examples of characterization activities are mapping and testing of rock formations during underground excavation, monitoring of groundwater pressures and chemistry via boreholes and within the repository, and in situ testing to measure rock properties.

Sulphide minerals – Mineral compounds of sulphur with one or more positive ions or radicals. Examples include pyrite (FeS_2) and Bornite ($CuFe_5S_4$).

Surfaces (minerals) – **Internal Surface** - Surface areas of water accessible interlayers of (expandable) clay minerals (smectites) mass of solids. **External Surfaces** - Surface areas of mineral grains or clay particles of a porous medium per mass of solids. **Total Surfaces** – The sum of external and internal surface areas.

Technical Computing Software – Software used by technical specialists for design, analysis or simulation of engineered systems. Examples include finite element stress analysis software, waste site safety analysis software, radiation shielding software, and waste inventory database software.

Tectonic – Said of or pertaining to the forces involved in, or the resulting structures or features of, *tectonics.* **Neotectonic** is tectonic activity that had occurred since the last *glaciation*, in the last 12,000 years.

Tectonics – A branch of geology dealing with a broad architecture of the outer part of the earth, that is, the regional assembling of structural or deformational features, a study of their mutual relations, origin, and historical evolution.

Tensile Strength - The capacity of a material to resist a normal stress that tends to pull apart the material on the opposite sides of the plane on which it acts.

Thermal Maturity – A measure of the state of a rock in terms of hydrocarbon generation. The sedimentary rock type, physical environment, and temperature of the environment will determine thermal maturity. Rocks that have been exposed to high temperatures, resulting in a different distribution of the various compounds (e.g. the alteration of organic molecules and petroleum to hydrocarbons - oil and/or gas) are defined as mature, and the extent of such alteration determines the level of maturity.

Till – Non-sorted, non-stratified sediment deposited by a glacier. Generally contain some proportion of all of the soil fractions (clay, silt, sand and gravel).

Time-Dependent Deformation – Deformation that occurs slowly and continuously through time leading to gradual *strain* failure of a rock mass. Synonymous with creep and swelling. An example is the gradual inward convergence of the walls of underground openings in response to *stress*.

Tortuosity (τ) – A geometric factor that accounts for the effective transport path length for solute transport within a porous medium (L_e) compared to the shortest straight-line transport path length (L) between two points, as follows: $\tau = (L_e / L)^2$. Note that $\tau \geq 1$.

Tortuosity Factor (τ_f) – An empirical factor that combines the *tortuosity* τ and the *constrictivity* δ to describe the geometric properties of the porous medium that influence diffusive transport. It is defined as $\tau_f = \delta / \tau$. Note that $\tau_f \leq 1$.

Total Organic Carbon (Groundwater) – The total of both dissolved and particulate carbon. The bulk of organic carbon in water is composed of humic substances and partly degraded plant and animal matter that is resistant to microbial degradation.

Total Stress – Also known as the applied stress. Defined as the sum of the *effective stress* plus the porewater pressure. See also *Effective Stress*.

Traditional ecological knowledge – Traditional ecological knowledge is a subset of Aboriginal traditional knowledge. Traditional ecological knowledge refers specifically to all types of knowledge about the environment derived from the experience and traditions of a particular group of people. There are four traditional ecological knowledge categories: knowledge about the environment; knowledge about the use of the environment; values about the environment; and the foundation of the knowledge system.

Transfer Fault – A strike-slip fault that links two segments of a rift that are offset relative to one another.

Transgressive - Applied to bodies of water and the sediments deposited therein during the gradual expansion of a shallow sea resulting in the progressive submergence of land, as when seal level rises or land subsides.

Transmissivity – The product of *hydraulic conductivity* and aquifer thickness; a measure of a volume of water to move through an aquifer. Transmissivity is a measure of the subsurface's ability to transmit groundwater through its entire saturated thickness and affects the potential yield of wells.

Tritium – Radioactive isotope of hydrogen (H^3).

Ultramafic – Term to describe an igneous rock composed of > 90% *mafic* minerals.

Uncertainty Analysis – An analysis of the amount of variation in the results of assessments or analyses due to incomplete knowledge about the current and future states of a system.

Unconformity – An erosion surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous. An unconformity refers to any substantial break in the geologic record, where a rock unit is overlain by another that is not the next in the stratigraphic succession.

Underground Service Areas – Any excavations within the deep geologic repository that provide the space for the infrastructure to characterize, demonstrate, construct, operate, monitor and decommission a deep geologic repository. Service areas include all excavations in a deep geologic repository that are not classified as tunnels, shafts, ramps, emplacement rooms or boreholes.

Uniaxial Compressive Strength - Represents the capacity of a material to withstand applied mechanical compressive forces; also is that value of uniaxial compressive stress reached when the material fails completely. The strength is usually expressed in units of stress.

Validation (Model) – The process of building confidence that a model adequately represents a real system for a specific purpose.

Valued Ecosystem Component (VEC) – VECs are features of the environment selected to be a focus of the environmental assessment because of their ecological, social, or economic value, and their potential vulnerability to the effects of the DGR project.

Verification (Model) – The process of determining whether a computer model correctly implements the intended conceptual or mathematical model.

Vug – A cavity, often with a mineral lining of different composition than the surrounding rock.

Wackestone – A mud-supported sedimentary rock containing >10% granular material.

Waste Acceptance Criteria (WAC) – Formal criteria which define the qualities of waste packages (including the waste) that are accepted for emplacement in the repository.

Waste Arisings – The amount of waste produced at the stations, prior to any *waste conditioning*.

Waste Characterization – Activities to define the physical, chemical and radiological characteristics of the radioactive waste.

Waste Conditioning – Those operations that produce a waste package suitable for handling, transport, storage and/or disposal. Conditioning may include the conversion of the waste to a solid waste form, enclosure of the waste in containers, and, if necessary, providing an overpack.

Waste Package – The waste material, the container, and any external barriers (e.g. shielding material), as prepared in accordance with requirements for handling, transfer and emplacement in the repository. It is a discrete unit that can be individually identified and handled at the repository facility. See also *Waste Packaging*.

Waste Packaging – The container and any external barriers (e.g., *overpack*, shielding material), used for handling, transfer and disposal of the waste. It does not include the waste itself. See also *Waste Package*.

Water Content – Also known as volumetric water content. Identical to *water loss porosity* for a fully saturated rock sample.

Water Loss Porosity – Refers to the ratio of the water-filled pore volume in a rock sample with respect to the total volume of the rock sample, and is typically measured during the heating and drying of the sample.

Water table (groundwater table) – The top water surface of an unconfined aquifer at atmospheric pressure.

Westbay Casing – A multi-level modular groundwater monitoring, sampling and testing system, consisting of multiple inflatable packers, valved ports, blank pipe segments and couplings to seal and provide access to multiple monitoring zones in one borehole. Monitoring, sampling and testing are carried out with the use of several available types of wireline operated probes.

Wetting phase – The preference of a solid to contact one liquid or gas, known as the wetting phase, rather than another. The wetting phase will tend to spread on the solid surface and a porous solid will tend to imbibe the wetting phase, in both cases displacing the non-wetting phase. Rocks can be water-wet, oil-wet or intermediate-wet. The intermediate state between water-wet and oil-wet can be caused by a mixed-wet system, in which some surfaces or grains are water-wet and others are oil-wet, or a neutral-wet system, in which the surfaces are not strongly wet by either water or oil. Both water and oil wet most materials in preference to gas, but gas can wet sulphur, graphite and coal.

Waste Package Receiving Building (WPRB) – The building at the DGR surface where waste packages arrive for transfer underground.

Wrench Fault – A regional scale *strike-slip fault*. Typically, the term wrench fault implies that the strike-slip movement resulted in the formation of a complex band of subsidiary faults and folds.

Waste Volume Reduction Building (WVRB) – The building at WWMF containing waste volume reduction equipment.

Western Waste Management Facility (WWMF) – The centralized processing and storage facility on the Bruce nuclear site for OPG's L&ILW and for the dry storage of used fuel from Bruce nuclear generating stations.

X-Ray Diffraction - The scattering of x-rays by matter, especially crystals, with accompanying variation in intensity due to interference effects. The amount of diffraction of a beam of known wavelength can provide a means of measuring the distance between atoms in a crystal, as well as their relative position in three dimensions (i.e. crystal structure).

X-Ray Radiography – involves the use of invisible, highly penetrating, short wavelength electromagnetic radiation to non-destructively obtain an image of the hidden details of a target.

Zone of Influence – The area around a pumping well within which the water table or potentiometric surface has been changed due to groundwater withdrawal.

APPENDIX B: BASIS FOR EIS

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Table B-1: Basis for the EA

<table>
<tr><th>Project Works and Activities</th><th>Description</th></tr>
<tr><td>Site Preparation</td><td>Site preparation would begin after receipt of a Site Preparation Licence and would include clearing approximately 30 ha of the DGR Project site and preparing the construction laydown areas. Activities would include:
Removal of brush and trees and transfer by truck to on-site storage;
Excavation for removal and stockpiling of topsoil and truck transfer of soil to stockpile on-site;
Grading of sites, including roads, construction laydown areas, stormwater management area, ditches;
Receipt of materials including gravel, concrete, and steel;
Installation of construction roads and fencing;
Receipt and installation of construction trailers and associated temporary services; and
Install and operate fuel depot for construction equipment.</td></tr>
<tr><td>Construction of Surface Facilities</td><td>Construction of surface facilities will include the construction of the waste transfer, material handling, shaft headframes and all other temporary and permanent facilities at the site. Activities would include:
establish a concrete batch plant;
receipt of construction materials, including supplies for concrete, gravel, and steel by road transportation;
excavation for and construction of footings for permanent buildings, and for site services such as domestic water, sewage, electrical;
construction of permanent buildings, including headframe buildings associated with main and ventilation shafts;
receipt and set up of equipment for shaft sinking;
construction of abandoned rail bed crossing between WWMF and the DGR site;
fuelling of vehicles; and
construction of electrical substation and receipt and installation of standby generators.</td></tr>
<tr><td>Excavation and Construction of Underground Facilities</td><td>Excavation and construction of underground facilities will include excavation of the shafts, installation of the shaft and underground infrastructure (e.g., ventilation system) and the underground excavation of the emplacement and non-storage rooms. Activities will include:
drilling and blasting (use of explosives) for construction of main and ventilation shafts, and access tunnels and emplacement rooms;
receipt and placement of grout and concrete, steel and equipment;
dewatering of the shaft construction area by pumping and transfer to the above-ground stormwater management facility;
temporary storage of explosives underground for construction of emplacement rooms and tunnels;
receipt and installation of rock bolts and services; and
installation of shotcrete.</td></tr>
</table>

Table B-1: Basis for the EA (continued)

Project Works and Activities	Description
Above-ground Transfer and Receipt of Waste	Above-ground handling of wastes will occur during the operations phase of the DGR Project and will include receipt of L&ILW from the WWMF at the staging area in the DGR Waste Package Receiving Building (WPRB) and on-site transfer to shaft. Above-ground handling of wastes includes: • receipt of disposal-ready waste packages from the WWMF by forklift or truck • offloading of waste packages at the WPRB; • transfer of waste packages within the WPRB by forklift or rail cart; • temporary storage of waste packages inside the WPRB.
Underground Transfer of Waste	Underground handling of wastes will take place during the operations phase of the DGR Project and will include: • receipt of waste packages at the the main shaft station; • offloading from cage and transfer of waste packages by forklift to emplacement rooms; • rail cart transfer of some large packages (Heat Exchangers/Shield Plug Containers) to emplacement rooms; • installation of end walls on full emplacement rooms; • remedial rock bolting and rock wall scaling; • fuelling and maintenance of underground vehicles and equipment; • receipt and storage of fuel for underground vehicles. Emplacement activities will be followed by a period of monitoring to ensure that the DGR facility is performing as expected prior to decommissioning.
Decommissioning of the DGR Project	Decommissioning of the DGR Project will require a separate environmental assessment before any activities can begin. Decommissioning of the DGR Project will include all activities required to seal shafts and remove surface facilities including: • removal of fuels from underground equipment; • removal of surface buildings, including foundations and equipment; • receipt and placement of materials, including concrete, asphalt, sand, bentonite for sealing the shaft; • construction of concrete monolith at base of two shafts, removal of shaft infrastructure and concrete liners, and reaming of some rock from the shafts and shaft stations; • sealing the shaft; and • grading of the site. The waste rock pile (limestones) will be covered and remain on-site.
Abandonment of the DGR Facility	Timing of abandonment of the DGR facility will be based on discussion with the regulator. Activities may include removal of access controls.
Presence of the DGR Project	Presence of the DGR Project represents the meaning people may attach to the existence of the DGR Project in their community and the influence its operations may have on their sense of health, safety and personal security over the life cycle of the DGR Project. This includes the aesthetics and vista of the DGR facility.

Table B-1: Basis for the EA (continued)

Project Works and Activities	Description
Waste Management	Waste management represents all activities required to manage waste during the DGR Project. During construction waste management will include managing the waste rock along with conventional waste management. During operations, waste management would include managing conventional and radiological wastes from the underground and above-ground operations. Decommissioning waste management may include management of conventional and construction wastes. Activities include: • transfer of waste rock, by truck to the WRMA; • placement of waste rock on the storage pile; • collection and transfer of construction waste to on-site or licensed off-site facility; • collection and transfer of domestic waste to licensed facility; • collection, processing and management of any radioactive waste produced at the DGR facility; • collection, temporary storage and transfer of toxic/hazardous waste to licensed facility.
Support and Monitoring of DGR Life Cycle	Support and monitoring of DGR life cycle will include all activities to support the safe construction, operation, and decommissioning of the DGR Project. This includes: • operation and maintenance of the ventilation fans, heating system, electrical systems, fire protection system, communications services, sewage and potable water system and the standby generator; • collection, storage, and disposal of water from underground sumps, and of wastewater from above-and below ground facilities; • management of surface drainage in a stormwater management facility; • monitoring of air quality in the facility, exhaust from the facility, water quality of run-off from the developed area around the shafts and Waste Rock Management Area, water quality from underground shaft sumps and geotechnical monitoring of various underground openings; • maintenance and operation of fuel depots above-ground (construction only) and below-ground; and • administrative activities above- and below-ground involving office space, lunch room and amenities space.
Workers, Payroll and Purchasing	Workers, payroll and purchasing will include all workers required during each phase to implement the DGR Project. Activities include: • spending in commercial and industrial sectors; • transport of materials purchased to the site; and • workers travelling to and from site.

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APPENDIX C: SAMPLE CALCULATIONS

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Radial Flow to a Well
Overburden and Shallow Bedrock (0-180 m)

Eqn 6.14	Ro=3(Ho-h)*sqrt(K)		
Eqn 6.12	Q=pi*K*B*(Ho-h) / [ln(Ro/Rw)]		
Highest value	K=	**1.00E-08**	**m/s**
Hydr. Cond.	K=	0.0100	um/s
Aquifer Thickness	B=	180.0	m
System Length	X=	3.5	m
	H=	180	m
	h=	0.1	m
Drawdown	(Ho-h)=	179.9	m
	(Ho-h)=	590.2230971	ft
Eqn 6.14	Ro=	177.067	ft
	Ro=	53.970	m
	Rw	4.00	
Eqn 6.15	L=	26.985	m
Eqn 6.12	Q=	7.82E-04	m^3/s
	Q(Total) =	7.82E-04	m^3/s
	Q=	47	L/min
	Q=	**67,557**	L/day
	Imp gal/day	14880.3	
	US gal/day	17778.0	
	Igpm	10.33	
	US gal/min	12.35	

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