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REPORT ON

LLW GEOTECHNICAL FEASIBILITY STUDY
WESTERN WASTE MANAGEMENT FACILITY
BRUCE SITE TIVERTON, ONTARIO

Submitted to:

Municipality of Kincardine
and
Ontario Power Generation
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SUMMARY

This report presents the results of an assessment of the geotechnical feasibility of constructing a LLW permanent repository at OPG's Western Waste Management Facility at the former Bruce Nuclear Power Development site near Tiverton, Ontario (the Bruce Site). The assessment was undertaken as part of activities associated with a Memorandum of Understanding between OPG and the Municipality of Kincardine and considered a number of generic LLW repository concepts previously developed by OPG, specifically:

- three near surface concepts involving emplacement of LLW in structural concrete vaults located on ground surface (**Covered Above Grade Concrete Vault**), in a shallow trench at a depth of about 10 m to 15 m below ground surface (**Shallow Concrete Vault**) and in a deep trench at a depth of about 25 m below ground surface (**Deep Concrete Vault**); and

- four Rock Cavern Vault concepts involving emplacement of LLW in unlined, mined caverns in the bedrock at a depth of about 50 m to 100 m below ground surface (**Shallow Rock Cavern Vault**) and at depths of about 200 m to 800 m below ground surface (**Deep Rock Cavern Vault**) in (i) a thick salt bed, (ii) a low permeability shale sequence, and (iii) a low permeability limestone sequence which were projected to underlie the Site.

Based on available site specific information (which is limited to a depth of about 100 m below ground surface) and projected geological, hydrogeological and geotechnical/geomechanical data from other sites in Southern Ontario, the Bruce Site is underlain by about 1.5 m to 18 m of overburden consisting of a complex sequence of surface sand and gravel from former beaches overlying clayey to sandy silt till with interbedded lenses of sand of variable thickness. The overburden is underlain by near flat lying Paleozoic age dolostone, shale and limestone sedimentary rock to an estimated depth of about 800 m where Precambrian granite basement is encountered. Significantly, the thick salt beds which are mined by underground and solution methods at Goderich were eroded from beneath the Bruce area in the geological past, resulting in collapse and differential subsidence of the overlying rocks (i.e. above a depth of about 300 m). Below this depth, the Ordovician age (approximately 430 to 500 million years old) shale and limestone bedrock formations are expected to be highly predicable and of uniformly low permeability.

For geotechnical feasibility assessment purposes, four groundwater zones were identified at the Bruce Site:

- a surficial groundwater zone which is characterized by glacial sediments of very low to moderate permeability and vertically downward groundwater flow into an underlying shallow bedrock groundwater zone
- a shallow bedrock groundwater zone comprising the upper approximately 150 m of Devonian and Silurian age bedrock which is characterized by dolostones of moderate

to high permeability and horizontal flow of fresh to brackish groundwater that discharges into the near-shore area of Lake Huron

- an intermediate bedrock groundwater zone comprising Silurian age dolostones and shales (about 150 m to 400 m depth zone) which are characterized by low to moderate permeability and horizontal flow of saline to brine groundwater that discharges into off-shore portions of Lake Huron
- a deep bedrock groundwater zone comprising Ordovician age shales and limestones which underlie the site below a depth of about 400 m and which are characterized by extremely low permeability with solute transport being dominated by chemical diffusion and no direct discharge to Lake Huron.

Based on the results of this assessment, including a review of precedent experience with underground openings in Southern Ontario, it appears that at least two of the generic LLW permanent repository options are geotechnically feasible at the Bruce Site. These are:

- **Covered Above Grade Concrete Vault (CAGCV)**
- **Deep Rock Cavern Vault (DRCV)** in either:
    - the Queenston or Georgian Bay **shale** Formations which are projected to underlie the Bruce Site at a depth of about 425 m to 600 m below ground surface; or
    - the Lindsay or Verulam **limestone** Formations which are projected to underlie the Bruce Site at a depth of about 630 m to 750 m below ground surface.

In addition, two other repository options may be geotechnically feasible at the Bruce Site but additional studies will be required to confirm their feasibility. These are:

- **Shallow Concrete Vault (SCV)**
- **Shallow Rock Cavern Vault (SRCV)** in the Amherstburg dolostone Formation at a depth of about 50 m to 100 m below ground surface.

Because of the absence of suitable host formations, two of the repository options are not geotechnically feasible at the Bruce Site. These are:

- **Deep Concrete Vault (DCV)**
- **Deep Rock Cavern Vault (DRCV)** in a thick Silurian age salt bed such as is currently being mined underground at Goderich.

Hydrogeological and geochemical input parameters for a co-dependent preliminary Safety Assessment are provided in the report.

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1.0 INTRODUCTION

1.1 Purpose of Study

Golder Associates Ltd. (Golder) has been retained by Ontario Power Generation (OPG), Nuclear Waste Management Division to assess the geotechnical feasibility of constructing a Low Level Waste (LLW) permanent repository at OPG's Western Waste Management Facility (WWMF) located at the former Bruce Nuclear Power Development site (now the Bruce Power site) near Tiverton, Ontario. The location of the Bruce Site together with other OPG facilities in Southern Ontario is shown on Figure 1.

It is understood that the study is being undertaken as part of activities associated with a Memorandum of Understanding between OPG and the Municipality of Kincardine on future LLW management at the Bruce Site. It is further understood that a separate but co-dependent preliminary Safety Assessment will be undertaken by Quintessa Ltd. to assess the long-term safety and performance of geotechnically feasible repository concepts.

For the purposes of this study, the "Bruce Site" is defined generally by the outer fence line of the former Bruce Nuclear Power Development site as shown on Figure 2.

1.2 Scope of Study

Identification of the site specific geological/hydrogeological conditions and site specific geotechnical characteristics at the Bruce Site was based exclusively on a review and synthesis of available, existing data as obtained from:

- Published regional geological reports, maps, etc;
- OPG site specific investigations;
- OPG investigations/studies at other facilities located within geologic units which underlie the Bruce Site;
- Golder files; and
- Ontario Water Well Records.

No original field investigations were undertaken as part of this study.

Further, the study considered the geotechnical feasibility of constructing any or all of four generic LLW permanent repository concepts at the Bruce Site. These generic concepts are described in a report prepared for OPG by Golder Associates Ltd. and Morrison Knudsen Corporation in 1998 (Reference 12). The four generic repository concepts are illustrated schematically on Figure 3. It should be noted that while the generic Rock Cavern Vault (RCV) assumed a vault depth of about 100 metres and a ramp access, the present study considered a vault at depths to about 800 metres and either a ramp or shaft access.

1.3 Study Organization

As illustrated diagrammatically on Figure 4, the geotechnical feasibility study comprised three main activities:

- synthesis and assessment of the geological, hydrogeological and geotechnical conditions at the Bruce Site;
- assessment of the design basis and geotechnical design requirements for each of the generic LLW permanent repository concepts; and
- assessment of the geotechnical feasibility of successfully adapting the generic concepts to the Bruce Site.

As further indicated on Figure 4, the feasibility assessment was carried out in two stages:

- a preliminary screening of the generic concepts to identify and eliminate those that were patently unsuitable to the Bruce Site; and
- a more detailed geotechnical assessment of those generic concepts deemed potentially applicable at the Bruce Site (i.e. those that passed the initial screening assessment).

This report follows the foregoing study organization.

Section 2	Describes the preliminary geotechnical screening analysis
Section 3	Describes the site-specific geological, hydrogeological and geotechnical conditions at the Bruce Site
Section 4	Describes at a conceptual level the application of the potentially feasible, generic LLW repository concepts to the Bruce Site
Section 5	Describes precedent experience in constructing unlined mined openings in the major bedrock formations which underlie the Bruce Site
Section 6	Describes the geotechnical feasibility assessment and identifies those LLW repository concepts considered geotechnically feasible at the Bruce Site
Section 7	Summarizes input parameters for the preliminary Safety Assessment of those repository concepts considered geotechnically feasible at the Bruce Site, notes significant information gaps identified during the course of the study and suggests additional studies which could be carried out if it is decided to pursue any of the options.
Section 8	Provides a list of reference material used in the assessment

2.0 PRELIMINARY SCREENING ASSESSMENT

The following discussion provides an overview of the geological and hydrogeological conditions beneath the Bruce Site for the purpose of preliminary screening of the LLW repository concepts to identify those concepts which are potentially applicable to the site. A more detailed discussion of the geological and hydrogeological conditions is provided in Section 3 of this report.

2.1 Overview of Site Geology

The Bruce Site 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 Holmes Bay in the southwest and Baie du Dore in the northeast (see Figure 5). The Douglas Point promontory is a bedrock controlled feature with near flat lying dolostone bedrock outcropping along the shoreline, hence the resistance of the promontory to lake erosion.

The relief of Douglas Point varies between elevation 176 m (Lake Huron level) and elevation 195 m, the higher areas coinciding with the Nipissing Bluff, as indicated on Figure 5. Further inland the topography rises steeply 20 to 30 m along the Algonquin Bluff. Both of these features are ancient beaches and shoreline bluffs eroded by post-glacial phases of Lake Huron.

- ***Overburden***

The overburden underlying the Bruce Site is comprised of a comparatively complex sequence of surface sand and gravel from former beach deposits overlying clayey to sandy silt till with interbedded lenses of sand of variable thickness. Near the shoreline, sand, gravel and boulders left from beach deposits thinly overlie the bedrock.

The distribution of overburden thickness overlying the bedrock throughout the site was assessed through contouring of the available geotechnical borehole information for the site previously compiled in 1986/87 by Ontario Hydro (Reference 27) and subsequently updated for a few additional drillholes (Reference 28). Details of the overburden thickness are discussed in Section 3. However, in general terms the thickness of overburden throughout the site varies from about 4.5 m beneath the northwestern half of the site to a maximum of 15 to 20 m within a localized area in the central eastern portion of the site in the vicinity of the Western Waste Management Facility. The approximate area with overburden thickness greater than 15 m is shown on Figure 5.

- ***Bedrock***

The Bruce Site is underlain by near flat lying Paleozoic age dolostone, limestone and shale sedimentary rocks to a depth of approximately 800 m where the Precambrian granitic basement is encountered. OPG has carried out investigations of the bedrock to depths of approximately 100 m below ground surface. To obtain an understanding of the full stratigraphic sequence, records were obtained for three deep natural gas exploration drillholes put down to the

Precambrian basement within 5 km of the site (see Figure 6). The records were obtained from the Oil Gas Salt Resources Library in London, Ontario and included the well cards listing formation contacts and the natural gamma and neutron borehole geophysical records. The records of the three holes were assessed and a representative stratigraphy was developed using the Texaco #6 drillhole as shown on Figure 6.

The bedrock sequence is discussed in detail in Section 3. In summary, the entire Paleozoic sedimentary sequence beneath the study area is in the order of 800 m thick and overlies the Precambrian basement. The sequence consists of approximately 375 m of Devonian and Silurian age dolostones extending downward through the Amherstburg, Bois Blanc, Bass Island, Salina, Guelph, Lockport and Reynales Formations. This sequence is underlain by an approximately 230 m thick section of predominately shale consisting of the Silurian age Cabot Head Formation (~30 m) and Manitoulin Formation dolostone (~6 m), the Ordovician age Queenston Formation (~80 m), the Georgian Bay Formation (~95 m) and the Collingwood Formation (~33 m). The shales overlie a 185 to 190 m thick sequence of Ordovician age very fine grained, non-porous argillaceous to shaly limestone including the Lindsay, Verulam, Bobcaygeon and Gull River Formations.

Beneath the Bruce Site, the Salina Formation (~200 m) is comprised of dolostone, shaly dolostone and shale with minor thin anhydrite beds (Figure 6). The Salina Formation is unique in that it hosts extensive salt deposits within some of its members in the Goderich area, but no salt has been identified north of Point Clark, approximately 30 km south of the Bruce Site (Reference 8). At Goderich, the total thickness of salt within these four members is approximately 150 m (Reference 8). The A_2 salt which is approximately 27 m thick is mined underground off-shore beneath Lake Huron and the B salt (~100 m) is mined by solution methods on-shore beneath Goderich.

In the geological past, the Salina salt deposits formerly extended beneath the Bruce Site and beyond. However, sub-erosion of the salt by circulating water during Late Silurian and Devonian times subsequently removed all of the salt beds. What remained was the insoluble component of the salt beds including anhydrite and dolostone breccias.

The sub-erosion of the Salina salts from beneath the Bruce Site has structurally influenced the entire overlying rock sequence through collapse and differential subsidence. This has resulted in warping of the overlying strata, development of vertical fracturing and overall enhancement of formational permeability extending through the Devonian sequence.

2.2 Overview of Site Hydrogeology

The areas surrounding the Bruce Site are dependent upon groundwater for both municipal well supplies and private domestic and agricultural supplies. MOE water well records indicate that approximately 80 percent of the wells are completed in the upper portion of the bedrock and that the balance of the wells are completed within water bearing granular layers in the overburden.

Based on reported water levels in the wells, groundwater flow in the upper bedrock is westward toward Lake Huron with groundwater discharging into the near-shore area of the lake (see also Section 3.3.2 and Figure 18).

Based on available site data (which is limited to the upper approximately 100 m of rock) and data extrapolated from deep hole testing at other sites along the north shore of Lake Ontario and along the Niagara Escarpment, the hydraulic conductivity of the bedrock underlying the Bruce Site is expected to be very variable, ranging from of the order of 10^{-5} to 10^{-7} m/sec in the Silurian and Devonian age dolostones to of the order of 10^{-12} m/sec in the Ordovician age shales and limestones (see also Section 3.3.1 and Figure 17). Similarly, the groundwater quality is expected to range from fresh to brackish in the Devonian age dolostones to brine (total dissolved solids of as much as about 300,000 mg/L) in the lower, Ordovician age shales and limestones.

Based on the foregoing, an overall conceptual hydrogeological model of the Bruce Site was developed to provide a hydrogeological framework for geotechnical feasibility assessment and preliminary Safety Assessment purposes. As discussed in Section 3.3.5, this model consists of four groundwater zones:

- a surficial groundwater zone which is characterized by glacial sediments of very low to moderate permeability and vertically downward groundwater flow into an underlying shallow bedrock groundwater zone
- a shallow bedrock groundwater zone comprising the upper approximately 150 m of Devonian and Silurian age bedrock which is characterized by dolostones of moderate to high permeability and horizontal flow of fresh to brackish groundwater that discharges into the near-shore area of Lake Huron
- an intermediate bedrock groundwater zone comprising the Silurian age dolostones and shales (about 150 m to 400 m depth zone) which are characterized by low to moderate permeability and horizontal flow of saline to brine groundwater that discharges into off-shore portions of Lake Huron
- a deep bedrock groundwater zone comprising the Ordovician age shales and limestones which underlie the site below a depth of about 400 m and which are characterized by extremely low permeability with solute transport being dominated by chemical diffusion and no direct discharge to Lake Huron.

2.3 Overview of LLW Permanent Repository Concepts

As indicated in Section 1.2, the study considered four generic LLW repository concepts. These four generic concepts were identified as:

1) Covered Above Grade Concrete Vault (CAGCV);
2) Shallow Concrete Vault (SCV);
3) Deep Concrete Vault (DCV); and
4) Rock Cavern Vault (RCV).

The four concepts are illustrated schematically on Figure 3.

These four LLW repository concepts, in part, rely on the design of multi-barrier measures to assure operational and long-term LLW safety and isolation. The multi-barrier concept is purposely designed to satisfy regulatory safety requirements for the site-specific geologic and hydrogeologic conditions provided by the site. These barriers may include LLW waste form conditioning and emplacement packaging, engineered repository structure, backfill and sealing systems, and the geological and hydrogeological setting. In general, the near-surface LLW repository concepts rely on waste form conditioning and engineered repository barrier systems (i.e. concrete vault and cover) for stability and containment, as well as, radionuclide retention and retardation in the geosphere. The Rock Cavern Vault (RCV) concept is intent on emplacing LLW within stable rock formations in which waste form conditioning and engineered barrier systems, if required, would provide additional long-term safety. The intent of this section is to describe the individual repository concepts relevant to understanding applicability at the Bruce Site.

- ***Covered Above Grade Concrete Vault Concept (CAGCV)***

The generic CAGCV (Covered Above Grade Concrete Vault) concept involves the construction of a concrete vault at the ground surface. The concrete vault is covered with an engineered soil cover as much as 5 m thick. With this concept, the principal contaminant release mechanism results from surface water infiltration (precipitation) entering the repository, contacting the LLW packages and waste forms, and then seeping into the underlying groundwater table (see Figure 7). To minimize contaminant release, the concept utilizes the engineered cover and the vault structure itself to divert surface water infiltration away from the LLW.

The repository can be constructed in either well drained soil or bedrock which is capable of safely supporting the weight of the vault. The footprint of the generic CAGCV repository, including buffer zone, is approximately 39 ha. Waste preparation and support facilities require approximately 61 ha of additional area on-grade.

- ***Shallow Concrete Vault Concept (SCV)***

The generic SCV (Shallow Concrete Vault) concept involves the excavation of a soil trench to a nominal depth of approximately 14 m, and construction of a concrete vault within the trench for waste containment and isolation purposes. The trench is backfilled on completion of waste emplacement and covered with an engineered soil cover at least 2 m thick. Due to the required excavation depth, it is most likely that a repository of this type would be situated across or below the groundwater table.

With the SCV concept, there are two potential contaminant release mechanisms: surface water infiltration (precipitation) which enters the repository, contacts the LLW packages and waste forms, and then escapes into the groundwater; and lateral groundwater flow which passes through the repository (see Figure 7). To minimize contaminant release, the concept utilizes the engineered cover and the vault structure itself to divert surface water infiltration away from the repository, and the low hydraulic conductivity of the host formation and trench backfill to control groundwater flow through the repository. To prevent flooding and overflow of the repository (i.e. prevention of the so-called "bathtub" effect) the amount of infiltration through the engineered cover must be less than the potential seepage flow out of the facility.

Geological and hydrogeological conditions required to facilitate the construction of this concept include:

- Dense to hard soils capable of supporting an approximately 14 m deep trench with minimal set back slope angles to facilitate construction.
- A soil thickness sufficient to accommodate the repository.

The footprint of the generic SCV repository, including buffer zone, is approximately 50 ha. Waste preparation and support facilities require 50 ha of additional area on grade.

- ***Deep Concrete Vault Concept (DCV)***

The generic DCV (Deep Concrete Vault) concept involves the excavation of a trench of the order of 25 m in depth and the construction of a concrete containment vault at significant depth below the groundwater table. Following waste emplacement operations, the repository is backfilled to grade with low permeability soil. As the DCV is isolated from the surface water infiltration zone, the principal contaminant release mechanism with this concept is groundwater flow passing through the repository and contacting the LLW packages and waste forms, (see Figure 7) or molecular diffusion out of the wastes. The concept utilizes the low hydraulic conductivity of the host formation and the trench backfill as well as the vault structure itself to minimize the amount of groundwater flow through the repository.

The desired soil conditions for the DCV concept include:

- Dense to hard soils to facilitate excavation of an approximately 20 m deep trench.
- A low hydraulic conductivity soil strata of massive composition and of sufficient thickness to accommodate the repository.

The footprint of the generic DCV repository, including the buffer zone, is approximately 63 ha. Waste preparation and support facilities require approximately 37 ha of additional area on grade.

- ***Rock Cavern Vault Concept (RCV)***

The RCV (Rock Cavern Vault) involves the construction of an unlined vault within stable, low permeability bedrock using conventional excavation (mining) methods. As the RCV is assumed to be located at a significant depth below the groundwater table, the principal contaminant release mechanism is groundwater flow passing through the repository and contacting the LLW packages and waste forms, (see Figure 7) or molecular diffusion out of the waste. The RCV concept utilizes the low hydraulic conductivity of the host bedrock formation to minimize the groundwater flow through the repository.

While the generic RCV concept assumed a vault at a depth of about 100 m below ground surface, for this study four host formations for the RCV were to be considered:

- The lower portion of the Amherstburg Formation or the Bois Blanc Formation dolostones which were projected to underlie the site area to a depth of about 100 m below ground surface;
- A thick salt bed within the Salina Formation which was projected to underlie the site area at a depth of about 200 m to 400 m below ground surface;
- The Queenston, Georgian Bay or Collingwood shale Formations which were projected to underlie the site area at a depth of about 400 m to 600 m below ground surface; and
- The Lindsay, Verulam, Bobcaygeon and Gull River limestone Formations which were projected to underlie the site area at a depth of about 600 m to 800 m below ground surface.

For the shallow option (less than 100 m depth) ramp access may be considered. For the deeper options, shaft access for mining, waste placement and ventilation has been assumed.

The required bedrock conditions include competent bedrock capable of long-term self support with minimal required ground control and low hydraulic conductivity.

The footprint of the generic RCV repository is approximately 18 ha (no buffer zone is required). Waste preparation and surface support facilities require approximately 82 ha of area on grade.

2.4 Applicability of Concepts to Bruce Site

Existing anthropogenic surface constraints at the Bruce Site such as power transmission corridors, existing waste management facilities including conventional waste landfills, and buildings are shown on Figure 5. Also shown on Figure 5 is the area of the site where the total overburden thickness exceeds 15 m (with a maximum proven thickness of 18 m).

Considering the surface constraints, with the possible exception of the Rock Cavern Vault, none of the generic permanent repository layouts identified in Section 2.3 are directly applicable to the Bruce Site. However, if it is assumed that the containment vault and related works can be physically separated from the waste preparation and support facilities, siting of the generic repository concepts becomes feasible.

It should be noted that for this preliminary geotechnical feasibility assessment, it has been assumed that required construction materials (e.g. concrete aggregate, earth fill and the like) can be obtained from off-site sources, if required, and that excess excavation spoil can be disposed of elsewhere on the Bruce Site or at an off-site location, if required.

- ***Covered Above Grade Concrete Vault Concept (CAGCV)***

The primary geotechnical constraint with respect to the CAGCV is the ability of the subgrade to safely support the concrete vault structure during construction and waste placement operations.

At a preliminary, screening level of assessment, it appears that, with the exception of thin, surficial organic/topsoil deposits, all of the overburden deposits and upper bedrock at the Bruce Site can safely support the vaults. Accordingly, the principal constraint on siting a CAGCV facility at the Bruce Site will be adaptation within existing surface facilities.

➢ ***Shallow Concrete Vault Concept (SCV)***

As indicated in Section 2.3, ideally the generic SCV would be located in a moderately low permeability glacial till deposit which is of sufficient thickness to accommodate the repository and which will avoid the "bathtub" affect. As the base of the generic vault is at a depth of about 12 m below ground surface, it appears probable that with minor redesign, a SCV structure could, from a geotechnical feasibility perspective, be developed in as little as about 15 m of overburden. Accordingly, it appears geotechnically feasible to site an SCV repository in the central eastern portion of the Bruce Site. However, it should be noted that:

i) As indicated on Figure 5, the area of thicker overburden is partially obstructed by existing power corridors and construction of a SCV repository in this area may require relocation of all or parts of two former construction landfills, the Bruce Learning Centre, the Central Gatehouse and entrance road and a section of the perimeter road (to avoid infringement in the buffer zone); and

ii) The overburden consists of a complex system of surface sand and gravel beach deposits overlying clayey to sandy silt till with interbedded lenses of sand of variable thickness (i.e. the overburden may be locally heterogeneous and of variable permeability).

➢ ***Deep Concrete Vault Concept (DCV)***

The generic DCV requires excavations to a depth of 25 m below ground surface in low permeability soils. Based on existing information, this condition does not exist at the Bruce Site. Consequently, the DCV concept is not considered geotechnically feasible at the Bruce Site.

➢ ***Rock Cavern Vault Concept (RCV)***

The principal siting constraints on a RCV facility would be the location of the surface support facilities, most specifically the access ramp entrance or access shaft works. While there are advantages to locating the shaft/ramp near the existing WWMF, conceptually, there are no geotechnical constraints on the location of the vault itself beneath the Bruce Site.

As indicated in Section 2.3, four potential host formations for a RCV repository are being considered.

i) <u>Amherstburg / Bois Blanc Formations</u>: - As discussed in Section 2.1 these Devonian age dolostone formations have been structurally influenced by sub-erosion of the underlying Salina salts resulting in enhanced formational permeability. Further, as discussed in Section 2.2, at least the upper portion of these formations forms a fresh-water aquifer which discharges into Lake Huron. Consequently, while construction of a RCV repository in the potentially high permeability dolostones may be geotechnically feasible, albeit difficult, significant groundwater inflows into the repository must be anticipated.

ii) Salina Formation: As indicated in Section 2.3, this option considered construction of a RCV in a thick salt bed within the Salina Formation. However, as indicated in Section 2.1, in the Douglas Point area (i.e. beneath the Bruce Site), the salt has been sub-eroded in the geologic past by circulating water leaving anhydrite and dolostone breccias which are not considered suitable for construction of a RCV repository. Consequently, this option is not considered geotechnically feasible at the Bruce Site.

iii) Queenston/Georgian Bay/Collingwood shale Formations: At this stage in the LLW geotechnical feasibility assessment, there is no geotechnical reason to screen-out construction of a RCV repository at a depth of 400 m to 600 m below ground surface in these formations.

iv) Lindsay/Verulam/Bobcaygeon/Gull River limestone Formations: At this stage in the LLW geotechnical feasibility assessment, there is no geotechnical reason to screen-out construction of a RCV repository at a depth of 600 m to 800 m below ground surface in these formations.

In summary, the results of this preliminary geotechnical screening assessment indicate that construction of a Covered Above Grade Concrete Vault (CAGCV) and a Rock Cavern Vault (RCV) in either the Ordovician age shale or limestone formations is potentially feasible at the Bruce Site. Construction of a Shallow Concrete Vault (SCV) and a Rock Cavern Vault in the Devonian age dolostones may be geotechnically feasible at the Bruce Site although the geological conditions may be less than ideal. Construction of a Deep Concrete Vault (DCV) and a Rock Cavern Vault (RCV) in Silurian age salt beds is not considered geotechnically feasible because of the absence of suitable host formations.

3.0 SITE CHARACTERIZATION

An overview of the geological and hydrogeological setting of the Bruce Site and the applicability of the generic LLW repository concepts to the setting were established in Section 2 of this report. The following sections discuss in more detail the geology, hydrogeology and geotechnical / geomechanical characterization of the site and form the basis for the development of a conceptual hydrogeological model of the site as discussed in Section 3.3.5 and Section 4. This model, in turn, formed the basis for the assessment of the geotechnical feasibility of the LLW repository concepts and the co-dependent preliminary Safety Assessment.

Hydrogeological properties and geomechanical properties for the surficial deposits and bedrock underlying the Bruce Site are summarized on Tables 1 and 2, respectively.

3.1 Topography, Drainage and Precipitation

➢ ***Topography***

The topography of the Bruce Site is shown on Figure 8. As indicated, the site lies between elevations 180 and 195 m; compared to the Lake Huron level of 176 m. The highest areas (elevation 190 to 195 m) occur within the eastern portion of the site around the Western Waste

Management Facility, the Administration Learning and Training Centre and the Central Gatehouse. The most prominent on-site topographic features are two former construction landfill mounds near the Gatehouse (see Figure 8).

Overall, the site appears relatively flat with variously open or forested areas including hardwoods in dry upland areas and cedar within low, poorly drained portions of the site.

In addition to the Douglas Point Promontory which forms the Bruce Site, the other two prominent physiographic features are the Nipissing Bluff and the Algonquin Bluff (see Figure 8). These bluffs are the remnants of raised shorelines of ancient stages of Lake Huron that occurred in the post-glacial period.

The Nipissing Bluff occurs between elevations of approximately 185 and 190 m. During this post-glacial lake stage, the area of the Western Waste Management Facility was a point of land with curving beach lines extending to the north and south. The bluff and former beach line forms an abrupt 3 to 4 m rise in land directly west of the Western Waste Management Facility, as well as along the southern edge of the site adjacent to Inverhuron Provincial Park.

The Algonquin Bluff is a very prominent ridge that rises 20 to 30 m in height and is situated 1 to 2 km east of the site. The bluff rises abruptly from elevations of 195 m at the base to 225 m along the crest. The land surface above the Algonquin Bluff continues to rise gently inland to elevations of 250 to 260 m within relatively flat farmland.

➢ ***Drainage***

The watershed of the Bruce Site is shown on Figure 18 together with those streams that enter the site or that pass directly to the north or south of the site to discharge in Lake Huron. Stream C enters the site north of the Central Gatehouse and discharges in Baie Du Dóre. As indicated on Figure 18, much of the area below the Algonquin Bluff is wetland, while the lower reaches of Stream C crossing the site are also swampy with drainage controlled by canal ditches. The area of the site directly adjacent to Inverhuron Park is also quite swampy, associated with localized groundwater discharge below the Nipissing Bluff.

➢ ***Precipitation***

To assess the precipitation characteristics at the Bruce Site, historical records for three meteorological stations were obtained from the Climate Source Office of Atmospheric Environmental Services, Environment Canada. These studies and their periods of record are Wiarton Airport (1947-1990), Chatsworth (1952-1990) and Goderich Township (1951-1980). Monthly average and daily extreme precipitation data for each of these stations are summarized in the following tables (Reference 6).

PRECIPITATION AT WIARTON AIRPORT (1947-1990)

Month	Monthly Average			Daily Extremes		
	Precipitation (mm)	Rain (mm)	Snow (cm)	Precipitation (mm)	Rain (mm)	Snow (cm)
Jan	94.0	15.1	115.9	47.6	26.9	51.4
Feb	63.4	17.2	71.2	33.5	26.4	30.7
Mar	67.0	31.8	44.1	47.2	36.1	45.5
Apr	64.4	53.7	12.4	45.3	45.3	18.8
May	66.7	65.4	1.3	48.8	48.8	14.5
Jun	71.4	71.4	0.0	67.8	67.8	0.0
Jul	71.3	71.3	0.0	104.6	104.6	0.0
Aug	88.6	88.6	0.0	73.4	73.4	0.0
Sep	107.4	107.4	0.0T	88.6	88.6	0.2
Oct	88.2	85.5	3.0	69.3	69.3	14.2
Nov	103.8	72.2	39.5	46.0	46.0	28.4
Dec	113.2	37.5	108.6	45.5	45.5	38.4
Annual	999.5	717.1	396.0	104.6	104.6	51.4

T – Trace amounts

PRECIPITATION AT CHATSWORTH (1952-1990)

Month	Monthly Average			Daily Extremes		
	Precipitation (mm)	Rain (mm)	Snow (cm)	Precipitation (mm)	Rain (mm)	Snow (cm)
Jan	110.2	14.4	95.8	36.8	25.4	36.8
Feb	79.0	16.7	62.3	38.1	30.0	38.1
Mar	73.2	38.7	34.5	51.4	51.4	41.7
Apr	72.8	63.0	9.5	54.1	54.1	30.5
May	77.1	76.5	0.7	60.7	60.7	8.1
Jun	81.9	81.9	0.0	64.0	64.0	0.0
Jul	78.2	78.2	0.0	55.4	55.4	0.0
Aug	99.7	99.7	0.0	88.9	88.9	0.0
Sep	105.9	105.9	0.0T	85.5	85.5	3.6
Oct	96.5	94.1	2.4	69.1	69.1	10.2
Nov	111.5	73.1	38.4	63.5	40.0	63.5
Dec	123.8	34.6	89.2	39.1	37.3	39.1
Annual	1109.9	776.8	332.8	88.9	88.9	63.5

T – Trace amounts

PRECIPITATION AT GODERICH TOWNSHIP (1951-1980)

Month	Monthly Average			Daily Extremes		
	Precipitation (mm)	Rain (mm)	Snow (cm)	Precipitation (mm)	Rain (mm)	Snow (cm)
Jan	99.9	25.3	69.7	28.4	28.4	20.3
Feb	77.5	27.7	50.8	48.3	48.3	25.4
Mar	55.5	36.8	23.6	55.1	55.1	25.4
Apr	67.4	70.0	3.7	39.9	39.9	12.7
May	73.3	73.1	0.3	62.0	62.0	5.1
Jun	63.2	63.2	0.0	72.9	72.9	0.0T
Jul	69.6	69.6	0.0	58.2	58.2	0.0
Aug	78.4	78.4	0.0	83.8	83.8	0.0
Sep	84.7	84.7	0.0	61.5	61.5	0.0
Oct	82.5	81.0	1.4	52.3	52.3	10.2
Nov	88.9	70.6	21.4	46.2	46.2	43.2
Dec	102.8	46.8	56.1	58.9	58.9	25.4
Annual	943.7	727.2	227.0	83.8	83.8	43.2

As indicated in the foregoing tables, precipitation in the region is quite consistent throughout the year with an average annual precipitation in the range of 944 mm at Goderich to 1110 mm at Chatsworth. Snowfall ranges from about 25 percent of the total precipitation at Goderich to about 40 percent of the total precipitation at Wiarton.

3.2 Geological Characterization

3.2.1 Surficial Deposits

The total overburden thickness overlying the bedrock throughout the site is shown on Figure 9. This figure represents a contouring of the available geotechnical borehole information for the site previously compiled in 1986/87 by Ontario Hydro (Reference 27) and subsequently updated for a few additional drillholes (Reference 28). The thickness of overburden throughout the northwestern half of the site is generally less than 4.5 m (areas of dark and light blue on Figure 9). Overburden thickness increases beneath the southeastern half of the site, reflecting both the rise in the ground surface (Figure 8) and a decline in the bedrock surface elevation (Figure 10). The inferred area of overburden thickness in excess of 15 m occurs in a localized area within the central eastern area of the site (see Figure 9).

The overburden is comprised of a comparatively complex sequence of surface sand and gravel from former beach deposits overlying clayey silt to sandy silt till with interbedded lenses and layers of sand of variable thickness and lateral extent. Near the present Lake Huron shoreline, sand, gravel and boulders left from beach deposits thinly overlie the bedrock. The bedrock surface, as shown on Figure 10, reflects erosional topography developed from glaciation that appears to have advanced southward across the site gouging and scouring the bedrock surface. The area of highest bedrock surface elevation (180 to 185 m) occurs beneath the western portion of the site in the vicinity of the Heavy Water Plant and the Bruce B generating station (Figure 10). The lowest bedrock surface elevations occur beneath the northwestern portion of the site (elevation 168 to 170 m). The results of the drilling investigations for the Bruce A and B intake tunnels indicate that the bedrock surface elevation decreases offshore consistent with the increasing depth of the lake.

The area of surficial deposits that has received the most intensive hydrogeological investigation lies around the Western Waste Management Facility (Reference 32 and 33). This area is underlain by up to 18 m of surficial deposits over bedrock. Detailed cross-sections of this area, shown on Figure 11, indicate that the sequence is subdivided in descending order into a surficial layer of sand and gravel, a weathered brown till horizon 2 to 4 m thick overlying fresh grey till comprised of dense silty sand to very hard clayey silt with sand and boulders (Reference 28). The till is massive in character and although saturated, it appears 'dry' when excavated due to its well-graded fine-grained composition and low permeability. The till is split by a middle sand layer of quite variable thickness and lateral extent that is locally in direct contact with the bedrock.

A stratigraphic layer described as 'Layered Till' on Figure 11 contains thin laminations and lenses of wet silt and sand which result in this till appearing 'wet' when exposed. This layer overlies the middle sand layer.

The upper sand layer is irregular in thickness and locally infills channels in the till surface. Previous work carried out in 1986 (Reference 27) identified areas beneath the southeastern portion of the Bruce Site where channels in the till surface were infilled with 8 to 12 m of sand and areas where the till is absent altogether with the upper sand in direct contact with the bedrock surface. This area, which borders the Inverhuron Park, is associated with a cedar swamp where bedrock groundwater discharges through the upper sand.

3.2.2 Bedrock Geology

The regional bedrock geology of the Bruce Site is shown on Figure 12. This map is part of the Geological Survey of Canada Map 1335A of Southern Ontario (Reference 10) and projects the positions of the geological formations at the bedrock surface both on- and off-shore beneath Lake Huron. As indicated, the formations that form the bedrock surface around the Bruce Site also occur beneath the communities of Walkerton and Listowel to the southeast and extend north-westward beneath Lake Huron.

The entire Paleozoic sedimentary sequence beneath the Bruce Site is in the order of 800 m thick and overlies the Precambrian basement. The sequence consists of approximately 375 m of Devonian and Silurian age dolostones extending downward through the Amherstburg, Bois Blanc, Bass Island, Salina, Guelph, Lockport and Reynales Formations. This sequence is underlain by an approximately 230 m thick section of predominately shale consisting of the Lower Silurian age Cabot Head Formation (~30 m), the Manitoulin Formation dolostone (~6 m), the Upper Ordovician age Queenston Formation (~80 m), the Georgian Bay Formation (~95 m) and the Collingwood Formation (~33 m). The shales overlie a 185 to 190 m thick sequence of

Middle Ordovician limestone including the Lindsay, Verulam, Bobcaygeon and Gull River Formations.

The stratigraphic sequence was established through a review of local deep natural gas exploration wells as summarized on Figure 6. The stratigraphic interpretation of the Texaco #6 well, located 2.5 km southeast of the site is considered representative of the full Paleozoic sequence to depths of 880 m where the granitic Precambrian basement rocks were encountered. The stratigraphic sequence encountered by Texaco #6 is shown on Section A-A of Figure 13. This section provides a correlation of formations from Lake Huron to the north shore of Lake Ontario based upon selected boreholes. The stratigraphy is shown with respect to a horizontal reference line taken at the top of the Verulam Formation such that lateral continuity of strata including thickness variations can be demonstrated. A more detailed section of the area along the north shore of Lake Ontario is shown on Section B-B of Figure 14. It is this area where the Ordovician limestone formations come to surface and are exposed within rock quarries and tunnels which have been driven within the Lindsay Formation at the Darlington Nuclear Generating Station and the previously proposed Wesleyville Thermal Generating Station. These stratigraphic sections demonstrate the lateral continuity of the formations across Southern Ontario including into the Ottawa area, providing evidence that the rock properties established within the strata adjacent to Lake Ontario can be extrapolated to the Bruce Site where the strata occur at depth.

The bedrock stratigraphy directly underlying the Bruce Site has been investigated through several geotechnical investigations carried out for Ontario Hydro between the late 1960's and the 1990's. These investigations extended to depths of as much as about 100 m below surface. The locations of some selected geotechnical boreholes that intersected both the Amherstburg and Bois Blanc Formations are shown on Figure 15. The central series of boreholes (US-1 to US-6) were drilled as part of previous waste management investigations (Reference 28) while the peripheral holes (BM1-4, BM1-6, DB-78, DB-87) were drilled as part of the initial investigations for the generating station designs (References 30 and 31). The Amherstburg Formation, which is the uppermost dolostone formation, extends from bedrock surface to a depth of up to 70 m, where the underlying Bois Blanc Formation cherty dolostone is encountered. There is no on-site drilling information extending below the Bois Blanc Formation.

Contouring of the elevation of the contact between the Amherstburg and Bois Blanc Formations is shown on Figure 15. As indicated, the formations dip gently toward the southwest at approximately 1 percent, with local variations. This dip continues southwestward beneath Lake Huron such that on the opposite shore near Harbour Beach Michigan (see Figure 12), the top of the Amherstburg Formation occurs at a depth of approximately 750 m below surface, while the Queenston Formation shale and Lindsay Formation limestone occur at depths of approximately 1700 m and 1900 m, respectively (Reference 46).

The entire stratigraphic sequence of Paleozoic sediments projected to underlie the site extending down to the Precambrian basement granitic gneiss is shown on Figure 16. This stratigraphy is based upon the local gas exploration well; Texaco #6, drilled approximately 2.5 km southeast of the site at the location shown on Figure 15. The original geophysical logging records for this hole (natural gamma and neutron logs) and the well card listing formation depths were acquired from the Oil Gas Salt Resources Library in London, Ontario. The contact of the Amherstburg and Bois Blanc Formations identified in Texaco #6 was used as a match point with the same contact identified within the on-site borehole US-4 such that a composite stratigraphy beneath the site could be developed. The projected formation depths below the borehole US-4 location are indicated on Figure 16.

It should be noted that the formation contact used as a match point in borehole US-4 is based directly upon rock core logging while the contact in Texaco #6 is based on geophysics and chip sample logging. Therefore, the actual formation contact match point between the two holes could vary by several metres. Also, formational thicknesses at depth can vary by several metres between locations. Therefore, the depths below ground surface shown on Figure 16 should be viewed with the understanding that they are not precise and are subject to variations, possibly in the range of tens of metres. However, in the overall context of this present assessment they are considered representative for the site.

➢ ***Geological History***

The geological history is represented by the various geological periods within which the formations are classified. The time for the various ages of the formations extends over hundreds of millions of years, between approximately the Middle Devonian Period (360 to 370 myr.) to the Cambrian Period (500 to 570 myr.) Following is a discussion of this history from the basal (oldest) strata successively upward to the existing bedrock surface.

The basal sedimentary sequence underlying the limestones is comprised of the Cambrian basal sandstone (~8 m) and Ordovician Shadow Lake Formation (~5 m) which lie unconformably on Precambrian granitic gneiss. These clastics represent the transgression of Cambrian and Middle Ordovician age seas over the eroded granitic gneiss of the Precambrian basement complex. The Cambrian age sandstone is locally porous in some areas where it occurs beneath Southwestern Ontario, such that it locally produces natural gas. However, no commercial gas deposits have been encountered by exploratory drilling in the Bruce area (Reference 43).

Following the advance of the Middle Ordovician seas and deposition of the relatively thin Shadow Lake Formation clastic sequence, which was derived from the Precambrian basement, the remainder of the period was dominated by a comparatively quiet geological environment associated with limestone deposition. The Ordovician limestones are typically very fine grained to lithographic, non-porous, argillaceous to shaly limestone of very consistent lateral continuity. For example, the Sherman Falls Member limestone is traceable across Southern Ontario at an average thickness of 10 m with little variation (Reference 24) as shown on Figures 13 and 14. As such, the formations are very predictable in both lithological composition and thickness.

The overlying thick shale sequence of the Collingwood, Georgian Bay and Queenston Formations was deposited in the Upper Ordovician and reflects the westward transport of sediment eroded from the contemporary uplift of the ancient Appalachian Mountain area. The Queenston Formation red shales reflect a marine deltaic deposit associated with the westward transport of material, hence the iron oxide colouration of the shale, caused by the filling of the basin and exposure to the atmosphere (Reference 5).

The Manitoulin Formation (No. 11 on Figure 16) is a thin sequence of dolostone rock (~6 m) of Lower Silurian age which represents the transgression of the Silurian seas back into the area as the basin continued to subside in response to regional continental tectonics. Influx of clastic sediment, again from the east, deposited the ~30 m thick Cabot Head Formation shale. The end of the Lower Silurian clastic deposition period coincided with the onset of the Middle Silurian which commenced the deposition of the dolostones of the Reynales, Lockport and Guelph Formations (~42 m) followed by the Upper Silurian Salina Formation (~250 m) and the overlying Bass Island Formation (~42 m).

The Guelph Formation is typically porous compared to the other underlying and overlying strata and hence is regionally significant as a potential reservoir of natural gas developed from pinnacle reefs. These reefs are localized coral reefs that formed coral islands which grew upward as the basin sank. Some of the reefs reached heights in the range of 100 m, extending into the lower portions of the A_1 Member of the Salina sequence. The reefs tend to be porous, hence collect oil, natural gas or water. No oil or gas producing reefs have been identified in the Bruce area (Bruce and Kincardine Townships) and the nearest producing reefs are located in Ashfield and West Wawanosh Townships approximately 30 km south of the Bruce Site (Reference 43). However, a local, non-gas producing reef was encountered in the Union Gas Kincardine #1 exploration drillhole beneath McRae Point approximately 5 km south of the Bruce Site (for location see Figure 6).

Beneath the Bruce Site, the Salina Formation is comprised of dolostone, shaly dolostone and shale with minor thin anhydrite beds. The Formation is subdivided into the A_1 through G Members as indicated on Figure 16. The Salina Formation is unique in that it hosts extensive salt deposits within some of its Members south of the Bruce area. The salts were deposited when water circulation within the basin was restricted, resulting in salt saturated conditions. The salt occurs in the A_2, B, D and F members in areas such as Goderich, but no salt has been identified north of Point Clark, approximately 30 km south of the Bruce Site (Reference 8). It was the deposition of the A_2 salt horizon that terminated the growth of the Guelph pinnacle reefs (References 8 and 24). At Goderich, the total thickness of salt within these four members is approximately 150 m (Reference 8). The A_2 salt is ~27 m thick and is mined underground off-shore from Goderich while the B salt (~100 m) is mined by solution methods beneath the on-shore area of Goderich. The D Member salts are not mined at Goderich.

In the geological past, the Salina salt deposits extended into the Bruce Site area and beyond (Reference 8). However, sub-erosion of the salt by circulating water during Late Silurian and Devonian times subsequently removed the salt beds. What remained was the insoluble components of the salt beds including anhydrite beds and dolostone collapse breccias. For example, the B Member near Bruce is represented by approximately 2 m of anhydrite and breccia compared to thicknesses of B salt of 100 m at Goderich. The A_2 salt would have been situated between the A_1 and A_2 dolostones at Bruce, but it has been removed, also leaving a similar thin anhydrite bed. The F Member salt is approximately 20 m thick at Goderich but is absent beneath the Bruce Site. Interestingly, the Texaco #6 well reported encountering salt water at the $A_1 – A_2$ contact.

The sub-erosion of up to 150 m of Salina salts from beneath the Bruce Site has structurally influenced the entire overlying rock sequence through collapse and differential settlement. This has resulted in warping of the overlying strata, development of vertical fracturing and overall enhancement of formational permeability along bedding horizons and breccia layers extending up through the Devonian sequence.

The Salina Formation contains shale and shaly dolostone sequences in the C Member (~46 m) and F Member (~38 m). Again, these shales reflect uplift and erosion in the Appalachian Mountain area to the east and the sequences also contain thin volcanic ashfall beds from the same provenance. The C Member did not contain salt and is likely less disrupted than the shale of the F Member where a substantial amount of salt was removed.

The Bass Island Formation dolostone (~42 m) represents carbonate deposition through to the end of the Silurian Period. The upper contact of the formation is a regional discontinuity marking an extended period of time when the entire area became subject to subarial erosion. A weathering profile several metres thick is recognizable at this horizon on a regional scale, associated with weak rock and permeable water-bearing conditions. The weathered nature of this contact can be seen on the walls of the Rockwood Quarry in southeastern Michigan (Reference 17).

The return of the Devonian seas deposited the cherty dolostone of the Bois Blanc Formation (~42 m) and dolostone of the Amherstburg Formation (~40 to 50m) which forms the present erosional bedrock surface.

The Silurian/Devonian contact zone shown on Figure 12 is associated with a regional escarpment feature called the Onandaga Escarpment which throughout much of its trend is either buried beneath Pleistocene glacial deposits within the Grand River and Saugeen River valleys or subcrops beneath Lake Huron (see Figure 12). This escarpment formed in the geological past due to the differential erosion of the soft Salina Formation shales (C and F Members) compared to the overlying hard dolostones. The Salina Formation E Member and the Bass Island and Bois Blanc Formations form caprocks. As shown on Figure 12, the subcrop location of the Onandaga Escarpment would be approximately 10 to 20 km off-shore to the north and northwest of the Bruce Site associated with the 50 to 100 m bathometric depth contours. The actual face of the escarpment in the lake bottom is likely buried by glacial deposits, such as occurs on land.

➢ ***Lithological Description***

A description of the lithology of the various formations that occur beneath the site is given in Appendix A to this report.

3.3 Hydrogeological Characterization

The objective of the hydrogeological characterization is the development of a descriptive, conceptual hydrogeological model for preliminary Safety Assessment purposes. An understanding of the hydrogeology is essential for assessing LLW repository construction conditions and long-term performance with regard to potential seepage from the proposed repository. To this end, the hydrogeological characterization of the Bruce Site has focused on establishing estimates of formation hydraulic conductivity, groundwater levels and flow directions, and groundwater quality for the various stratigraphic horizons identified in Section 3.2. The understanding is based upon previous on-site investigations and correlation with investigations of other areas within Southern Ontario where the same strata occur near surface. The hydrogeological characterization has also addressed groundwater quality conditions within the rock sequence to depth. Where available, solute transport parameters have also been identified. A summary of hydrogeological parameters is provided in Table 1.

3.3.1 Assessment of Hydraulic Conductivity

The hydraulic conductivity (K) of a medium is a measure of its ability to transmit a fluid. It is controlled primarily by the nature of the pore space in the medium, in particular the size and effective porosity or amount of interconnected pore space available for fluid transmission. As the present assessment considers only groundwater flow, the terms permeability (or coefficient of permeability) and hydraulic conductivity are used interchangeably, in the following discussion.

The hydraulic conductivity of the glacial sediments and bedrock beneath the Bruce Site was assessed through a review of on-site studies which provide information within 100 m of ground surface. Conditions within the deep Ordovician rock section were assessed from the extrapolation of deep hole testing carried out along the north shore of Lake Ontario. Existing information on conditions within the Silurian strata of Southern Ontario is largely limited to the outcrop areas along the Niagara Escarpment where the rock is exposed at shallow depths and is weathered. These conditions are not considered directly analogous to the conditions of the Silurian strata at depth beneath the Bruce Site, but inference has been used to provide current best estimates for the Bruce Site. The results of the hydraulic conductivity testing have also been viewed in light of the dewatering experiences associated with the Bruce A and B generating station construction (see Section 5.1), as well as reported yields of water supply wells within the area.

The results of the assessment of hydraulic conductivity are summarized in Table 1. The table provides the range of test values and the geometric mean for the data reviewed for specific formational horizons. It also provides estimated values based upon our understanding of the lithological conditions of the strata where site specific test data was not available (e.g. the Silurian sequence, as discussed above).

Appendix B provides a series of five figures that summarize the results of hydraulic conductivity testing carried out in the overburden (Figure B.1), shallow bedrock (Figure B.2), the Amherstburg and Bois Blanc Formations (Figures B.3 and B.4) and the deep Ordovician bedrock (Figure B.5). A summary of all the hydraulic conductivity testing results for the various horizons in the geological sequence beneath the Bruce Site is provided on Figure 17. This figure plots the geometric mean values of the tested sections, provided in Appendix B, and estimated values for the intervening untested Silurian sections. As such, it reflects our current understanding of the potential conditions beneath the Bruce Site.

The surficial deposits and bedrock beneath the Bruce Site reflect a broad range of hydraulic conductivity extending over several orders of magnitude as shown on Figure 17. The values shown represent the geometric mean values (measured and estimated) summarized in Table 1 and discussed in Appendix B. The values reflect an overall trend of decreasing hydraulic conductivity with depth. This trend, coupled with the understanding of the soil and rock formations, has been used to divide the stratigraphic sequence into four zones of permeability, as summarized below.

The first, uppermost zone consist of the surficial deposits where the massive tills are of low permeability (10^{-10} m/s) while the interlayered or overlying sand horizons are of moderate permeability (10^{-5} m/s).

The second horizon is the shallow bedrock zone including the upper 150 m of strata comprised of the Amherstburg, Bois Blanc and Bass Island Formations as well as the top of the Salina Formation. On-site testing has indicated that the upper two formations have moderate to high permeabilities with a geometric mean of approximately 1×10^{-5} m/s. These results are consistent with the foundation and tunnel excavation work carried out for the Bruce A and Bruce B generating stations where significant groundwater inflows were experienced from the Amherstburg and Bois Blanc Formations (see Section 5.1). The strata below the depth of testing are anticipated to have the same permeability based on the similarity of rock type and geological history. For example, the municipal well for the community of Underwood is 122 m deep and develops sufficient water from the Bois Blanc/Bass Island Formations contact zone to service 40 homes (see Figure 18).

The intermediate bedrock zone includes the shale and dolostone of the Silurian age Salina Formation, the underlying dolostone sequence of the Guelph, Lockport and Reynales Formations, the Cabot Head Formation shale and Manitoulin Formation dolostone. Little directly applicable test information is available for these strata where they occur at depth, such as beneath the Bruce Site. However, it is reasonable to assume that the shale strata have low permeability, in the order of 1×10^{-10} m/s, while the dolostone sequences may have higher permeability, in the order of 1×10^{-7} m/s. There will likely be considerable variation in the permeability within these horizons, for example, shales may have lower permeabilities in part, while the range of permeability for the dolostones may be greater.

The deep bedrock zone comprised of Ordovician shales and limestones, have consistently demonstrated very low permeability conditions where tested at depth beneath the north shore of Lake Ontario (see Figure B-5, Appendix B). Geological correlation suggests conditions in that area are analogous to conditions beneath the Bruce Site where permeabilities in the range of 1×10^{-13} to 1×10^{-12} m/s are anticipated (see Figure 17). These values are a million times lower than those of the shallow bedrock zone. In this type of very low permeability environment, movement of dissolved constituents is limited to chemical diffusion.

The above discussion of bedrock permeability is considered most representative of horizontal permeability associated with bedding partings within the rock. The vertical permeability will be limited by the massive nature of intervening intact beds. This anisotropy may reflect a vertical permeability of an order of magnitude lower then the horizontal permeability.

3.3.2 Groundwater Levels and Directions of Groundwater Flow

The understanding of groundwater levels and directions of groundwater flow within the Bruce site 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 on-site monitoring wells. All of the wells were completed within either the surficial deposits or the underlying formations of the shallow bedrock zone. As such, the reported groundwater levels and inferred direction of groundwater flow are representative of these horizons.

The only information available for the intermediate or deep bedrock zones is obtained from the records of natural gas exploration drillholes. These data are sparse and the representativeness of the reported water levels (usually saline or brine water) is not entirely clear. It is assumed that the groundwater levels within the intermediate bedrock zone will still reflect the general patterns of fresh groundwater flow within the overlying shallow horizons; i.e. toward Lake Huron. The groundwater within the deep bedrock zone is typically dense brine. Therefore, little in the way of vertical hydraulic gradient is anticipated and this brine will remain stagnant beneath the overlying lighter saline and fresh water zones.

The areas surrounding the Bruce Site are dependent upon groundwater for both municipal well supplies and private domestic and agricultural supplies. The MOE water well records indicate that there are approximately 1,000 wells in the Municipality of Kincardine. The location of the wells within the Bruce Site vicinity are shown on Figure 18. Approximately 80 percent of the wells are completed in the bedrock, typically to depths of 30 to 100 m into the upper bedrock of the Amherstburg and Bois Blanc Formations. The balance of the wells are completed within water bearing granular layers in the overburden. Over 95 percent of all wells report fresh water conditions.

The communities of Tiverton, Underwood, Scott Point and the Woodland Trailer Park are serviced by municipal wells that provide water for 40 to 250 homes (Reference 40) as indicated on Figure 18.

The MOE well records report the static water levels (depths) in the wells at the time of drilling and the approximate elevations from which the levels were measured. This information was used to contour the groundwater elevations for the wells as shown on Figure 18. As indicated, the elevations vary from 220 m to 240 m in the Tiverton and Underwood areas and decrease westward toward Lake Huron which lies at an elevation of approximately 176 m. This westward decrease in groundwater levels indicates that the direction of groundwater flow is also westward from the Tiverton and Underwood areas toward the Bruce Site and Lake Huron. As such, the Bruce Site is downgradient from the various well users in the Municipality of Kincardine. The Bruce Site itself does not use groundwater, rather it obtains all of its domestic and industrial supplies directly from Lake Huron via a water treatment plant.

Groundwater levels beneath the Bruce Site are available from monitoring wells installed around the Bruce A and Bruce B generating stations and within the Western Waste Management Facility. The groundwater levels in the bedrock around the generating stations are slightly above to slightly below the lake level of 176 m. The stations have deep foundation drains within the bedrock that locally depress the surrounding groundwater levels.

Beneath the Western Waste Management Facility, monitoring wells installed in the shallow bedrock have groundwater levels 9 to 12 m below the ground surface. These levels correspond to elevations in the range of 180 to 184 m, or approximately 4 to 8 m above the lake level (Reference 38).

Groundwater levels in the overburden beneath the Western Waste Management Facility are typically shallower than in the underlying bedrock, occurring at depths of 1 to 2 m below ground surface or at elevations of 190 to 192 m. Deeper within the overburden, where sand lenses connect with the bedrock, the groundwater levels in the overburden are consistent with the bedrock groundwater levels.

The groundwater levels indicate downward hydraulic gradients from the overburden to the bedrock beneath the eastern portion of the Bruce Site in the vicinity of the Western Waste Management Facility. These downward hydraulic gradients, in the range of 40 percent, indicate that the dominant direction of groundwater flow in the overburden is downward to the underlying bedrock. Within the bedrock, groundwater flows horizontally toward Lake Huron where it discharges.

3.3.3 Groundwater Quality

The groundwater quality in the overburden and shallow bedrock is characteristic of fresh, hard, neutral to slightly alkaline pH, calcium, magnesium, bicarbonate and sulphate mineralized water typical of water within limestone and dolostone terrain. The total dissolved solids within the shallow bedrock typically fall within a range of 1,000 to 2,500 mg/L, showing a tendency to increase slightly with depth, largely due to increasing sulphate concentration. The fresh water in the upper shallow bedrock represents water that has evolved from infiltration of precipitation over time and that is actively circulating within the shallow formations.

The petroleum exploration drilling beneath southwestern Ontario (Reference 42), and the deep geotechnical drilling in the Lake Ontario area typically encountered saline to brine water at depth within the intermediate to deep bedrock zones (References 14, and 45). Total dissolved solids can vary up to 300,000 mg/L. The principal dissolved constituents vary from sodium chloride in the saline water to calcium chloride in the brine water. These waters are characteristic of ambient waters that have resided in the formations over geological time.

3.3.4 Solute Transport Parameters

Table 1 provides the estimated values for the following solute transport parameters:

- Effective diffusion coefficient and tortuosity factor;
- Matrix porosity and effective transport porosity;
- Matrix distribution coefficient; and
- Dispersivity.

The effective diffusion coefficient (D) values are based on proprietary laboratory diffusion tests carried out by Golder on similar rock/soil materials using chloride as the conservative tracer.

The tortuosity factor (τ) is the ratio of the solute effective diffusion coefficient to the diffusion coefficient in purely aqueous solution (i.e. $\tau = D/D_o$). The values provided in Table 1 are also based on laboratory diffusion tests carried out by Golder using chloride as the tracer. The tortuosity factor is less than 1.0 due to diffusion pathways around solid particles being much longer and more "tortuous" than in aqueous solution. The tortuosity factor is assumed to be strictly a physical property of the porous media, dependent on soil/rock fabric (i.e. pore structure and pore size) rather than the nature of the solute species.

The matrix porosity (n) is defined as the volume of voids within the undisturbed soil/rock matrix per unit volume of the matrix. Not all of the matrix porosity will be available for diffusion/advection of contaminants, as some of the pores may be too small to accommodate the contaminants and/or not interconnect with other pores.

The effective transport porosity (n_e) represents the porosity through which the most of the contaminant mass transport occurs, such as fractures and solution weathered bedding partings. For the simplest case of a parallel and continuous fracture system, the effective transport porosity is taken as the fracture aperture divided by the fracture spacing and is typically less than about 0.1%. For the geological units referenced in Table 1, the spacing and continuity of the fractures/bedding partings is variable and the aperture unknown. Approximation of the effective transport porosity using the parallel fracture system approach is therefore not possible. Instead, the values provided were estimated on the basis of obtaining reasonable groundwater seepage velocities for the geological units when applying the Darcy Equation.

The matrix distribution (i.e. adsorption) coefficients (K_d) for the given radionuclides are "default values" for clay or sand based materials, as reported by Sheppard and Thibault (Reference 44). The geological units that are known to contain significant quantities of clay mineral are assigned the clay default values whereas units containing predominantly non-clay minerals are assigned the sand default values. These K_d values are intended for modelling contaminant migration through the pores of the rock/soil matrix and are not appropriate for modelling sorption along fracture surfaces. The latter would require an adsorption coefficient reflecting contaminant uptake per unit surface area of the fracture rather than per unit mass of the matrix solids.

The longitudinal dispersity (α) value is given as 10% of the travel path length along the geological unit (Domenico and Schwartz; Reference 9). This is a recommended value for initial safety judgement in the absence of more site specific information. The travel path length is the distance from the vault to the point of interest downgradient of the facility. The transverse dispersivity is typically an order of magnitude lower than the longitudinal dispersivity, based on the above reference.

3.3.5 Conceptual Hydrogeological Model

A descriptive conceptual hydrogeological model has been developed for the Bruce Site based upon the understanding of the geological conditions extending from ground surface to the Precambrian basement, the hydraulic conductivity of the strata, groundwater levels and flow directions and groundwater quality as discussed in the preceding sections and summarized in Table 1. The conceptual hydrogeological model is shown on Figure 19 and is a true scale (i.e. no vertical exaggeration of scale) version of the site stratigraphy previously shown on Figure 16. The conceptual hydrogeological model includes four groundwater zones as discussed below.

➢ ***Surficial Groundwater Zone***

The surficial glacial sediments overlying the bedrock consist of interbedded dense, low permeability glacial till and moderately permeable lenses to layers of sand or sand and gravel. The total thickness of the deposits varies between less than 1.5 m and 20 m.

Most of the central elevated portion of the site in the vicinity of the Western Waste Management Facility is a recharge area where water from precipitation infiltrates into the soil forming fresh groundwater in the subsurface. Groundwater flow within these deposits is vertically downward in response to downward hydraulic gradients into the underlying shallow bedrock groundwater zone (see below). In the dense till horizons, downward groundwater flow occurs at very low velocities, in the order of a few centimetres per year. In the more permeable sand horizons, groundwater velocities are in the order of ten metres per year. Groundwater recharged to the surficial deposits from precipitation ultimately discharges along the shoreline of Lake Huron.

- ***Shallow Bedrock Groundwater Zone***

The shallow bedrock groundwater zone is considered to include the Devonian age dolostone sequence of the Amherstburg, Bois Blanc and Bass Island Formations and the contact zone with the underlying Salina Formation. These formations constitute a regional aquifer system which is utilized for domestic and municipal well supplies. The upper portions of this rock sequence contain fresh water while at greater depths, sulphur water occurs based upon a review of MOE water well records and drilling card records for gas wells.

The formations are moderately to highly permeable. The permeability of the formations is associated with weathered, solution enhanced open bedding plane joints, interconnecting vertical joints and weathered intraformational breccia horizons. Permeable features of this nature resulted in significant groundwater inflows which presented substantial dewatering difficulties with tunnelling and surface bedrock excavation during the construction of the Bruce generating stations (see Section 5.1). The direction of groundwater flow within this horizon is typically westward toward Lake Huron where the groundwater is anticipated to discharge in the near-shore area. Horizontal groundwater flow velocities are expected to be in the order of tens to hundreds of metres per year.

- ***Intermediate Bedrock Groundwater Zone***

The intermediate bedrock groundwater zone includes the Silurian age dolostone and the sequence of the Salina, Guelph, Lockport, Reynales, Cabot Head and Manitoulin Formations. The upper portion of the Salina Formation is typically a fresh to brackish water zone but the lower dolostone strata can contain either sulphur or saline water such as encountered in the Texaco #6 well. The shales within the Salina Formation act as aquitards restricting vertical circulation between the overlying freshwater zone and the underlying sulphur or saline zone. The formation also contains anhydrite beds, as discussed in Appendix A, that are laterally continuous and of low permeability.

The Guelph and Lockport Formations are associated with reef structures and accordingly have some inter-granular porosity. Gas exploration wells typically encountered sulphur or saline water in these strata. Lake Huron is likely the ultimate receptor of groundwater within these strata where they outcrop on the lake bottom several kilometres off-shore, coinciding with the submerged section of the Onondaga Escarpment (see Figure 12).

The permeability of the dolostone horizons is considered to be low to moderate with horizontal groundwater velocities in the order of 1 to 10 m/yr. Vertical movement of groundwater, allowing circulation with the overlying shallow zone, would be greatly restricted by the horizontally bedded shale members and anhydrite beds within the Salina Formation.

➢ ***Deep Bedrock Groundwater Zone***

The deep bedrock groundwater zone is associated with the thick Ordovician age shale and limestone sequences. None of these strata have been influenced by the geological activity associated with the dissolution of the overlying Salina Formation salt sequences or other major structural events. These formations have remained below sea level since their deposition, removing them from the influences of subareal erosion. The Ordovician rocks are of very low permeability, including both the shales and limestones, and as such form regional aquitards. The porewater within these strata is typically brine and movement of pore water is very slow, measured in the context of geological time. Groundwater velocities are considered to be in the order of millimetres per year or less and mass transport is dominated by chemical diffusion.

3.4 Geotechnical/Geomechanical Characterization

3.4.1 Overburden Material

As previously noted (Section 3.2.1), the overburden at the Bruce Site consists of sands and till of variable thicknesses. The following description and properties of the sand and till are based on borehole data provided in References 32 and 33. The sand is described as typically dense to very dense, fine to medium sand with coarse sand to medium gravel. Standard penetration resistance (N-values) range from the mid teens to over 100 blows per foot and the average is in the order of 40 blows per foot. Two types of till are described at the Bruce Site, namely, weathered and unweathered. The weathered till is described as compact to very dense silt to fine sand with some coarse sand to medium angular gravel and occasional cobbles. Standard penetration resistance varies between the twenties to well over 100 blows per foot with an average of about 50 to 60 blows per foot. The unweathered till is described as dense to very dense fine sand and silt, with some coarse sand to medium angular gravel and occasional angular cobbles. Standard penetration resistance ranges from the thirties to over 100 blows per foot with the average being in the order of 60 to 70 blows per foot or higher.

Grain size characterization of the till indicates the following composition:

	Range %
Sand/gravel	30 – 50
Silt	38 – 52
Clay	11 - 18

3.4.2 Amherstburg Formation (Dolostone)

The description and properties of the Amherstburg Formation dolostone are largely based on the borehole logs and laboratory testing on core from the studies described in Ontario Hydro’s Report No. 78024 (Reference 31) and Report No. GHED–DR–8801 (Reference 28).

The rock of the Amherstburg Formation is consistently described in the borehole logs as comprising hard, fossiliferous, finely laminated, horizontally bedded, lightly fractured dolostone.

The bedding is medium to massive with some soft thin bituminous seams on bedding planes (partings). The distance between bedding partings varies between 0.3 m to 3 m with an average of about 1 m to 1.2 m. Vertical joint spacing is 0.6 m to 1 m on average, with a slightly closer spacing within the upper 7 m of the bedrock surface. The joint spacing increases with depth and is in excess of 1 m at the Amherstburg–Bois Blanc contact. The joints are described as tight with minor surface weathering. Localized highly fractured zones, leached zones, and vuggy to very vuggy zones are intersected in almost every borehole, which is consistent with reports of high acceptance during water pressure tests. The rock in the Bois Blanc Formation reportedly has chert nodules and the joints are very rough with bituminous coatings. The chert in this formation is known to spall when exposed. The joint spacing is generally wider that in the Amherstburg Formation. An assessment of the rock mass quality was undertaken using the Norwegian Geotechnical Institute (NGI) Rock Tunneling Quality Index, Q, as well as the Rock Mass Rating System, RMR, also known as the Geomechanics Classification, for corroboration. A description of these systems can be found in Appendix C. The NGI–Q rating for the Amherstburg is approximately 4.75 (equivalent RMR = 58) indicating that the overall quality of the rock would be classified as "Fair". The detailed rating for the Amherstburg Formation is presented on Figure 20. Intact values for σ_c (uniaxial compressive strength), E (elastic modulus), Q (tunnel quality index) and expected in situ stresses are reported in Table 2.

3.4.3 Salina Formation (Evaporites)

The description and properties of the shales, dolostones, and evaporites of the Salina Formation are based on gypsum and salt mining experience in Southern Ontario, namely, the Goderich Mine in Goderich, the Ojibway Mine in Windsor, the Caledonia No. 3 Mine in Caledonia, the Hagersville Mine in Hagersville and Drumbo Mine near Drumbo.

The carbonate rocks in the Salina Formation range from thinly to medium bedded (2 cm to 20 cm), medium grained dolostones to gypsiferous dolostones with vugs or infillings of gypsum, to strong, massive or medium bedded dolomitic limestones. In the thinly bedded units, bedding partings vary from 0.5 mm to 4 mm in thickness and can exhibit gypsum coatings. Solution action is evident in some units and varies from moderate to none in the very strong fine grained dolostones. The gyspiferous dolostones have a brecciated matrix infilled with gypsum stringers or nodules. The shales and mudstones are very thinly to thinly bedded and can be lightly dolomitized. The bedding has occasional millimetric gypsum infillings. The strength of the shales and mudstones is considerably less than that of the carbonate rocks. Exposed shale and mudstone tend to slake.

Underground field observations and core logging suggests that the dominant joint set is represented by the horizontal bedding planes. Spacing of these planes varies from millimetres in the shale to centimetres in the gypsiferous mudstones. The surface conditions along the discontinuities (when present) vary from smooth and planar in the gypsum, gypsiferous mudstones and shales, to rough and planar to wavy in the massive dolostones. Intact values for

σ_c (uniaxial compressive strength), E (elastic modulus), Q (tunnel quality index) and expected in situ stresses are reported in Table 2.

3.4.4 Queenston and Georgian Bay Formations (Shale)

The description and properties of the Queenston Formation shale are mainly based on the borehole logs and laboratory testing on core from the studies described in the Baseline Report for the Tunnel Diversion Project for the Sir Adam Beck power stations (Reference 2); the description and properties of the Georgian Bay shale are based on the experience in Toronto and on Ontario Hydro's Report No. 86101 (Reference 35).

The majority of the Queenston Formation comprises reddish-brown shale (mudstone) with occasional interbeds and nodules of green siltstone. The formation is massive to blocky with some fissile sections. The upper beds show an upwards fining sequence of reddish brown shales and siltstones with less than 30 percent of green muddy siltstone interbeds. The lower beds comprise reddish brown muddy siltstone and siltstone with frequent green siltstone bands. The rock is susceptible to slaking on exposure.

Within the Queenston Formation, sub-horizontal bedding planes associated with thin siltstone beds form discontinuities occurring at spacings of 5 m to somewhat greater than 10 m. Many are clay rich and form weak discontinuity surfaces. The rock mass rating values (see below) are fairly uniform across the formation, except at the contact with the overlying Silurian age rocks, where the values are slightly lower.

The Georgian Bay Formation consists of soft, thin to thick bedded grey shale (13 mm to 600 mm) with interbedded grey limestone beds throughout. One steeply dipping joint set has been identified in addition to the bedding in borehole OHD-1 which is consistent with known regional joint mapping.

These shale formations (Queenston and Georgian Bay) exhibit anisotropic deformational behaviour and tend to be susceptible to swelling when unconfined. They weather very rapidly and require a layer of protective cover, such as shotcrete, soon after excavation.

The NGI–Q rating for the Queenstown shale is approximately 10.75 (equivalent RMR = 65) indicating that the overall quality of the rock would be classified as "Good". The detailed rating for the Queenston Formation is presented on Figure 21. Intact values for σ_c (uniaxial compressive strength), E (elastic modulus), Q (tunnel quality index) and expected in situ stresses are reported in Table 2.

3.4.5 Lindsay Formation (Limestone)

The description and properties of the Lindsay Formation limestone are based on Ontario Hydro's Report No. 86101 (Reference 35) and Golder Associates Report No. 001-1542 (Reference 15).

The upper member of the Lindsay Formation comprises fresh, fine grained, thin to medium bedded, nodular textured (10 mm to 50 mm dia. nodules) argillaceous limestone. Occasional interbeds of shaly limestone and thin black shale partings occur. The Sherman Falls member of the Lindsay Formation is noticeably less argillaceous in nature. The rock is fresh, fine grained, medium to thickly bedded, nodular textured (10 mm to 15 mm dia. nodules) micritic limestone. It contains occasional laminar to thin interbeds of fine to medium grained, partly crystalline calcarenitic limestone.

In addition to the bedding, there is a major steeply dipping joint set striking E-W. The joints are planar or stepped with smooth to rough walls and the joint spacing is of the order of 1 m. A large number of joints are healed with calcite.

The NGI–Q rating for the Lindsay limestone is approximately 31.7 (equivalent RMR = 75) indicating that the overall quality of the rock would be classified as "Good". The detailed rating for the Lindsay limestone is presented on Figure 22. Intact values for σ_c (uniaxial compressive strength), E (elastic modulus), Q (tunnel quality index) and expected in situ stresses are reported in Table 2.

3.5 Seismicity

The Bruce Site lies within the tectonically stable interior of the North American continent which is characterized by low rates of seismicity. The seismic zone map in the National Building Code, for example, places the site in Zone 0, corresponding to the least seismically active regions of the country. The results of a site specific seismic hazard analyses (Reference 7) carried out as part of Bruce Powers' Bruce A Units 3 & 4 Restart Environmental Assessment concluded that, within the "*Regional Study Area*" defined for that study (an area bounded by Latitudes 42° to 48° N; Longitudes 78° to 84°W), the historic rates of seismic activity were:

47 events of Magnitude M≥ 3 in 100 years; and

8 events of Magnitude M≥ 4 in 100 years.

However, within a 100 km radius of Bruce there have been no earthquakes of M≥4 in the period of historic record (which would extend back about 200 years for events of this magnitude). Based on this data, the study further concluded that, within the "*Regional Study Area"*:

- The recurrence rate for a Magnitude M≥5 event would be 0.013 per annum (1 to 2 events every 100 years);
- The recurrence rate for a Magnitude M≥6 event would be about 0.002 per annum (one event every 500 years); and
- The maximum magnitude for the Region is M = 7.0.

For earthquakes with probabilities of occurrence of 1/2,500 per annum and 1/10,000 per annum, the peak ground velocities in hard rock at the Bruce Site were predicted to be 1.4 cm/sec and

2.7 cm/sec, respectively, and the corresponding peak ground accelerations were predicted to be 0.05 g[(1)] and 0.11 g[(1)], respectively. Peak ground velocities of these magnitudes are not expected to adversely affect monolithic concrete structures such as the concrete vaults proposed for the generic near surface LLW permanent repositories or the stability of underground openings such as proposed for the Shallow and Deep Rock Cavern Vault repositories.

4.0 APPLICATION OF GENERIC LLW PERMANENT REPOSITORY CONCEPTS TO BRUCE SITE CONDITIONS

As discussed in Section 2.4 of this report, the preliminary geotechnical screening assessment indicated that three of the generic LLW repository concepts are potentially applicable to the Bruce Site. These concepts are:

1. Covered Above Grade Concrete Vault;
2. Shallow Concrete Vault; and
3. Rock Cavern Vault located in either the Amherstburg / Bois Blanc Formations at a depth of about 50 m to 100 m below ground surface, the Queenston / Georgian Bay / Collingwood shale Formations at a depth of about 400 m to 600 m below ground surface or the Lindsay / Verulam / Bobcaygeon / Gull River limestone Formations at a depth of about 600 m to 800 m below ground surface.

This section of the report describes, at a conceptual level, how these generic LLW repository concepts could be applied at the Bruce Site and describes the conceptual hydrogeological model for each concept (i.e. the potential groundwater pathways from the repositories to the biosphere) based on the site specific geological/hydrogeological/geotechnical conditions set-out in Section 3.

4.1 Covered Above Grade Concrete Vault (CAGCV)

The generic CAGCV consists of 50 reinforced concrete vaults arranged in two parallel rows of 25 vaults which are separated by a central access aisle for transporting waste containers to the individual vaults. The vaults themselves have a plan area of about 485 m by 70 m and the facility has a LLW capacity[2] of approximately 130,000 m^3. A conceptual cross-section through the generic CAGCV is given on Figure 23. As shown on this figure, the vaults are covered by an approximately 4 m thick, multi-layer soil cover system which incorporates a geosynthetic composite cap (60 mil HDPE geomembrane over 0.7 m thick compacted clay) which is designed to minimize surface water infiltration into the facility. Based on accepted design practice (e.g. Bonaporte et.al.; Reference 4) the leakage through a properly installed geosythetic membrane cap should be less than about 0.1 mm of rainfall equivalent per year and, as set out in the Ontario Ministry of the Environment “Landfill Standards” (Reference 41), the service life of a

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[1] g = acceleration due to gravity or about 980 cm/sec/sec

[2] While the generic conceptual design study assumed a total LLW capacity of 130,000 m^3, all of the repository concepts can readily accommodate changes in the required capacity by simply adding or deleting individual vaults (caverns).

2.7 cm/sec, respectively, and the corresponding peak ground accelerations were predicted to be 0.05 g[(1)] and 0.11 g[(1)], respectively. Peak ground velocities of these magnitudes are not expected to adversely affect monolithic concrete structures such as the concrete vaults proposed for the generic near surface LLW permanent repositories or the stability of underground openings such as proposed for the Shallow and Deep Rock Cavern Vault repositories.

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geosynthetic membrane in a protected environment such as a landfill cover may be assumed to be 350 years. Thereafter, the leakage through the cap is estimated to be about 25 mm of rainfall equivalent per year.

Outside the vaults, the cover slopes down at 4.75 horizontal to 1 vertical (about 12 degrees). Thus, the total footprint of the generic CAGCV, including cover, is about 625 m by 200 m.

For geotechnical feasibility study purposes, the generic CAGCV is considered directly applicable to the Bruce Site without modification.

Again for geotechnical feasibility study purposes and for preliminary Safety Assessment purposes, two potential geologic settings for the CAGCV have been considered, referred to as Reference Facility 1 and Reference Facility 2. These two potential locations, shown on Figure 24, represent a range of subsurface conditions which can be anticipated at the Bruce Site as discussed below. In both cases, the CAGCV is oriented with the long axis of the facility aligned perpendicular to the inferred direction of shallow groundwater flow.

4.1.1 Reference Facility 1

Reference Facility 1 is located in the north-western portion of the site (see Figure 24), in an area which is underlain by relatively thin deposits of free-draining granular overburden (silts, sands and gravels) directly overlying fractured dolostone bedrock of the Amherstburg Formation. A conceptual hydrogeological model showing the inferred hydro-stratigraphy through the repository and parallel to the inferred direction of shallow groundwater flow is shown on Figure 25. As indicated on Figure 25, the groundwater table (upper phreatic surface) beneath the Reference Facility 1 location is below the bedrock surface and groundwater flow is toward the Lake Huron shoreline at an estimated hydraulic gradient of about 0.006 m/m.

Potential contaminant migration out of the repository is as a result of surface water infiltration through the multi-layer soil cover (see Figure 23) which penetrates the reinforced concrete vault roof and contacts the LLW packages and waste forms. Resultant contaminated seepage which escapes the vault containment system passes vertically downward through the unsaturated overburden and upper portion of the bedrock until it contacts the groundwater table. Contaminants then move laterally with the groundwater and discharge into the near-shore area of Lake Huron. Based on the inferred site characteristics (Section 3) and site geometry; flow pathway lengths, hydraulic conductivities, hydraulic gradients and effective porosities for the overburden and bedrock are given on Figure 25.

4.1.2 Reference Facility 2

Reference Facility 2 is located partially within the WWMF in the central eastern portion of the site (see Figure 24) in an area which is underlain by relatively thick deposits of low permeability overburden (clayey to silty till) overlying fractured dolostone bedrock of the Amherstburg

Formation. A conceptual hydrogeological model showing the inferred hydrostratigraphy through the repository and parallel to the inferred direction of groundwater flow is shown on Figure 26. As indicated on Figure 26, for feasibility and Safety Assessment purposes, it has been assumed that:

- any surficial granular deposits (sands) are removed from beneath the footprint of the CAGCV; and
- the clayey to silty till deposit is considered homogeneous. There are known sand lenses within the till, but the till layers will control the vertical downward movement of contaminated seepage. Therefore, the reported range of hydraulic conductivity for the till are considered representative (see Section 3).

As further indicated on Figure 26, based on the review of the site characteristics (Section 3), the groundwater table in the till beneath the Reference Facility 2 location is about 1 m below the till surface and the piezometric water level in the underlying bedrock is about 8 m below the till surface. Within the bedrock, groundwater flow is toward Lake Huron at an estimated hydraulic gradient of about 0.004 m/m.

As with Reference Facility 1, potential contaminant migration out of the repository is as a result of surface water infiltration through the multi-layer soil cover penetrating the vault roof and contacting the LLW. Resultant contaminated seepage which escapes the vault containment system passes vertically downward through the till (vertical hydraulic gradient of approximately 0.4) and enters the bedrock. Contaminants then move laterally with the groundwater in the bedrock flow system and discharge into the near-shore area of Lake Huron. If the contaminated seepage flux exceeds the hydraulic capacity of the till (i.e. the ability of the till to accept infiltration) then part of the contaminated seepage will be diverted laterally at the till surface and will emerge at the edge of the facility as surface water. Based on the inferred site characteristics (Section 3) and site geometry; flow pathway lengths, hydraulic conductivities, hydraulic gradients and effective porosities of the overburden and bedrock are given on Figure 26.

4.2 Shallow Concrete Vault (SCV)

The generic SCV consists of 50 concrete vaults arranged in two parallel rows of 25 vaults which are separated by a central access aisle for transporting waste containers to the individual vaults. A conceptual cross-section through the generic SCV is shown on Figure 27. As indicated on Figure 27, the concrete vaults are constructed in a “shallow” trench. In the case of the generic repository, the base of the vaults were proposed to be at a depth of 11.4 m below original ground surface. Thus, with provision for an underdrain and base liner the overall depth of the trench was about 14 m. Considering the limited depth of overburden at the Bruce Site (see Section 2.4 and 3.2), for geotechnical feasibility and preliminary Safety Assessment purposes, it is assumed that the base of the vaults will be placed at a depth of 10.0 m below site grade. Thus, the height of the generic vaults will be reduced by 1.4 m or about 20 percent. To maintain the same LLW capacity (assumed to be 130,000 m^3 for assessment purposes), it is assumed that the number of vaults is increased by about 25 percent (i.e. 12 vaults) giving an overall vault dimension of approximately 70 m by 600 m.

Following completion of waste placement, the "shallow" trench is backfilled and the vaults are covered by a multi-layer soil cover system similar to that proposed for the CAGCV (see Figure 27).

As discussed in Section 2.4, siting opportunities for the SCV at the Bruce Site are restricted to an area of relatively thick overburden in the central eastern portion of the site (see Figure 5). Consequently, for geotechnical feasibility study purposes and for subsequent Safety Assessment purposes, it is assumed that the SCV repository is located within this area of thicker overburden in the same position as CAGCV Reference Facility 2 (see Figure 28 for location). The conceptual hydrogeological model previously developed for the CAGCV Reference Facility 2 as modified to reflect the SCV is shown on Figure 29.

As indicated on Figure 29, for assessment purposes, the overburden has been assumed to be homogeneous. However, from previous investigations, it is known that the area of thicker overburden consists of till containing discontinuous sand lenses which, locally, may be in direct hydraulic communication with the bedrock. To accommodate this range of conditions, it is assumed that the overburden consists of either: (i) homogenous till (hydraulic conductivity of 10^{-9} to 10^{-10} m/sec); or (ii) homogeneous sand (hydraulic conductivity of 10^{-5} to 10^{-7} m/sec).

For the case of the SCV, potential contaminant migration out of the repository is assumed to be as a result of the combination of surface water infiltration through the multi-layer soil cover and lateral groundwater inflow from the till[3] penetrating the roof and walls of the concrete vault and contacting the LLW. Resultant contaminated seepage which escapes the vault containment either:

a) Emerges at ground surface immediately adjacent to the vault as a result of flooding of the backfilled trench (i.e. the rate of surface water infiltration exceeds the rate of potential seepage out of the repository); or

b) Migrates vertically downward through the till underlying the floor of the vault where it enters the bedrock groundwater flow system and moves laterally with the groundwater to emerge in the near-shore area of Lake Huron (under this scenario, for the geometry indicated on Figure 29, the maximum vertical gradient through the till is 1.

Which of the above release mechanisms governs is dependant on the rate of surface water infiltration through the multi-layer soil cover and the potential seepage rate through the till underlying the base of the trench (which is in turn governed by the hydraulic conductivity of the till). For the range of hydraulic conductivities given above (10^{-9} to 10^{-10} m/sec), the rate of surface water infiltration would have to be restricted to less than 30 mm/yr. to 3 mm/yr. to

[3] Lateral groundwater inflow from the till will only occur if the water level in the backfilled repository is below the surrounding groundwater level in the till.

prevent overflow. Based on the inferred site characteristics (Section 3) and site geometry; flow pathway lengths, hydraulic conductivities, hydraulic gradients and effective porosities of the overburden and bedrock are given on Figure 29.

4.3 Rock Cavern Vault (RCV)

The generic RCV consists of 20 individual disposal vaults (excavated bedrock tunnels) each of which is 10.5 m wide by 7.5 m high by 121 m long and which have a combined LLW capacity of 130,000 m^3. The generic RCV repository is located at a depth of about 100 m below ground surface in competent bedrock and is accessed by a ramp from ground surface. The individual vaults (tunnels) are arranged in two parallel rows of 10 vaults separated by a central access tunnel for mining and for transporting waste containers to the individual vaults. An isometric view of the generic RCV is shown on Figure 30.

At the Bruce Site, two variations of the generic RCV concept were assessed as being potentially applicable (see Section 2.4):

- a “Shallow” RCV repository located in the Devonian age dolostones at a depth of less than about 100 m; and
- a “Deep” RCV repository located in the Ordovician age shales or limestones at a depth in excess of about 400 m.

As the method of access and the potential contaminant release mechanisms for these two variations are significantly different, they are discussed separately in the following sections of this report.

4.3.1 Shallow Rock Cavern Vault (SRCV)

Based on the results of geotechnical investigations carried out in 1986-87 by Ontario Hydro (Reference 28), it was concluded that construction of mined openings (caverns) having a height of about 18 m and a span (width) of about 13 m was geotechnically feasible in the Amherstburg Formation dolostone at a depth of about 55 m below the WWMF. Consequently, for the purpose of the present geotechnical feasibility study, it was decided to assess the applicability of the generic RCV concept in the same bedrock horizon identified by the previous OPG study (i.e. a vault horizon between elevations 139.5 m and 132.0 m). Further, it was decided to locate the repository in the area previously investigated (i.e. directly below the WWMF; see Figure 31 for location). Finally, to take advantage of an area of thinner overburden, it was decided to locate the ramp portal (entrance) to the south of the “Bruce Stores” as indicated on Figure 31. It is stressed, however, that the foregoing realization is intended simply to illustrate the application of the concept and that other realizations are possible.

A conceptual hydrogeological model showing the inferred hydrostratigraphy through the repository and parallel to the inferred direction of regional groundwater flow in the shallow bedrock is shown on Figure 32. As indicated on Figure 32, potential contaminant migration out of the repository is as a result of groundwater entering the unlined vaults and contacting the LLW. Resultant contaminated seepage, which leaves the vault, is carried laterally with the groundwater and discharges into the bed of Lake Huron about 1 to 1.5 km offshore of the site. Based on the inferred site characteristics (Section 3), and site geometry; flow pathway lengths, hydraulic conductivities, hydraulic gradients and effective porosities of the bedrock are given on Figure 32.

4.3.2 Deep Rock Cavern Vault (DRCV)

For geotechnical feasibility study purposes, it has been assumed that the layout of the DRCV will be the same as the generic RCV (i.e. a total of 20 individual disposal vaults each of which is 10.5 m wide by 7.5 m high by 121 m long arranged in two parallel rows of 10 vaults each). However, because of the depth of the DRCV it is assumed that the vaults will be accessed by means of a vertical, concrete lined shaft having an inside diameter of 4.0 m. This shaft will be equipped to support both mining and waste placement operations. There will be a second, smaller lined shaft for ventilation and emergency egress purposes. An isometric view of the conceptual DRCV is shown on Figure 33.

As indicated on Figure 33, following completion of operations the access shaft and ventilation shaft will be sealed within an appropriate low permeability bedrock unit and the repository itself will be allowed to fill with water (resaturate) as a result of inward groundwater seepage.

Finally, for feasibility study purposes, it was assumed that the DRCV repository will be located directly beneath the WWMF (i.e. directly below the assumed location for the SRCV; see Figure 34 for location).

As previously discussed, two options for the DRCV were considered:

i) Construction of the vaults within the low permeability, Ordovician age shales which are projected to underlie the Bruce Site between depths of about 420 m and 630 m below ground surface. For geotechnical feasibility study purposes and preliminary Safety Assessment purposes, it was assumed that the facility would be located in the upper portion of the shale sequence within the Queenston Formation red shale at a depth of 460 m below ground surface (about 270 m below Mean Sea Level).

ii) Construction of the vaults within the low permeability, Ordovician age limestones which are projected to underlie the Bruce Site between depths of about 630 m and 820 m below ground surface. For geotechnical feasibility study purposes and preliminary Safety Assessment purposes, it was assumed that the facility would be located in the upper portion of the limestone sequence within the Lindsay Formation at a depth of 660 m below ground surface (about 470 m below Mean Sea Level).

A conceptual hydrogeological model showing the inferred hydrostratigraphy through the two repositories and parallel to the inferred direction of regional groundwater flow in the intermediate flow zone is shown on Figure 35.

As indicated on Figure 35, because of the very low hydraulic conductivity of the rock (typically less than 5 x 10^{-12} m/sec) and the highly saline groundwater regime (see Section 3), potential contaminant migration out of either repository will be controlled by chemical diffusion following resaturation of the vaults. Contaminants which diffuse vertically upward will enter the intermediate groundwater flow system within the Guelph/Lockport and lower portion of the Salina Formations where they will move horizontally by advective flow to eventually discharge into the bed of Lake Huron some 10 to 20 km off-shore of the site, as previously discussed in Section 3. Based on the inferred site characteristics (Section 3), hydraulic properties of the bedrock are given on Figure 35.

5.0 PRECEDENT EXPERIENCE – ROCK EXCAVATIONS AND SHAFTS

One test of the geotechnical feasibility of a potential permanent repository option is the existence of precedent experience with similar construction in similar geological/geotechnical settings. In this regard, it is considered that there is a broad range of experience with construction of reinforced concrete structures and associated earthworks (i.e. excavations and embankments) on and/or in dense glacial tills and granular overburden deposits such as underlie the Bruce Site. Further, construction of the near surface LLW repository options (i.e. Covered Above Grade Concrete Vault and Shallow Concrete Vault) will not require any unique construction techniques/expertise.

While construction of the generic Rock Cavern Vault option(s) is not expected to require any construction techniques which are not common in mining and underground civil engineering, examples of such construction in the sedimentary bedrock underlying Southern Ontario (and the Bruce Site) are not common. Following is an overview of precedent construction experience with similar size underground openings in the bedrock units which are being considered as potential host formations for the Shallow and Deep Rock Cavern Vault repository options at the Bruce Site (i.e. the Amherstburg, Queenston/Georgian Bay and Lindsay/Verulam Formations). A more comprehensive inventory of underground openings in sedimentary rock is given in a report prepared by Interra Technologies Ltd. in 1988 (Reference 22).

5.1 Amherstburg/Bois Blanc Formations

As discussed in Section 4.3.1, for geotechnical feasibility study purposes it is assumed that the Shallow Rock Cavern Vault (SRCV) option is constructed in the Amherstburg Formation at a depth of about 55 m below ground surface (i.e. between elevations 139.5 m and 132.0 m above sea level). The repository is assumed to consist of 20 individual caverns (tunnels) each of which is 10.5 m wide by 7.5 m high by 120 m long. The caverns are accessed by a ramp or decline from ground surface.

The most applicable, precedent experience in the Amherstburg/Bois Blanc Formations is the Bruce A and Bruce B cooling water intake tunnels which were driven off-shore from the Bruce Site through these formations at a depth of about 50 m to 60 m below lake level (about elevation 120 m above sea level). The tunnels had a span (width) of about 9 m and were excavated by drill-and-blast technique. The tunnel roofs were temporarily supported by a systematic pattern of rock bolts with wire mesh and shotcrete, as required. The tunnels were fully lined (concrete liner) on completion. No untoward excavation or support problems per-se were reported, although pre-excavation grouting was required in both tunnels to control groundwater inflows (see below). A photograph of the Bruce B intake tunnel under construction is shown on Figure 36.

Based on observations during construction (Reference 23) it was estimated that without pre-excavation grouting the total groundwater inflow into the approximately 800 m long Bruce B intake tunnel would have been about 112,000 L/min. (about 25,000 Igpm). Pre-excavation grouting reduced this inflow to about 7,500 L/min. (about 1,600 Igpm). While this tunnel was completed successfully, two "*problem*" areas, primarily associated with groundwater inflows, were encountered:

- A zone of open, waterbearing joints which could not be successfully grouted and which required re-alignment of the tunnel during construction; and
- A brecciated fold zone which required construction of a 4.5 m thick concrete bulkhead and grout cut-off wall to control flow during grouting (a total of 240 m^3 of grout was required to grout the flow zone).

This on-site experience suggests that, while excavation of openings of the size contemplated in the generic SRCV concept is geotechnically feasible in the Amherstburg/Bois Blanc Formations, even with extensive pre-excavation grouting significant groundwater inflows to the facility must be anticipated.

5.2 Amherstburg-Salina Formations

As discussed in Section 4.3.2, both of the Deep Rock Cavern Vault (DRCV) options require construction of a vertical shaft through the potentially water-bearing Devonian age Amherstburg and Bois Blanc Formations and the Silurian age Bass Island, Salina and Guelph/Lockport Formations. Consequently, precedent experience in sinking shafts through these formations is pertinent to the current study. Shafts associated with three gypsum/salt mines developed within the Salina Formation evaporite deposits were reviewed (see Figure 1 for mine locations):

- Domtar's (Sifto Salt Division) **Goderich** Salt **Mine** at Goderich, Ontario;
- Westrock Industries Ltd's. **Drumbo** Gypsum **Mine** near Drumbo, Ontario; and
- Canadian Salt Co. Ltd's. **Ojibway** Salt **Mine** near Windsor, Ontario.

The **Goderich Mine** mines an approximately 27 m thick salt bed within the A2 Member of the Salina Formation at a depth of about 530 m. Stratigraphically, the A2 Member is projected to underlie the Bruce Site at a depth of about 300 m. The 16 ft. (4.9 m) diameter, concrete lined shaft extends through the Dundee (not present at Bruce) Amherstburg, Bois Blanc and Bass Island Formations and terminates at the Salina Formation at a depth of about 550 m. The shaft was sunk in 1955 using then conventional drill-and-blast techniques. While no major geomechanical problems were reported during shaft sinking operations, significant groundwater inflows of up to 40,000 L/min. (8,800 Igpm) were reported in the upper 200 m from the porous and permeable dolomites of the Amherstburg and Bass Island Formations (Reference 22). Extensive grouting was required to control these inflows but, following grouting, flows were reduced to less than 20 L/min. The area of the mine workings was reported to be completely dry.

The **Drumbo Mine** mines a gypsum bed near the base of the Salina Formation which is at a depth of about 140 m. Stratigraphically, the base of the Salina Formation underlies the Bruce Site at a depth of about 350 m. The 4.2 m diameter Drumbo shaft extends through some 50 m of overburden and 90 m of Salina Formation dolomitic shale, mudstone, gypsum and anhydrite and terminates at or within the Guelph dolomite at a depth of about 140 m. The shaft was drilled from surface and was lined with a pre-formed concrete/steel liner grouted in place. While groundwater inflows were reported at depths of 50 m (top of rock), 68 m and at the bottom of the shaft (Reference 22), no significant construction problems were reported.

The **Ojibway Mine** mines two salt beds within the F Member of the Salina Formation at depths of about 275 m and 300 m. Stratigraphically, the top of the F Member underlies the Bruce Site at a depth of about 150 m. The shaft extends through some 30 m of overburden and 180 m of Amherstburg, Bois Blanc and Bass Island Formation dolostones and terminates at a depth of about 300 m in shaley dolomites of the Salina Formation. While groundwater inflows of up to 5,000 L/min (1,100 Igpm) were encountered within the Amherstburg Formation and near the Bass Island/Salina Formations contact (Reference 22) no serious shaft sinking problems were reported and, following liner installation, groundwater inflows were negligible.

The fore-going experience suggests that while pre-excavation groundwater control (e.g. grouting, ground freezing, etc.) will probably be required, construction of a shaft of the diameter envisaged through the Amherstburg, Bois Blanc, Bass Island, Silurian and Guelph/Lockport Formations is geotechnically feasible using either conventional drill-and-blast or surface drilling techniques. Experience further indicates that following lining of the shaft, groundwater inflows into the completed shaft should be negligible.

5.3 Queenston/Georgian Bay Formations

As discussed in section 4.3.2, one of the Deep Rock Cavern Vault (DRCV) options involves construction of the disposal vault in the Ordovician age shales which are projected to underlie the Bruce Site at depths of between about 400 m and 600 m; specifically, within the Queenston shale at a depth of about 460 m below ground surface.

While numerous municipal service tunnels (e.g. sewers, sewage treatment plant outfalls, water filtration plant intakes) have been successfully constructed in the Georgian Bay shale in the Greater Toronto Area, most of these tunnels were of relatively small diameter (3 m to 4 m or less) and were constructed at relatively shallow depth (10 m to 30 m).

As part of the Niagara River Hydroelectric Development scheme, in 1991-93 OPG constructed an exploratory adit in the Queenston shale at Niagara Falls (see Figure 1 for location). This adit was approximately 700 m long. A 13.5 m diameter enlargement at the end of the adit was heavily instrumented to investigate the response of the rock to the excavation. The exploratory adit was excavated using a road-header; the production tunnels were to be excavated by a full face Tunnel Boring Machine (TBM). While no major excavation problems were encountered, the rock was harder (better quality) than had been anticipated. High *in situ* stresses were measured in the rock and bolting, meshing and shotcreting were required to control slabbing and slaking. The adit was essentially dry but what groundwater seepage did occur was very salty. A photograph showing the mining face of the exploratory adit enlargement is given on Figure 37.

As an aside, the excavated rock (muck) was found to deteriorate rapidly and because of its high salt content required special disposal considerations.

In summary, while precedent experience suggests that excavation of openings of the size contemplated in the generic DRCV concept is geotechnically feasible in the Queenston shale, systematic rock support in the form of rock bolts, mesh and shotcrete will probably be required to control slabbing and slaking. However, groundwater inflows to the excavation should be negligible.

5.4 Lindsay/Verulam Formations

As discussed in Section 4.3.2, the second Deep Rock Cavern Vault (DRCV) option involves construction of the disposal vault in the Ordovician age limestones which underlie the Bruce Site at depths of between 600 m and 800 m; specifically, within the Lindsay Formation limestone at a depth of about 660 m below ground surface.

Two precedent tunnel excavations in the Ordovician limestones where they sub-crop east of Toronto were reviewed: the Darlington NGS cooling water intake tunnel and the proposed Wesleyville TGS underground oil storage cavern access tunnel (see Figure 1 for locations).

The Darlington intake tunnel was an approximately 8 m diameter, horseshoe shaped tunnel which was constructed in the Lindsay Formation limestone in late 1981-1982. The tunnel extends about 800 m under Lake Ontario at a maximum depth of about 35 m. The tunnel was constructed using conventional drill-and-blast techniques and no significant construction problems were reported. The tunnel was reported to be very dry with no visible seepage. A photograph of the outer end of the tunnel showing the rock condition and the nominal roof support (bolts and mesh) is given on Figure 38.

The Wesleyville access tunnel was excavated in late 1978-1979 and was intended as a construction and operational decline access to a series of unlined oil storage caverns for the then proposed oil-fired thermal generating station (which was subsequently cancelled). The tunnel is an approximately 6 m wide by 5 m high rectangular opening, the horizontal limb of which is constructed in the Sherman Falls Member of the Lindsay Formation. The tunnel is about 470 m long and extends to a maximum depth of about 60 m. The tunnel was constructed using conventional drill-and-blast techniques and no significant construction problems were reported Excluding minor groundwater inflows near the bedrock/overburden contact (about 20 L/min) and from a shale seam at a depth of about 23 m below the bedrock surface; the tunnel was reported to be completely dry (Reference 22). A photograph of the tunnel showing drilling operations underway is given on Figure 39.

While the fore-going excavations were slightly smaller than the proposed DRCV disposal caverns and were constructed at relatively shallow depth where the Ordovician age limestones sub-crop at surface, they do suggest that construction of a DRCV in the limestone is geotechnically feasible and that groundwater inflows to the excavation should be negligible.

6.0 GEOTECHNICAL FEASIBILITY ASSESSMENT

As discussed in Section 2.4, three of the generic LLW permanent repository concepts previously developed by OPG were considered potentially applicable to the Bruce Site. These were:

1. Covered Above Grade Concrete Vault (CAGCV)
2. Shallow Concrete Vault (SCV)
3. Rock Cavern Vault (RCV)

Further, three variations of the Rock Cavern Vault concept were considered to be potentially applicable:

a) Shallow Rock Cavern Vault (SRCV) constructed at a depth of less than about 100 m in the Amherstburg / Bois Blanc Formation dolostone
b) Deep Rock Cavern Vault (DRCV) constructed at a depth of 400 m to 600 m in Ordovician age shale of the Queenston / Georgian Bay / Collingwood Formations
c) Deep Rock Cavern Vault (DRCV) constructed at a depth of 600 m to 800 m in Ordovician age limestone of the Lindsay / Verulam / Bobcaygeon / Gull River Formations

Site specific applications of these generic concepts to the geological/hydrogeological conditions anticipated at the Bruce Site (described in Sections 3.2 and 3.3) were developed in Section 4 of this report. As discussed in Section 4, site specific application of the three Rock Cavern Vault variations were:

a) a Shallow Rock Cavern Vault constructed in the Amherstburg dolostone at a depth of 55 m below ground surface;

b) a Deep Rock Cavern Vault constructed in the Queenston shale at a depth of 460 m below ground surface; and

c) a Deep Rock Cavern Vault constructed in the Lindsay limestone at a depth of 660 m below ground surface.

The geotechnical/geomechanical characteristics of each of the potential host formations (both overburden and bedrock) are described in Section 3.4.

This section of the report presents an assessment of the geotechnical feasibility of constructing each of the site specific applications of the LLW repository options (Section 4) in the anticipated geological/hydrogeological/geotechnical conditions at Bruce (Section 3).

6.1 Covered Above Grade Concrete Vault (CAGCV)

The primary geotechnical constraint on the construction of the CAGCV is the ability of the foundation subgrade to safely support the loads imposed by the vaults and associated cover. Based on the generic CAGCV conceptual cross-section (Figure 23), it is estimated that the foundation load imposed by the vault, LLW and cover soil will be of the order of 150 to 200 kN/m^2. As discussed in Section 3.2.1, the overburden at the Bruce Site consists of a comparatively complex sequence of surface sands and gravels from former beach deposits overlying clayey silt to sandy silt till with interbedded lenses and layers of sand of variable thickness and lateral extent. As further discussed in Section 3.4.1, the surface sands and gravels and interbedded sand lenses are typically dense to very dense and the till is typically very dense. Based on the results of Standard Penetration Tests (average N-values) given in Section 3.4.1, it is anticipated that the allowable bearing capacity of the sands (based on settlement criteria) will be about 200 to 300 kN/m^2 and that the allowable bearing capacity of the till will be greater than 400 kN/m^2. As such, excluding any surficial organic deposits, it is anticipated that below the depth of seasonal frost penetration most of the overburden deposits at the Bruce Site will be capable of safely supporting the CAGCV repository. Consequently, based on presently available information it appears that construction of a CAGCV repository is geotechnically feasible at the Bruce Site and that, from a geotechnical perspective, there are fairly broad siting alternatives for the repository. There are, however, a number of potential surface constraints associated with power generation/transmission infrastructure and support facilities.

6.2 Shallow Concrete Vault (SCV)

As discussed in Section 4.2, the generic SCV vault structure is the same as the CAGCV structure. However, in the case of the SCV the vault is constructed in an open trench at a depth of about 10 m below ground surface. Accordingly, with the SCV the load bearing capacity of the soil is less of a concern than the ability to safely excavate the trench. This, in turn, involves two considerations:

(i) a sufficient thickness of overburden to permit the excavation; and

(ii) maintenance of the stability of the sides and base of the excavation.

As discussed in Section 4.2, even with a redesign of the generic SCV repository, it is probable that construction of the repository will be restricted to the area of thicker overburden (i.e. greater than 15 m thick) in the central eastern area of the site (see Figure 5). However, in this area the till is known to be heterogeneous and contain extensive lenses of permeable sand which, at least locally, are in direct hydraulic communication with the bedrock (see Section 3.2.1). Such lenses, if encountered in the trench excavation, could require extensive groundwater pumping from sumps or dewatering wells to control the stability of the excavation. Alternatively, if the trench excavation is in low permeability till, groundwater lowering within the underlying bedrock may be required to prevent hydraulic fracturing (uplift) of the excavation bottom.

Considering the limited siting opportunities at the site and the known heterogeneity of the till, on the basis of the presently available information it is not possible to conclude whether or not construction of an SCV repository is geotechnically feasible at the Bruce Site. Consequently, if it is decided to pursue this option, additional investigation will be required to further delineate the thickness and composition of the overburden.

6.3 Rock Cavern Vault (RCV)

6.3.1 Shallow Rock Cavern Vault (SRCV)

As discussed in Section 4.3.1, for geotechnical feasibility assessment purposes, it is assumed that the SRCV repository is constructed in the Amherstburg Formation dolostone at a depth of about 55 m below ground surface (i.e. between elevations 139.5 m and 132 m). Further, it is assumed that the disposal vaults are accessed by a ramp from ground surface.

Because of the shallow depth of the repository, the stability of the caverns will be controlled by the rock structure which is known to be fractured. Based on site specific geomechanical data (Section 3.4.2),. the dolostone is of moderate strength (average unconfined compression strength of about 60 MPa) but of only “fair” overall quality with an estimated NGI Tunnelling Quality Index, Q, of 4.75 (see Figure 20).

Based on international experience with a wide range of excavation types and sizes in a broad range of rock types and qualities, a generally accepted empirical correlation between rock support requirements, excavation span and purpose, and NGI Tunnelling Quality Index, Q, has been developed (see Figure 40). This empirical design system considers 9 categories of rock reinforcement, ranging from “no support” for small openings in good rock to “cast concrete lining” for larger openings in poor rock. As indicated on Figure 40, assuming the generic RCV span of 10.5 m and an Excavation Support Ratio of 1.0 (Excavation Category D), the required rock reinforcement for a rock mass quality classification, Q, of 4.75 would be “Systematic bolting (at a spacing of 2.3 m) with 40 – 100 mm of unreinforced shotcrete” (Reinforcement Category 4). This may be classified as moderate reinforcement and is generally compatible with the precedent experience at the Bruce A and B cooling water intake tunnels (see Section 5.1). Consequently, from a purely geomechanical perspective, construction of a SRCV repository in the Amherstburg dolostone, which underlies the Bruce Site, appears feasible.

The above notwithstanding, site specific hydrogeological information (Section 3.3.1 and 3.3.2) and precedent experience (Section 5.l) indicate that the Amherstburg Formation forms part of a freshwater aquifer and that groundwater inflows into the unlined caverns could be very significant. It is almost certain that extensive grouting of the rock would be required and even with grouting groundwater inflows to the facility will probably be of the order of thousands of litres per minute during construction and operation of the repository. While such inflows may be tolerable during construction, additional studies will be required to assess the significance of the groundwater inflows during operations (i.e. waste placement) and the potential long-term significance of groundwater following closure of the repository.

6.3.2 Deep Rock Cavern Vault (DRCV)

As previously noted, two DRCV options are being considered for the Bruce Site; one in the Queenston shale at a depth of about 460 m and the second in the Lindsay limestone at a depth of about 660 m. As indicated on Figure 33, a common element to the geotechnical feasibility of both of these options is the ability to successfully complete an access/working shaft and ventilation shaft through the overlying Devonian and Silurian age dolostones and shales.

As discussed in Section 5.2, precedent experience in Southern Ontario indicates that while groundwater inflow problems requiring pre-excavation grouting of the rock must be anticipated, shafts of the size anticipated for the DRCV have been successfully completed through the Devonian and Silurian age formations which underlie the Bruce Site. Further, following lining, groundwater leakage into the completed shafts has generally been negligible. Consequently, it is concluded that construction of the access shaft and ventilation shaft required for a DRCV is geotechnically feasible at the Bruce Site.

Based on geomechanical data from other sites in Southern Ontario (Section 3.4.4 and 3.4.5), the Queenston shale is considered to be of low to moderate strength (average unconfined compression strength of about 40 MPa) and the Lindsay limestone is of moderate strength (average unconfined compression strength of about 60 MPa). The overall quality of both rocks is classified as “good” with an estimated NGI Tunnelling Quality Index, Q, of 10.75 for the shale (Figure 21) and 31.67 for the limestone (Figure 22).

Because of the depths of the DRCV repositories and associated high vertical stresses, two stability mechanisms must be considered in assessing the feasibility of the two DRCV options:

(i) the stability of the cavern roofs themselves as discussed in Section 6.3.1 and

(ii) the stability of the pillars between the caverns

A preliminary assessment of pillar stability for the deep rock caverns based on anticipated average unconfined compressive strengths for the shale and limestone is given in Appendix D.

Based on the empirical cavern roof design system described in Section 6.3.1 (shown on Figure 41 for Queenston shale), and assuming the generic RCV span of 10.5 m, the rock reinforcement in the shale (rock mass quality classification, Q, of 10.75) would fall on the border between "Systematic bolting" and "Systematic bolding with 40 – 100 mm of unreinforced shotcrete" (Reinforcement Categories 3 and 4). However, because the Queenston shale is known to slab and slake on exposure as a result of the high in situ stresses (see Section 5.3), for conceptual design purposes, it is suggested that the cavern roofs be supported by a pattern of systematic rock bolts at about 2 m centres, mesh and shotcrete.

As shown on Figure 42, for the Lindsay limestone (rock mass quality classification, Q, of 31.7) the required rock reinforcement would be "Spot bolting" only (Reinforcement Category 2).

With regard to the stability of the pillars between the caverns (see Figure 33 for isometric view of generic cavern layout), as discussed in Appendix D the generic pillar width of 10 m is considered too small for the DRCV repository in both the Queenston shale (depth of 460 m) and the Lindsay limestone (depth of 660 m). Consequently, it is suggested that the pillar widths be increased to 15 m for the conceptual design of both DRCV options[4].

Finally, based on available hydrogeological information (Section 3.3.1) and precedent experience in Ordovician shales and limestone (Sections 5.3 and 5.4), it is anticipated that groundwater inflows to the disposal caverns will be minimal and may be removed by the ventilation air flow (i.e. the excavations will appear dry).

Based on the foregoing, it appears that construction of a DRCV repository, including access shafts, in either the Queenston shale at a depth of about 460 m or the Lindsay limestone at a depth of about 660 m is geotechnically feasible at the Bruce Site. However, it is anticipated that somewhat more extensive roof support will be required in the shale than in the limestone and that with both options, the generic pillar width will probably have to be increased.

While not discussed in the foregoing, it should be noted that construction of the DRCV will produce in excess of 500,000 tonnes of excavated (broken) rock. In the case of the Queenston shale, the broken rock will breakdown rapidly on exposure and, because of its high salt content

[4] This modification will result in an increase of about 25 percent in the overall length of the conceptual Deep Rock Cavern Vault shown on Figure 4.11. This increase is not reflected in the Section 4 text or figures.

may require special disposal considerations (see Section 5.3). The Lindsay limestone, on the other hand, is quarried commercially as aggregate.

6.4 Summary and Conclusions

Based on available geological, hydrogeological and geotechnical information and on precedent experience, it appears that at least two of the generic LLW repository options are geotechnically feasible at the Bruce Site. These are:

- **Covered Above Grade Concrete Vault (CAGCV)**
- **Deep Rock Cavern Vault (DRCV)** in either the Queenston shale Formation which is projected to underlie the Bruce Site at a depth of about 425 m to 500 m below ground surface or the Lindsay limestone Formation which is projected to underlie the Bruce Site at a depth of about 630 m to 670 m below ground surface.

In addition, two other repository options may be geotechnically feasible at the Bruce Site but additional studies will be required to confirm their feasibility. These are:

- **Shallow Concrete Vault (SCV)**
- **Shallow Rock Cavern Vault (SRCV)** in the Amherstburg dolostone Formation at a depth of about 50 m to 100 m below ground surface.

Because of the absence of suitable host formations, two of the repository options are not geotechnically feasible at the Bruce Site (see Section 2.4). These are:

- **Deep Concrete Vault (DCV)**
- **Deep Rock Cavern Vault (DRCV)** in a thick Silurian age salt bed such as is currently being mined underground at Goderich.

7.0 SAFETY ASSESSMENT INPUT PARAMETERS, INFORMATION GAPS AND ADDITIONAL STUDIES

7.1 Safety Assessment Input Parameters

Application of each of the potentially feasible LLW repository concepts to the Bruce Site together with a conceptual hydrogeological model for each concept is discussed in Sections 4.1, 4.2 and 4.3 and shown on Figures 25, 26, 29, 32 and 35. For each repository concept, these conceptual models show the inferred:

- hydrostratigraphic cross-section;
- contaminant release mechanism in the geosphere;
- flow path(s);
- hydraulic conductivities;

may require special disposal considerations (see Section 5.3). The Lindsay limestone, on the other hand, is quarried commercially as aggregate.

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- hydrostratigraphic cross-section;
- contaminant release mechanism in the geosphere;
- flow path(s);
- hydraulic conductivities;

- hydraulic gradients; and
- effective porosities.

Additional contaminant transport parameters and geomechanical parameters are given in Tables 1 and 2, respectively.

7.2 Information Gaps

The major information gap, at least from the perspective of the Deep Rock Cavern Vault repository options, is the complete lack of site specific stratigraphic, hydrogeological and geotechnical/geomechanical data below a depth of about 100 m. While reasonable predictions of the conditions can be made on the basis of geological projections from known sites, these predictions need to be confirmed by site specific investigation.

From the perspective of the Covered Above Grade Concrete Vault, there is little site specific information pertinent to siting of a facility in presently unoccupied areas of the Bruce Site (e.g. the north-eastern portion of the site). Similarly, if it is decided to pursue the Shallow Concrete Vault option additional information will be required regarding the thickness, areal distribution and homogeneity of the till in the central eastern portion of the Site.

Finally, there is little or no project specific contaminant transport parameter data (e.g. matrix distribution coefficient, K_d, data) available for the specific lithologies and radionuclides associated with a permanent LLW repository at the Bruce Site.

7.3 Additional Studies

From a geotechnical engineering design perspective only, if it is decided to pursue one or more of the LLW repository options, it is suggested that the following types of additional studies be carried out:

- Develop a detailed rational and methodology for drilling, testing, instrumenting and abandoning a deep geotechnical borehole(s) at the Bruce Site.
- Carry out site specific hydrogeologic modelling of particularly the Deep Bedrock Groundwater Zone with specific reference to the potential effects of the dense (brine) groundwater in this zone.
- Carry out geophysical surveys and, if necessary, preliminary geotechnical boreholes in areas potentially available for siting a CAGCV facility.
- Carry out preliminary design studies to adapt the generic RCV to the deep geologic formations (i.e. the Ordovician age shales and limestones) beneath the Bruce Site, with particular reference to access (including shaft sealing), operation and ventilation of the DRCV facility.

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APPENDIX A

LITHOLOGICAL DESCRIPTION OF BEDROCK FORMATIONS PROJECTED TO UNDERLIE THE BRUCE SITE

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A1.0 INTRODUCTION

This Appendix describes the lithology of the various bedrock formations that are projected to occur beneath the Bruce Site. The shallow formations (Amherstburg and Bois Blanc Formations) have been encountered in drilling investigations on the Bruce Site. The understanding of the deeper sequence is limited to interpretation of the deep gas wells, Texaco #4 and #6, and regional correlation with the same strata elsewhere in Southern Ontario. The lithological nature of the stratigraphic sequence is discussed below from the bedrock surface downward to the Precambrian.

A2.0 LITHOLOGY

A2.1 Devonian Dolostones

The Devonian dolostone sequence beneath the Bruce Site includes the Amherstburg and Bois Blanc Formations. The Amherstburg Formation forms the bedrock surface. Both of the formations were investigated by a core drilling program near the Western Waste Management Facility by the US series boreholes shown on Figure 15. Borehole US-5 was the deepest (108.0 m) of this series of holes, terminating near the base of the Bois Blanc Formation (Reference 28).

The **Amherstburg Formation** varies in thickness up to 65 m and is comprised of brown, fine grained crystalline, to grey, very fine grained lithographic dolostone with occasional vuggy horizons and breccia zones with varying degrees of weathering. A grey, coarse grained, massive bedded fossiliferous coral limestone bed varying in thickness from 4 to 10 m occurs near the base of the formation.

The **Bois Blanc Formation** is approximately 38 m thick. It is described as being grey to brown, fine grained, massive bedded limestone and dolostone. The Formation is characterized by the abundant occurrence of chert nodules.

A2.2 Upper Silurian Dolostones

The Upper Silurian sequence includes the Bass Island Formation and the Salina Formation.

The **Bass Island Formation** is a brown dolostone approximately 42 m thick based on the Texaco #6 well. This formation is not exposed in the Bruce area nor was it encountered during the various site investigations for the Bruce A and B generating stations. However, it has been investigated by Golder where exposed in the Rockwood Quarry in southeastern Michigan (Reference 17). There, the rock is a light brown, faintly porous, fine crystalline, faintly petroliferous medium bedded dolostone with occasional stylolite beds and thin black shale partings.

At the Rockwood Quarry, the nature of the Silurian/Devonian discontinuity can be observed. The contact can be seen to undulate several metres over hundreds of metres of exposure in the quarry face and the upper 2 to 3 m of the rock directly beneath the Bois Blanc Formation was comparatively soft and fractured, representative of a geologic weathering profile. Also, the underlying 6 to 8 m of rock was comprised of fine grained, medium to thickly bedded marly dolostone of a comparatively less dense and softer nature than the underlying brown dolostone. The contact between the Bass Island and overlying Bois Blanc Formations at the Rockwood Quarry causes difficulty in blasting because of the weak and open nature of the contact. It is necessary to stem blast holes through this interface to control the blast performance. Considering that this contact is a regional discontinuity, it is likely that a similar condition could occur beneath the Bruce Site area where it would also be associated with a zone of enhanced permeability.

The **Salina Formation** is a comparatively complex interbedded sequence of dolostones and shales with minor anhydrite where encountered in the Texaco #4 and #6 wells. The Formation is approximately 205 m thick and it is subdivided into seven members (see Figure 16). As previously discussed, the salt horizons that would formerly have occurred within this Formation beneath the Bruce Site are absent due to solution activity in the geological past.

The **G Member** (~9 m) is the uppermost member of the Formation and it is comprised of a dark grey shale overlying a brown dolostone.

The underlying **F Member** is approximately 38 m thick and is predominately dark grey shale. The geophysical log for the Texaco #6 well indicates a 1 m thick anhydrite bed approximately 5 m above the basal contact of the Member. The F Member contains salt elsewhere in the basin, therefore it can be anticipated that solutioning of salt has occurred within this shale beneath the site which may have left collapse breccia. Also, the F Member contains anhydrite nodules where it is encountered in the Grand River Valley (Reference 13). Solution weathering of these nodules from the top of the Member has locally produced very porous, vuggy permeable conditions.

The **E Member** is approximately 33 m thick. The geophysical records for Texaco #6 indicate it is largely comprised of dolostone, typically a brown, fine grained, faintly porous, faintly petroliferous rock with some thin shale beds and anhydrite beds 0.5 to 1.0 m thick. Thinner anhydrite beds not identifiable in the geophysical logs can be reasonably anticipated.

The **D Member** of the Salina is a salt horizon but it is entirely absent beneath the Bruce Site.

The **C Member** is a comparatively thick shale sequence (~46 m) with some thin (0.5 to 1.0 m) anhydrite beds in the middle of the member. The C Member apparently did not contain salt and accordingly would not have been subject to the effects of salt solution.

The **B Member** beneath Bruce is an anhydrite bed approximately 2 m thick.

The underlying **A2 and A1 Members** have a combined thickness of approximately 78 m. These members are largely comprised of dolostone and shaly dolostone similar in lithology to that of the E Member. An anhydrite bed 2 m thick separates the A1 from the A2 Member and there may be some similar beds of 0.5 to 1 m thickness interbedded near the base of the A1 Member.

The A1 and A2 anhydrite beds are similar to the horizons mined at the Drumbo and Caledonia gypsum mines while the E Member anhydrite is likely similar to that of the Hagersville gypsum mine.

A2.3 Middle Silurian Dolostone

The Middle Silurian sequence includes, in descending order, the Guelph, Lockport and Reynales Formations with a combined thickness of approximately 42 m (Texaco #6).

The **Guelph Formation** is approximately 10 m thick and tends to be porous, hence it is a potential gas or water-bearing horizon. No gas was encountered in either of the Texaco #4 and #6 holes or the Kincardine #1 hole, but sulphur water was encountered.

The **Lockport Formation** includes the Goat Island Member (~20 m thick) and Gasport Member (~8 m thick), both of which are dolostone beds of variable porosity.

The **Reynales Formation** (~5.5 m thick) is a fine grained thin to medium bedded argillaceous to shaly dolostone.

A2.4 Lower Silurian Shale and Dolostone

This sequence includes the Cabot Head Formation and the Manitoulin Formation (total thickness of approximately 36 m).

The **Cabot Head Formation** is a 30 m thick sequence of soft greenish grey to maroon, fissile shale becoming a shaly dolostone in the lower 10 m in transition to the Manitoulin Formation.

The **Manitoulin Formation** (approximately 6 m thick) is a grey, fine to coarsely crystalline, thinly bedded dolostone with shaly partings.

A2.5 Ordovician Shale Sequence

The Ordovician shale sequence identified beneath the Bruce Site includes in descending order, the Queenston Formation, the Georgian Bay Formation and the Collingwood Formation. The total thickness of the shale sequence is approximately 207 m. The Queenston Formation and the Georgian Bay Formation are relatively distinct where encountered in the Texaco #6 well, while the contact between the Georgian Bay and Collingwood Formations is less distinct. These formations outcrop below the Niagara Escarpment from the Bruce Peninsula to Niagara Falls.

The **Queenston Formation** is approximately 80 m thick beneath the Bruce Site. The Formation is typically a distinct rock horizon comprised of reddish brown mudstone with occasional thin interbeds of siliceous to calcareous siltstone. The mudstone is not particularly fissile but it is highly susceptible to slaking on exposure, whereby the rock tends to fracture, swell and disintegrate to clayey soil when exposed to wetting and drying cycles. This formation was extensively investigated in Niagara Falls, Ontario during the Ontario Hydro Sir Adam Beck III feasibility study which included the excavation of a large underground opening, as discussed further in Section 5.3 of this report.

The **Georgian Bay Formation** represents the start of the grey shale sequence. The formation is indicated to be approximately 95 m in thickness. The geophysical record for the Texaco #6 well indicates that the upper 50 to 52 m of the sequence is comprised of interbedded shale, shaly limestone and siltstone. Where exposed in the Niagara Escarpment and beneath the City of Toronto, the shale is fissile and the shaly limestone and siltstone occurs in thin beds. The lower half of the formation (45 to 47 m) encountered in the Texaco #6 well appears to be predominately shale based on the geophysical records. This would likely include the unsubdivided Blue Mountain Formation recognized in the Bruce Peninsula – Lake Ontario area. The shale of this sequence is likely grey fissile shale with few limestone or siltstone beds.

The **Collingwood** Formation is comprised of approximately 32 m of predominately shale, as indicated by the Texaco #6 geophysical record. It is not clear from the available logs if black petroliferous shale occurs at the base of the shale sequence, but black shales were reported in the rock core of the Ontario Geological Survey's Corbetton OGS-82-0 deep borehole to the east of the Bruce Site, shown on Figure 13 (Reference 25).

A2.6 Ordovician Limestone Sequence

The Ordovician limestones are exposed in rock quarries north of Lake Ontario and they have been investigated by several deep drilling programs, including investigations by Golder (References 11 and 15), Ontario Hydro (References 26 and 35) and the Ontario Geological Survey (Reference 25). A fundamental character of the Ordovician limestones is the very fine granularity and non-porous nature of the rock. The rock description for each formation based on information from the Bowmanville Quarry site where they have been extensively studied (Reference 15) is summarized below. The description has been modified for the Bruce Site based upon the assessment of the geophysical signatures for Texaco Wells #4 and #6.

The **Lindsay Formation** has a full formational thickness of approximately 45 m where encountered in Texaco Well #6. The Lindsay Formation has been sub-divided into an **Upper Member** approximately 36 m thick and a **Lower Member** referred to as the **Sherman Falls Member** which is approximately 9 m thick. The Sherman Falls Member is regionally recognized throughout Southern Ontario due to its consistent thickness and distinctive geophysical signature. Both of these members are exposed in the Bowmanville Quarry (see Figure 14).

The **Upper Member** of Lindsay Formation is comprised of fresh, very fine grained, medium to dark grey, thin to medium bedded, nodular textured (10 mm to 50 mm dia. nodules) argillaceous limestone. The limestone is largely micritic with minor thin beds of medium grained bioclastic calcarenite. Occasional interbeds of shaly limestone and thin black shale partings occur and the rock contains occasional fossil burrow casts, pelletal horizons, gastropod, brachiopod and crinoid fossil fragments. The natural gamma and neutron logs for the Upper Member sequence distinguish the occurrence of more argillaceous partings within the rock sequence as noted by the associated positive log spikes. However, in close examination of the rock core (Reference 15), the Upper Member sequence is quite monotonous with no visually distinguishable marker horizons. The rock is quite sound and fragments well during quarrying but occasionally breaks into larger angular blocks with dimensions of 1 m to 3 m.

The **Sherman Falls Member** is visually distinguishable in rock core due to its noticeably less argillaceous nature compared to that of the enclosing strata. The upper and lower contacts of the Sherman Falls Member are transitional but occur within a narrow interval. The rock comprising the member is fresh, medium grey to brownish grey, fine grained, medium to thickly bedded, nodular textured (10 mm to 15 mm dia.) micritic limestone. It contains occasional laminar to thin interbeds of fine to medium grained, partly crystalline calcarenitic limestone and occasional gastropod, brachiopod and crinoid fossil fragments.

The **Verulam Formation** limestone has a total thickness of approximately 70 m beneath the Bruce Site. The formation is distinguishable by its noticeably more shaly nature compared to the overlying and underlying formations. The formation has been sub-divided into an **Upper Member** and a **Lower Member** based upon its geophysical signature and the relative percentage of slake susceptible shaly beds and lithoclastic beds, which visually distinguish the two members within the overall rock sequence.

The **Upper Member** is approximately 38 m in thickness. The upper contact is gradational. The rock is fresh, laminar to thinly bedded and comprised of a monotonous sequence of dark grey to black, very fine to fine grained, argillaceous to shaly limestone and calcareous shale interbedded with medium grey, fine grained micritic limestone and medium grey to brownish grey, medium grained, crystalline, faintly petroliferous calcarenitic limestone. The rock contains occasional brachiopod and crinoid fossil fragments, pelletal beds and burrow casts.

The argillaceous to shaly component of the rock where encountered beneath Bowmanville varies from approximately 20 to 40 percent. The shaly beds are reflected by the associated spikes in the geophysical records. The individual shaly beds range from 10 mm to 100 mm in thickness and tend to slake on exposure. The slake susceptibility of the Upper Member is quite noticeable compared to the rest of the rock sequence where examined in core and at outcrop north of Lake Ontario. The degree of slaking was measured in rock core from the Bowmanville Quarry where between 1 and 15 percent of the rock was found to slake following cycles of wetting and drying in the core axis. Likely all of the black shale would slake on prolonged exposure.

The Verulam Formation, and specifically the Upper Member is also characterized by the occurrence of light grey lithoclastic calcarenitic limestone beds 10 mm to 250 mm thick that contain 2 mm to 50 mm dia. sub-rounded rip-up clasts of shale and limestone. These beds also contain some fossil shell fragment debris. The lithoclastic beds collectively comprise 5 to 30 percent of the rock sequence on a per core run basis (average 3 m length), based on the detailed logging of DH00-1 at Bowmanville (Reference 15). These beds likely represent deposits formed from the effects of severe storm events during deposition and typically occur in fining upward sequences that grade into micritic limestone and shale.

The **Lower Member** of Verulam Formation limestone is approximately 30 m thick. The contact with the Upper Member is transitioned and it is mainly distinguishable from the Upper Member by a sharp shift in the geophysical signature associated with its lower argillaceous component. The lithological character of the limestone comprising the Lower Member is essentially the same as that of the Upper Member, but the percentage of slake susceptible shale beds and lithoclastic beds is lower. The shale content varies between 15 to 25 percent of the rock sequence.

The **Bobcaygeon Formation** was found to have a thickness of approximately 30 m beneath the Bruce Site. The Bobcaygeon Formation marks a sharp transition into noticeably less argillaceous and more crystalline calcarenitic limestone compared to the overlying strata. This change is marked by a distinct negative shift in the natural gamma log and positive shift in the neutron log compared to that of the overlying Lindsay and Verulam Formations.

The rock is typically comprised of fresh, medium grey to brownish grey, fine to medium grained, thinly to medium bedded, crystalline, faintly petroliferous calcarenitic to bioclastic limestone interbedded with lesser amounts of argillaceous, nodular textured micritic limestone with occasional fossil burrow casts and pelletal horizons. Occasional 25 mm to 75 mm thick dark grey shaly partings also occur. The overall shale content of the rock is approximately 5 to 10 percent. The shale is slightly susceptible to slaking and some lithoclastic beds also occur. The formation also contains beds of fresh, medium grey to brownish grey, medium to coarse grained, medium to thickly bedded, faintly petroliferous, crystalline calcarenite. The rock has occasional stylolites and 2 mm to 5 mm thick grey shale partings. The shale content of the calcarenite beds is typically less than 5 percent of the rock in the form of discrete partings.

The **Gull River Formation** is distinguished from the overlying strata as a very fine grained to lithographic limestone. The total thickness of the formation is estimated to be approximately 43 m to 45 m beneath the Bruce Site. The rock is similar to the Bobcaygeon Formation with respect to the comparatively low shale content such that the upper contact does not have a particularly distinct geophysical signature.

The formation contains beds of fresh, light to medium brownish grey, very fine grained, medium to thickly bedded, faintly petroliferous, porcellenaceous textured, lithographic limestone with well developed stylolites, minor disseminated medium grained laths and intergranular crystals of anhydrite and occasional argillaceous to shaly partings. The rock also includes medium grey to brownish grey and medium brown, very fine to fine grained, thinly to medium bedded, lithographic to argillaceous limestone and interbedded horizons of light creamy grey, tan to medium brownish grey, lithographic to fine to medium grained, medium to thickly bedded limestone with occasional dolomitic limestone beds. The basal section of the Gull River Formation tends to be comprised of dolomitic limestone with thin shaly beds.

APPENDIX B

SUMMARY OF
HYDRAULIC CONDUCTIVITY TESTING DATA

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B1.0 INTRODUCTION

This Appendix summarizes the available results of hydraulic conductivity testing carried out in the geological units projected to underlie the Bruce Site. The summary is based on two primary sources of data:

(i) site specific data regarding the surficial (overburden) deposits and upper portion of the bedrock (i.e. to a depth of about 100 m below ground surface); and

(ii) extrapolated data from deep borehole testing carried out in the Ordovician age shales and limestones at sites located along the north shore of Lake Ontario.

While factual data is available regarding the hydraulic conductivity of near-surface, weathered expressions of the Silurian age sediments along the Niagara Escarpment, the data is not considered directly applicable to the deep, unweathered Silurian sediments underlying the Bruce Site.

B2.0 SUMMARY OF HYDRAULIC CONDUCTIVITY TESTING

B2.1 Surficial Deposits Hydraulic Conductivity

The surficial deposits beneath the Bruce Site vary from very dense clayey silt to sandy silt till to sand and gravel (ref. Figure 11 for example). A series of field tests was carried out in the multi-level piezometers within the Western Waste Management Facility between 1977 and 1980 (Reference 33). The hydraulic conductivity test work included Hvorslev rising and falling head slug tests in wells sealed in the till and the middle sand layer, as well as pumping test responses from the middle sand. The results are shown both graphically and in tabular summary on Figure B.1.

The hydraulic conductivity tests in till fall within a narrow range between 1.0×10^{-10} and 5.6×10^{-10} m/s with a geometric mean of 2.4×10^{-10} m/s (see Figure B.1). These results are consistent with the massive, dense, fine grained character of the till.

The slug test performed within the middle sand layer indicate a range of hydraulic conductivity from 3.7×10^{-8} to 3.1×10^{-5} m/s with a geometric mean of 1.6×10^{-6} m/s. In contrast, the drawdown responses to pumping tests in the middle sand fall within a higher but narrower range of 2.1×10^{-5} to 3.1×10^{-5} m/s with a geometric mean of 2.5×10^{-5} m/s. As discussed in Reference 33, the pump test results are considered to be more representative of the middle sand layer.

B2.2 Bedrock Hydraulic Conductivity

Hydraulic conductivity testing is available for the shallow bedrock on-site (Amherstburg and Bois Blanc Formations) while test data considered representative of the deep Ordovician strata is available from deep hole testing along the north shore of Lake Ontario.

Figure B.2 represents the results of both rising head recovery slug tests and pumping tests from bedrock monitoring wells set in the upper 3.5 m of the bedrock beneath the Western Waste Management Facility (Reference 38). Again, the pump test results provide higher estimates of hydraulic conductivity, ranging between 6 x 10^{-6} and 4 x 10^{-5} m/s with a geometric mean of 2 x 10^{-5} m/s.

The hydraulic conductivity results of constant head pumping tests carried out in the open boreholes for the Bruce A monitoring wells (Wells BA-1 to BA-5) and Bruce B monitoring wells (Wells BB-1 to BB-5) (Reference 39) are also shown on Figure B.2. These values range between 9.1 x 10^{-7} and 2.9 x 10^{-4}m/s with a geometric mean of 2.6 x 10^{-5} m/sec. When viewing the combined pumping test data, the representative hydraulic conductivity within the upper 15 m of bedrock appears to be in the order of 1 x10^{-4} to 1 x 10^{-6} m/s.

The hydraulic conductivity results of extensive packer injection testing from geotechnical investigations of the bedrock to depths of 60 m beneath the Bruce A power station (References 29 and 30) are summarized on Figure B.3. The testing was carried out within the Amherstburg and Bois Blanc Formations. The data are divided into two populations, “tight” tests with no measured flow (‘take’) which provide a lower bound for unfractured rock and tests for measurable flow which represents rock with open fractures. For the latter set of data, there is little indication of a permeability change with depth. The data fall within a range of 5 x 10^{-8} to 2 x 10^{-4} m/s with a geometric mean of 2 x 10^{-6} m/s within the Amherstburg and Bois Blanc Formation to depths of 100 m below surface.

A similar trend is represented for the packer test results from the US series geotechnical holes drilled near the Western Waste Management Facility area (Reference 28), as shown on Figure B.4. The results for the US series boreholes are an order of magnitude lower than for the similar strata beneath Bruce A. Response slug tests were carried out within Westbay monitoring well installations in boreholes US-5 and US-6 as summarized on Figure B.4. The results varied between 1x10^{-6} and 9x10^{-5} m/s, being significantly higher than the packer test results.

The results of the packer injection testing are not consistent with the actual construction dewatering experience (see Section 5.1). Therefore, the response test and pumping test results shown on Figures B.3 and B.4 are considered to be more representative of the anticipated hydraulic conductivity conditions within the Amherstburg and Bois Blanc Formations, such that the entire Amherstburg and Bois Blanc Formations are likely characterized by hydraulic conductivities in the order of 1x10^{-4} to 1x10^{-6} m/s.

The hydraulic conductivity of the Ordovician shale and limestone sequence was tested using high resolution pressure pulse testing systems in four deep boreholes along the north shore of Lake Ontario. This included two 60 degree inclined boreholes (DH00-1 and DH00-2) drilled from surface to the Precambrian basement at the Bowmanville Quarry (Reference 15), a deep borehole (UN-2) drilled at a 70^{o} angle from horizontal extending to the Precambrian basement at the Darlington Nuclear Station (Reference 21) and a vertical drillhole (OHD-1) drilled to the

Precambrian basement at the Lakeview Generating Station (Reference 37). The stratigraphy encountered in these boreholes is shown on Figures 13 and 14 while the hydraulic conductivity data is summarized on Figure B.5.

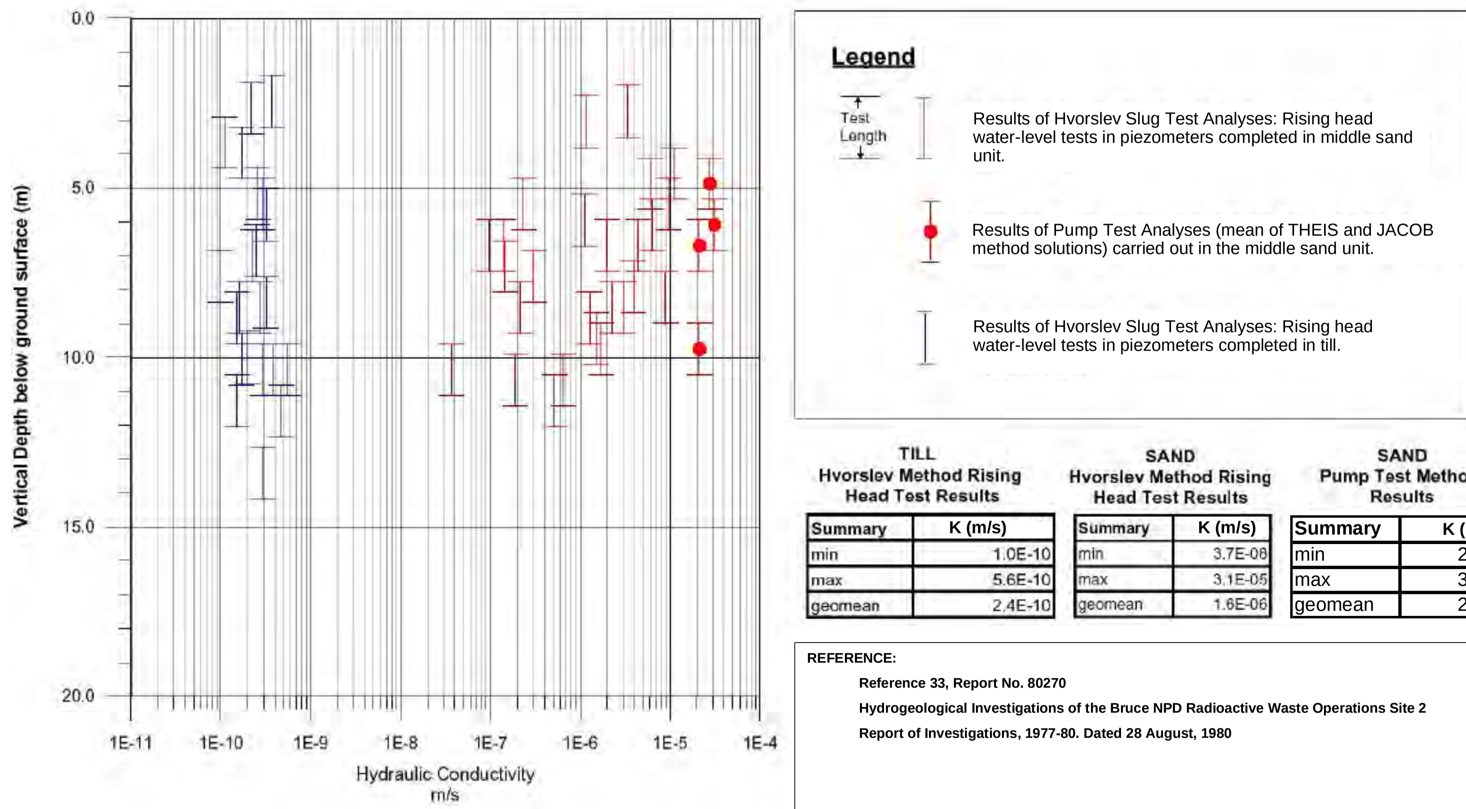
The test results from the four deep boreholes reflect extremely low hydraulic conductivities in both the shale and limestone. The test results for the Georgian Bay, Blue Mountain and Collingwood Formation shales and the underlying Lindsay Formation limestone ranged between 10^{-10} and 10^{-14} m/s with geometric means of 1 x 10^{-12} m/s (shale) and 7 x 10^{-13} m/s (limestone). A somewhat larger range of results (1 x 10^{-8} to 1 x 10^{-14} m/s) was obtained from the underlying limestone strata with the higher values occurring within discrete intervals, likely associated with bedding parting permeability within weaker shaly horizons. Although the range is wider, the geometric means of the data are within an order of magnitude of the overlying strata. Overall, the geometric mean of the data for these strata, as shown on Figure B.5, varies between 1 x 10^{-11} and 1 x 10^{-12} m/s, which is considered representative of the bulk hydraulic conductivity.

SUMMARY OF HYDRAULIC CONDUCTIVITY TESTING FOR OVERBURDEN (TILL AND MIDDLE SAND) FROM BRUCE RWO SITE 2 PROGRAM

FIGURE B.1

HYDRAULIC CONDUCTIVITY TEST RESULTS FOR OVERBURDEN FROM PREVIOUS RADIOACTIVE WASTE OPERATIONS SITE 2 INVESTIGATIONS (1977-1980)

SHALLOW OVERBURDEN PIEZOMETERS IN TILL AND SAND



TILL
Hvorslev Method Rising Head Test Results

Summary	K (m/s)
min	1.0E-10
max	5.6E-10
geomean	2.4E-10

SAND
Hvorslev Method Rising Head Test Results

Summary	K (m/s)
min	3.7E-08
max	3.1E-05
geomean	1.6E-06

SAND
Pump Test Method Results

Summary	K (m/s)
min	2.1E-05
max	3.1E-05
geomean	2.5E-05

REFERENCE:

Reference 33, Report No. 80270

Hydrogeological Investigations of the Bruce NPD Radioactive Waste Operations Site 2

Report of Investigations, 1977-80. Dated 28 August, 1980

Date: JANUARY 2003

Project: 021-1570

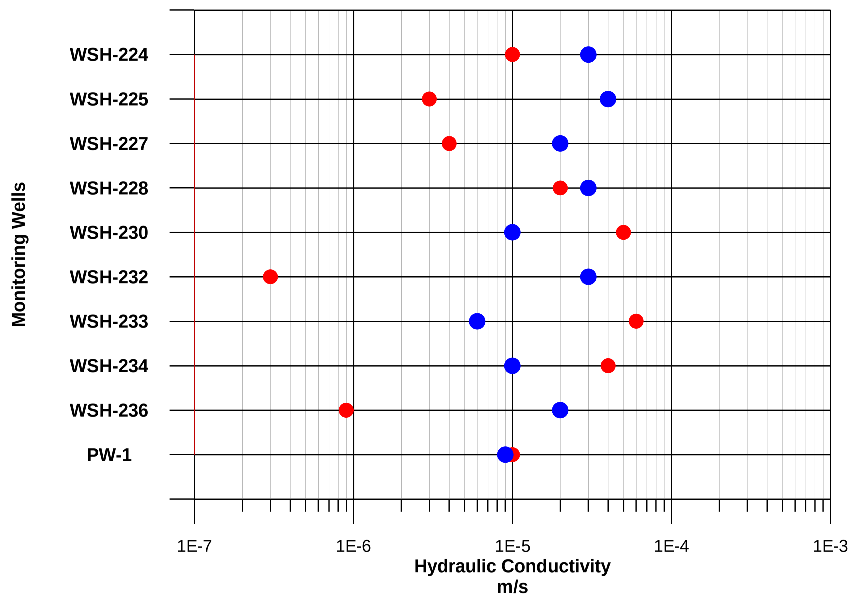
Golder Associates

Drawn: MR

Chkd: RB

SUMMARY OF HYDRAULIC CONDUCTIVITY TESTING FOR SHALLOW BEDROCK
BRUCE RWO SITE 2 INVESTIGATIONS 1995

FIGURE B.2



Legend

(Red) Rising Head Hydraulic Conductivity Test Results, except for PW-1, which is a Constant Discharge Test result.

(Blue) Pump Test Hydraulic Conductivity Test Results

Average test depth inferred to be 3.5m from top of bedrock.

Statistical Summary of All Data Plotted

Summary	K (m/s)
min	3.E-07
max	6.E-05
geomean	1E-05

Statistical Summary of Rising Head Data

Summary	K (m/s)
min	3.E-07
max	6.E-05
geomean	8E-06

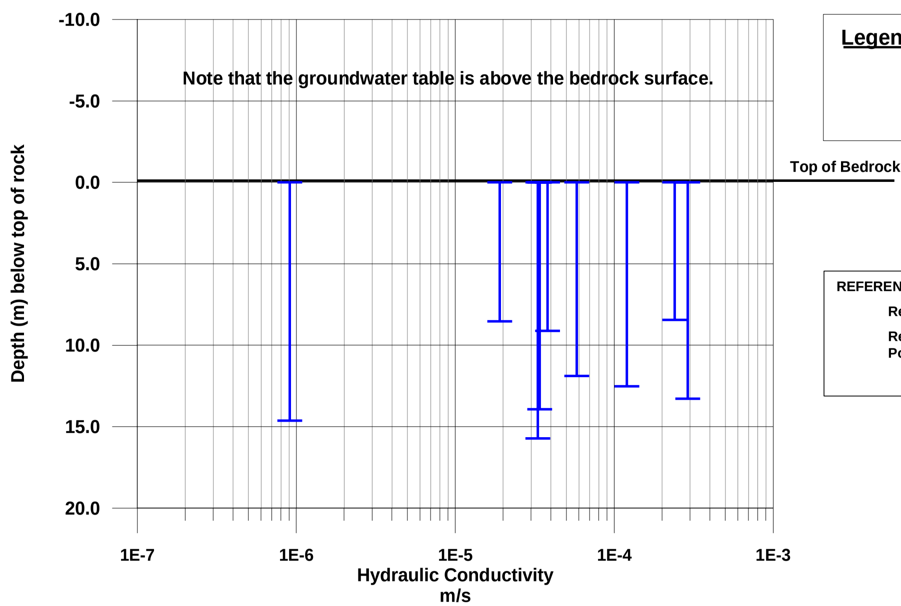
Statistical Summary of Pump Test Data

Summary	K (m/s)
min	6.E-06
max	4.E-05
geomean	2E-05

REFERENCE:

Reference 38, Ontario Hydro Report No. NK37-03480-94014 (UFMED) R00

BNPD RWO Site 2 HYDROGEOLOGICAL INVESTIGATIONS AND NUMERICAL GROUNDWATER FLOW SYSTEMS ANALYSIS. Dated March 1995.



Legend

Shallow bedrock test interval. Hydraulic Conductivity estimated from pumping test Q/H data at steady state.

Summary	K (m/s)
min	9E-07
max	3E-04
geomean	4E-05

REFERENCE:

Reference 39, Ontario Hydro Technologies Report 6292-001-1997-RA-001-R00

Reconnaissance Level Groundwater Quality Monitoring Program, Bruce Nuclear Power Development Generating Stations Bruce 1-4 and Bruce 5-8. Dated May 1998

Date: JANUARY 2003
Project: 021-1570

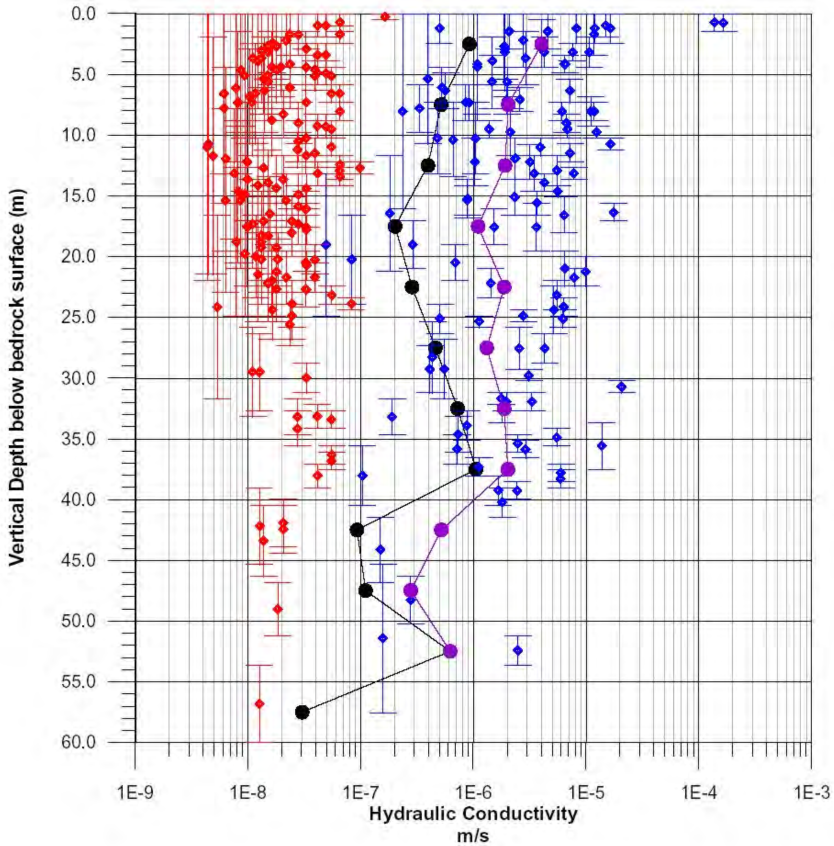
Golder Associates

Drawn: MR
Chkd: RB

SUMMARY OF HYDRAULIC CONDUCTIVITY TESTING FOR AMHERSTBURG AND BOIS BLANC FORMATIONS FROM BRUCE A SITE INVESTIGATIONS 1969-1970

FIGURE B.3

HYDRAULIC CONDUCTIVITY TEST RESULTS FOR BEDROCK FROM PREVIOUS BRUCE GENERATING STATION GEOTECHNICAL INVESTIGATIONS (1969-1970)



Legend

Test Length

(Red) Test Results reported as "Tight". A flow and pressure of 0.1 cu ft/min and 210 psi, respectively, were assumed in order to calculate an estimated hydraulic conductivity for "Tight" intervals.

(Blue) Test Results with measured flows and pressures. Generally, the lowest reported flow is 0.1 cu ft/min.

Weighted (geometric) mean hydraulic conductivity per 5 m interval (All data).

Weighted (geometric) mean hydraulic conductivity per 5 m interval based on tests with measured flows (Blue data).

STATISTICAL SUMMARY OF ALL DATA PLOTTED

Summary	K (m/s)
min	4E-09
max	2E-04
geomean	2E-07

BLUE DATA ONLY

Summary	K (m/s)
min	5E-08
max	2E-04
geomean	2E-06

REFERENCES:

Reference 29, Ontario Hydro Report No. 181-18

Bruce Generating Station Geotechnical Site Evaluation (MacPherson Point Area). Dated December 1969

Reference 30, Ontario Hydro Report No. 181-23

Bruce Generating Station Intake Tunnel, Report on the Geological Investigations. Dated November 1970

Date: JANUARY 2003

Project: 021-1570

Golder Associates

Drawn: MR

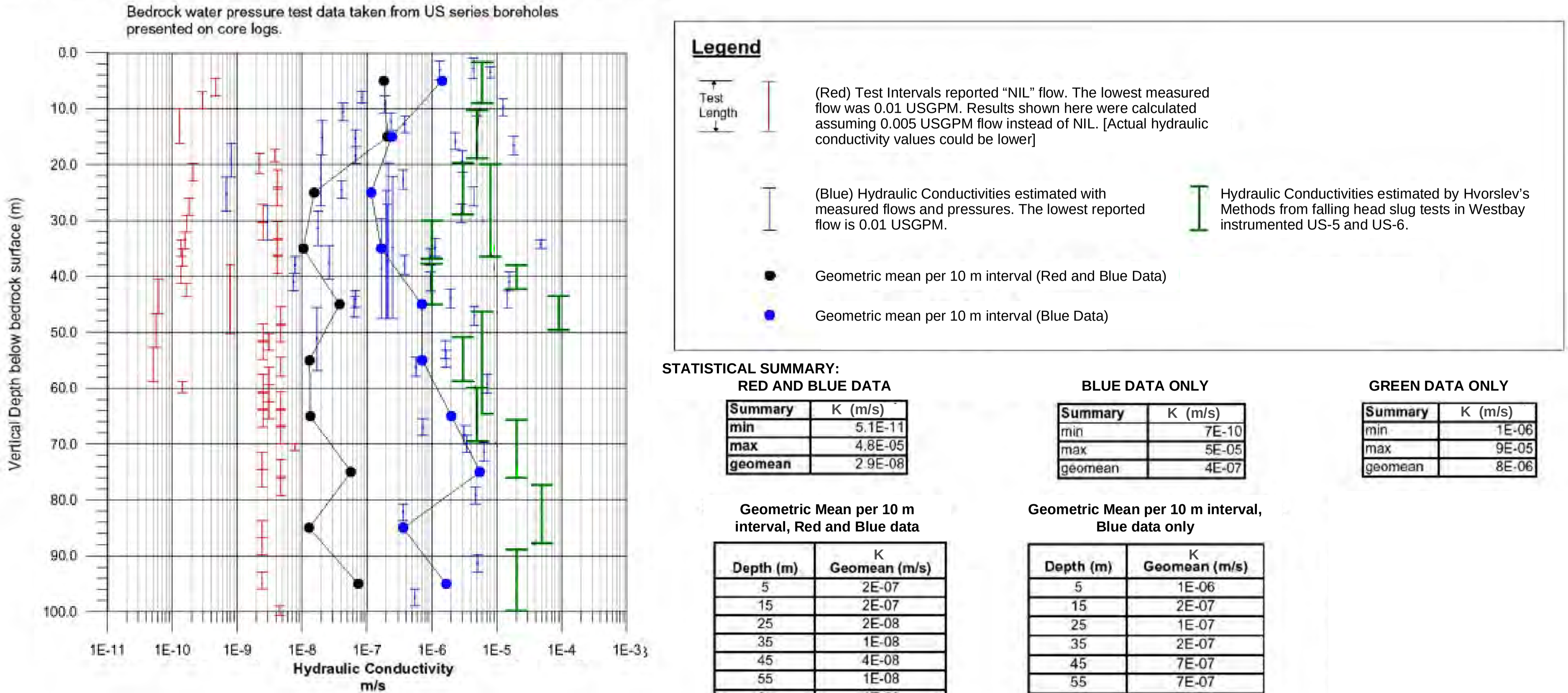
Chkd: RB

SUMMARY OF HYDRAULIC CONDUCTIVITY TESTING FOR AMHERSTBURG AND BOIS BLANC FORMATIONS FROM BRUCE SITE INVESTIGATIONS 1986 TO 1988

FIGURE B.4

HYDRAULIC CONDUCTIVITY TEST RESULTS FOR BEDROCK FROM PREVIOUS BRUCE GENERATING STATION GEOTECHNICAL INVESTIGATIONS (1986-1988)

DEEP GEOTECHNICAL HOLES US-1 to US-7 HYDRAULIC CONDUCTIVITY RESULTS



STATISTICAL SUMMARY:

RED AND BLUE DATA

Summary	K (m/s)
min	5.1E-11
max	4.8E-05
geomean	2.9E-08

BLUE DATA ONLY

Summary	K (m/s)
min	7E-10
max	5E-05
geomean	4E-07

GREEN DATA ONLY

Summary	K (m/s)
min	1E-06
max	9E-05
geomean	8E-06

Geometric Mean per 10 m interval, Red and Blue data

Depth (m)	K Geomean (m/s)
5	2E-07
15	2E-07
25	2E-08
35	1E-08
45	4E-08
55	1E-08
65	1E-08
75	6E-08
85	1E-08
95	7E-08

Geometric Mean per 10 m interval, Blue data only

Depth (m)	K Geomean (m/s)
5	1E-06
15	2E-07
25	1E-07
35	2E-07
45	7E-07
55	7E-07
65	2E-06
75	6E-06
85	4E-07
95	2E-06

REFERENCES:

Reference 28, Ontario Hydro Report No. GHED-DR-8801

BNPD Proposed Underground Irradiated Fuel Storage Facilities Geological Investigations 1986-1987. Dated May 1988.

Date: JANUARY 2003

Project: 021-1570

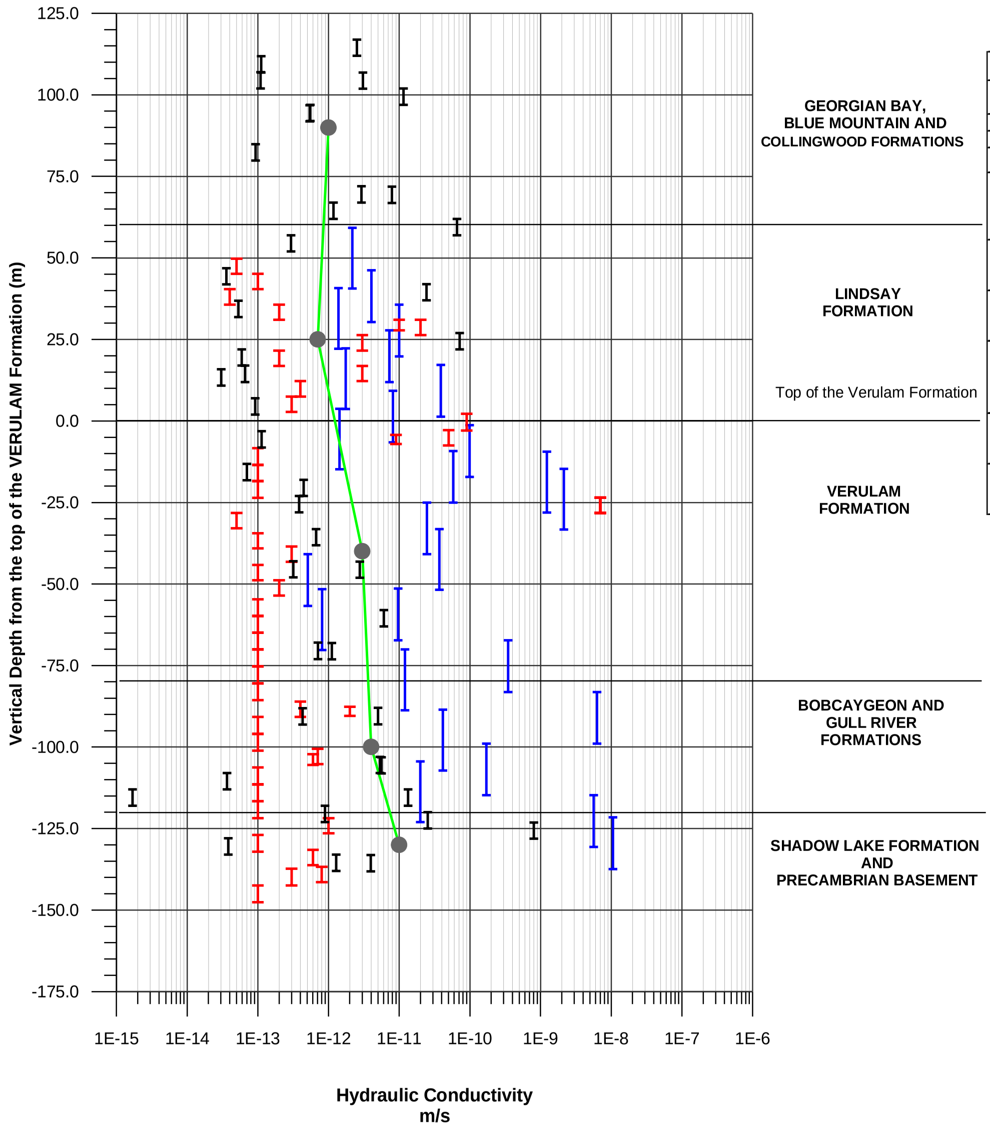
Golder Associates

Drawn: MR

Chkd: RB

SUMMARY OF HYDRAULIC CONDUCTIVITY RESULTS FOR DEEP GEOTECHNICAL BOREHOLES IN SOUTHERN ONTARIO ORDOVICIAN ROCK

FIGURE B.5



HYDRAULIC CONDUCTIVITIES (m/s)

Hole	BOREHOLE ODH-1			UN-2			DDH-01 and DDH-02		
Site	Lakeview			Darlington			Bowmanville		
Inclination (°)	90 °			70 °			60 ° (both)		
Formation	**min**	**max**	**GeoMean**	**min**	**max**	**GeoMean**	**min**	**max**	**GeoMean**
Georgian Bay and Blue Mountain	9E-14	7E-11	1E-12	Not Intersected			Not Intersected		
Lindsay	3E-14	7E-11	3E-13	4E-14	9E-11	9E-13	2E-12	4E-11	8E-12
VERULAM	7E-14	6E-12	6E-13	5E-14	7E-09	3E-12	5E-13	2E-09	2E-11
Bobcaygeon and Gull River	2E-15	3E-11	1E-12	1E-13	2E-12	2E-13	5E-12	4E-11	2E-11
Shadow Lake	4E-14	8E-10	6E-12	1E-13	8E-10	2E-13	1E-09	1E-08	8E-09
Precambrian	1E-12	4E-12	2E-12	1E-13	8E-13	3E-13			

LEGEND

Test Length

LAKEVIEW OHD-1 (Reference 37)

DARLINGTON UN-2 (Reference 21)

BOWMANVILLE DH-01 and DH-02 (Reference 15)

● Geometric Mean per Formation Grouping (All Data)

NOTE:
All test intervals corrected to vertical depth from borehole inclination.

Date: JANUARY 2003
Project: 021-1570

Golder Associates

Drawn: MR
Chkd: RB

APPENDIX C

ROCK MASS CLASSIFICATION DESCRIPTIONS

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C1.0 INTRODUCTION

Over the years, two empirical, semi-qualitative systems for classifying rock masses for the purpose of predicting the response of the rock to a change in stress (e.g. an excavation opening) have been developed. These are the Geomechanics Classification or Rock Mass Rating (RMR) system developed by Bieniawski in 1976 (Reference 3) and the Tunnelling Quality Index (Q) developed by the Norwegian Geotechnical Institute in 1974 (Reference 1). While largely empirical, these systems have gained broad, practical application on hundreds of excavations in a broad range of rock conditions around the world. As a result, they represent a widely accepted, practical tool for classifying rock masses. The following descriptions of the two systems are excerpted from Dr. Evert Hoek's "Practical Rock Engineering Notes" which have been published on the Internet at http://www.rockscience.com/roc/Hoek/Hoek.htm.

C2.0 ROCK MASS CLASSIFICATIONS DESCRIPTIONS

C2.1 Geomechanics Classification, *RMR*

Bieniawski (1976) published the details of a rock mass classification called the Geomechanics Classification or the Rock Mass Rating (*RMR*) system. Over the years, this system has been successively refined as more case records have been examined and the reader should be aware that Bieniawski has made significant changes in the ratings assigned to different parameters. The discussion which follows is based upon the 1976 version of the classification (Reference 3). The following six parameters are used to classify a rock mass in the *RMR* system:

1. Uniaxial compressive strength of rock material.
2. Rock Quality Designation (*RQD*).
3. Spacing of discontinuities.
4. Condition of discontinuities.
5. Groundwater conditions.
6. Orientation of discontinuities.

The Rock Mass Rating is the sum of the ratings for the first five parameters, with a possible maximum of 100, and an additional adjustment based on the sixth parameter. In applying this classification system, the rock mass is divided into a number of structural regions and each region is classified separately. The boundaries of the structural regions usually coincide with a major structural feature such as a fault or with a change in rock type. In some cases, significant changes in discontinuity spacing or characteristics, within the same rock type, may necessitate the division of the rock mass into a number of smaller structural regions.

C2.2 Rock Tunnelling Quality Index, *Q*

On the basis of an evaluation of a large number of case histories of underground excavations, Barton et al (1974) of the Norwegian Geotechnical Institute proposed a Tunnelling Quality Index

(*Q*) for the determination of rock mass characteristics and tunnel support requirements (Reference 1). The numerical value of the index *Q* varies on a logarithmic scale from 0.001 to a maximum of 1,000 and is defined by:

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

where

RQD is the Rock Quality Designation
Jn is the joint set number
Jr is the joint roughness number
Ja is the joint alteration number
Jw is the joint water reduction factor
SRF is the stress reduction factor

In explaining the meaning of the parameters used to determine the value of *Q*, Barton et al (1974) offer the following comments:

The first quotient (*RQD*/*Jn*), representing the structure of the rock mass, is a crude measure of the block or particle size, with the two extreme values (100/0.5 and 10/20) differing by a factor of 400. If the quotient is interpreted in units of centimetres, the extreme 'particle sizes' of 200 to 0.5 cm are seen to be crude but fairly realistic approximations. Probably the largest blocks should be several times this size and the smallest fragments less than half the size. (Clay particles are of course excluded).

The second quotient (Jr/Ja) represents the roughness and frictional characteristics of the joint walls or filling materials. This quotient is weighted in favour of rough, unaltered joints in direct contact. It is to be expected that such surfaces will be close to peak strength, that they will dilate strongly when sheared, and they will therefore be especially favourable to tunnel stability.
When rock joints have thin clay mineral coatings and fillings, the strength is reduced significantly. Nevertheless, rock wall contact after small shear displacements have occurred may be a very important factor for preserving the excavation from ultimate failure. Where no rock wall contact exists, the conditions are extremely unfavourable to tunnel stability.

The third quotient (*Jw/SRF*) consists of two stress parameters. *SRF* is a measure of: 1) loosening load in the case of an excavation through shear zones and clay bearing rock, 2) rock stress in competent rock, and 3) squeezing loads in plastic incompetent rocks. It can be regarded as a total stress parameter. The parameter *Jw* is a measure of water pressure, which has an adverse effect on the shear strength of joints due to a reduction in effective normal stress. Water may, in addition, cause softening and possible out-wash in the case of clay-filled joints. The quotient (*Jw/SRF*) is a complicated empirical factor describing the 'active stress'.

APPENDIX D

PILLAR STABILITY FOR DEEP ROCK CAVERNS

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D1.0 INTRODUCTION

Analysis of *in situ* performance of pillars, based on the tributary area method of calculating the level of stress, suggests that the strength of a pillar is related to its volume and shape. Increase in pillar volume results in natural fractures and other defects adversely affecting the pillar strength. The dependency on the pillar shape is a function of three factors: confinement, which develops in the core of the pillar due to constraint on lateral dilation; redistribution of field stress components into the pillar domain; and change in pillar failure mode with change in aspect ratio. The strength of a pillar can then be represented by the relationship:

$$S = S_o h^{\alpha} w_p^{\beta}$$

where S_o - strength parameter representative of the rock mass
h - pillar height
w_p - pillar width
α,β - strength components

Salamon and Munro (1967) summarized some estimated values of the pillar strength exponents for square pillars. Golder Associates' experience in pillar design is embodied in the following expression:

$$S = UCS \times 0.3478 \times \left(\frac{w_p}{h}\right)^{0.75}$$

where UCS - unconfined compressive strength
h, w_p - pillar width

There is field evidence that rib pillars are stronger than square pillars of the same width. Wagner (1980) indicated that the operating area (perpendicular to the pillar axis) is important and an effective width equal to twice the hydraulic radius of the pillar cross-section should be used in the pillar strength formula. The hydraulic radius of the pillar is defined as four times the cross-sectional area of the pillar divided by the perimeter of the pillar. This effective width is equal to the actual pillar width in the case of a square pillar, as expected, and equal to two times the actual pillar width for rib pillars.

D2.0 RESULTS OF PRELIMINARY ANALYSES

D2.1 Stress Level and Pillar Stability in Queenston Shale

The rock cavern in the Queenston shale is set at a depth of 460 m below surface. Assuming an average unit weight 0.026 MN/m^3, the in situ vertical stress is approximately 12 MPa.

The generic cavern layout is based on 10.5 m wide by 7.5 m high rooms with 10 m wide rib pillars. This is equivalent to a tributary area approximately twice the pillar area, resulting in an average pillar stress of 24 MPa. The pillar strength, as estimated by the pillar strength formula, is equal to 29 MPa, yielding a safety factor of 1.21. Maintaining the size of the rooms and increasing the pillar width to 15 m lowers the average pillar stress to 20 MPa and increases the pillar strength to 39.3 MPa. This results in a factor of safety of about 2, which should be taken as the minimum acceptable factor of safety.

D2.2 Stress Level and Pillar Stability in Lindsay Limestone

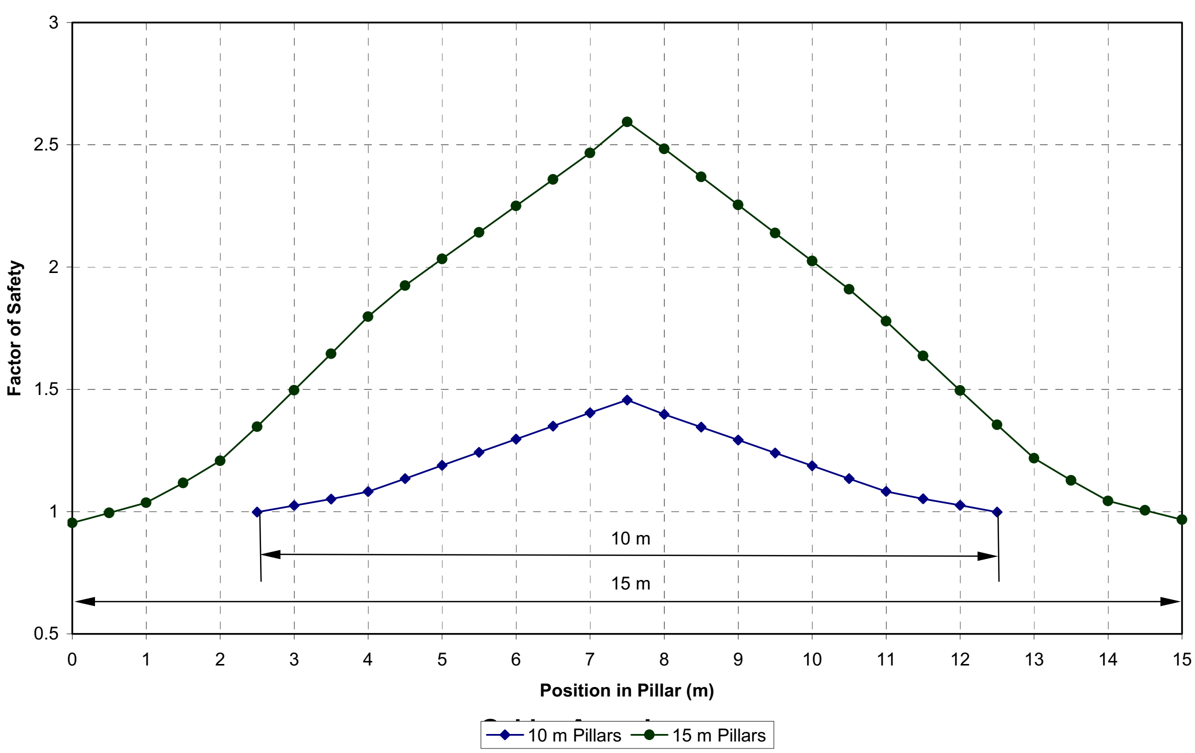
The rock cavern in the Lindsay limestone is set at a depth of 660 m below surface. Assuming an average unit weight 0.026 MN/m^3, the in situ vertical stress is approximately 17 MPa.

As previously noted, the generic cavern layout results in a tributary area approximately twice the pillar area, resulting in an average pillar stress of 34 MPa. The pillar strength, as estimated by the pillar strength formula, is equal to 43.6 MPa, yielding a safety factor of 1.28. Maintaining the size of the rooms and increasing the pillar width to 15 m lowers the average pillar stress to 28 MPa and increases the pillar strength to 59 MPa. This results in a factor of safety of about 2, which should be taken as the minimum acceptable factor of safety.

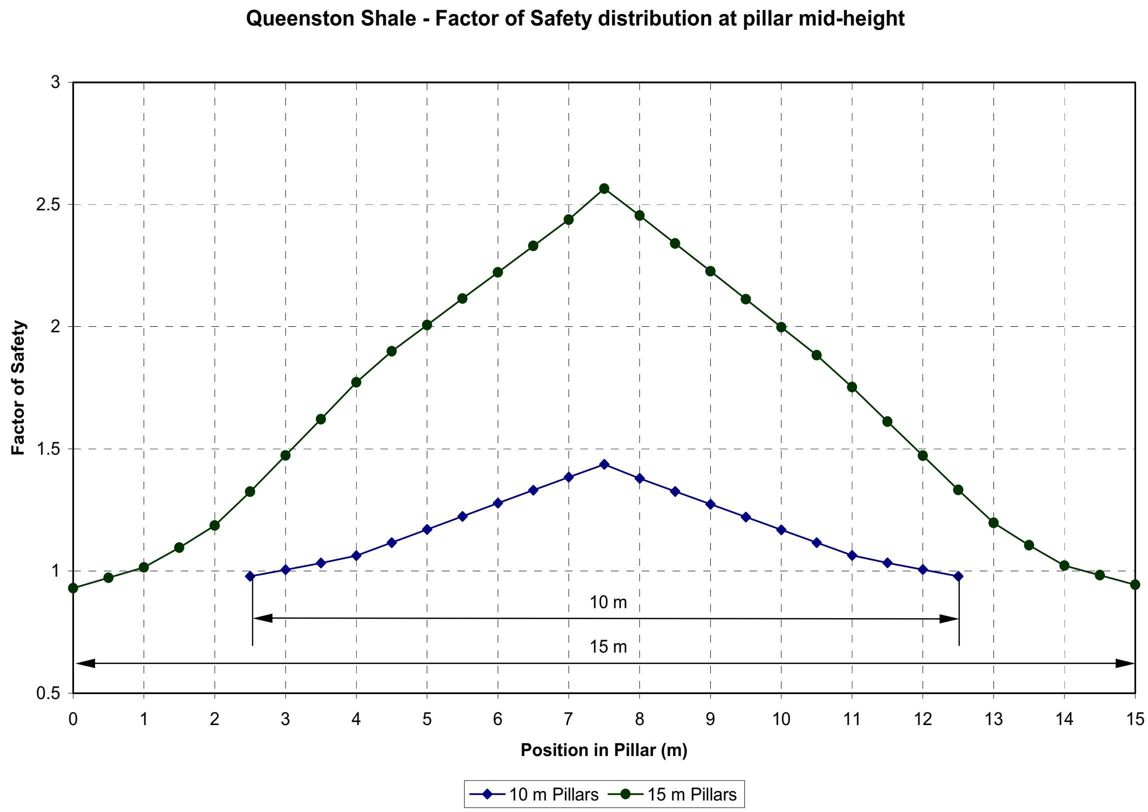
D2.3 Factors of Safety Estimated by Stress Analyses

Finite element analyses of the room and rib pillar arrangements described above result in factors of safety of 1.21 and 1.28 for the Queenston shale and Lindsay limestone, respectively, when using 10 m pillars between rooms. When 15 m pillars are used between the rooms, the factors of safety for the Queenston shale and the Lindsay limestone are 1.68 and 1.71, respectively. These

Lindsay Limestone - Factor of Safety distribution at pillar mid-height



factors of safety are average factors of safety, calculated from the distributions shown on the figures below.



D3.0 REFERENCES

Salamon, M.D.G. and Munro, A.H. (1967) *A study of the strength of coal pillars*. J. S. Afr. Inst. Min. Metall., **68**, 55–67.

Wagner, H. (198). *Pillar Design in Coal Mines*. J.S. Afr. Inst. Min. Metall., **81**, 37-45.

TABLE 1
ESTIMATED HYDROGEOLOGICAL AND MASS TRANSPORT PROPERTIES

TABLE 1

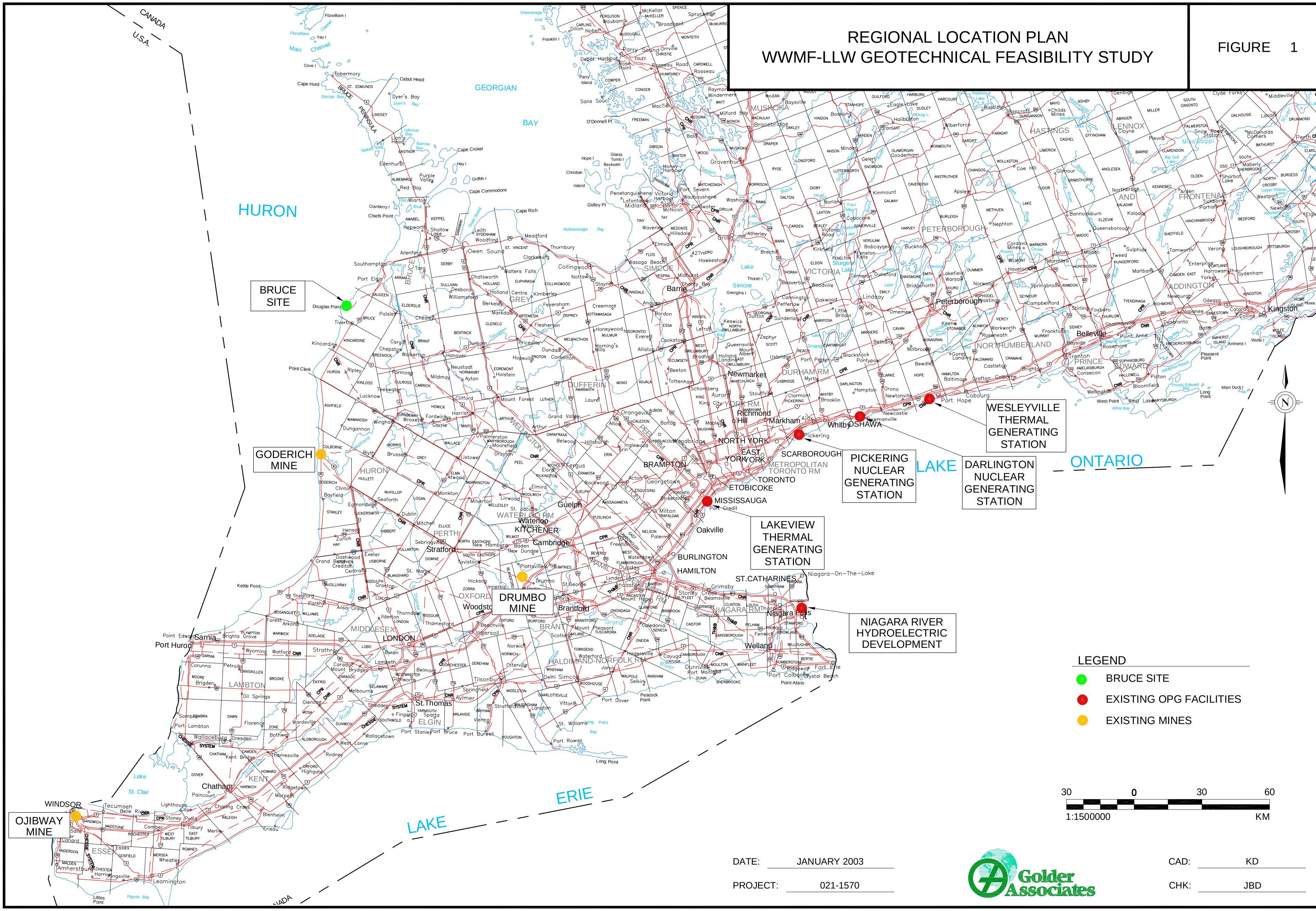
Stratigraphic Sequence	Effective Hydraulic Conductivity (m/s)[1]			Groundwater Chemistry				Matrix Porosity	Effective Transport Porosity[3]	Dry Density	Chloride-Matrix Effective Diffusion Coefficient	Distribution Coefficient[4] (K_d)	Dispersivity (α)	Matrix Tortuosity Factor (τ)[5]
	min	max	Geometric Mean	TDS (mg/L)[2]	Chloride (mg / L)	pH	Redox Condition (mV)	%	%	(t/m3)	m^2/s @23°C	(mL/g)	(m)	Estimate
SURFICIAL SEDIMENTS GROUNDWATER SYSTEM						Neutral to slightly alkaline								
Sand and Gravel	4×10^{-8}	3×10^{-5}	(1×10^{-5})	Fresh	1-45	7.0 - 8.3	>100	30%	30%	1.8	7×10^{-10}	C=5 Cl=0 I=0 Nb=160 Pu=550 Tc=0.1	Longitudinal=10% of travel path length (m) transverse=1% of travel path length (m)	0.7
TILL	1×10^{-10}	6×10^{-10}	2×10^{-10}								6×10^{-10}	C=20 Cl=0 I=0 Nb=160 Pu=1200 Tc=0.1		0.6
SHALLOW BEDROCK GROUNDWATER SYSTEM				Fresh to Brackish		Slightly Alkaline								
Bedrock Surface (Upper 15 m)	3×10^{-7}	6×10^{-5}	(1×10^{-5})	1,000 - 2,500	1-100		> 100	5 - 15	0.5 - 1.5	2.7	1.5×10^{-10}	C=5 Cl=0 I=0 Nb=160 Pu=550 Tc=0.1	Longitudinal=10% of travel path length (m) transverse=1% of travel path length (m)	0.15
Devonian/Silurian/Limestone/ Dolostone				Fresh to Brackish, sulphurous										
Amherstburg, Bois Blanc and Bass Island Formations	7×10^{-10}	2×10^{-4}	(1×10^{-5})	1,000 - 2,500	10-100	7.2 - 7.7				2.6 - 2.7	1.5×10^{-10}	C=5 Cl=0 I=0 Nb=160 Pu=550 Tc=0.1	Longitudinal=10% of travel path length (m) transverse=1% of travel path length (m)	0.15
INTERMEDIATE BEDROCK GROUNDWATER SYSTEM				Saline to Brine Sulphurous		Slightly Acidic								
Silurian Dolostones			(1×10^{-7})											
Salina, Guelph and Lockport & Reynales Formations	n.a.	n.a.		100,000 - 300,000	50,000 - 200,000	6.3 - 6.7	<0	4.8 - 11.0	0.5 - 1.1%	2.5 - 2.7	0.65×10^{-10} to 1.2×10^{-10}	C=5Cl=0 I=0 Nb=160 Pu=550 Tc=0.1	Longitudinal=10% of travel path length (m) transverse=1% of travel path length (m)	0.04 - 0.08
Silurian Shales: Salina C and F members,	n.a.	n.a.	(1×10^{-10})					1.9 - 3.1	0.2 - 0.3	2.6 - 2.7	0.5×10^{-10} to 1×10^{-10}	C=20 Cl=0 I=0 Nb=160 Pu=1200 Tc=0.1	Longitudinal=10% of travel path length (m) transverse=1% of travel path length (m)	0.03 - 0.07
DEEP BEDROCK GROUNDWATER SYSTEM				Saline to Brine Sulphurous		Slightly Acidic								
Silurian Dolostones/Shales														
Cabot Head Formation	n.a	n.a.	(1×10^{-10})	100,000 - 300,000	50,000 - 200,000	n.a.	<0	1.9 - 3.1	0.2 - 0.3	2.6 - 2.7	0.5×10^{-10} to 1×10^{-10}	C=20 Cl=0 I=0 Nb=160 Pu=1200 Tc=0.1	Longitudinal=10% of travel path length (m) transverse=1% of travel path length (m)	0.03 - 0.07
Manitoulin Formation			(1×10^{-8})											
Ordovician Shales				Brine, Sulphurous		Slightly Acidic								
Queenston Formation	n.a.	n.a.	1×10^{-12}	150,000 - 300,000	25,000 - 150,000	n.a.	<0	10.2- 11.4	1.0	2.6	1.4×10^{-10} to 1.6×10^{-10}	C=1 Cl=0 I=0 Nb=900 Pu=5100 Tc=1		0.095 to 0.108
Georgian Bay, Blue Mountain and Whitby Formations	9×10^{-14}	7×10^{-11}	1×10^{-12}											
Ordovician Limestones				Brine, Sulphurous		Slightly Acidic								
Lindsay Formation	3×10^{-14}	7×10^{-11}	7×10^{-13}					0.5 - 3	0.05 - 0.3	2.6	1×10^{-10}	C=5 Cl=0 I=0 Nb=160 Pu=550 Tc=0.1	Longitudinal=10% of travel path length (m) transverse=1% of travel path length (m)	0.1
Verulam Formation	5×10^{-14}	7×10^{-9}	3×10^{-12}			6.2 - 6.3								
Bobcaygeon and Gull River Formations	2×10^{-15}	6×10^{-9}	4×10^{-12}	40,000-300,000	25,000-200,000		<0							
Shadow Lake Formation Cambrian Sandstone Precambrian Granitic Gneiss	4×10^{-4}	1×10^{-8}	8×10^{-12}			Slightly Acidic 5.1 - 6.2		<0.5	0.05	2.8	0.1×10^{-10}	C=5 Cl=0 I=0 Nb=160 Pu=550 Tc=0.1	Longitudinal=10% of travel path length (m) transverse=1% of travel path length (m)	0.01

1 (1×10^{-5}) Bracketed values indicate "*Best Estimate*"
2 For TDS (total dissolved solids) classification:
Classification:
TDS mg/L
Fresh 100 - 1,000
Brackish 1,000 - 10,000
Saline 10,000 - 100,000
Brine >100,000
3 Effective Transport Porosity is assumed to be 10 percent of the Matrix Porosity
4 Distribution Coefficients for radionuclides (excluding iodine) are taken from Sheppard and Thibault 1990, Default Soil Solid/ Liquid Partition Coefficients, K_ds, for Four Major Soil Types: A Compendium, Health Phyries Vol. 59, No. 4 (October) pp 471-482,1990.
5 Matrix Tortuosity Factor x Free Water Diffusion Coefficient = Effective Diffusion Coefficient
n.a. indicates data not available.

TABLE 2
GEOMECHANICAL PROPERTIES OF SEDIMENTARY ROCKS AT THE BRUCE SITE

Formation	Rock Type		γ (MN/m^3)	σ_c (MPa)	E_i (GPa)	ν	Q (RMR)	σ_t (MPa)	σ_H* (MPa)
Amherstburg	Dolostone	Median	2.45	60	45	-	4.75 (58)	-	-
		Range	2.35 - 2.60	12 - 136	9 - 117	-	-	-	-
Salina	Dolostone	Median	2.6	100	35	0.25	3.5 (56)	5	-
		Range	-	85 - 120	30 - 40	0.25 - 0.30	-	4 - 7.5	-
	Shale	Median	2.6	35	8	0.35	0.8 (42)	1.5	-
		Range	-	-	8 - 10	-	-	1 - 2.6	-
	Gypsum	Median	2.4	30	8	0.35	3.0 (54)	1.5	-
		Range	-	25 - 35	-	-	-	1.1 - 2.7	-
Queeston	Shale	Median	2.68	40	12	0.30	10.75 (65)	3	-
		Range	-	33 - 46	6 - 23	0.10 - 0.44	-	2 - 4.6	5 - 9
Georgian Bay	Shale	Median	2.6	36	20	0.20	7.5 (62)	-	-
		Range	-	11 - 97	11 - 41	0.10 - 0.20	-	-	1 - 9
Lindsay	Limestone	Median	2.65	60	40	0.3	31.7 (75)	-	-
		Range	2.6 - 2.65	25 - 140	16 - 66	-	-	-	9 - 13

σ_c - Uniaxial compressive strength of intact rock
E_i - Intact elastic modulus
Q - NGI Tunnel Quality Index
RMR - CSIR Rock Mass Rating
ν - Poisson's ratio
σ_t - Tensile strength of intact rock
σ_H - Horizontal in situ stress
γ - Unit weight of rock
* - In situ stresses are dependent on depth. Values shown on this table were measured at depths < 200 m



REGIONAL LOCATION PLAN
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 1

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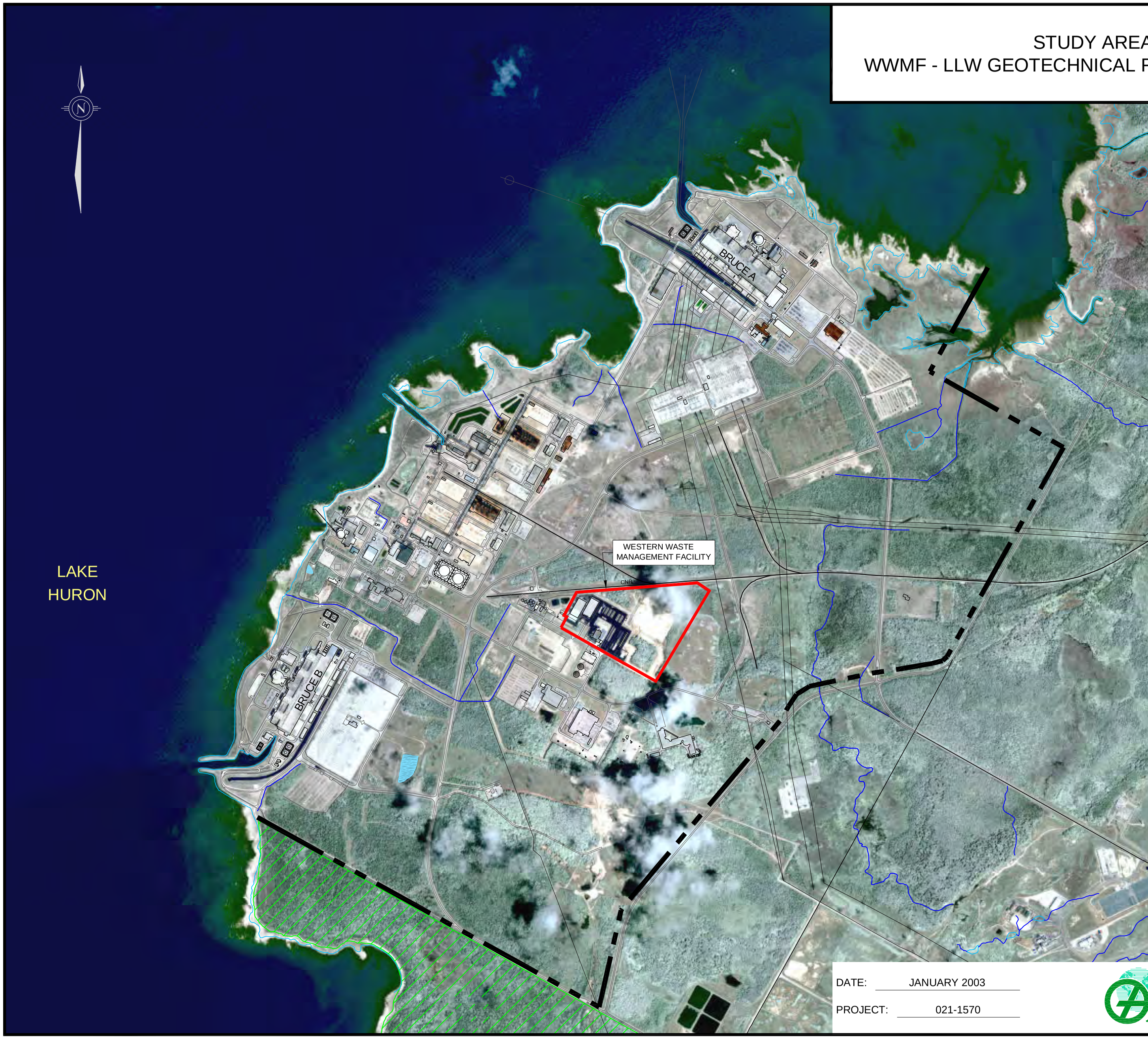
STUDY AREA
WWMF - LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 2



LEGEND

SOUTH EASTERN LIMIT OF STUDY AREA (APPROXIMATE OUTER FENCE LINE OF BRUCE NUCLEAR POWER DEVELOPMENT SITE)

REFERENCES

IKUNOS-1-1m HYBRID IMAGE 1 METRE PAN/4 METRE MSS FUSED IMAGE, JULY 12, 2001.

400 0 400 800

SCALE 1:20000 METRES

DATE: JANUARY 2003

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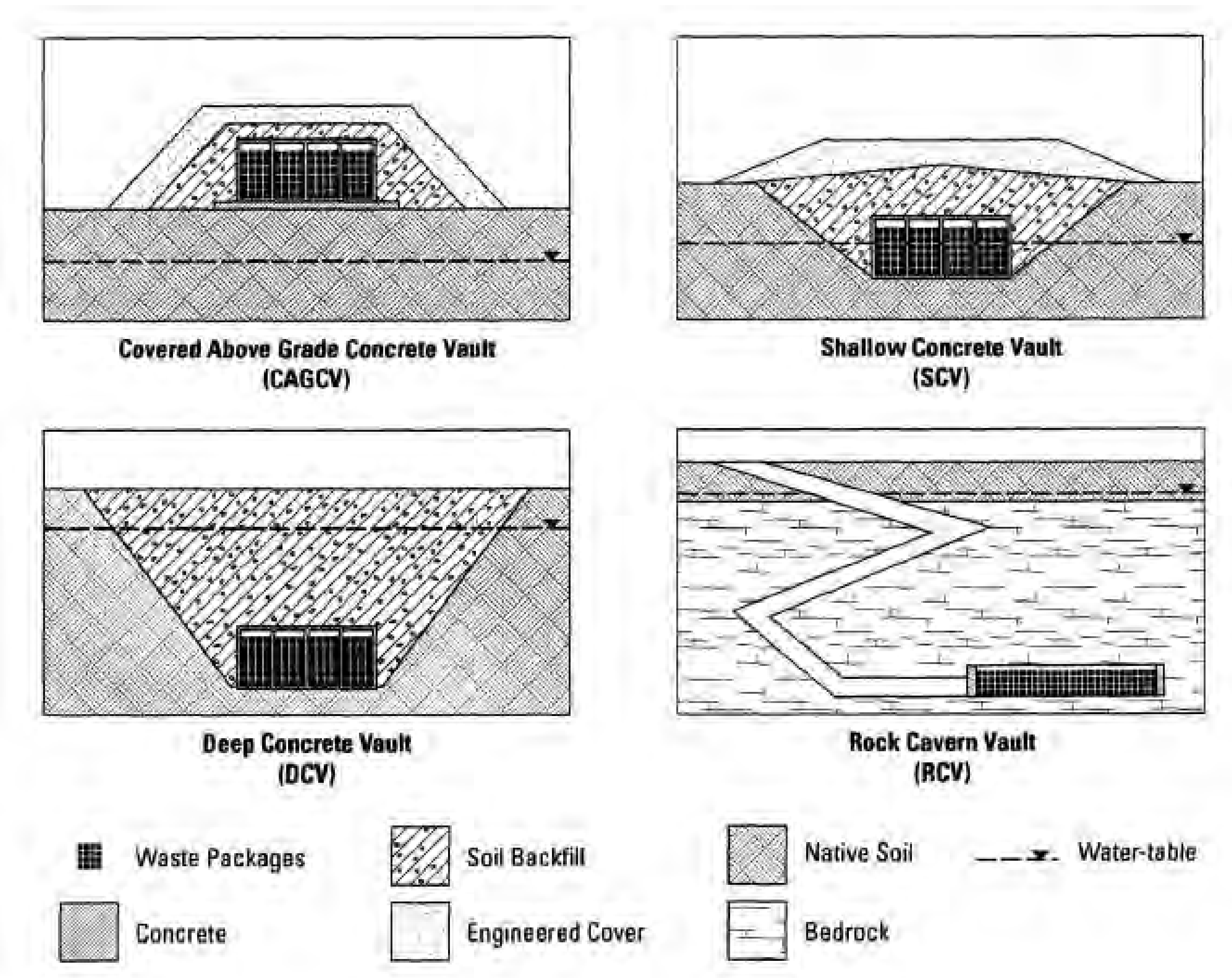
SCHEMATIC ILLUSTRATION OF GENERIC
PERMANENT REPOSITORY CONCEPTS
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 3



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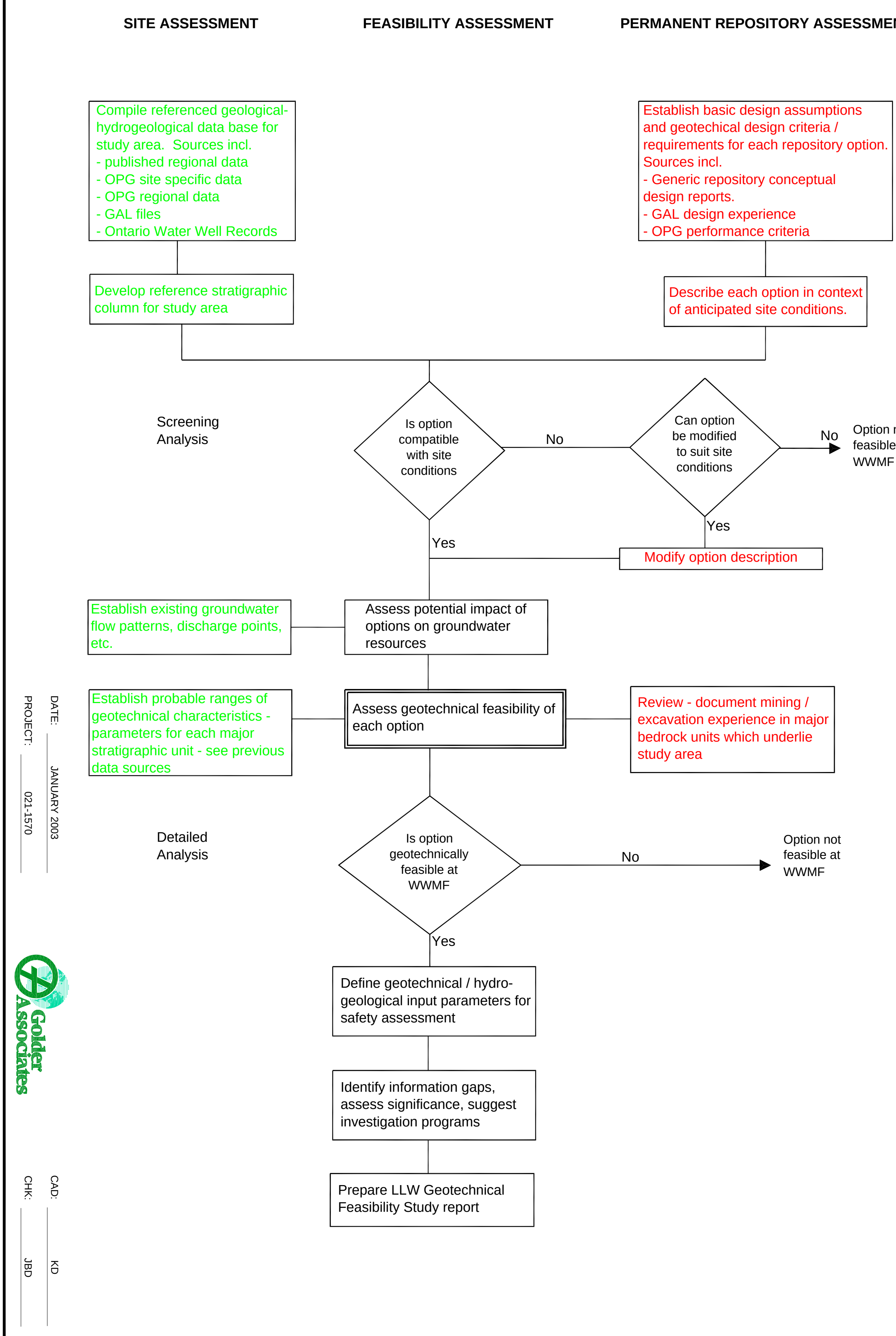


STUDY PLAN
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 4

SITE STUDY AREA
SHOWING SURFACE CONSTRAINTS AND AREAS
OF THICK (>15 m) OVERBURDEN DEPOSITS
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

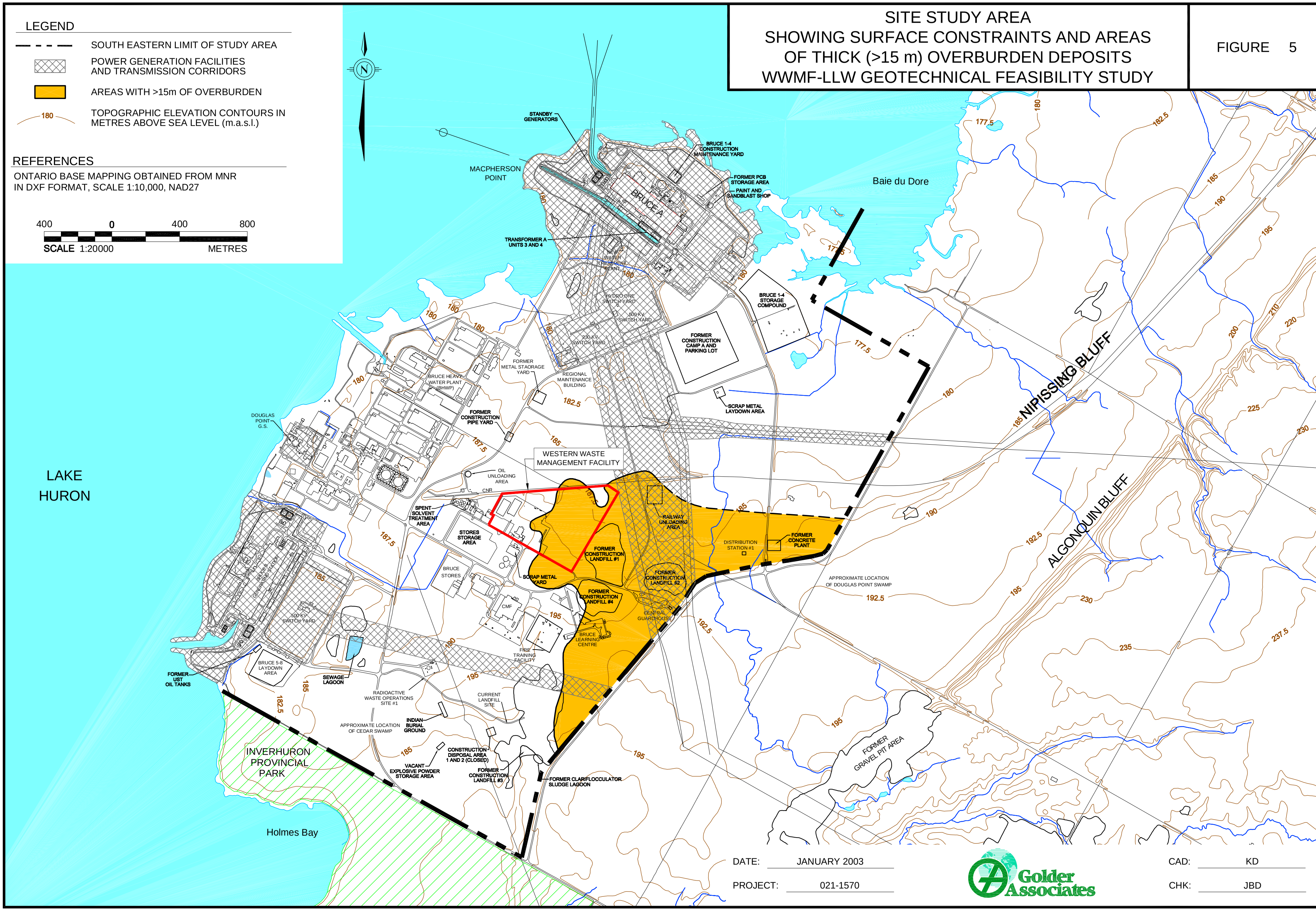
FIGURE 5

LEGEND

- SOUTH EASTERN LIMIT OF STUDY AREA
- POWER GENERATION FACILITIES AND TRANSMISSION CORRIDORS
- AREAS WITH >15m OF OVERBURDEN
- TOPOGRAPHIC ELEVATION CONTOURS IN METRES ABOVE SEA LEVEL (m.a.s.l.)

REFERENCES

ONTARIO BASE MAPPING OBTAINED FROM MNR IN DXF FORMAT, SCALE 1:10,000, NAD27



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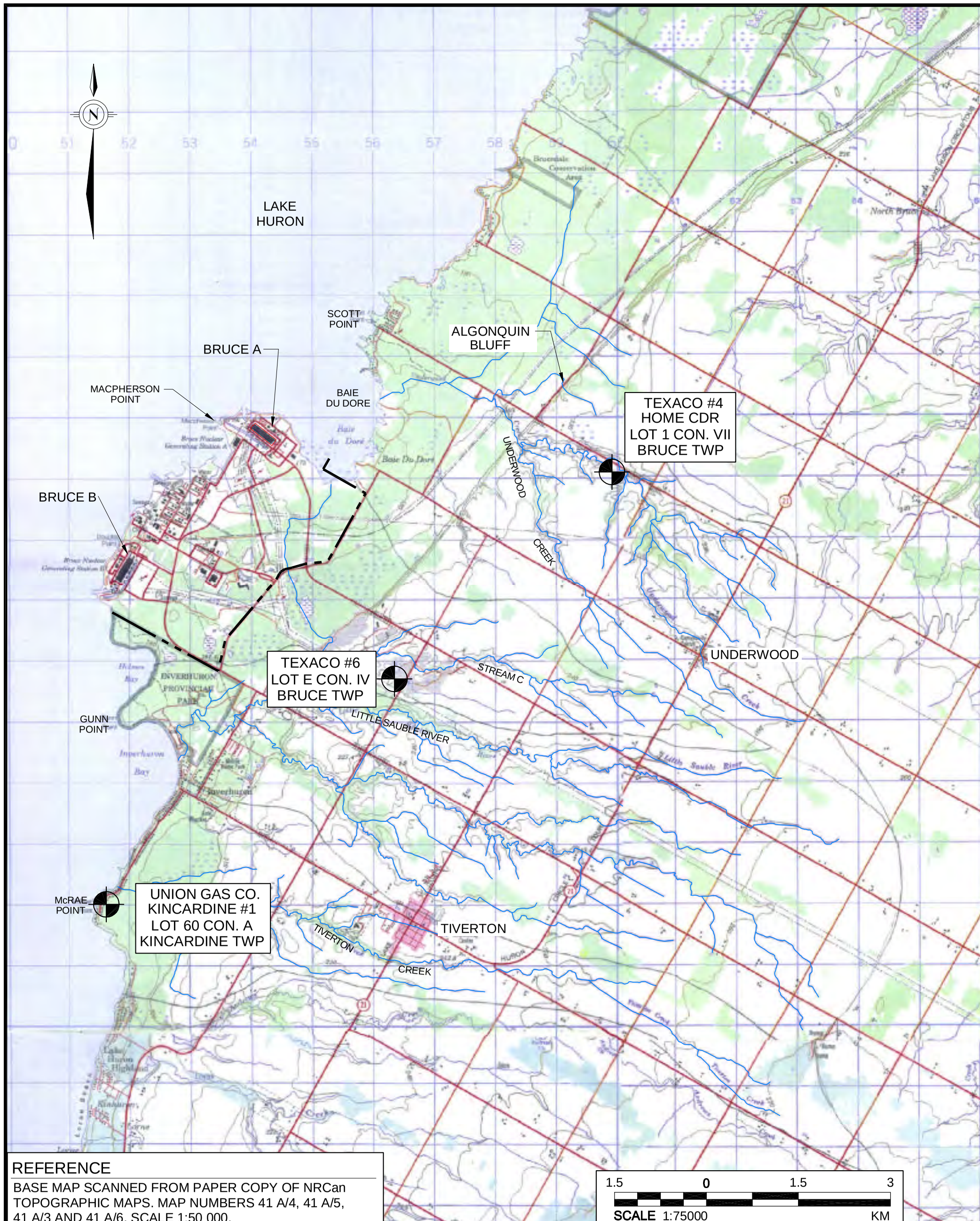
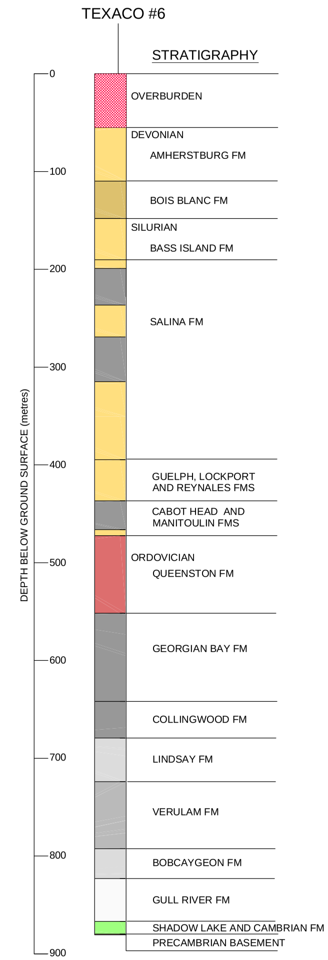
LOCATION OF GAS EXPLORATION WELLS AND INTERPRETIVE BEDROCK STRATIGRAPHY WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 6





LITHOLOGY

- OVERBURDEN
- DOLOSTONE
- CHERTY DOLOSTONE
- GREY SHALE
- RED SHALE
- ARGILLACEOUS LIMESTONE
- SHALY LIMESTONE
- LITHOGRAPHIC LIMESTONE
- SILTSTONE, SANDSTONE
- GRANITIC GNEISS

LEGEND

- BRUCE SITE BOUNDARY
- RIVERS AND CREEKS
- GROUND SURFACE CONTOUR
- LOCATION OF GAS EXPLORATION DRILLHOLE

REFERENCE

BASE MAP SCANNED FROM PAPER COPY OF NRCan TOPOGRAPHIC MAPS. MAP NUMBERS 41 A/4, 41 A/5, 41 A/3 AND 41 A/6, SCALE 1:50 000.

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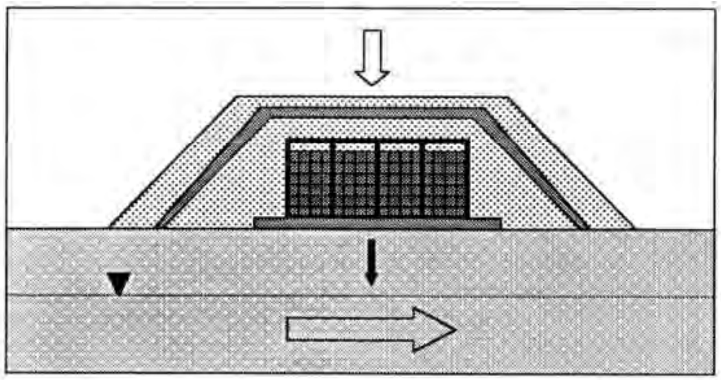
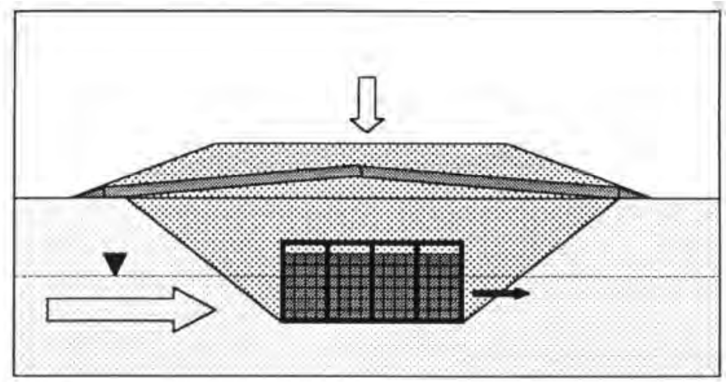
SCHEMATIC ILLUSTRATION OF POTENTIAL CONTAMINANT RELEASE MECHANISMS, GENERIC PERMANENT REPOSITORY CONCEPTS, WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

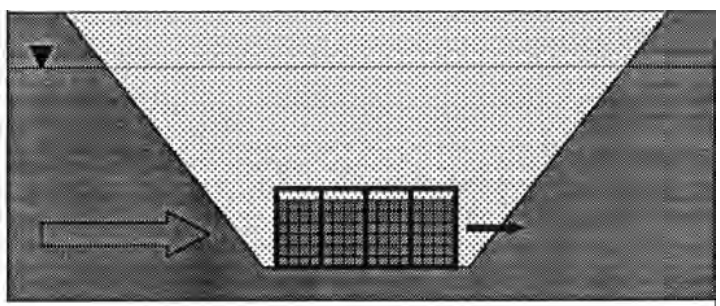
FIGURE 7



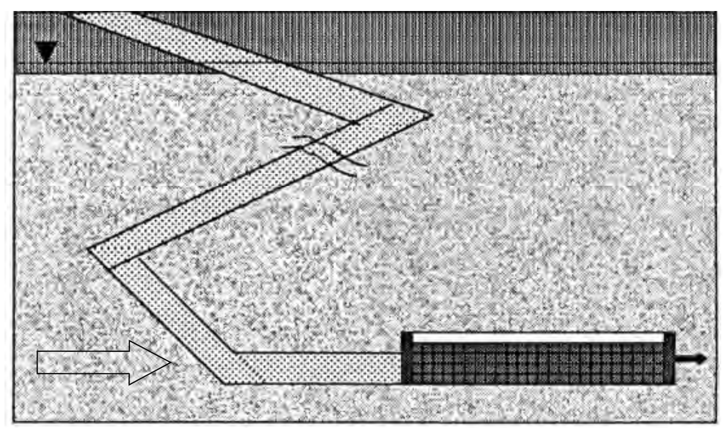
COVERED ABOVE GRADE CONCRETE VAULT



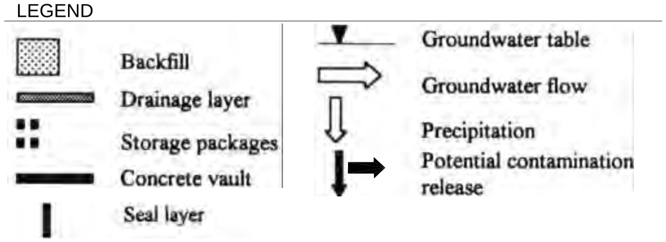
SHALLOW CONCRETE VAULT



DEEP CONCRETE VAULT



ROCK CAVERN VAULT



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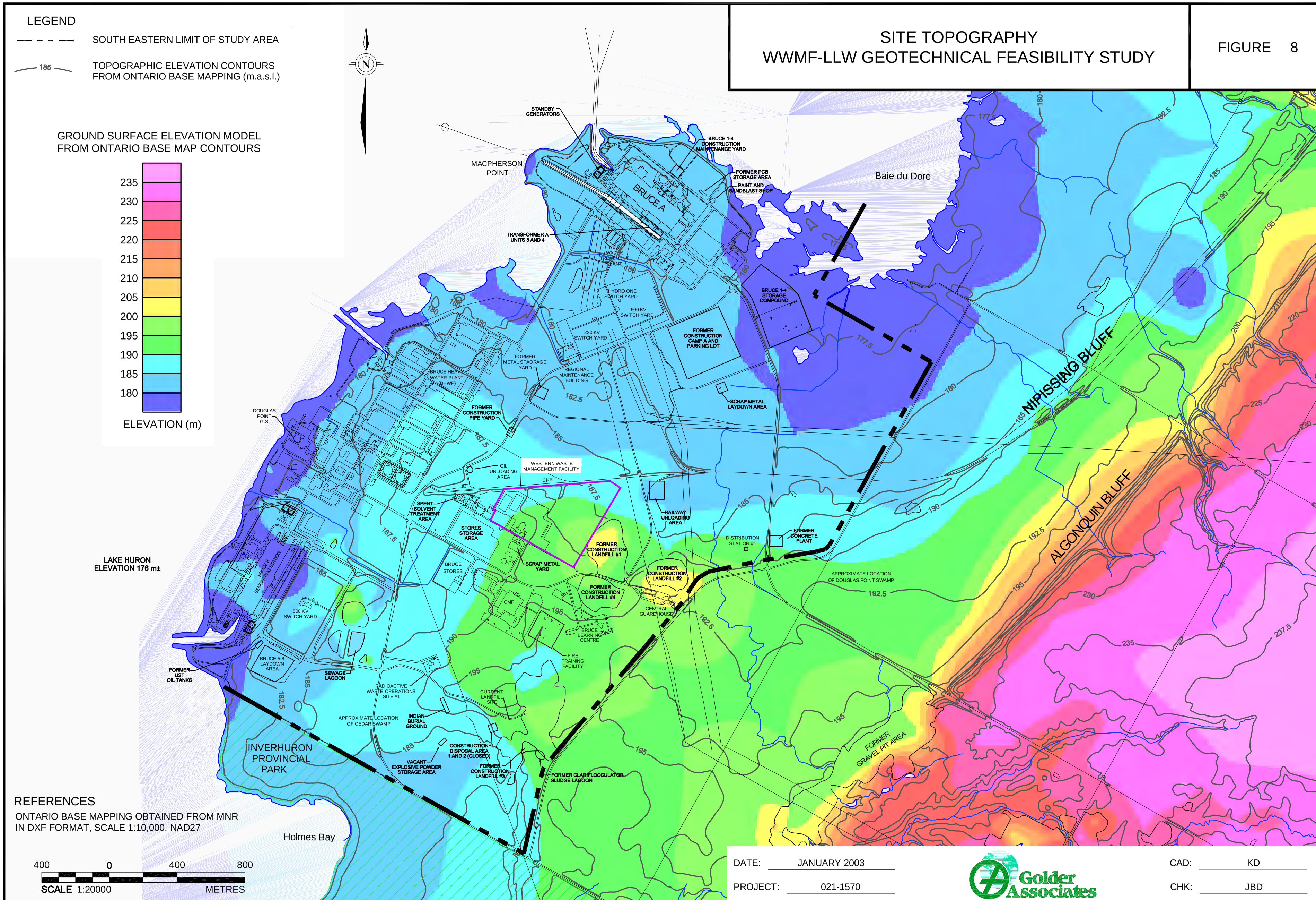
SITE TOPOGRAPHY
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 8



REFERENCES

ONTARIO BASE MAPPING OBTAINED FROM MNR IN DXF FORMAT, SCALE 1:10,000, NAD27

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CHK:	JBD

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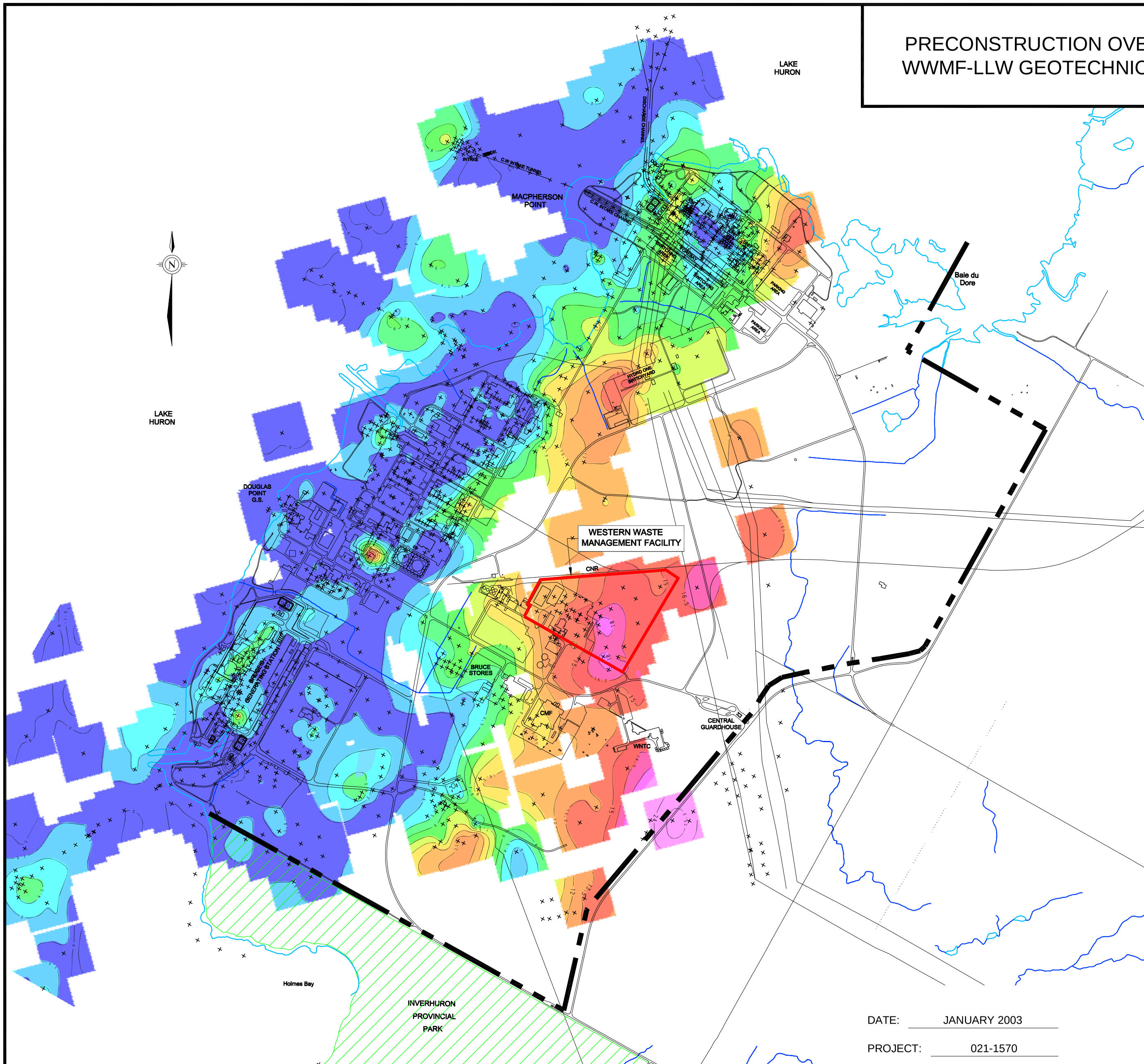
PRECONSTRUCTION OVERBURDEN THICKNESS
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 9



LEGEND

- SOUTH EASTERN LIMIT OF STUDY AREA
- WATERCOURSE
- GEOTECHNICAL DRILLHOLE LOCATION

21.0
19.5
18.0
16.5
15.0
13.5
12.0
10.5
9.0
7.5
6.0
4.5
3.0
1.5
0.0

OVERBURDEN THICKNESS (m)

REFERENCES:

BASE MAP OBTAINED FROM MNR IN DXF FORMAT, SCALE 1:10,000 AND NAD27 PROJECTION.

GEOTECHNICAL DRILLHOLE DATA TAKEN FROM OHT REPORT 6292-001-1997-RA-001-R00 DATED MAY 8, 1998.

400 0 400 800
SCALE 1:20000 METRES

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PROJECT: 021-1570

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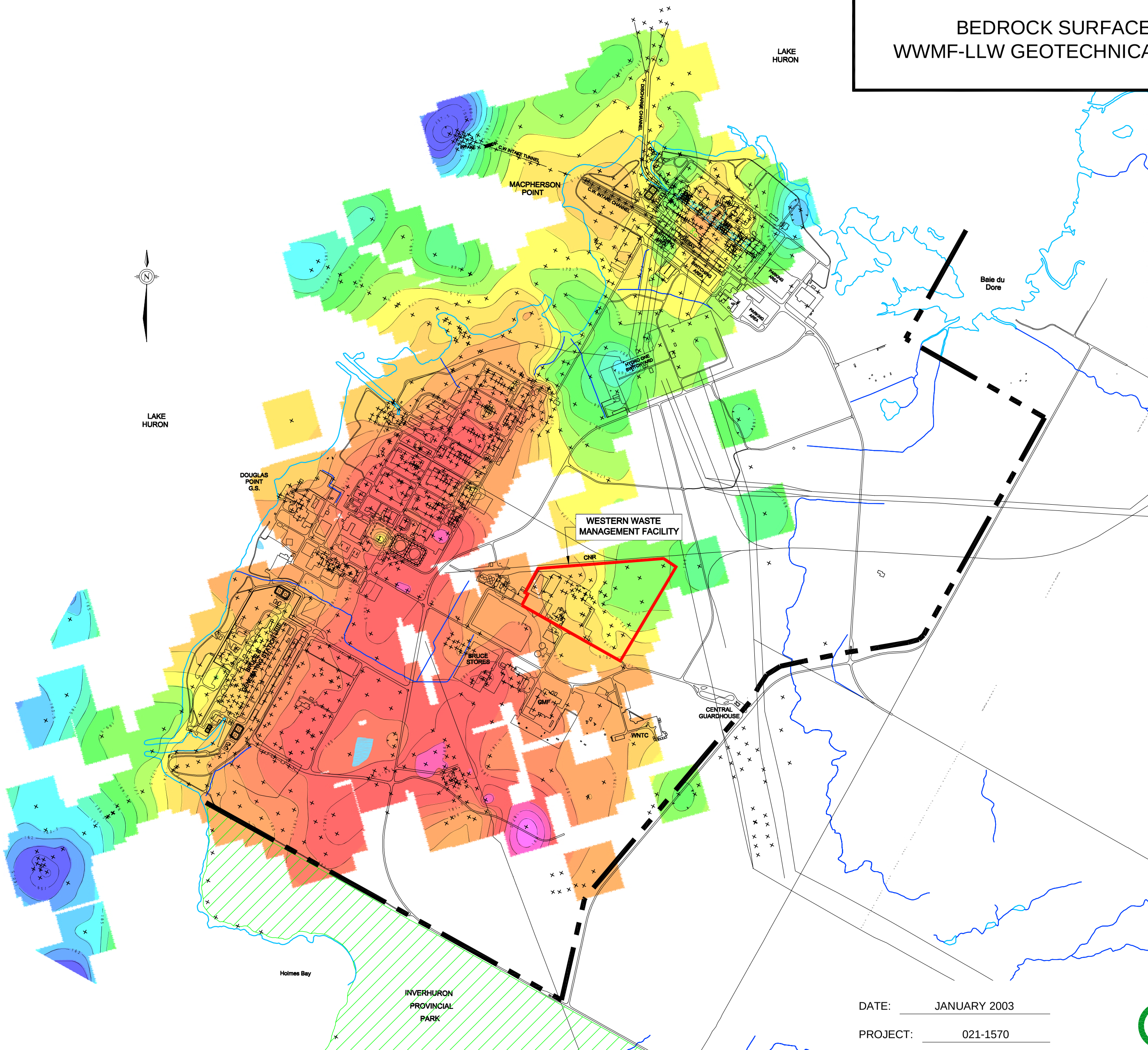
BEDROCK SURFACE TOPOGRAPHY
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 10



LEGEND

SOUTH EASTERN LIMIT OF STUDY AREA

GEOTECHNICAL DRILLHOLE LOCATION

190.5, 189.0, 187.5, 185.0, 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

BEDROCK ELEVATION (m)

REFERENCES:

BASE MAP OBTAINED FROM MNR IN DXF FORMAT, SCALE 1:10,000 AND NAD27 PROJECTION.

GEOTECHNICAL DRILLHOLE DATA TAKEN FROM OHT REPORT 6292-001-1997-RA-001-R00 DATED MAY 8, 1998.

400 0 400 800

SCALE 1:20000 METRES

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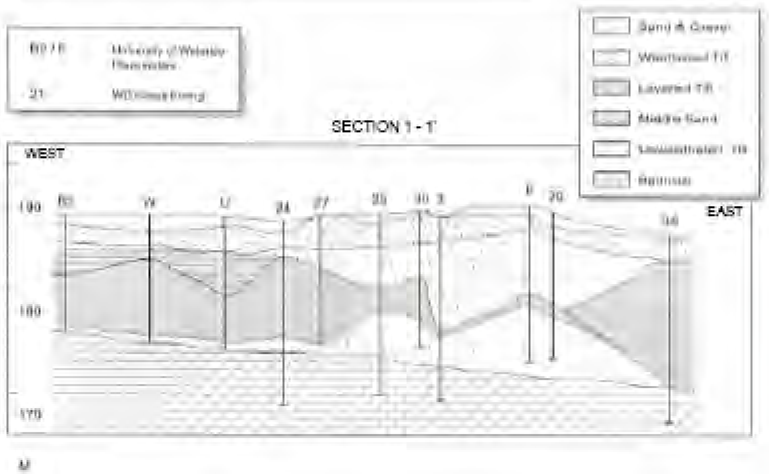
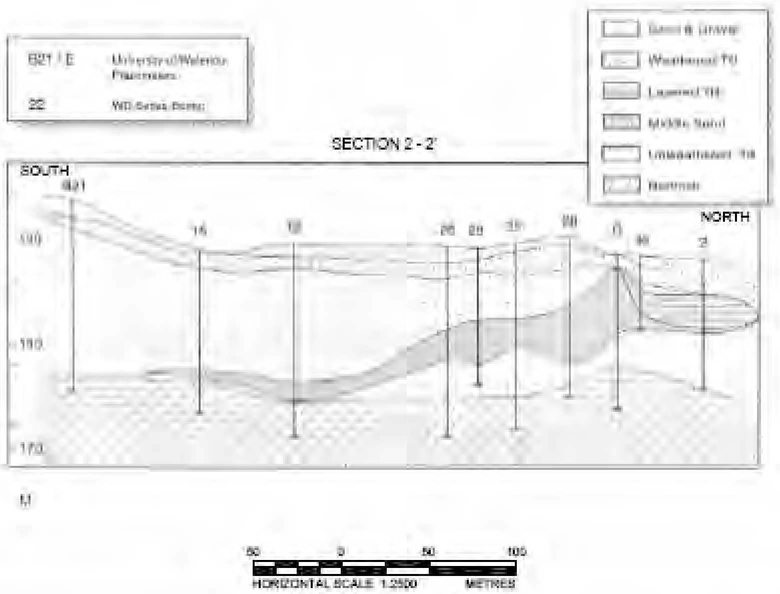
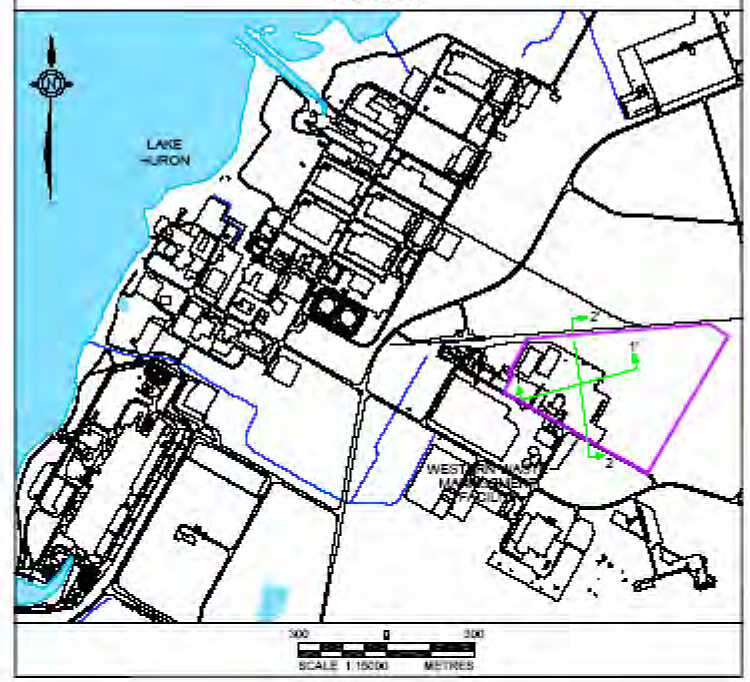
EXAMPLE OF SURFICIAL DEPOSIT STRATIGRAPHY WESTERN WASTE MANAGEMENT FACILITY GEOLOGIC SECTIONS 1-1' AND 2-2' WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 11





KEY PLAN



REFERENCE

SECTIONS 1-1' AND 2-2' WERE SCANNED FROM FIGURES 2 AND 3 RESPECTIVELY FROM ONTARIO HYDRO REPORT No. NK37-03480-94014 (UFMED) R00, DATED MARCH 1995.

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CHK: JBD

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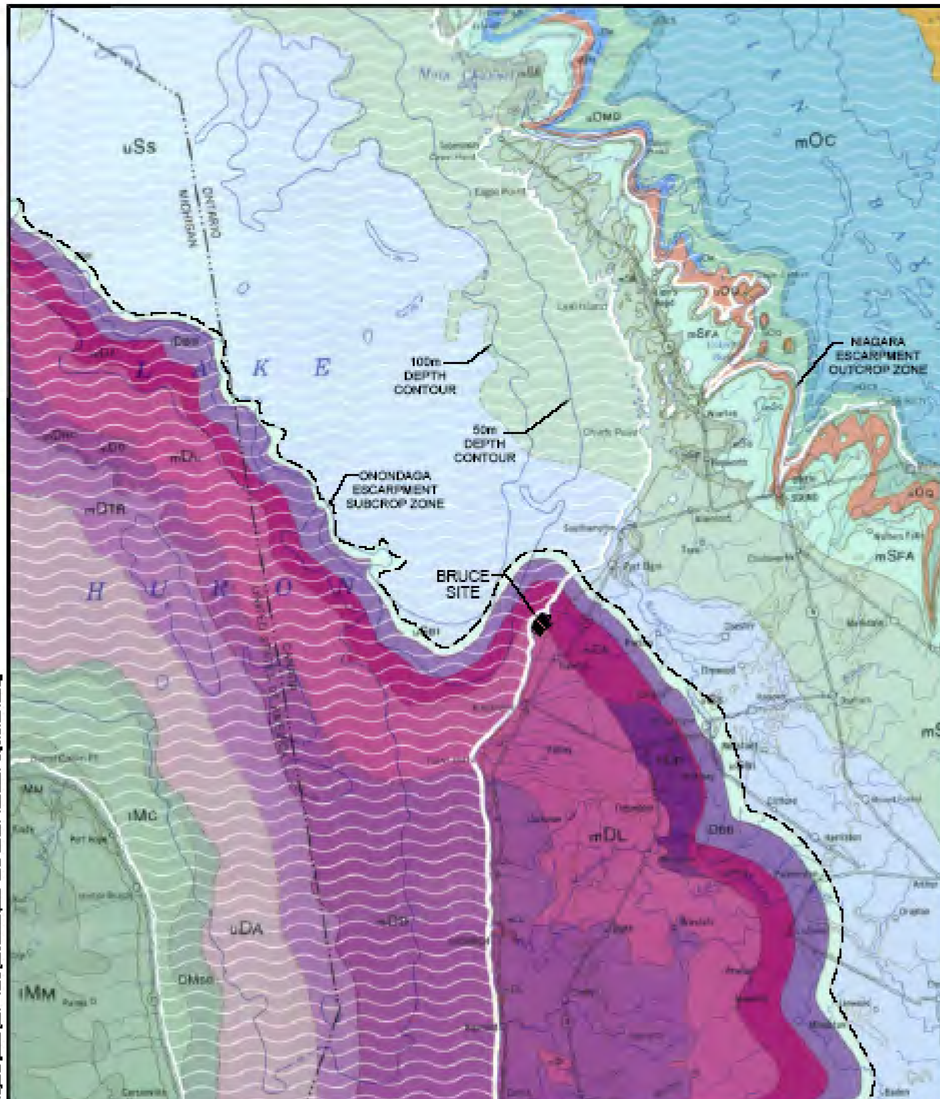
REGIONAL BEDROCK GEOLOGY
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 12



LEGEND

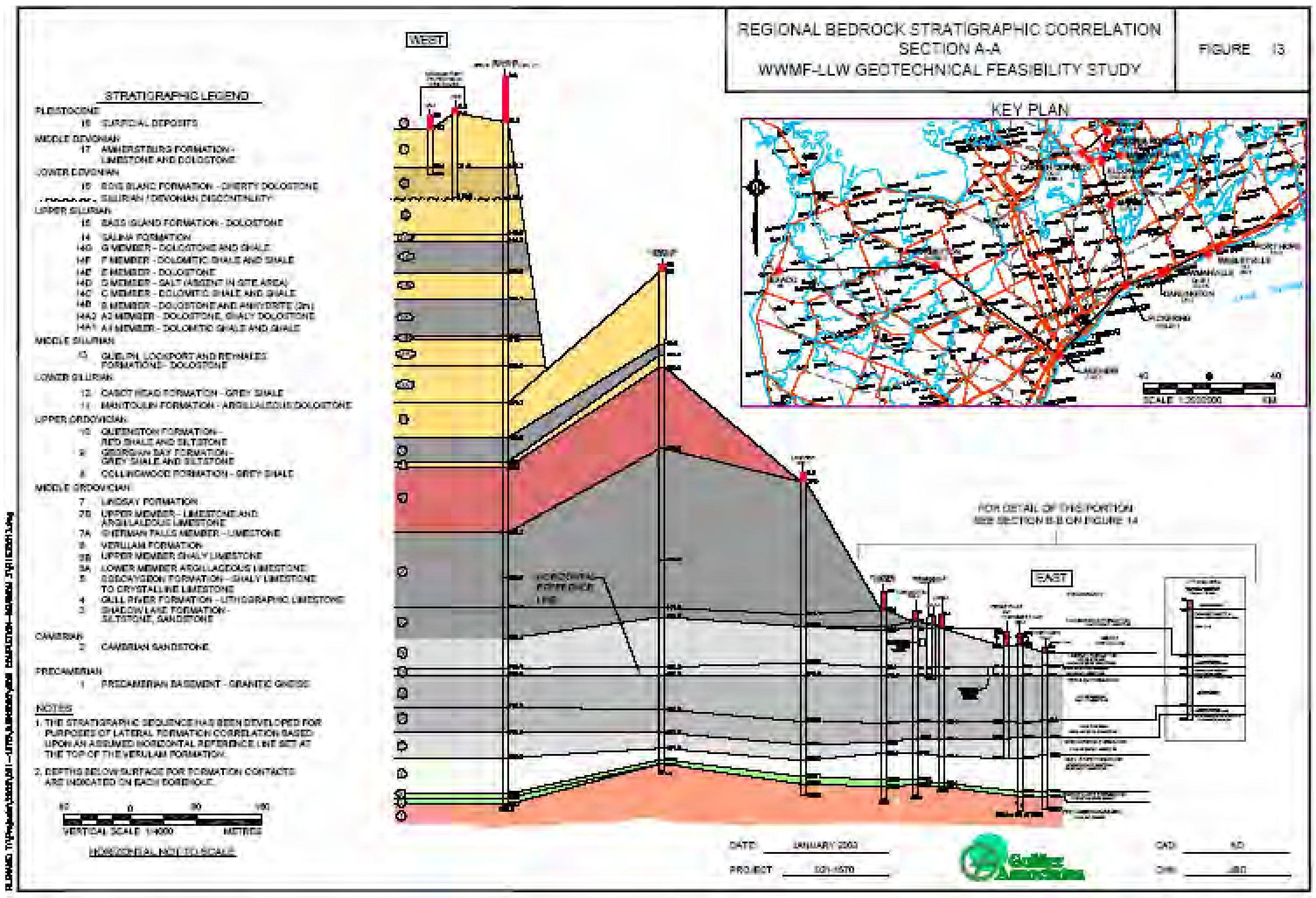
ST LAWRENCE PLATFORM

NOTE
LARGE BODIES OF WATER ARE INDICATED BY WHITE WAVE PATTERN.

REFERENCE
GEOLOGY SCANNED FROM GEOLOGICAL SURVEY OF CANADA, MAP 1335A
SHEET 30S, SOUTHERN ONTARIO, SCALE 1:1000000.

SCALE 1:1000000 KM

DATE: JANUARY 2003
PROJECT: 021-1570
CAD: KD
CHK: JBD


REGIONAL BEDROCK STRATIGRAPHIC CORRELATION
SECTION A-A
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY
FIGURE 13
KEY PLAN
WEST
EAST
FOR DETAIL OF THIS PORTION SEE SECTION B-B ON FIGURE 14
HORIZONTAL REFERENCE LINE
STRATIGRAPHIC LEGEND
PLEISTOCENE
18 SURFICIAL DEPOSITS
MIDDLE DEVONIAN
17 AMHERSTBURG FORMATION - LIMESTONE AND DOLOSTONE
LOWER DEVONIAN
16 BOIS BLANC FORMATION - CHERTY DOLOSTONE
SILURIAN / DEVONIAN DISCONTINUITY
UPPER SILURIAN
15 BASS ISLAND FORMATION - DOLOSTONE
14 SALINA FORMATION
14G G MEMBER - DOLOSTONE AND SHALE
14F F MEMBER - DOLOMITIC SHALE AND SHALE
14E E MEMBER - DOLOSTONE
14D D MEMBER - SALT (ABSENT IN SITE AREA)
14C C MEMBER - DOLOMITIC SHALE AND SHALE
14B B MEMBER - DOLOSTONE AND ANHYDRITE (2m)
14A2 A2 MEMBER - DOLOSTONE, SHALY DOLOSTONE
14A1 A1 MEMBER - DOLOMITIC SHALE AND SHALE
MIDDLE SILURIAN
13 GUELPH, LOCKPORT AND REYNALES FORMATIONS - DOLOSTONE
LOWER SILURIAN
12 CABOT HEAD FORMATION - GREY SHALE
11 MANITOULIN FORMATION - ARGILLACEOUS DOLOSTONE
UPPER ORDOVICIAN
10 QUEENSTON FORMATION - RED SHALE AND SILTSTONE
9 GEORGIAN BAY FORMATION - GREY SHALE AND SILTSTONE
8 COLLINGWOOD FORMATION - GREY SHALE
MIDDLE ORDOVICIAN
7 LINDSAY FORMATION
7B UPPER MEMBER - LIMESTONE AND ARGILLACEOUS LIMESTONE
7A SHERMAN FALLS MEMBER - LIMESTONE
6 VERULAM FORMATION
6B UPPER MEMBER SHALY LIMESTONE
6A LOWER MEMBER ARGILLACEOUS LIMESTONE
5 BOBCAYGEON FORMATION - SHALY LIMESTONE TO CRYSTALLINE LIMESTONE
4 GULL RIVER FORMATION - LITHOGRAPHIC LIMESTONE
3 SHADOW LAKE FORMATION - SILTSTONE, SANDSTONE
CAMBRIAN
2 CAMBRIAN SANDSTONE
PRECAMBRIAN
1 PRECAMBRIAN BASEMENT - GRANITIC GNEISS
NOTES
1. THE STRATIGRAPHIC SEQUENCE HAS BEEN DEVELOPED FOR PURPOSES OF LATERAL FORMATION CORRELATION BASED UPON AN ASSUMED HORIZONTAL REFERENCE LINE SET AT THE TOP OF THE VERULAM FORMATION.
2. DEPTHS BELOW SURFACE FOR FORMATION CONTACTS ARE INDICATED ON EACH BOREHOLE.
50 0 50 100
VERTICAL SCALE 1:4000 METRES
HORIZONTAL NOT TO SCALE
DATE: JANUARY 2003
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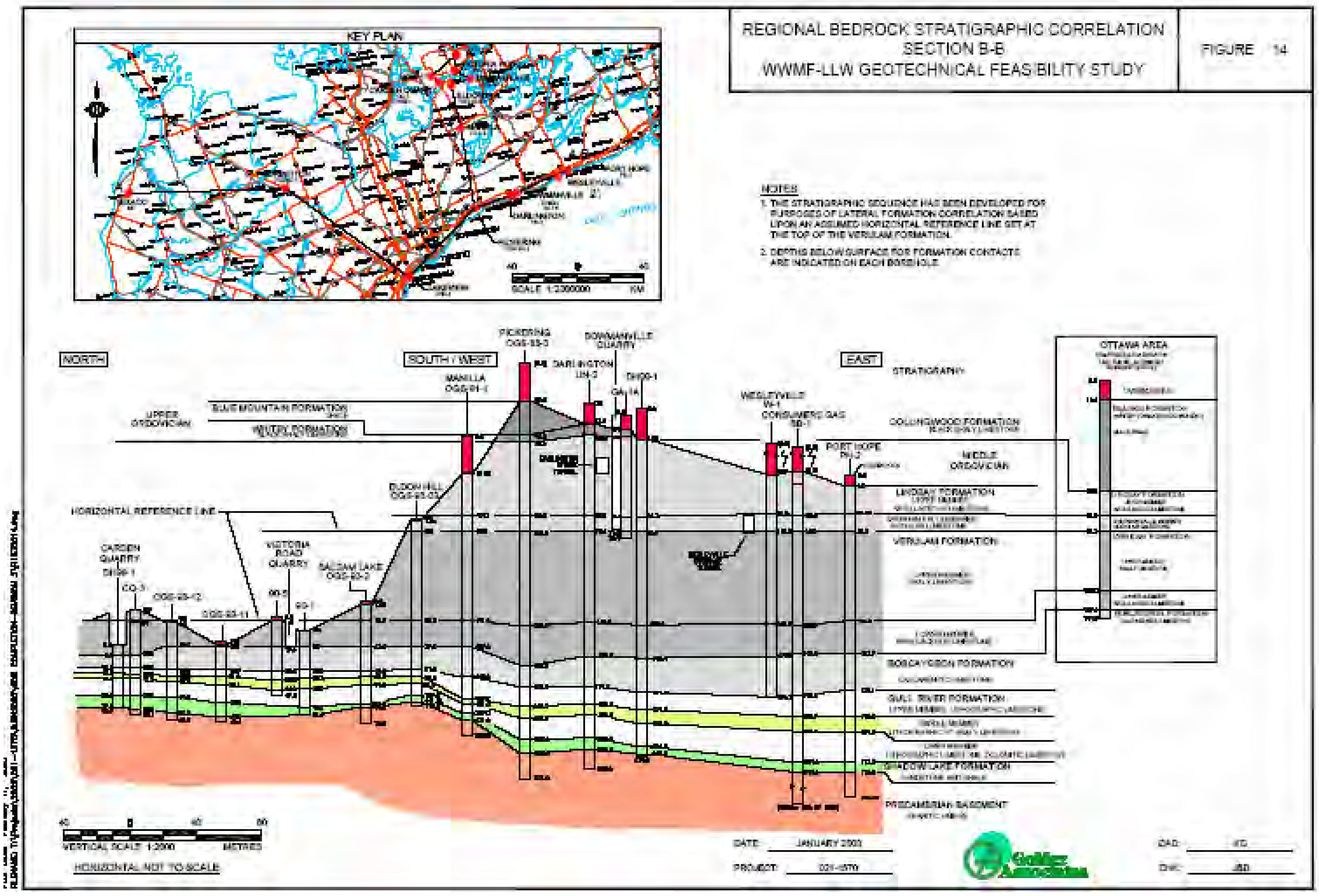
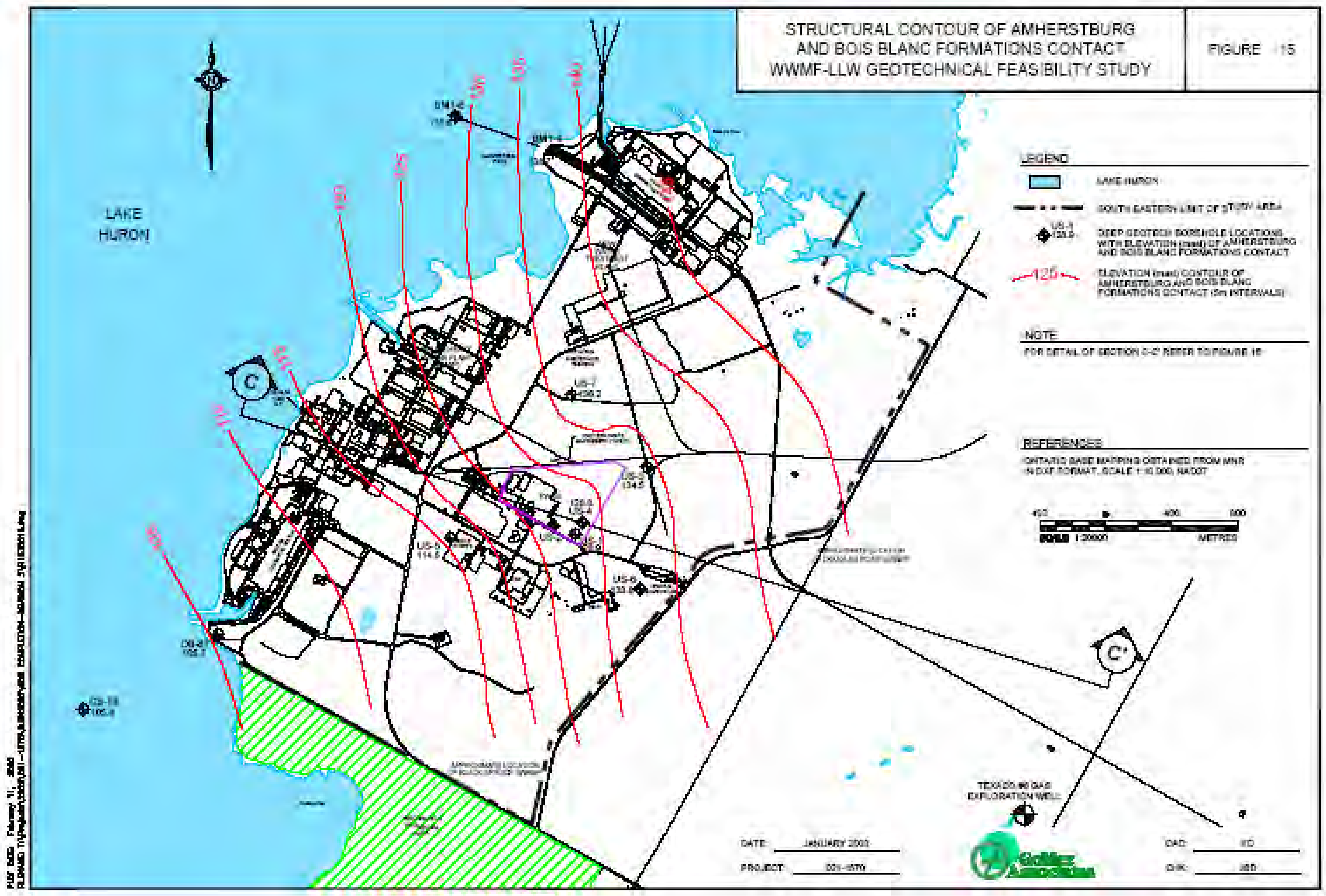
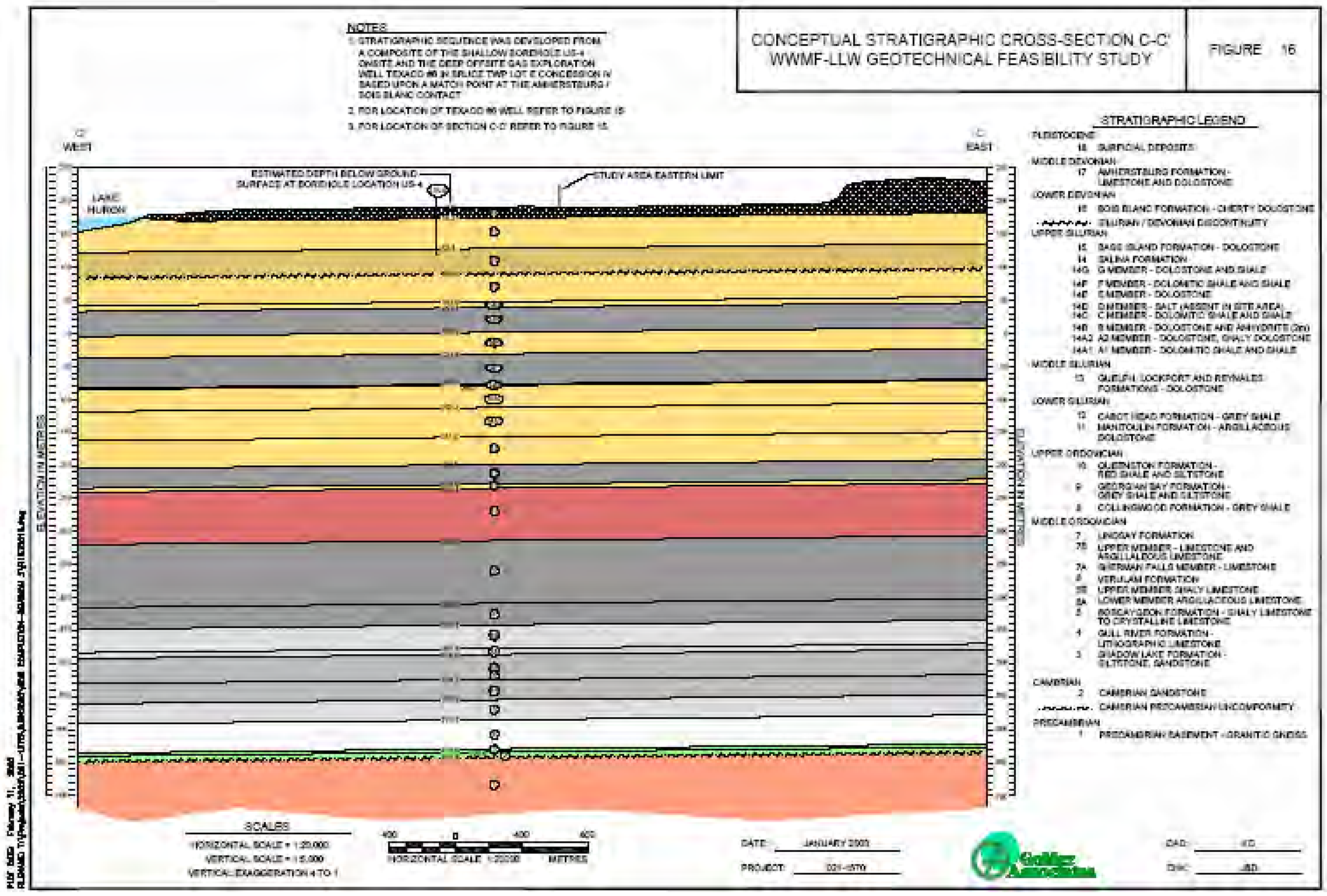
CAD: AD
CHK: JBD


REGIONAL BEDROCK STRATIGRAPHIC CORRELATION
SECTION B-B
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY
FIGURE 14
KEY PLAN
SCALE 1:2000000
KM
NOTES
1. THE STRATIGRAPHIC SEQUENCE HAS BEEN DEVELOPED FOR PURPOSES OF LATERAL FORMATION CORRELATION BASED UPON AN ASSUMED HORIZONTAL REFERENCE LINE SET AT THE TOP OF THE VERULAM FORMATION.
2. DEPTHS BELOW SURFACE FOR FORMATION CONTACTS ARE INDICATED ON EACH BOREHOLE.
NORTH
SOUTH / WEST
EAST
STRATIGRAPHY
PICKERING
OGS-93-3
BOWMANVILLE
QUARRY
DARLINGTON
MANILLA
OGS-91-1
WESLEYVILLE
W-1
CONSUMERS GAS
PORT HOPE
UPPER
ORDOVICIAN
BLUE MOUNTAIN FORMATION
WHITBY FORMATION
COLLINGWOOD FORMATION
MIDDLE
ORDOVICIAN
HORIZONTAL REFERENCE LINE
EUDON HILL
CARDEN
QUARRY
VICTORIA
ROAD
QUARRY
BALSAM LAKE
LINDSAY FORMATION
VERULAM FORMATION
BOBCAYGEON FORMATION
GULL RIVER FORMATION
SHADOW LAKE FORMATION
PRECAMBRIAN BASEMENT
OTTAWA AREA
VERTICAL SCALE 1:2000
METRES
HORIZONTAL NOT TO SCALE
DATE
JANUARY 2003
PROJECT
CAD
CHK


STRUCTURAL CONTOUR OF AMHERSTBURG
AND BOIS BLANC FORMATIONS CONTACT
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY
FIGURE 15
LAKE HURON
LEGEND
LAKE HURON
SOUTH EASTERN LIMIT OF STUDY AREA
DEEP GEOTECH BOREHOLE LOCATIONS WITH ELEVATION (masl) OF AMHERSTBURG AND BOIS BLANC FORMATIONS CONTACT
ELEVATION (masl) CONTOUR OF AMHERSTBURG AND BOIS BLANC FORMATIONS CONTACT (5m INTERVALS)
NOTE
FOR DETAIL OF SECTION C-C' REFER TO FIGURE 16
REFERENCES
ONTARIO BASE MAPPING OBTAINED FROM MNR IN DXF FORMAT, SCALE 1:10 000, NAD27
SCALE 1:20000
METRES
TEXACO-96 GAS EXPLORATION WELL
DATE: JANUARY 2003
PROJECT: 021-1570



NOTES
1. STRATIGRAPHIC SEQUENCE WAS DEVELOPED FROM A COMPOSITE OF THE SHALLOW BOREHOLE US-4 ONSITE AND THE DEEP OFFSITE GAS EXPLORATION WELL TEXACO #6 IN BRUCE TWP LOT E CONCESSION IV BASED UPON A MATCH POINT AT THE AMHERSTBURG / BOIS BLANC CONTACT
2. FOR LOCATION OF TEXACO #6 WELL REFER TO FIGURE 15
3. FOR LOCATION OF SECTION C-C' REFER TO FIGURE 15
CONCEPTUAL STRATIGRAPHIC CROSS-SECTION C-C'
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY
FIGURE 16
C' WEST
C EAST
ESTIMATED DEPTH BELOW GROUND SURFACE AT BOREHOLE LOCATION US-4
STUDY AREA EASTERN LIMIT
LAKE HURON
ELEVATION IN METRES
STRATIGRAPHIC LEGEND
PLEISTOCENE
18 SURFICIAL DEPOSITS
MIDDLE DEVONIAN
17 AMHERSTBURG FORMATION - LIMESTONE AND DOLOSTONE
LOWER DEVONIAN
16 BOIS BLANC FORMATION - CHERTY DOLOSTONE
SILURIAN / DEVONIAN DISCONTINUITY
UPPER SILURIAN
15 BASS ISLAND FORMATION - DOLOSTONE
14 SALINA FORMATION
14G G MEMBER - DOLOSTONE AND SHALE
14F F MEMBER - DOLOMITIC SHALE AND SHALE
14E E MEMBER - DOLOSTONE
14D D MEMBER - SALT (ABSENT IN SITE AREA)
14C C MEMBER - DOLOMITIC SHALE AND SHALE
14B B MEMBER - DOLOSTONE AND ANHYDRITE (2m)
14A2 A2 MEMBER - DOLOSTONE, SHALY DOLOSTONE
14A1 A1 MEMBER - DOLOMITIC SHALE AND SHALE
MIDDLE SILURIAN
13 GUELPH, LOCKPORT AND REYNALES FORMATIONS - DOLOSTONE
LOWER SILURIAN
12 CABOT HEAD FORMATION - GREY SHALE
11 MANITOULIN FORMATION - ARGILLACEOUS DOLOSTONE
UPPER ORDOVICIAN
10 QUEENSTON FORMATION - RED SHALE AND SILTSTONE
9 GEORGIAN BAY FORMATION - GREY SHALE AND SILTSTONE
8 COLLINGWOOD FORMATION - GREY SHALE
MIDDLE ORDOVICIAN
7 LINDSAY FORMATION
7B UPPER MEMBER - LIMESTONE AND ARGILLACEOUS LIMESTONE
7A SHERMAN FALLS MEMBER - LIMESTONE
6 VERULAM FORMATION
5B UPPER MEMBER SHALY LIMESTONE
5A LOWER MEMBER ARGILLACEOUS LIMESTONE
5 BOBCAYGEON FORMATION - SHALY LIMESTONE TO CRYSTALLINE LIMESTONE
4 GULL RIVER FORMATION - LITHOGRAPHIC LIMESTONE
3 SHADOW LAKE FORMATION - SILTSTONE, SANDSTONE
CAMBRIAN
2 CAMBRIAN SANDSTONE
CAMBRIAN PRECAMBRIAN UNCONFORMITY
PRECAMBRIAN
1 PRECAMBRIAN BASEMENT - GRANITIC GNEISS
SCALES
HORIZONTAL SCALE = 1:20,000
VERTICAL SCALE = 1:5,000
VERTICAL EXAGGERATION 4 TO 1
400 0 400 800
HORIZONTAL SCALE 1:20000 METRES
DATE: JANUARY 2003
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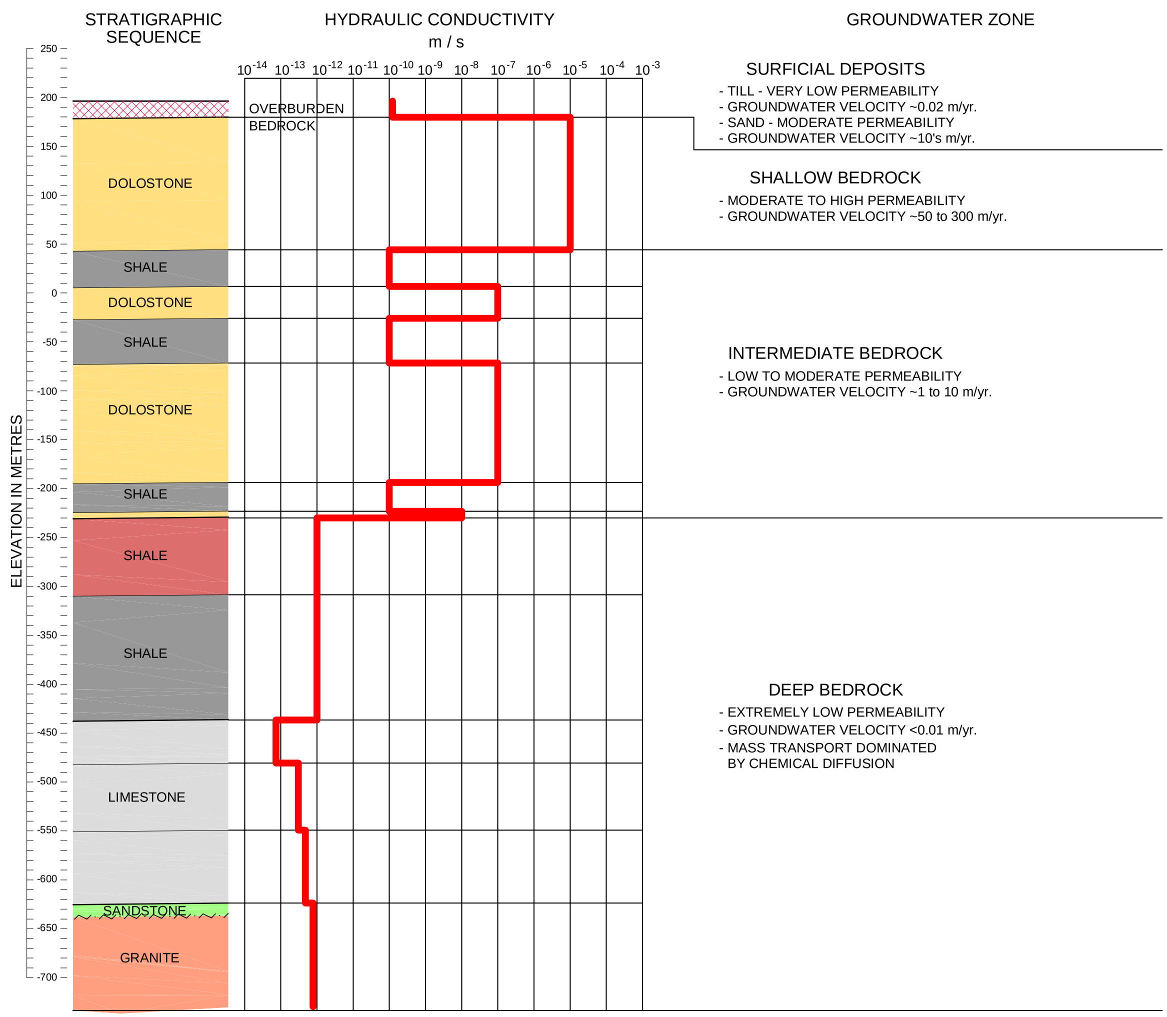
CAD: KD
CHK: JBD

SUMMARY OF HYDRAULIC CONDUCTIVITY
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 17



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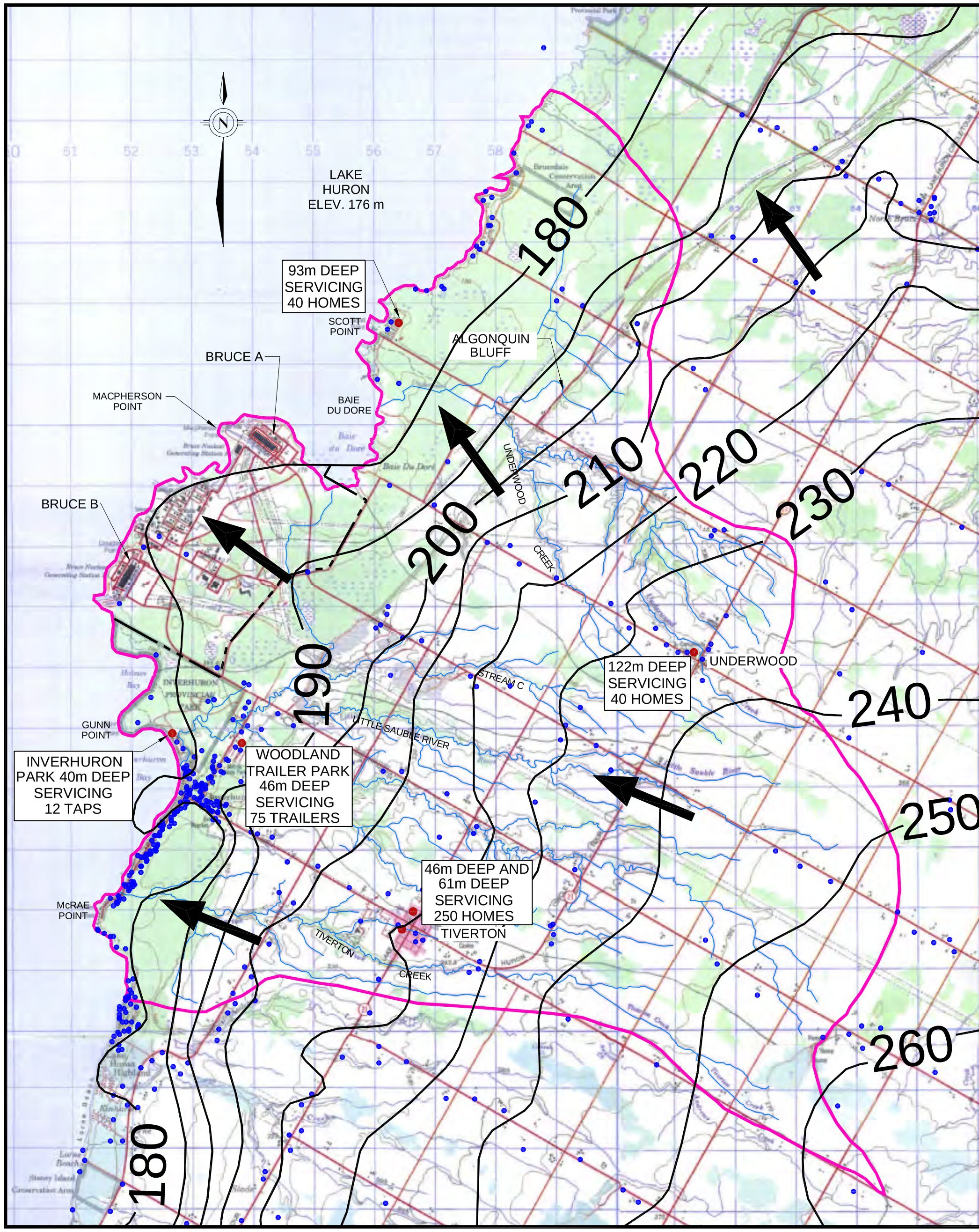
SURFACE DRAINAGE, GROUNDWATER LEVELS AND DIRECTION OF GROUNDWATER FLOW IN SHALLOW BEDROCK GROUNDWATER ZONE WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 18



LEGEND

- BRUCE SITE BOUNDARY
- RIVERS AND CREEKS
- SURFACE WATERSHED BOUNDARY
- MUNICIPAL WELL WITH DEPTH IN METRES AND NUMBERS OF HOMES SERVICED
- DOMESTIC WELL
- 230 GROUNDWATER ELEVATION CONTOUR IN METRES BASED ON MOE WELL RECORDS
- INFERRED DIRECTION OF GROUNDWATER FLOW

REFERENCE

BASE MAP SCANNED FROM PAPER COPY OF NRCan TOPOGRAPHIC MAPS. MAP NUMBERS 41 A/4, 41 A/5, 41 A/3 AND 41 A/6, SCALE 1:50 000.

1.5 0 1.5 3
SCALE 1:75000 KM

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CONCEPTUAL HYDROGEOLOGICAL MODEL OF THE BRUCE SITE WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 19

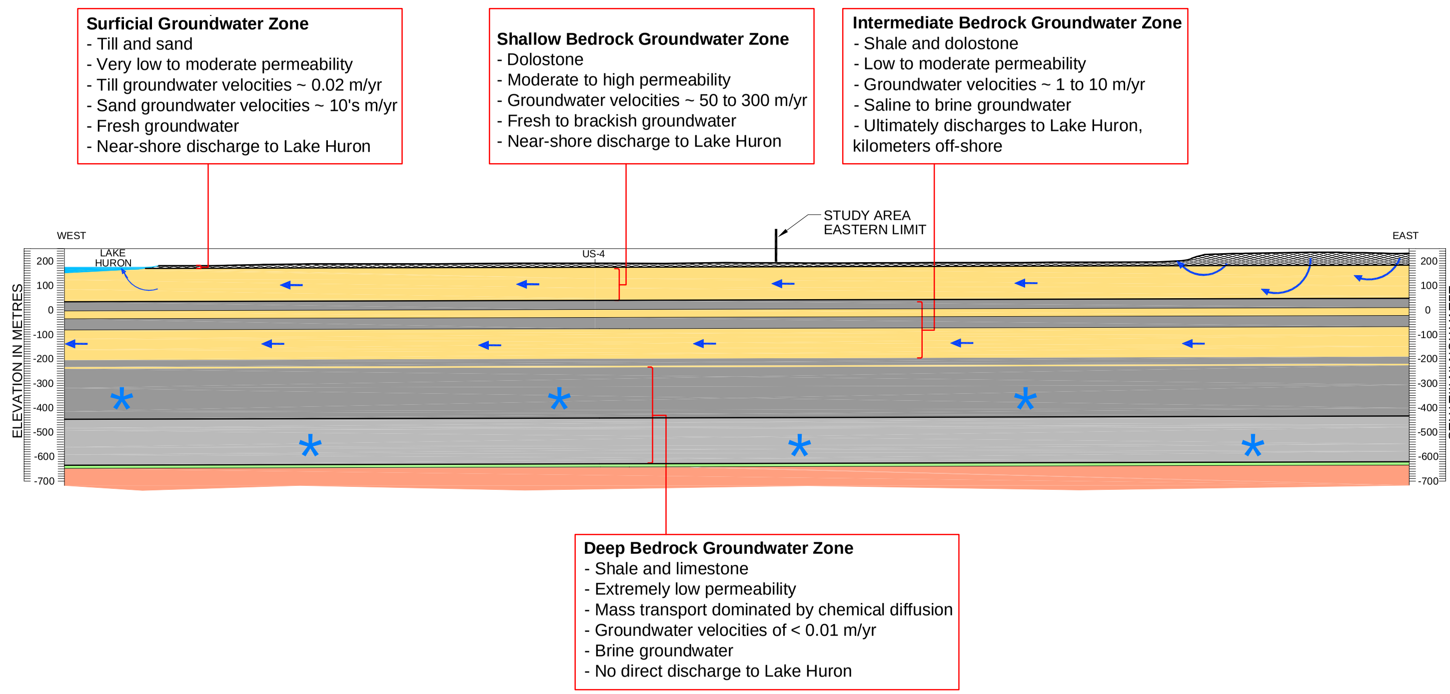
LEGEND

- ← ADVECTIVE GROUNDWATER FLOW ZONE, INFERRED DIRECTION INDICATED
- * MASS TRANSPORT DOMINATED BY CHEMICAL DIFFUSION

SCALE 1:20000 — 400 0 400 800 METRES

LITHOLOGY

- DOLOSTONE
- SHALE
- LIMESTONE
- SILTSTONE, SANDSTONE
- GRANITIC GNEISS



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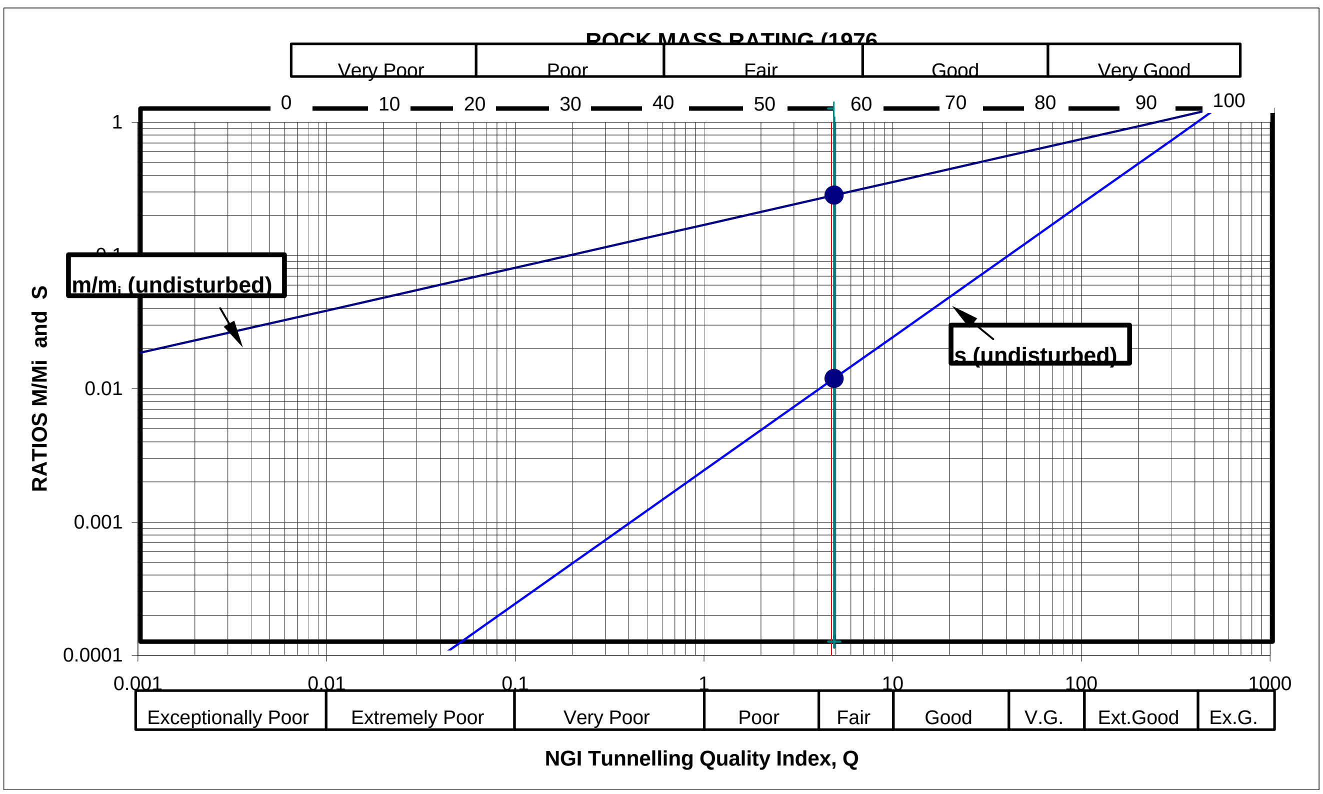
ROCK MASS CLASSIFICATION
AMHERSTBURG DOLOSTONE

FIGURE 20

PARAMETER	DESCRIPTION (OR) RANGE OF VALUES	RATING NGI-Q	RATING RMR76
DRILL CORE QUALITY (RQD%)	~76% (range 30-100%)	76	18
NUMBER OF JOINT SETS (JN)	2 (predominantly) + random	6	
SPACING OF JOINTS and /or FRACTURE INDEX	0.3 to 1m		20
CONDITION OF JOINTS ROUGHNESS (JR) ALTERATION (JA) CONTACT STRENGTH	tight, rough to very rough bituminous coating	1.5 / 1	12
INTACT STRENGTH from UCS or PLI or ISRM estimate	12 MPa to 130 MPa(UCS) ~ Av 60 MPa		8
GROUNDWATER INFLOW CONDITIONS	Large inflows in competent rock	0.5	0
STRUCTURE ORIENTATION RATING	Not derated for general conditions		0
STRESS REDUCTION FACTOR	Low to medium stress, near surface	2	
		4.75	58
	Equivalents	4.74	58

HOEK-BROWN m_i,	8	
and derived m & s	1.79	0.0094



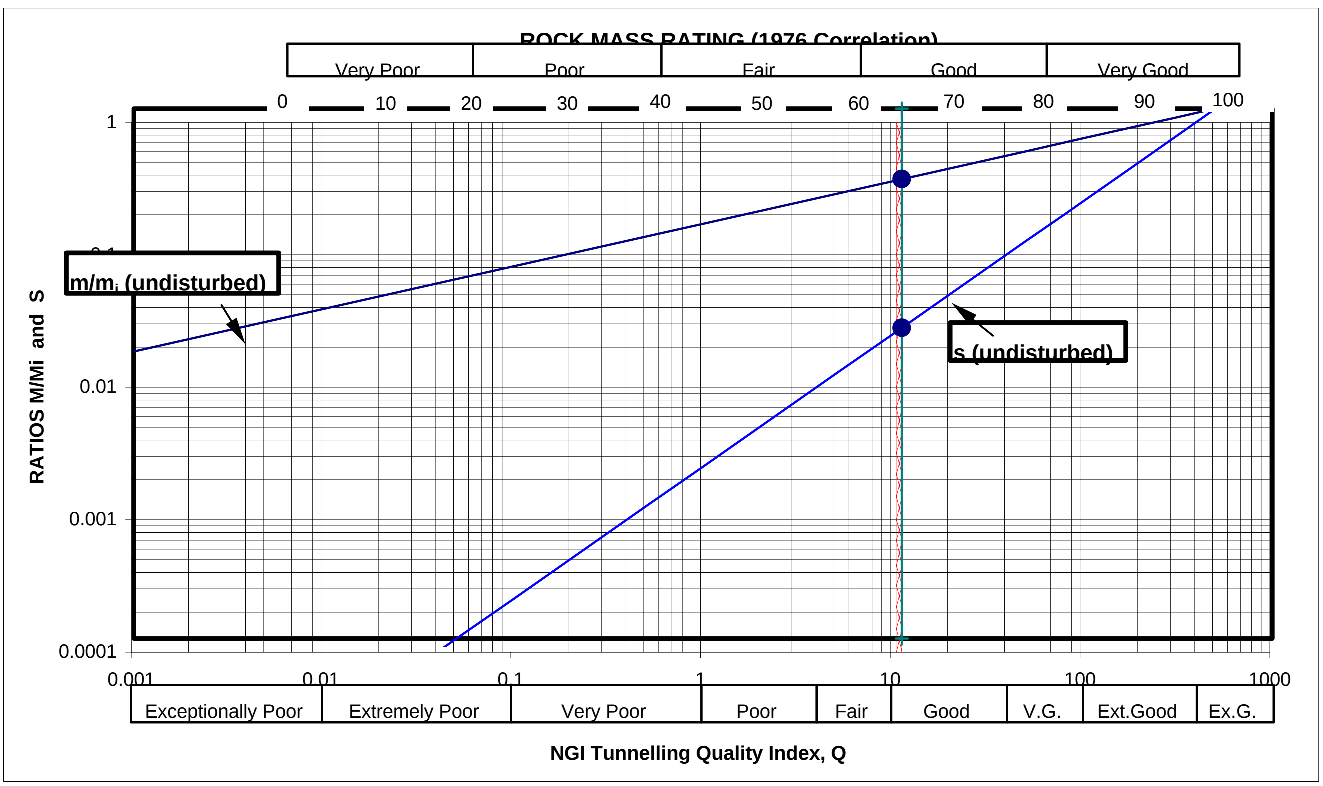
Notes: NGI Q Parameter designations after Barton, 1974
RMR ratings based on Bieniawski, 1976; = GSI per Hoek Kaiser & Bawden, 1995
m and s undisturbed relationships from Hoek and Brown,1988

ROCK MASS CLASSIFICATION
QUEENSTON SHALE

FIGURE 21

PARAMETER	DESCRIPTION (OR) RANGE OF VALUES	RATING NGI-Q	RATING RMR76
DRILL CORE QUALITY (RQD%)	~85%	86	18
NUMBER OF JOINT SETS (JN)	2 (predominantly) + random	6	
SPACING OF JOINTS and /or FRACTURE INDEX	0.3 to 1m		20
CONDITION OF JOINTS ROUGHNESS (JR) ALTERATION (JA) CONTACT STRENGTH	smooth planar slickensided surfaces, gouge	1.5 / 1	12
INTACT STRENGTH from UCS or PLI or ISRM estimate	33 MPa to 46 MPa(UCS) ~ Av 40 MPa		6
GROUNDWATER INFLOW CONDITIONS	Dry	1	10
STRUCTURE ORIENTATION RATING	Not derated for general conditions		0
STRESS REDUCTION FACTOR	High stress, at depth	2	
		10.75	**66**
	Equivalents	11.52	65

HOEK-BROWN m_i,	14.5	
and derived m & s	4.26	0.0221



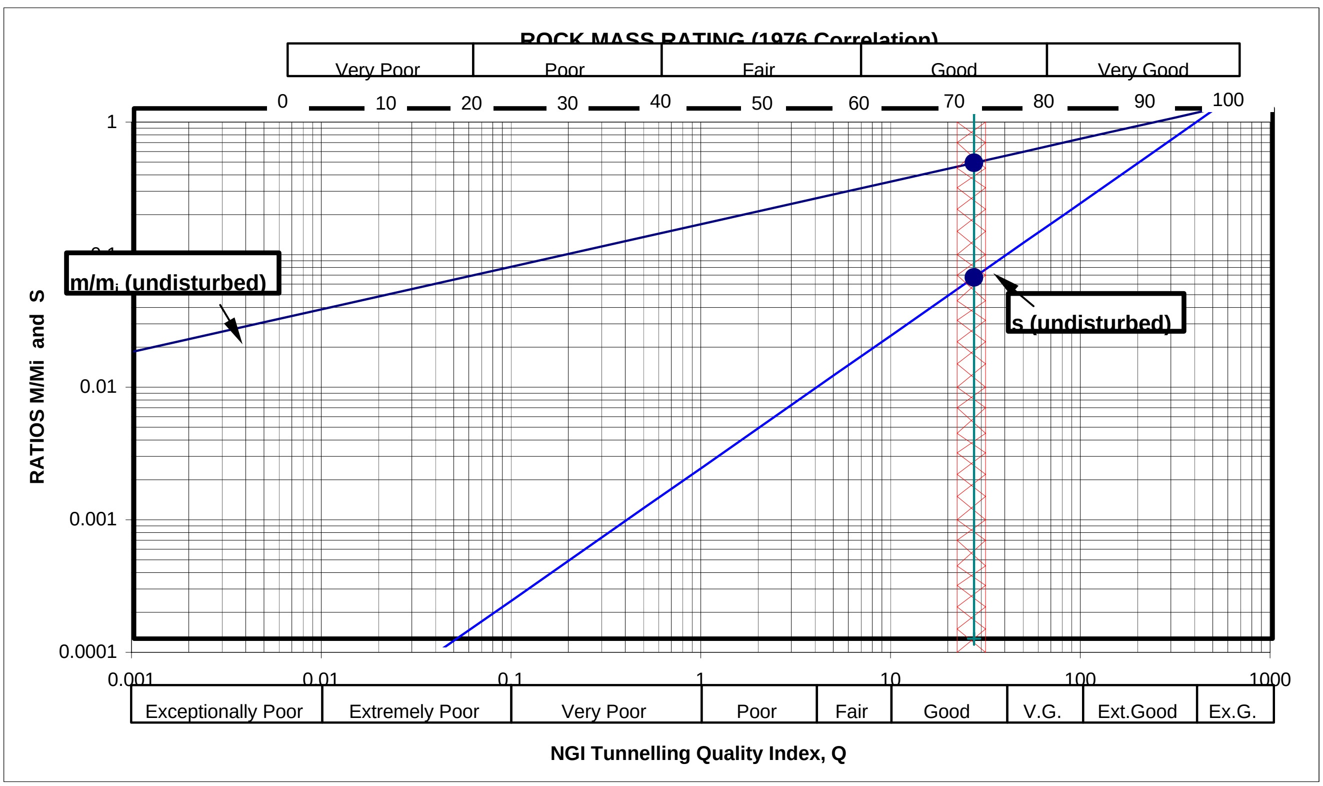
Notes: NGI Q Parameter designations after Barton, 1974
RMR ratings based on Bieniawski, 1976; = GSI per Hoek Kaiser & Bawden, 1995
m and s undisturbed relationships from Hoek and Brown,1988

ROCK MASS CLASSIFICATION
LINDSAY LIMESTONE

FIGURE 22

PARAMETER	DESCRIPTION (OR) RANGE OF VALUES	RATING NGI-Q	RATING RMR76
DRILL CORE QUALITY (RQD%)	**~95% (range 90-100%)**	**95**	**20**
NUMBER OF JOINT SETS (JN)	**1 (predominantly) + random**	**3**	
SPACING OF JOINTS and /or FRACTURE INDEX	**0.3 to 1m**		**20**
CONDITION OF JOINTS ROUGHNESS (JR) ALTERATION (JA) CONTACT STRENGTH	**smooth or stepped planar rough, gouge**	**1.5** / **1**	**12**
INTACT STRENGTH from UCS or PLI or ISRM estimate	**25 MPa to 140 MPa(UCS) ~ Av 60 MPa**		**10**
GROUNDWATER INFLOW CONDITIONS	**Dry**	**1**	**10**
STRUCTURE ORIENTATION RATING	**Not derated for general conditions**		**0**
STRESS REDUCTION FACTOR	**High stress, at depth**	**1.5**	
		31.67	**72**
	Equivalents	22.45	75

HOEK-BROWN m_i,	**10**	
and derived m & s	**3.89**	**0.0529**



Notes: NGI Q Parameter designations after Barton, 1974
RMR ratings based on Bieniawski, 1976; = GSI per Hoek Kaiser & Bawden, 1995
m and s undisturbed relationships from Hoek and Brown,1988

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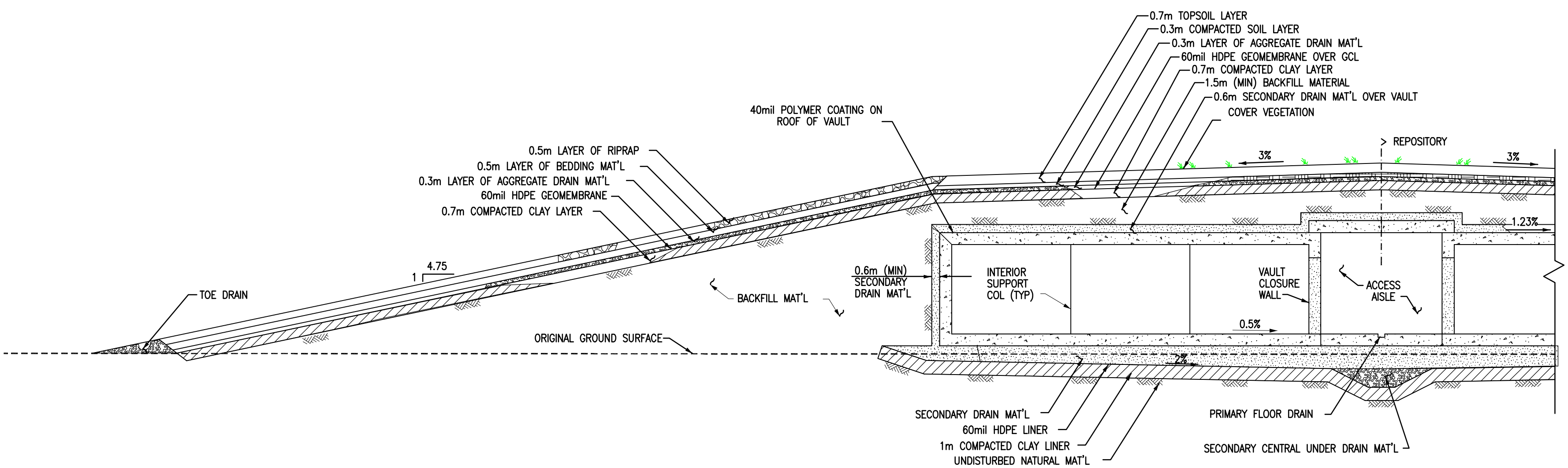
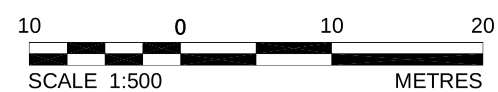
CONCEPTUAL CROSS-SECTION
GENERIC COVERED ABOVE GRADE CONCRETE VAULT
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 23





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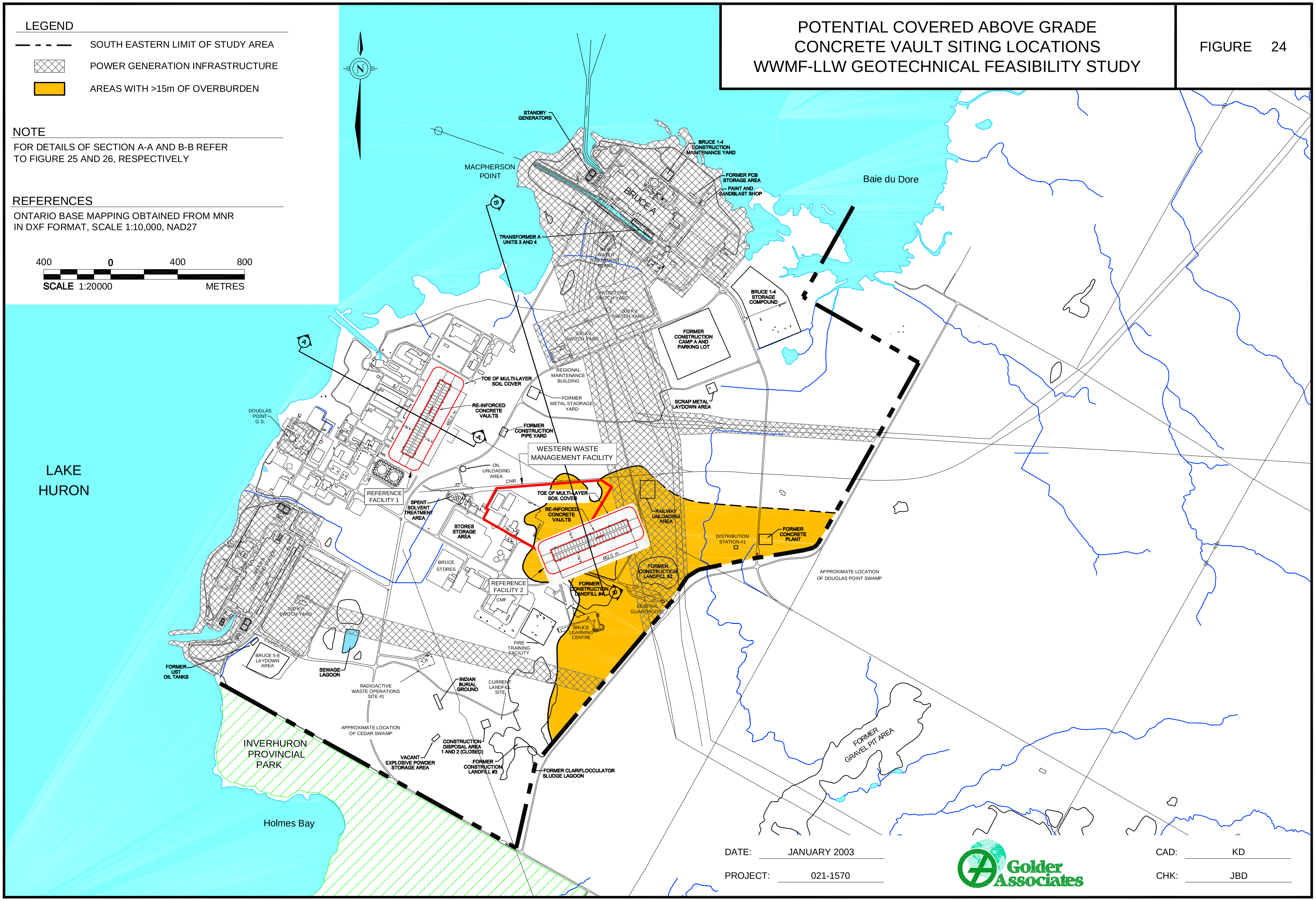
CAD: KD

CHK: JBD

POTENTIAL COVERED ABOVE GRADE CONCRETE VAULT SITING LOCATIONS WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 24



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CONCEPTUAL HYDROGEOLOGICAL MODEL
COVERED ABOVE GRADE CONCRETE VAULT
REFERENCE FACILITY 1 - SECTION A-A
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 25

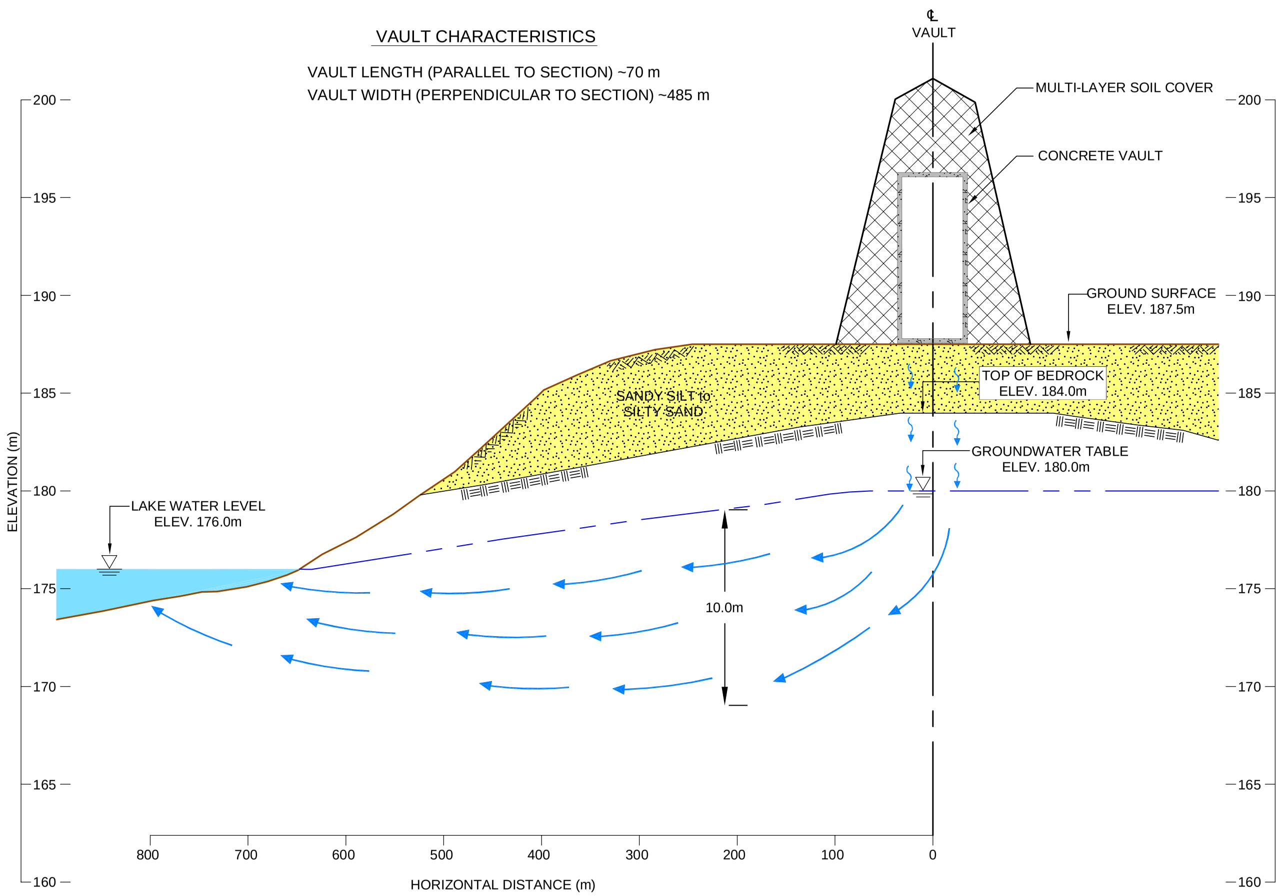
HYDRAULIC CHARACTERISTICS

MATERIAL	LENGTH (m)	HYDRAULIC CONDUCTIVITY (m/s)		HYDRAULIC GRADIENT		EFFECTIVE POROSITY (n%)
		K_H	K_V	i_H	i_V	
SANDY SILT & SILTY SAND	3.5	-	10^{-4} to 10^{-6}	-	1.0	30
UNSATURATED BEDROCK	4	-	10^{-5} to 10^{-7}	-	1.0	0.5 to 1.5
SATURATED BEDROCK	650 to 800	10^{-4} to 10^{-6}	10^{-5} to 10^{-7}	0.006	-	0.5 to 1.5

VAULT CHARACTERISTICS

VAULT LENGTH (PARALLEL TO SECTION) ~70 m

VAULT WIDTH (PERPENDICULAR TO SECTION) ~485 m



LEGEND

GROUND SURFACE

BEDROCK SURFACE

GROUNDWATER TABLE

POTENTIAL CONTAMINANT MIGRATION PATHWAY (UNSATURATED ZONE)

POTENTIAL CONTAMINANT MIGRATION PATHWAY (SATURATED ZONE)

NOTE

1. FOR LOCATION OF SECTION A-A SEE FIGURE 24

HORIZONTAL SCALE 1:5000 — 100 0 100 200 METRES

VERTICAL SCALE 1:250 — 5 0 5 10 METRES

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CONCEPTUAL HYDROGEOLOGICAL MODEL COVERED ABOVE GRADE CONCRETE VAULT REFERENCE FACILITY 2 - SECTION B-B WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 26

LEGEND

- GROUND SURFACE
- BEDROCK SURFACE
- GROUNDWATER TABLE
- POTENTIAL CONTAMINANT MIGRATION PATHWAY (OVERBURDEN)
- POTENTIAL CONTAMINANT MIGRATION PATHWAY (BEDROCK)

NOTE

1. FOR LOCATION OF SECTION B-B SEE FIGURE 24

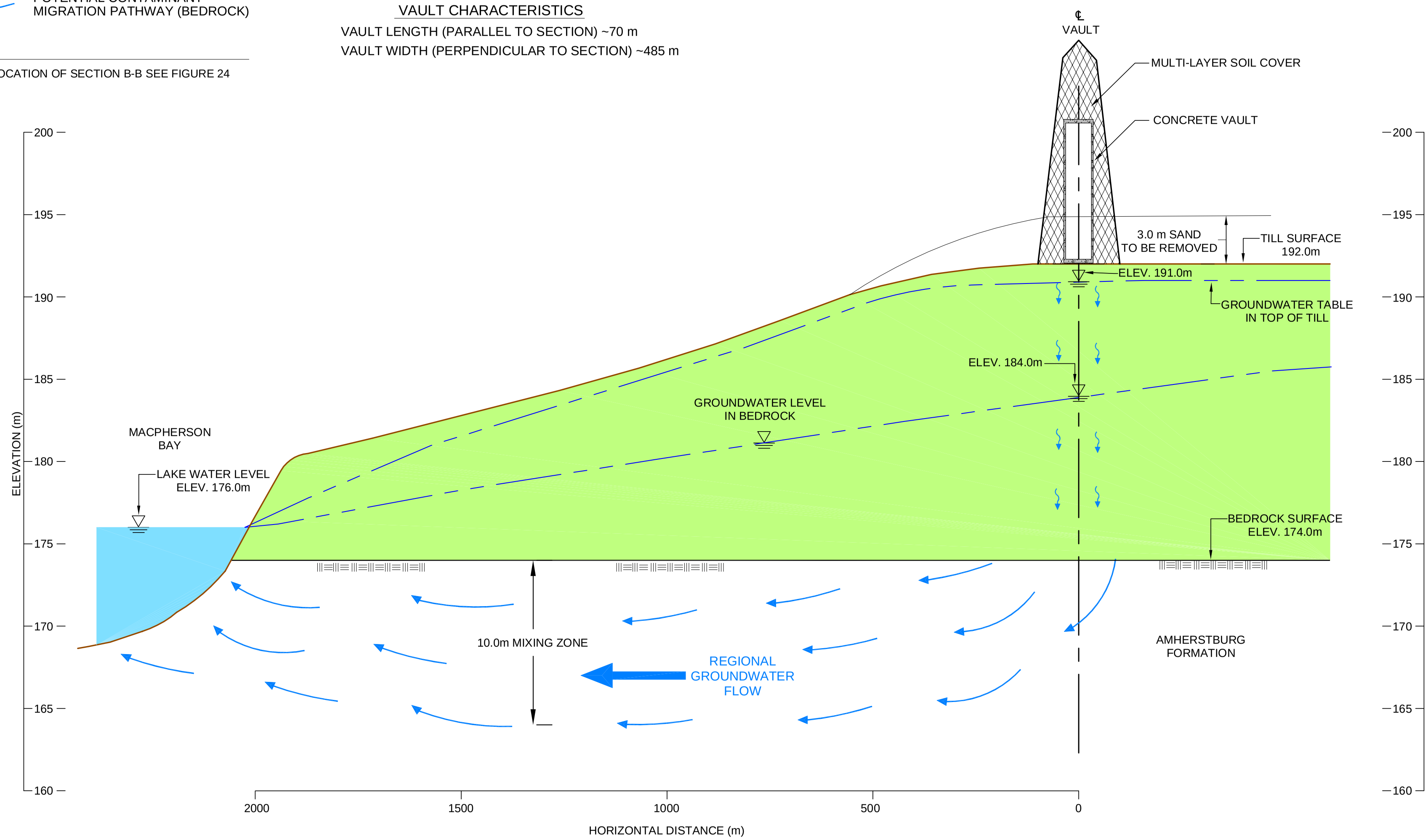
HYDRAULIC CHARACTERISTICS

MATERIAL	LENGTH (m)	HYDRAULIC CONDUCTIVITY (m/s) K_H	HYDRAULIC CONDUCTIVITY (m/s) K_V	HYDRAULIC GRADIENT i_H	HYDRAULIC GRADIENT i_V	EFFECTIVE POROSITY (n%)
TILL	17	-	10^{-9} to 10^{-10}	-	0.4	30
BEDROCK	2000 to 2500	10^{-4} to 10^{-6}	10^{-5} to 10^{-7}	0.004	-	0.5 to 1.5

VAULT CHARACTERISTICS

VAULT LENGTH (PARALLEL TO SECTION) ~70 m

VAULT WIDTH (PERPENDICULAR TO SECTION) ~485 m



200 0 200 400
HORIZONTAL SCALE 1:10000 METRES

5 0 5 10
VERTICAL SCALE 1:250 METRES

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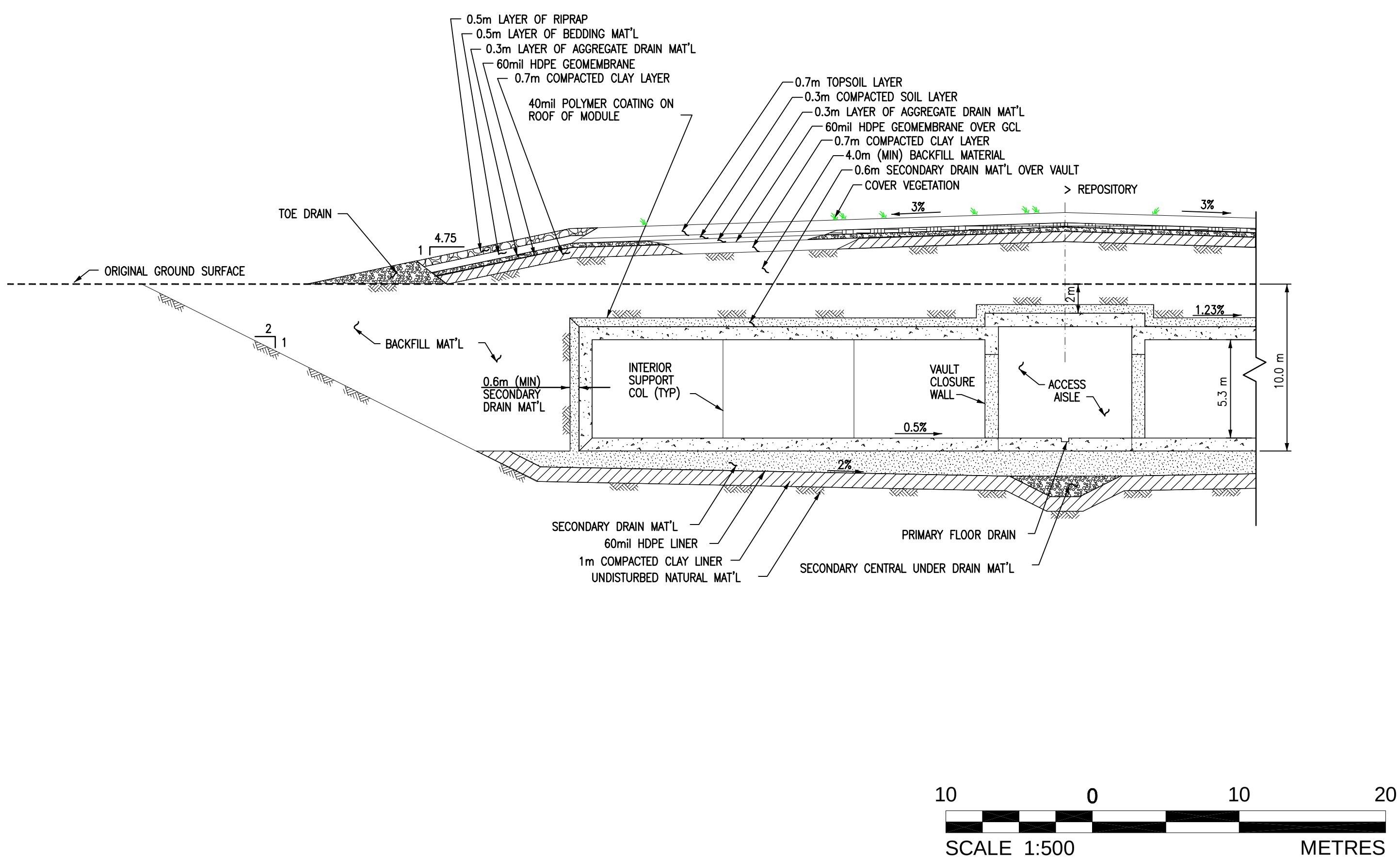
CONCEPTUAL CROSS-SECTION
GENERIC SHALLOW CONCRETE VAULT
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 27



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POTENTIAL SHALLOW CONCRETE VAULT SITING LOCATION
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 28

LEGEND

- SOUTH EASTERN LIMIT OF STUDY AREA
- POWER GENERATION INFRASTRUCTURE
- AREAS WITH >15m OF OVERBURDEN

NOTE

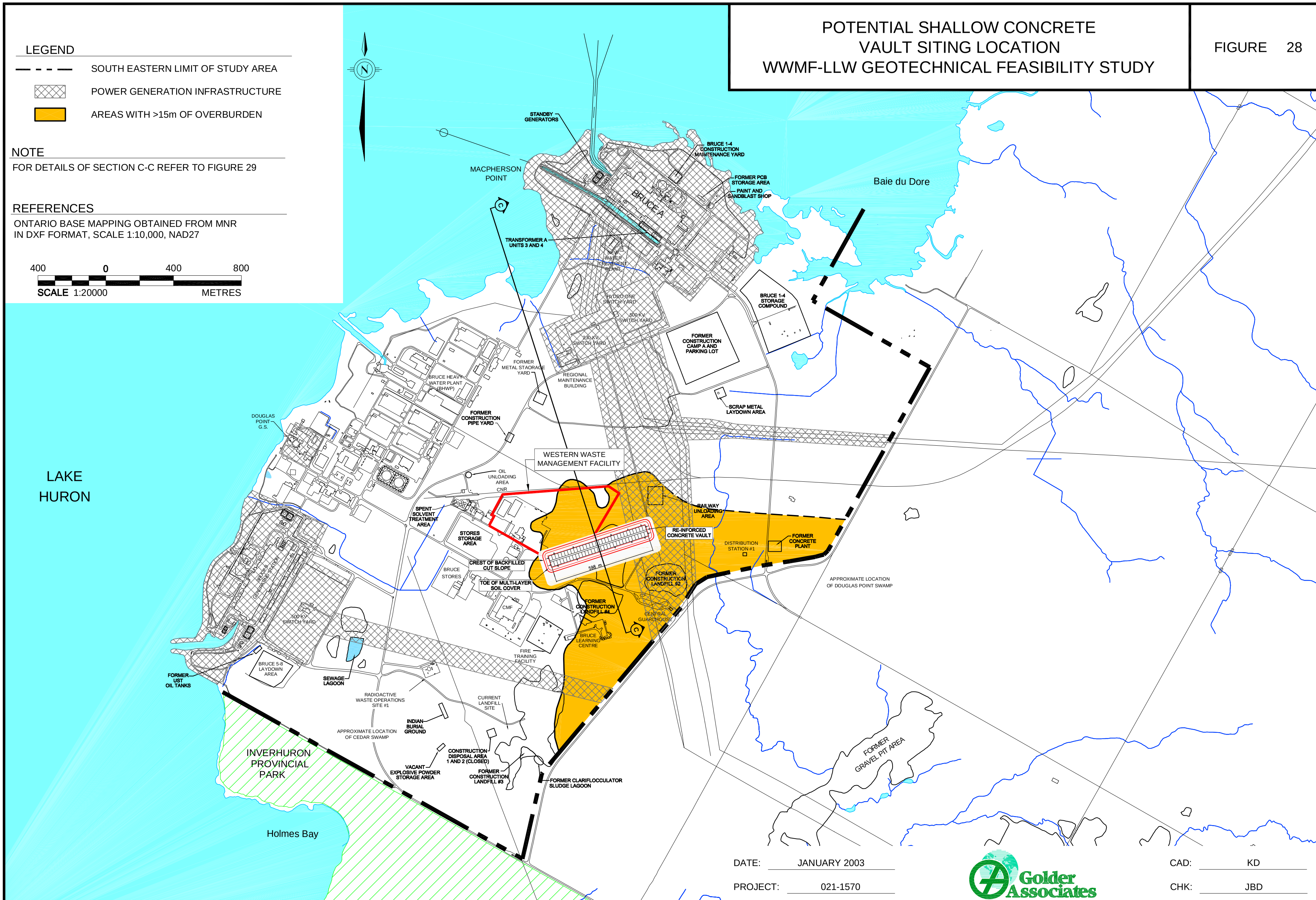
FOR DETAILS OF SECTION C-C REFER TO FIGURE 29

REFERENCES

ONTARIO BASE MAPPING OBTAINED FROM MNR IN DXF FORMAT, SCALE 1:10,000, NAD27

400 0 400 800

SCALE 1:20000 METRES



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CONCEPTUAL HYDROGEOLOGICAL MODEL
SHALLOW CONCRETE VAULT - SECTION C-C
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 29

LEGEND

- GROUND SURFACE
- BEDROCK SURFACE
- GROUNDWATER TABLE
- POTENTIAL CONTAMINANT MIGRATION PATHWAY (OVERBURDEN)
- POTENTIAL CONTAMINANT MIGRATION PATHWAY (BEDROCK)

NOTE

1. FOR LOCATION OF SECTION C-C SEE FIGURE 28

HYDRAULIC CHARACTERISTICS

MATERIAL	LENGTH (m)	HYDRAULIC CONDUCTIVITY (m/s)		HYDRAULIC GRADIENT		EFFECTIVE POROSITY (n%)
		K_H	K_V	i_H	i_V	
TILL	7	-	10^{-9} to 10^{-10}	-	1.0**	30
SAND	7	-	10^{-5} *	-	1.0**	30
BEDROCK	2000 to 2500	10^{-4} to 10^{-6}	10^{-5} to 10^{-7}	0.004	-	0.5 to 1.5

* FOR ASSUMED CASE WITHOUT SAND LENSES IN TILL, USE THE RANGE OF TILL HYDRAULIC CONDUCTIVITY.

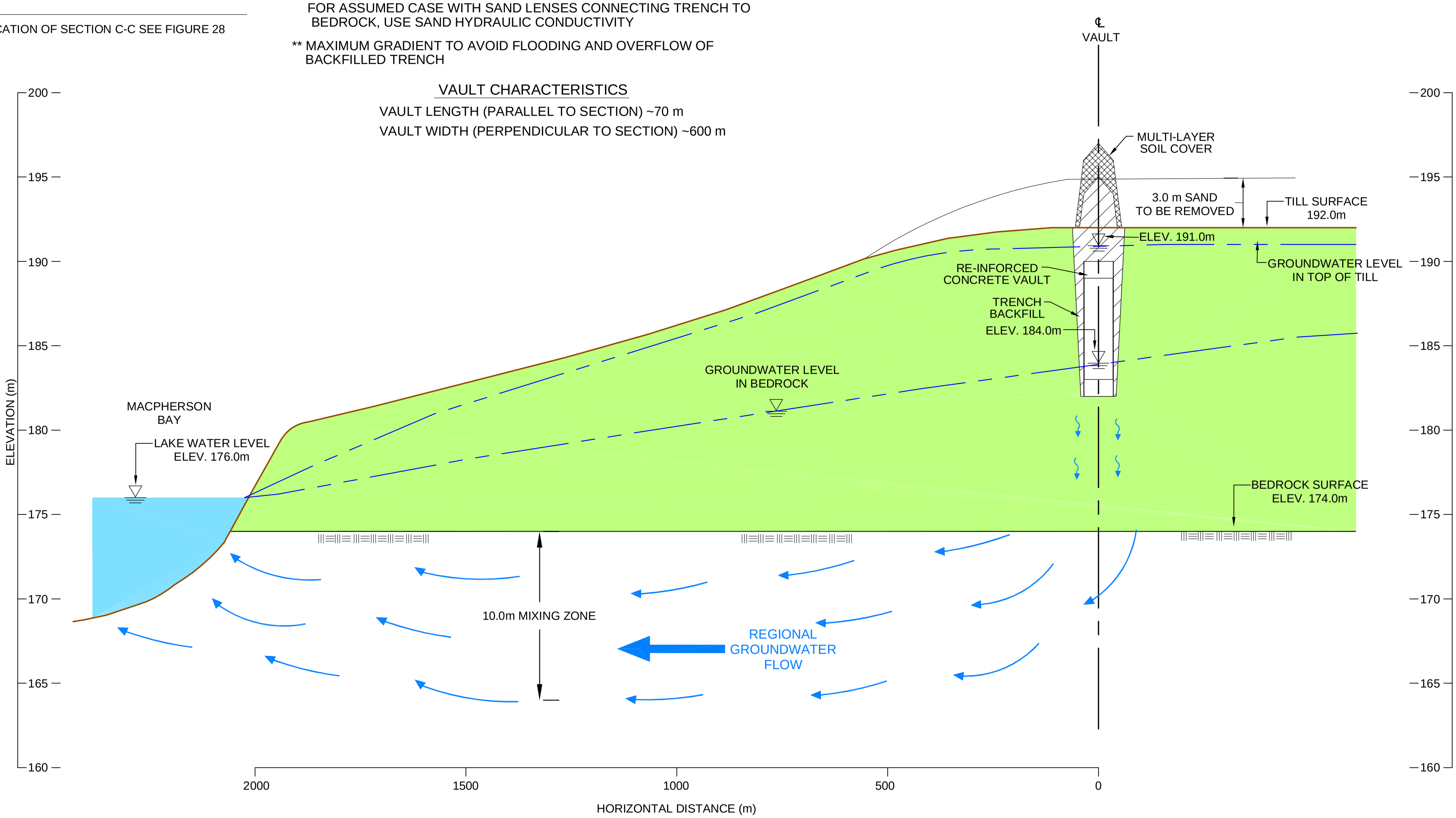
FOR ASSUMED CASE WITH SAND LENSES CONNECTING TRENCH TO BEDROCK, USE SAND HYDRAULIC CONDUCTIVITY

** MAXIMUM GRADIENT TO AVOID FLOODING AND OVERFLOW OF BACKFILLED TRENCH

VAULT CHARACTERISTICS

VAULT LENGTH (PARALLEL TO SECTION) ~70 m

VAULT WIDTH (PERPENDICULAR TO SECTION) ~600 m



HORIZONTAL SCALE 1:10000 — 200 0 200 400 METRES

VERTICAL SCALE 1:250 — 5 0 5 10 METRES

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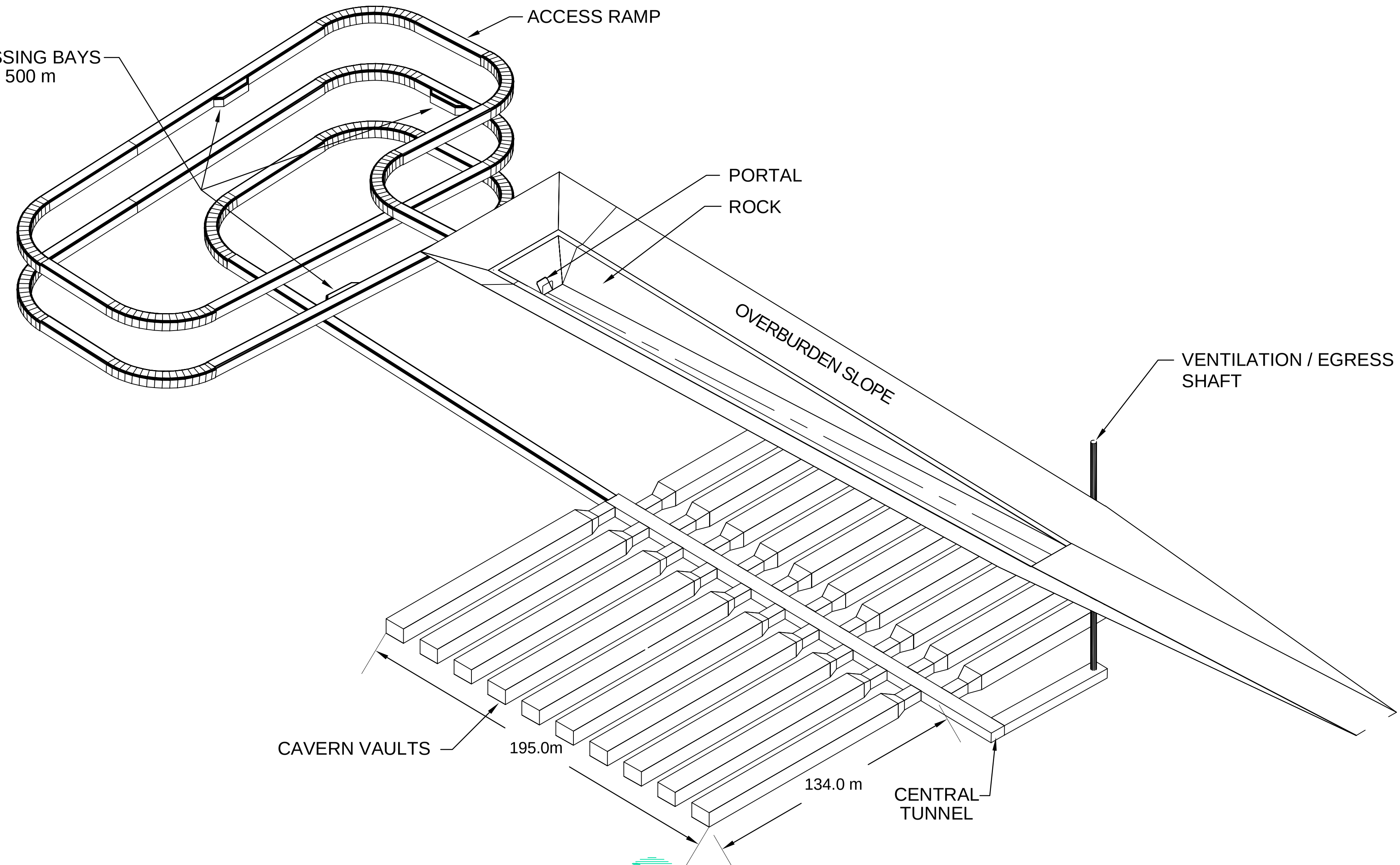
ISOMETRIC VIEW OF GENERIC ROCK CAVERN VAULT
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 30



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CAD: KD

CHK: JBD

POTENTIAL SHALLOW ROCK CAVERN VAULT
SITING LOCATION
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 31

LEGEND

SOUTH EASTERN LIMIT OF STUDY AREA

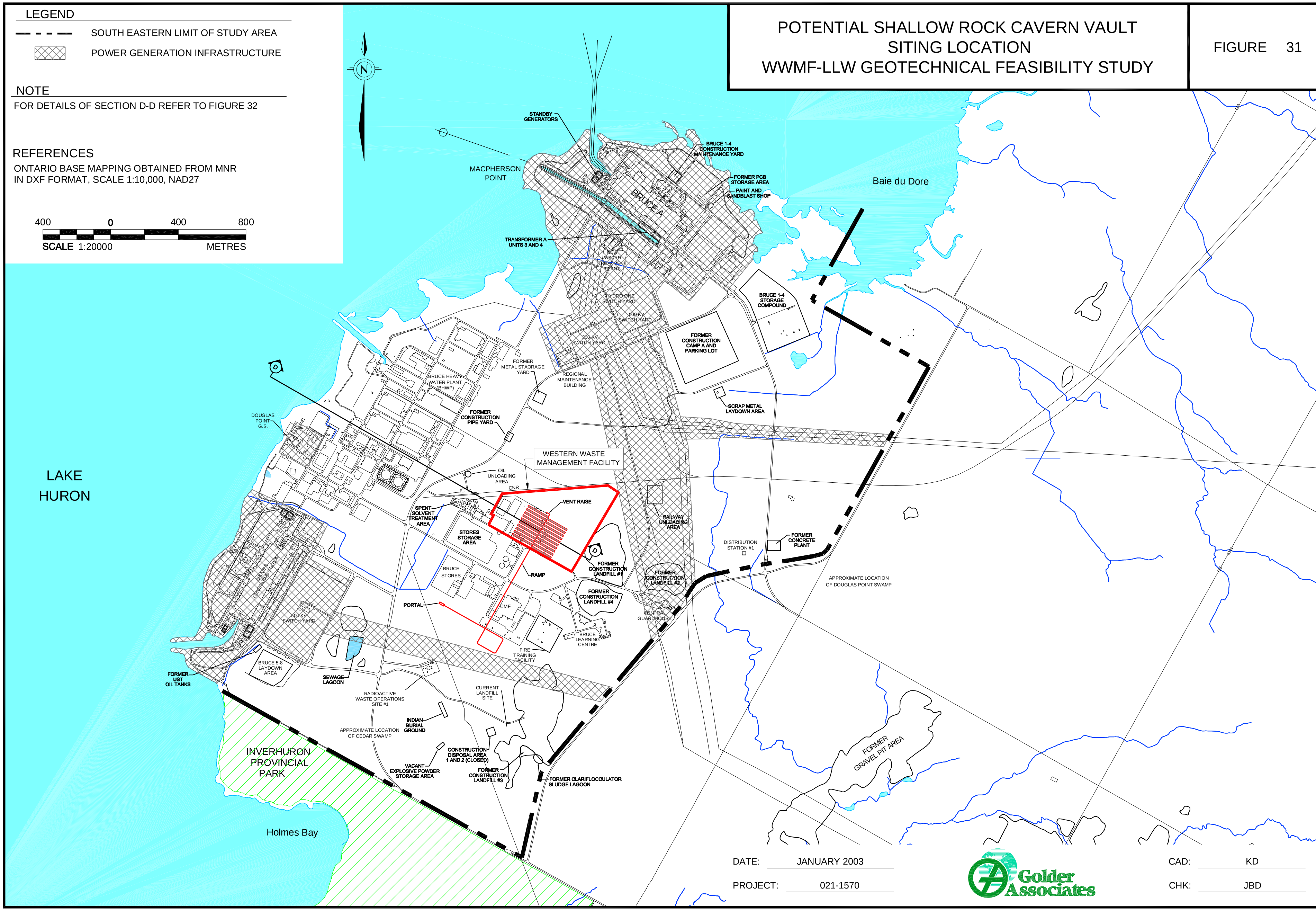
POWER GENERATION INFRASTRUCTURE

NOTE

FOR DETAILS OF SECTION D-D REFER TO FIGURE 32

REFERENCES

ONTARIO BASE MAPPING OBTAINED FROM MNR
IN DXF FORMAT, SCALE 1:10,000, NAD27



DATE: JANUARY 2003

PROJECT: 021-1570

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CAD: KD

CHK: JBD

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CONCEPTUAL HYDROGEOLOGICAL MODEL
SHALLOW ROCK CAVERN VAULT - SECTION D-D
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 32

LEGEND

- GROUND SURFACE
- BEDROCK SURFACE
- GROUNDWATER TABLE
- FORMATION CONTACT
- POTENTIAL CONTAMINANT MIGRATION PATHWAY

NOTE

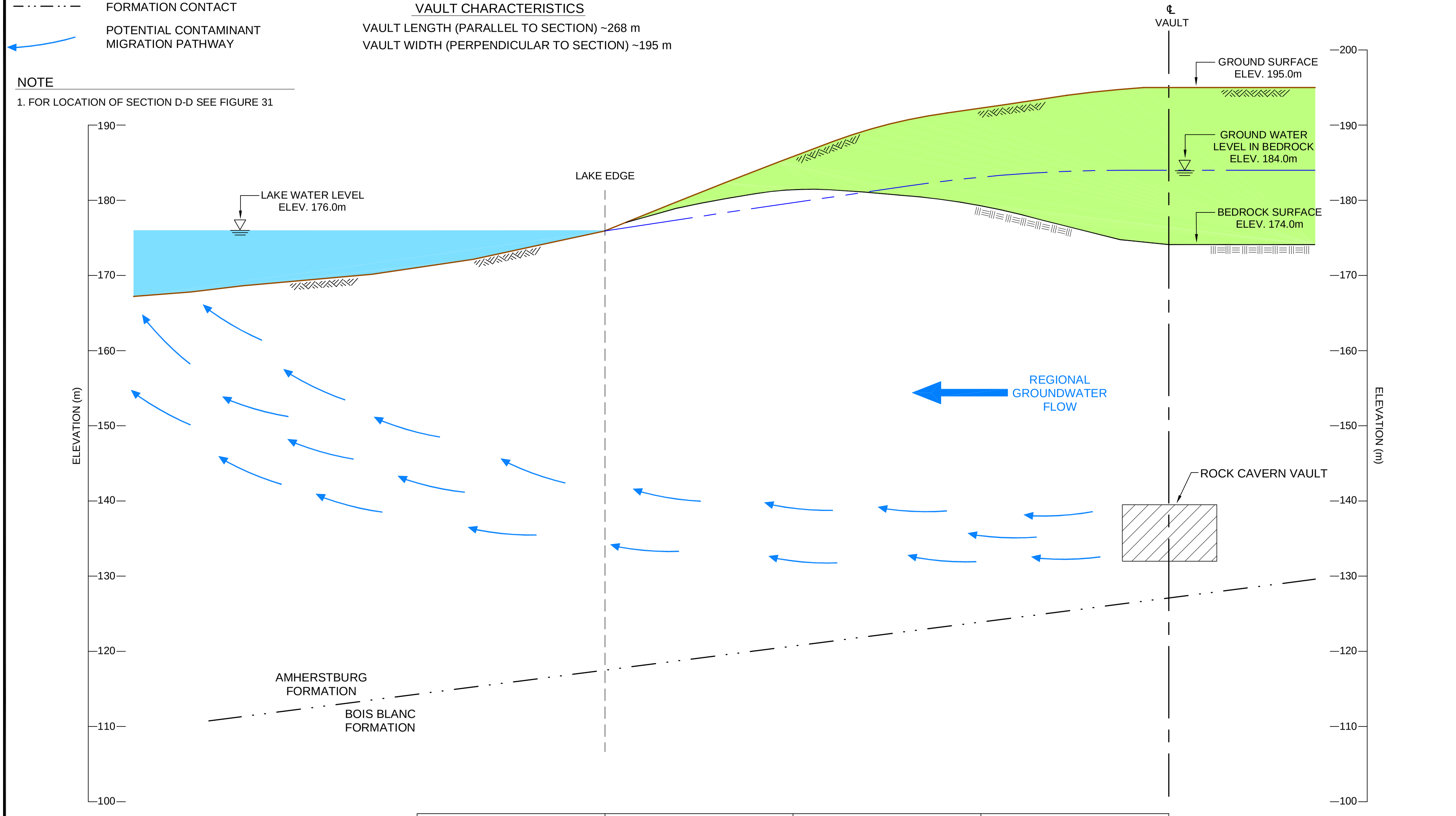
1. FOR LOCATION OF SECTION D-D SEE FIGURE 31

HYDRAULIC CHARACTERISTICS

MATERIAL	LENGTH (m)	HYDRAULIC CONDUCTIVITY (m/s)		HYDRAULIC GRADIENT		EFFECTIVE POROSITY (n%)
		K_H	K_V	i_H	i_V	
BEDROCK	2500 to 3000	10^{-4} to 10^{-6}	10^{-5} to 10^{-7}	0.005	-	0.5 to 1.5

VAULT CHARACTERISTICS

VAULT LENGTH (PARALLEL TO SECTION) ~268 m
VAULT WIDTH (PERPENDICULAR TO SECTION) ~195 m



HORIZONTAL SCALE 1:10000 METRES (200 0 200 400)

VERTICAL SCALE 1:500 METRES (10 0 10 20)

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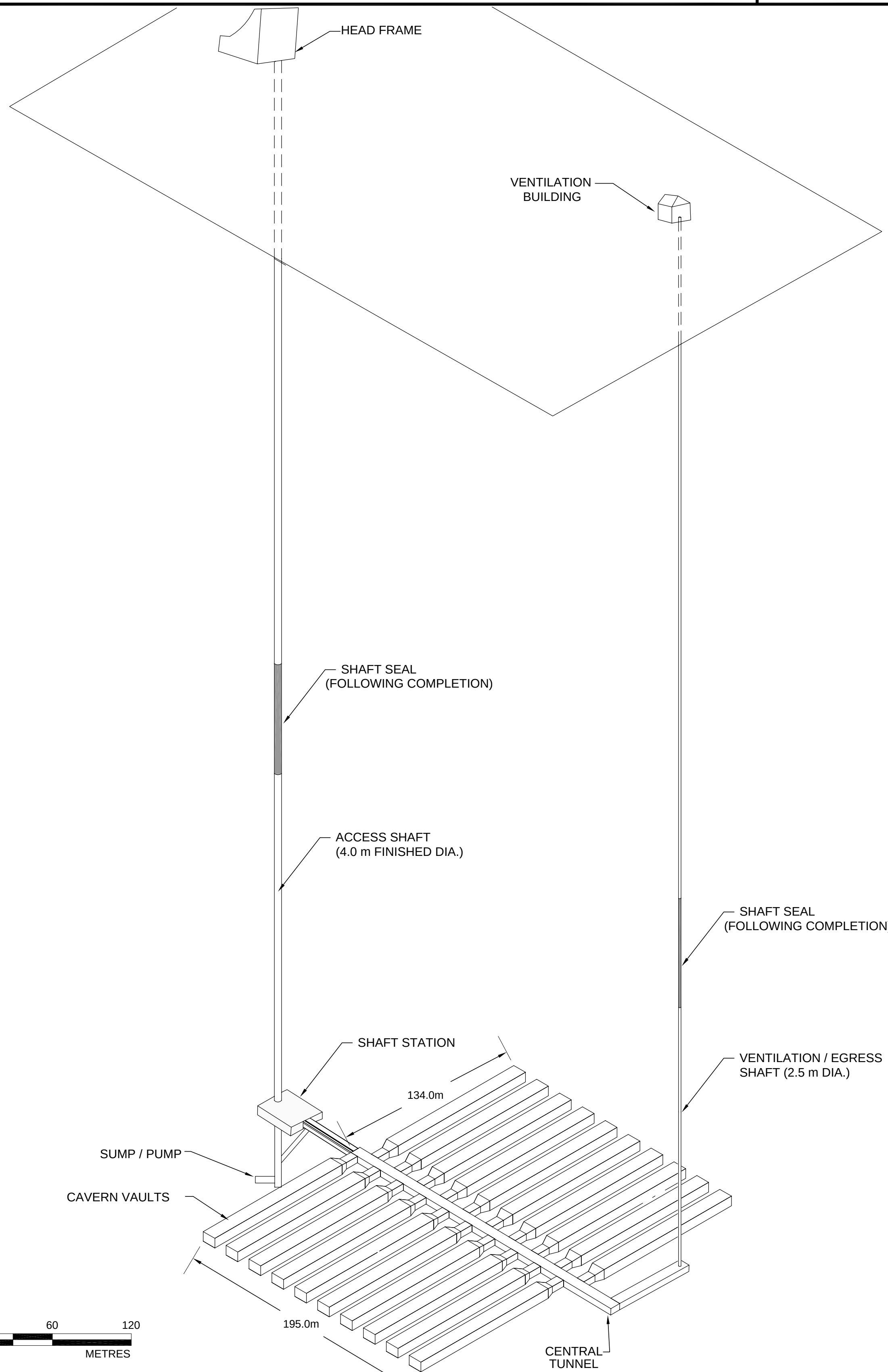
FILENAME: T:\Projects\2002\021-1570\RJAN2003\80% COMPLETION-REVISION 3\R1570033.dwg

ISOMETRIC VIEW OF CONCEPTUAL DEEP ROCK CAVERN VAULT
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 33



60 0 60 120
1:3000 METRES

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CAD: KD
CHK: JBD

POTENTIAL DEEP ROCK CAVERN VAULT
SITING LOCATION
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 34

LEGEND

- - - SOUTH EASTERN LIMIT OF STUDY AREA

POWER GENERATION INFRASTRUCTURE

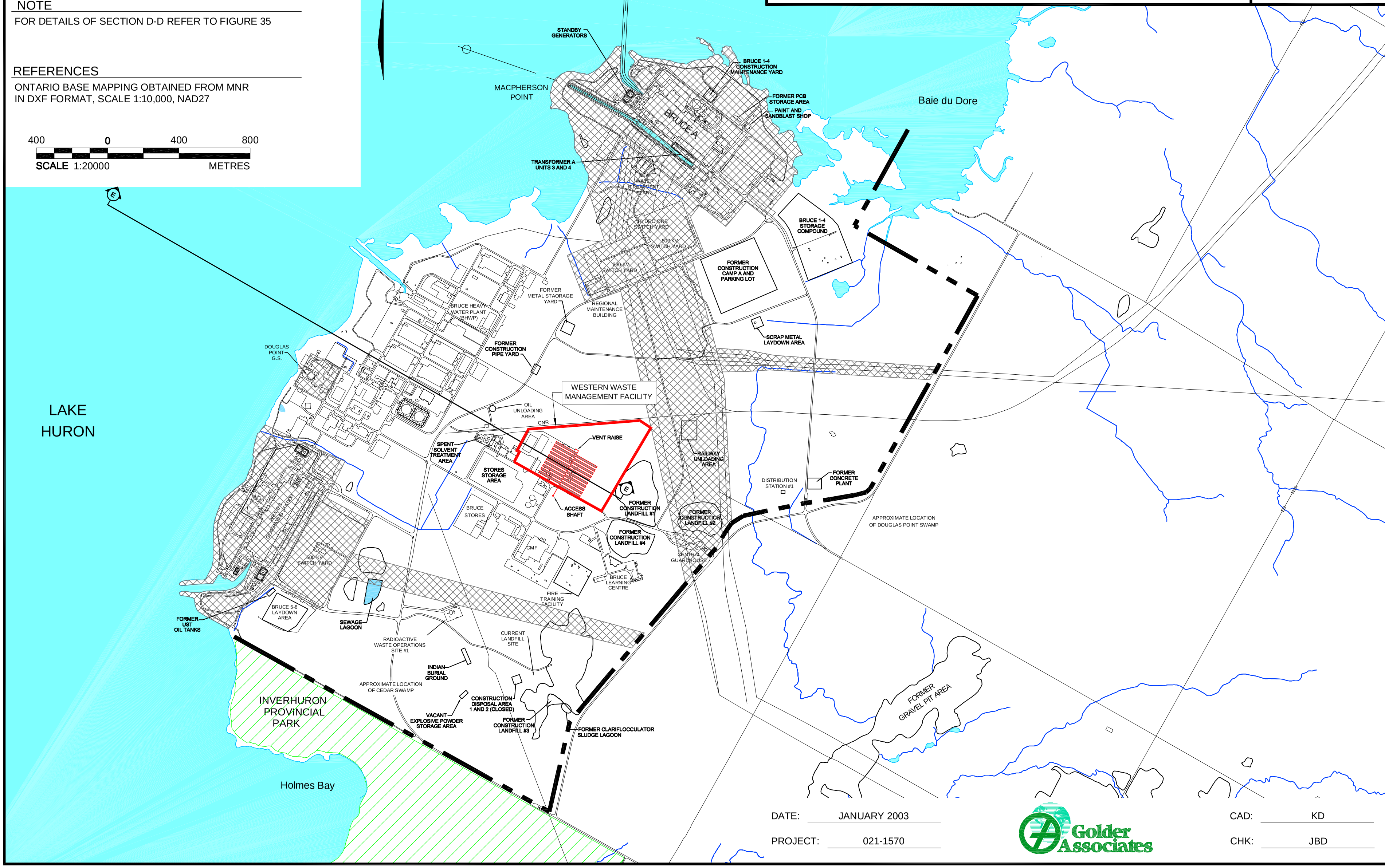
NOTE

FOR DETAILS OF SECTION D-D REFER TO FIGURE 35

REFERENCES

ONTARIO BASE MAPPING OBTAINED FROM MNR
IN DXF FORMAT, SCALE 1:10,000, NAD27

400 0 400 800
SCALE 1:20000 METRES



DATE: JANUARY 2003

PROJECT: 021-1570

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CAD: KD

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PLOT DATE: February 11, 2003
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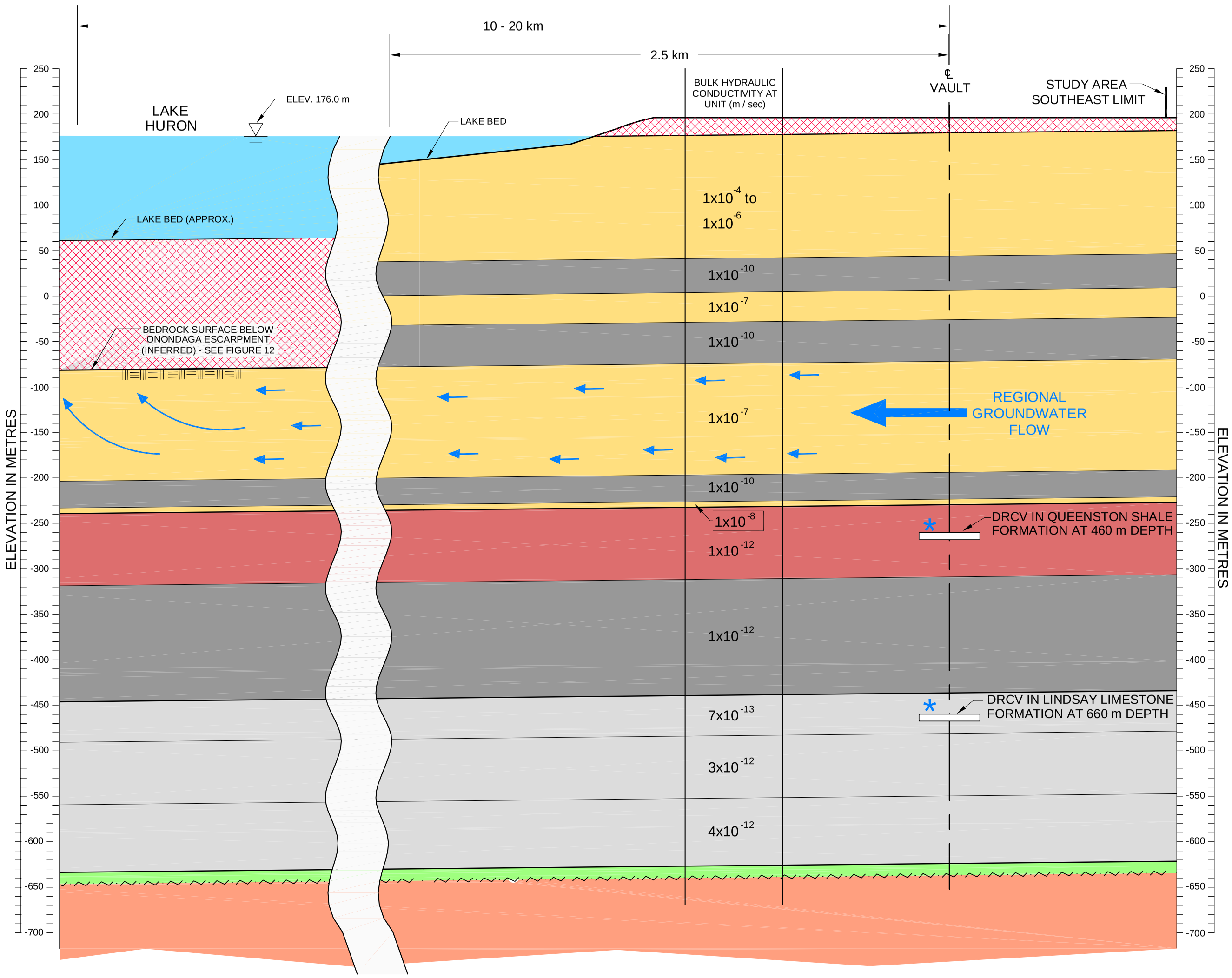
CONCEPTUAL HYDROGEOLOGICAL MODEL
DEEP ROCK CAVERN VAULT - SECTION E-E
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 35



LITHOLOGY

- OVERBURDEN
- DOLOSTONE
- RED SHALE
- GREY SHALE
- LIMESTONE
- SILTSTONE, SANSTONE
- GRANITIC GNEISS

LEGEND

- * DIFFUSION IN LOW PERMEABILITY SHALE AND LIMESTONE UNITS
- ← HORIZONTAL ADVECTIVE FLOW IN MODERATELY PERMEABLE SILURIAN DOLOSTONE

GEOMETRIC PARAMETERS

DIFFUSION PATHWAY LENGTH

QUEENSTON SHALE RCV - 63 m RANGE 60 m to 80 m
LINDSAY LIMESTONE RCV - 263 m RANGE 250 m to 300 m

ADVECTIVE FLOW PATHWAY

PATHWAY LENGTH 10,000 to 20,000 m
HYDRAULIC GRADIENT 0.0005 to 0.001
HYDRAULIC CONDUCTIVITY $1x10^{-7}$ m/s
EFFECTIVE POROSITY 0.5 to 1.0%

NOTE

1. FOR LOCATION OF SECTION E-E SEE FIGURE 34
2. OFF-SHORE CONDITIONS ARE INFERRED FROM AVAILABLE BATHYMETRIC AND GEOLOGICAL INFORMATION (SEE FIGURE 12) AND ARE INTENDED FOR ILLUSTRATION PURPOSES ONLY.

SCALES

HORIZONTAL SCALE = 1:20,000
VERTICAL SCALE = 1:5,000
VERTICAL EXAGGERATION 4 TO 1

400 0 400 800
HORIZONTAL SCALE 1:20000 METRES

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BRUCE B COOLING WATER INTAKE TUNNEL
(AMHERSTBURG / BOIS BLANC DOLOSTONE)
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 36

DATE: JANUARY 2003

PROJECT: 021-1570

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CAD: KD

CHK: JBD

PLOT DATE: February 11, 2003
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NIAGARA RIVER HYDROELECTRIC DEVELOPMENT
EXPLORATORY ADIT (QUEENSTON SHALE)
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 37

PLOT DATE: February 11, 2003
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DATE: JANUARY 2003
PROJECT: 021-1570

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CAD: KD
CHK: JBD

DARLINGTON NGS COOLING WATER INTAKE TUNNEL
(LINDSAY LIMESTONE)
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 38

PLOT DATE: February 11, 2003
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DATE: JANUARY 2003
PROJECT: 021-1570

Golder Associates

CAD: KD
CHK: JBD

WESELYVILLE OIL STORAGE CAVERN ACCESS TUNNEL
(LINDSAY LIMESTONE)
WWMF-LLW GEOTECHNICAL FEASIBILITY STUDY

FIGURE 39

PLOT DATE: February 11, 2003
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DATE: JANUARY 2003
PROJECT: 021-1570

Golder Associates

CAD: KD
CHK: JBD

EMPIRICAL DESIGN OF ROCK CAVERN
AMHERSTBURG DOLOSTONE
(After Grimstad and Barton, 1993)

FIGURE 40

$$D_e = \frac{\text{Excavation span, diameter or height (m)}}{\text{Excavation Support Ratio } (ESR)}$$

Excavation Category		*ESR*
A	Temporary mine openings	3–5
B	Permanent mine openings, water tunnels for hydro power (excluding high pressure penstocks), pilot tunnels, drifts and headings for large excavations.	1.6
C	Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels.	1.3
D	Power stations, major road and railway tunnels, civil defense chambers, portal intersections.	1.0
E	Underground nuclear power stations, railway stations, sports and public facilities, factories.	0.8

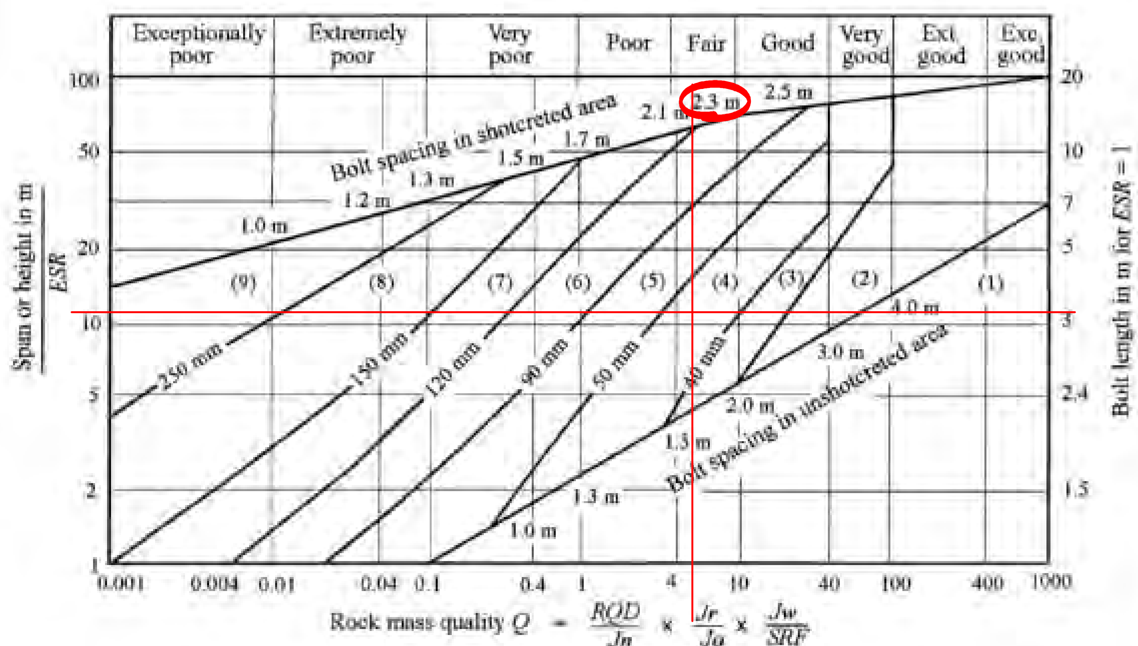
Bolt Length:

Grimstad and Barton (1993):

$$L = \frac{2 + 0.15B}{ESR}, \text{ where B = excavation width}$$

E. Hoek (Practical Rock Engineering)

$$L = 0.4 \times \text{span}$$



Limestone
Q = 4.75 (RMR ≈ 58)

REINFORCEMENT CATEGORIES

1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting with 40-100 mm unreinforced shotcrete
5) Fibre reinforced shotcrete, 50 - 90 mm, and bolting
6) Fibre reinforced shotcrete, 90 - 120 mm, and bolting
7) Fibre reinforced shotcrete, 120 - 150 mm, and bolting
8) Fibre reinforced shotcrete, > 150 mm, with reinforced ribs of shotcrete and bolting
9) Cast concrete lining

Room Span, $D = 10.5$ m

$ESR = 1.0 \quad \therefore \quad D_e \cong 10.5$ m, $\quad L = 3.5$ m (Barton), $L = 4.$ m (Hoek)

Room Support:

Bolts : 4 m long bolts @ 2 m c/c.
40 mm to 50 mm shotcrete

EMPIRICAL DESIGN OF ROCK CAVERN QUEENSTON SHALE (After Grimstad and Barton, 1993)

FIGURE 41

$$D_e = \frac{\text{Excavation span, diameter or height (m)}}{\text{Excavation Support Ratio }(ESR)}$$

Excavation Category		***ESR***
A	Temporary mine openings	3–5
B	Permanent mine openings, water tunnels for hydro power (excluding high pressure penstocks), pilot tunnels, drifts and headings for large excavations.	1.6
C	Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels.	1.3
D	Power stations, major road and railway tunnels, civil defense chambers, portal intersections.	1.0
E	Underground nuclear power stations, railway stations, sports and public facilities, factories.	0.8

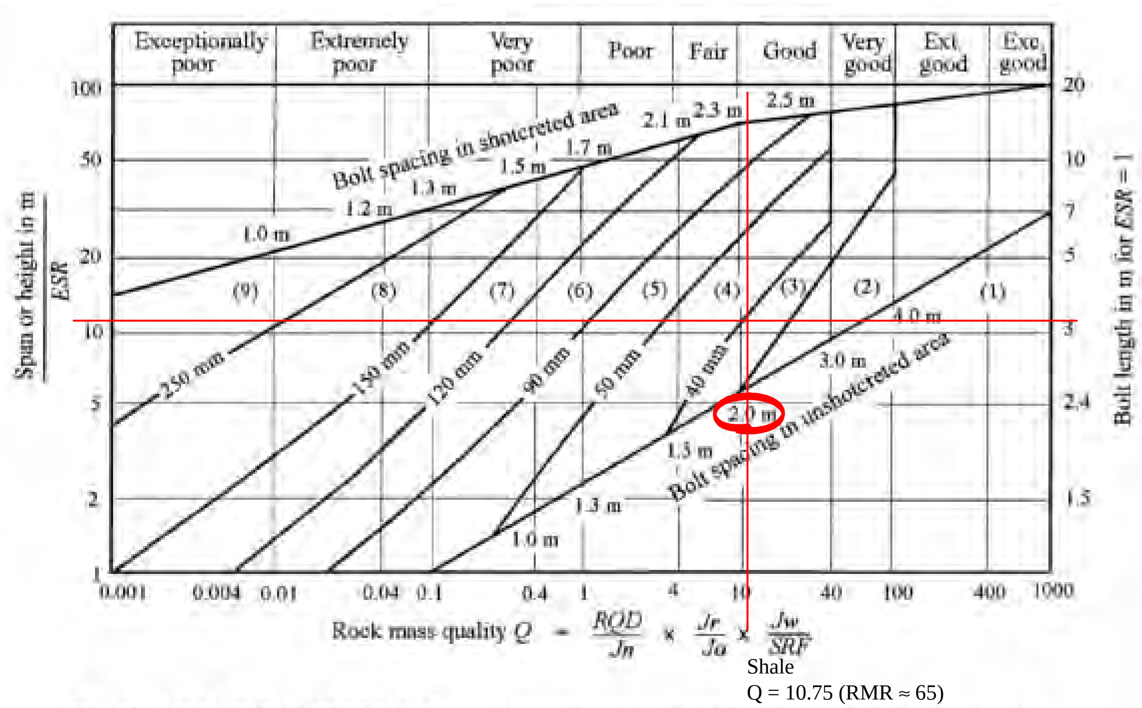
Bolt Length :

Grimstad and Barton (1993) :

$$L = \frac{2 + 0.15B}{ESR}, \text{ where B = excavation width}$$

E. Hoek (Practical Rock Engineering)

$$L = 0.4 \times \text{span}$$



REINFORCEMENT CATEGORIES

1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting with 40-100 mm unreinforced shotcrete
5) Fibre reinforced shotcrete, 50 - 90 mm, and bolting
6) Fibre reinforced shotcrete, 90 - 120 mm, and bolting
7) Fibre reinforced shotcrete, 120 - 150 mm, and bolting
8) Fibre reinforced shotcrete, > 150 mm, with reinforced ribs of shotcrete and bolting
9) Cast concrete lining

Room Span, $D = 10.5$ m

$ESR = 1.0 \quad \therefore \quad D_e \cong 10.5$ m, $\quad L = 3.5$ m (Barton), $\; L = 4.$ m (Hoek)

Room Support:

Bolts : 4 m long bolts @ 2 m c/c.

40 mm shotcrete – mostly for immediate weathering protection

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EMPIRICAL DESIGN OF ROCK CAVERN
LINDSAY LIMESTONE
(After Grimstad and Barton, 1993)

FIGURE 42

$$D_e = \frac{\text{Excavation span, diameter or height (m)}}{\text{Excavation Support Ratio } (ESR)}$$

Excavation Category		***ESR***
A	Temporary mine openings	3–5
B	Permanent mine openings, water tunnels for hydro power (excluding high pressure penstocks), pilot tunnels, drifts and headings for large excavations.	1.6
C	Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels.	1.3
D	Power stations, major road and railway tunnels, civil defense chambers, portal intersections.	1.0
E	Underground nuclear power stations, railway stations, sports and public facilities, factories.	0.8

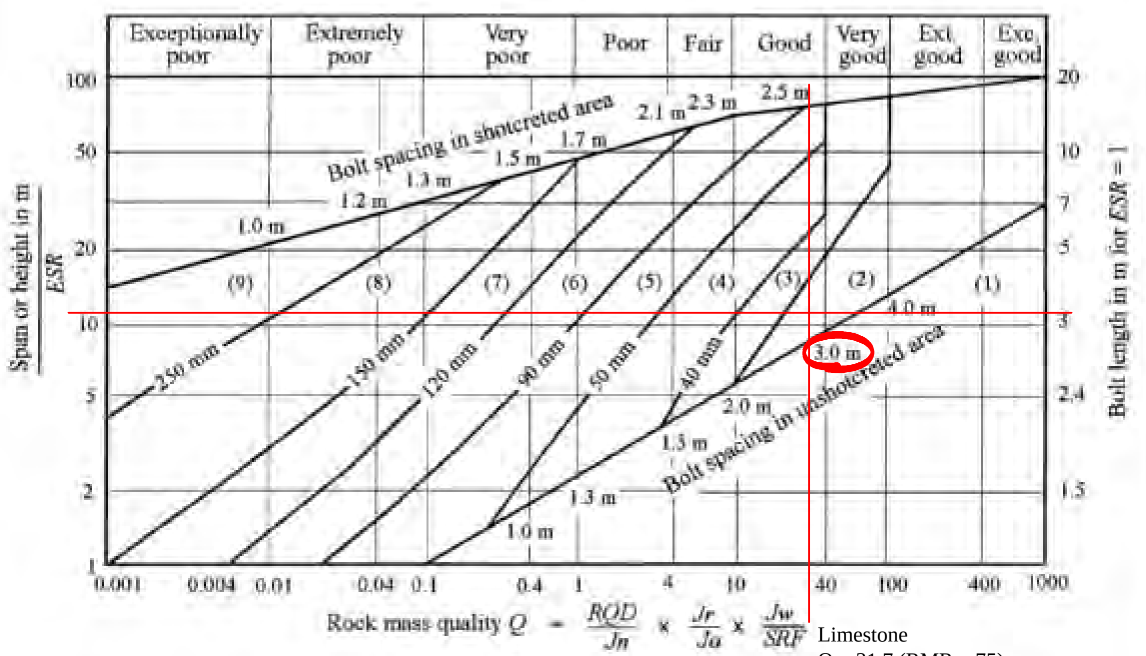
Bolt Length :

Grimstad and Barton (1993) :

$$L = \frac{2 + 0.15B}{ESR}, \text{ where } B = \text{excavation width}$$

E. Hoek (Practical Rock Engineering)

$$L = 0.4 \times \text{span}$$



Limestone
Q = 31.7 (RMR ≈ 75)

REINFORCEMENT CATEGORIES

1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting with 40-100 mm unreinforced shotcrete
5) Fibre reinforced shotcrete, 50 - 90 mm, and bolting
6) Fibre reinforced shotcrete, 90 - 120 mm, and bolting
7) Fibre reinforced shotcrete, 120 - 150 mm, and bolting
8) Fibre reinforced shotcrete, > 150 mm, with reinforced ribs of shotcrete and bolting
9) Cast concrete lining

Room Span, $D = 10.5\text{ m}$

$ESR = 1.0 \quad \therefore \quad D_e \cong 10.5\text{ m}, \quad L = 3.5\text{ m (Barton)}, \; L = 4.\text{ m (Hoek)}$

Room Support:

Bolts : 4 m long spot bolts

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