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April 24, 2009
P10008(16).40.02

Manitoba Hydro Place
Hydro Power Planning
360 Portage Avenue
Winnipeg, MB
R3C 0G8

Attention: D.S. Magnusson, P.Eng
Section Head
Nelson River Keeyask Station
Hydro Power Planning Department

Dear Mr. Magnusson:

Keeyask Generating Station
Stage IV Studies - Axis GR-4
Bedrock Geology
Review of Bedrock Conditions
in the Spillway Area
Memorandum GN-1.5.5, Rev 0
Manitoba Hydro File 00195-11610-0018_02

Enclosed please find one copy of Revision 0 of the above noted memorandum as well as two sign-off sheets containing the relevant KGS Acres signatures.

An electronic copy of the memorandum showing the most recent revisions in highlighted italics, has been posted in eRoom (refer to HPP-Acres Manitoba/Gull 00195/Design Memos).

Please add Manitoba Hydro signatures to the sign-off sheets and return one copy for our files.

Yours very truly,

N.J. Smith, P.Eng
Project Manager

PRP:spa
Encl

cc G.P. Schick

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Manitoba Hydro
Hydro Power Planning Department
Power Projects Development Division

Keeyask Generating Station
Stage IV Studies - Axis GR-4

Design Memorandum GN-1.5.5

Rev. 0, April 24, 2009

Bedrock Geology
Review of Bedrock Conditions in the Spillway Area

Manitoba Hydro File 00195-11610-0018_02

Prepared by P. Pantel (P. PANTEL) April 24, 2009
KGS Acres Ltd.

Checked by (R. HALIM) April 24, 2009
KGS Acres Ltd.

Reviewed by (I.R. Dewar) April 24, 2009
KGS Acres Ltd.

Approved by (N.J. Smith) April 24, 2009
KGS Acres Ltd.

Accepted by (O.S. Magnusson) MAY 12, 2009
Manitoba Hydro

KGS Acres Ltd.
Winnipeg, Manitoba

Keeyask Generating Station
Stage IV Engineering Phase
Quality Review Summary Sheet - Design Memorandum

Memorandum Name:	GN-1.5.5 Bedrock Geology - Review of Bedrock Conditions in the Spillway Area
Version / date:	Rev. 0 / April 24, 2009
Manitoba Hydro File:	00195-11610-0018_02
Author / Company or MH Dept.:	P.R. Pantel/KA

	Summary of Comments Breakdown				
Review Conducted By	**Review Requested**	**Reviewed**	**Rejected Request to Review**	**Review Not Completed**	**Deferred to Final Design**
Civil Engineering Department					
Dam Safety					
Hydrotechnical					
Geotechnical					
Structural					
Civil Site Investigations					
Electrical Engineering Department					
Mechanical Engineering Department					
Engineering Services Dept. - Eng. Controls & Protection					
Hydro Power Planning Department					
Water Resources Engineering Department					
New Generation Construction Department					
Major Projects Assessment/Licensing Department					
Transmission and Civil Design Department					
System Control Department					
System Planning					
Emergency Operations					
Stantec					
ECOSTEM					
Wildlife Resources					
Northern Lights Heritage					
InterGroup					
KGS Acres					
North South Consultants Inc.					

Recommendations:

This memo did not undergo a formal quality review process during Stage IV Engineering Studies. It is recommended that this memo undergo a quality review during the Final Design Stage.

Date: *August 30, 2011* *Summary Author:* *Stephanie Gilmour*

KGS ACRES **Office Memorandum**

To	I.R. Dewar	**Date**	April 24, 2009
		File No.	P10008(16).40.02
From	P.R. Pantel	**cc**	
Subject	**Keeyask Generating Station Stage IV Studies, Axis GR-4 Bedrock Geology Review of Bedrock Conditions in the Spillway Area Memorandum GN-1.5.5, Rev 0 Manitoba Hydro File 00195-11610-0018_02**		

1 Introduction

The site of the proposed Keeyask Generating Station (Keeyask GS) is approximately 730 km north of Winnipeg, at the head of Stephens Lake on the Nelson River. Stephens Lake is the reservoir for the existing Kettle GS, the upstream limit of which is the Keeyask Rapids. The proposed Axis GR-4 for the structures crosses the Nelson River at the rapids. This places the Principal Structures approximately 50 km downstream of Split Lake and 30 km west of Gillam. A site plan is shown in Figure 1.

The latest investigation program, 2003 Summer Stage IV Investigation, is described in a Memorandum GN-1.1.19, "Proposed Additional Investigation for GR-4 Axis Alignment" [Ref 1]. This program included three diamond drill holes in the Spillway Area. Investigation of the bedrock in this area was undertaken in 1991 and 2003.

This memorandum discusses the preliminary results of the 2003 Spillway investigations and the overall interpretation of the findings of all of the investigations undertaken within this area. This review includes the following results:

- General bedrock lithology.
- Core losses/recovery.
- Rock Quality Designation (RQD) and rock mass characteristics.
- Water Pressure Testing (WPT).

- Dominant joint orientation trends.
- Rock Mass Rating (RMR) and Geological Strength Index (GSI).

2 Previous Subsurface Investigation Programs

Field and laboratory investigations of the site's overburden and bedrock have been conducted at and in the vicinity of the proposed Keeyask GS site during several phases of the Keeyask GS design development. The first investigations were conducted in 1962 and 1963, followed by other programs between 1987 and 1991, 1999 and 2000, and in the summer of 2003. A significant understanding has been developed with respect to the regional and site engineering geology, the foundation conditions for the Principal Structures, and the quality and availability of construction materials. These explorations are summarized in Table 2.1.

Previous exploration work within the Principal Structures areas includes the following:

- Material reconnaissance survey of Nelson River site, conducted in 1962 by Manitoba Hydro [Ref 2].
- Seismic survey conducted in 1962 by Geo-Recon Exploration [Ref 3].
- Geological mapping in 1963 between Birthday Rapids and downstream of Keeyask Rapids [Ref 4].
- Geophysical (seismic, EM, magnetic) surveys, diamond drilling and geological mapping which were performed in 1988 at both the Keeyask Rapids and Birthday Rapids sites [Ref 5 to 7]. Horizontal and vertical controls surveys were conducted at Birthday Rapids, Keeyask Rapids and Conawapa in the summer of 1988 [Ref 8].
- Seismic surveys, EM surveys and a limited program of auger drilling were conducted on the proposed dyke lines during 1990 [Ref 9 and 10]. Field terrain mapping was also performed along the proposed dyke lines in 1990 [Ref 11].
- Sonic drilling, hollow stem augering, diamond drilling and test pitting were conducted along the proposed dyke lines during the 1990/91 winter [Ref 12].
- Sonic drilling, diamond drilling and test pitting were conducted at the Principal Structures area, along alternative dyke alignments, and at potential borrow areas, during the 1991 summer investigation program. Detailed joint mapping and core orientation and review of the regional/site geology were completed during this program [Ref 13].

- Diamond drilling, hollow and solid stem augering were conducted along the Axis of the Principal Structures for Axis GR-4 during the 2003 summer investigation program [Ref 14].

- In the summer of 2003, the Manitoba Geological Survey, in collaboration with the Universities of Alberta and Waterloo, started a 3-year integrated bedrock mapping and structural data program [Ref 15 and 16].

3 Geology

The Keeyask GS site is located within the Canadian Shield physiographic region, at the northeastern margin of the Superior Province in Manitoba. The Precambrian bedrock within the area consists of granitic intrusions, amphibolite, greywacke gneiss and diabase. The greywacke gneiss contains bands or sills of granitic material throughout. Diabase occurs as continuous and discontinuous dykes, which have intruded the greywacke gneiss, amphibolite and granitic rocks. The contacts between the diabase dykes and the host rock are typically open at ground surface, but tighten with depth.

Figure 2 illustrates the local bedrock conditions within the vicinity of Axis GR-4. The purpose of this figure is two fold:

- To update local Keeyask GS geology with the latest bedrock mapping field work [Ref 15 and 16].

- To simplify bedrock geology nomenclature that will enable individuals to correlate with previous geology logs and reports.

The bedrock within the Keeyask GS area is typically fresh, strong to very strong with moderately spaced joints. Most of the joints appear tight with little or no alteration. Open joints are typically widely to very widely spaced, slightly to faintly altered and may be infilled with clay. Carbonate and chlorite coatings were frequently observed on joint surfaces.

During the 1988, 1991 and 2003 geological mapping programs, fracture/shear zones were observed within bedrock outcrops [Ref 13]. The zones are generally less than 0.5 m in width, and are typically healed or recrystallized and strong.

3.1 Geology of the Spillway Area

The Spillway area consists of metasedimentary rocks (Archean Supracrustal rocks) with up to 80% granitoid injections (Archean Felsic Intrusive rocks). In addition, gabbro dykes (Paleoproterozoic rocks) up to 50 m wide, have intruded into the metasedimentary rocks and granitoid injections. A geological description of the rock types encountered in the Spillway area is provided below.

Metasedimentary Rocks

Metagreywacke, interlayered pelite and psammite, medium to dark grey, Fe-rich, composed of quartz, biotite, feldspar, garnet, amphibole, staurolite, and cordierite. The Metasedimentary rocks are locally arkosic with calcsilicate layers and contain up to 80% granitoid injections. Metasedimentary rocks are identified in the drill hole logs as greywacke gneiss.

Banded oxide, sulphide, and silicate faces iron formation form discontinuous boundinaged layers in the metagrewacke. Formation is composed of quartz, chert, magnetite, hematite, biotite, amphibolite, and sulphide.

Granitoid Injections and Pegmatite

Granitoid injections and pegmatite form intrusive veins and bodies in the Metasedimentary rocks. Granitic injection veins, sheets and bodies; including leucocratic, and locally up to 5 cm aggregates of biotite, garnet, amphibole and pyroxene, retrogressed to mainly chlorite (chlorite clotted texture). Granitoid injections are identified in the drill hole logs as granite.

Gabbro Dykes

Gabbro dykes, medium to coarse grained, massive to weakly foliated, composed of amphibole, plagioclase and pyroxene. Gabbro dykes occur up to 50 m wide. Gabbro is identified in the drill hole logs as diabase.

Two fault zones were observed on bedrock outcrops to the south of the Spillway area. The relative movement of these ancient fault zones is unknown. These zones are inactive, typically well healed, and strong.

An orthographic photograph of the Spillway area is provided in Figure 3.

Both the regional and site specific bedrock geology is discussed in detail in the 2003 summer investigation report [Ref 14].

4 Investigation Drilling Results for the Spillway Area

A total of eight drill holes were advanced in the Spillway Area. The drill holes were inclined holes, set at either 45° or 70° angles, to intercept the jointing of the bedrock in the Spillway Area. The three holes drilled in 2003 were advanced down into the bedrock to el 115 m, which is approximately 19.9 m below the lowest point of the proposed foundation of the Spillway structure. The proposed Spillway structure foundation is at approximately el 134.9 m.

Figures 4, 5 and 6 show the location of explorations and sections within the Spillway Area, respectively. A summary of the drilling data for those holes that have been used for the analyses contained herein is provided in Table 4.1. Individual drill hole summaries are contained in Appendix A. The information contains both NQ and HQ size drill holes. The size of the hole and use of either single or triple core barrel rods will affect the quality of the sample obtained, with HQ and triple core barrels typically producing samples with fewer fractures.

4.1 Overburden

The presence of overburden in the Spillway Area is sporadic and generally absent, consisting of layers of silty sands and sandy silts, gravel, and till with occasional cobbles and boulders. The thickness of the overburden ranges from zero to 3 m. The overburden in this area was removed during ice staging in 2000; therefore, the boreholes drilled in this area prior to 2000 may show overburden overlying bedrock, which has subsequently been removed.

4.2 Bedrock Lithology

The exploratory holes drilled in the Spillway Area encountered greywacke gneiss and granite, as well as diabase dykes.

The greywacke gneiss is typically described as being dark grey, fine to medium grained, moderately strong to strong, with distinct foliation.

The granite is typically described as being light grey, medium to coarse grained, strong to very strong, with no distinct foliation.

The diabase is typically described as being dark green, very fine grained, strong, with no foliation evident.

4.3 Drill Core Recovery

The percent recovery is defined as the ratio of the total length of the pieces of rock core retrieved from the drill run, to the total length of the drill run. The percent recovery for each of the drill holes analyzed on a run-by-run basis, are presented in the individual drill hole summary in Appendix A.

In the Spillway Area, the percent recovery averaged 99% for all investigations. A core recovery percentage less than 100% indicates a core loss, reflecting rock core that has been ground by the drilling process or contains open features (e.g., joints, fractures, etc). In addition, core that is left down the hole at the end of the drilling was classified as a core loss.

The zones where core loss occurred are summarized in Table 4.2. Individual core loss zones within the eight drill holes in the Spillway Area range between 10 mm to 240 mm (averaging 66 mm), excluding any core left down the hole at the end of the last drill run.

Core losses are typically less than 70 mm in any one individual zone and generally occur in narrow broken core zones associated with drill action and closely spaced joints. Many joint surfaces within these zones are noted to have chlorite, kaolinite and limonite staining/coatings.

The largest broken and lost core zone occurs at a depth of 16.41 m to 17.03 m (620 mm length) in Drill Hole G-0047. The core loss within this zone is estimated to be 240 mm (39% of the zone). The lost core is associated with redrilling the core pieces left down the hole from the previous run.

For the final run of each drill hole, the rock core piece that was left down the hole was recorded as a core loss. Rock core left down the hole was recorded in five drill holes (62.5% of the holes), with lengths varying between 20 and 490 mm (averaging 104 mm).

4.4 Rock Quality

The rock quality for the bedrock recovered in a diamond drill hole is typically expressed in terms of RQD (Rock Quality Designation). It is generally reported on a run-by-run basis, and is computed using the following equation:

$$RQD_{NQ} = \frac{\sum length\ of\ core\ pieces > 10\ cm\ length}{total\ length\ of\ core\ run} x100\%$$

The length of the core pieces, as utilized in the formula, are based on natural breaks only. Care was taken to ensure that the fractures that were caused by handling of drilling process were identified, and ignored when determining the RQD values.

The following list provides a typical relationship between the RQD and the anticipated engineering quality of the rock [Ref 17].

RQD (%)	Rock Quality
<25	Very Poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
90 – 100	Excellent

The RQDs for each of the drill holes, analyzed on a run-by-run basis, are presented in the drill hole summary in Appendix A. In addition, the RQD values were plotted versus elevation, as shown in Figure 7.

The rock mass in the Spillway Area can be characterized as strong to very strong, with RQD values ranging from 42% to 100%, and averaging 90%. Generally, the RQD values increase with depth. Below el 137 m, the RQDs for the subsequent runs are generally above 75%, indicating good to excellent rock quality.

There were two drill runs where the recorded RQD values were less than 10%. These occurred when the drill bit became blocked at the start of the run, due to closely spaced joints. The core recovered from the blocked drill bit was generally less than 40 mm in length with four or more joints.

Out of the 221 drill runs in the Spillway Area, 142 (65%) indicate that the bedrock is of excellent quality (RQD>90%). In addition, 52 (24%) indicate that the rock is of good quality, and 18 (8%) indicate that the rock is of fair quality. In summary, 194 (89%) of the drill runs show that the bedrock in the Spillway Area ranges between good to excellent quality.

The joint spacing is generally described as moderately spaced, averaging approximately280 mm.

4.5 Water Pressure Tests

Water Pressure Testing (WPT) was undertaken to determine the rock's permeability, with the results being presented in terms of the Lugeon values. This method of interpretation is widely used in grouting and dam design.

The Lugeon value, which reduces water pressure data to a common base, is defined as the volume of water (in litres) pumped into a zone of drill hole per metre of test length, per minute, at an excess pressure of 1000 kPa. Since the tests are carried out at various pressures and over varying length of hole, the data is proportionally reduced back to the common values of 1 m length and 1000 kPa pressure.

WPT conducted at Keeyask GS were modified from Houlsby's [Ref 19] five-step test to three steps, to reduce the time spent on the individual tests. Since the bedrock is relatively tight, it was felt that little information would be lost due to the elimination of the first and last steps. The modified procedure employed was as follows:

1) First 5 minutes run at low pressure – (approximately 50% maximum pressure).
2) Second 5 minutes run at peak pressure – (approximately 75% maximum pressure).
3) Third 5 minutes run at a low pressure – (approximately 50% maximum pressure).

Flow characteristic and Lugeon interpretation were determined using the flow chart [Ref 19] shown in Figure 8.

The analysis of the WPT results assumed that Lugeons (Lu) less than 0.1 (Lu = 0) indicate No Take, and results between 0.1 and 1.49 are reported as 1 Lu. All other Lugeon values are rounded to the nearest number (i.e., 1.5 to 2.4 = 2 Lu). WPT exceeding the pump capacity or greater than 100 Lu are assigned a value of 101 Lu, as values in this upper range represent relatively high bedrock permeability.

The permeability of the bedrock is based on the interpreted Lugeon value and described as follows [Ref 13].

Bedrock Permeability	**Lugeon Value**
High	> 100
Medium	5 – 100
Low	1 – 5
Practically Impermeable	0

4.5.1 Water Pressure Test Results

The Lugeon values determined, and their associated flow characteristics, for all of the WPT conducted in the Spillway Area are listed in Table 4.3. The following is a summary of the test results for the WPT conducted during the 1991 and 2003 investigation programs.

1991 Investigations

Five drill holes (BH G-0043, G-0045, G-0047, G-0049 and G-0051) totaling 194.09 m of bedrock drilling were advanced during the 1991 investigations. These holes are all located to the downstream of the present location selected for the Spillway. A total of 19 WPT were conducted on 70.41 m of bedrock (including the overlap of the test zones). The test stage length ranged between 2.0 and 20.4 m, typically averaging 3.7 m.

Out of the 19 WPT conducted, 15 (79%) of the tests indicate the rock to be practically impermeable (0 Lu). In addition, two (11%) of the tests indicate that the rock has a medium permeability and two (11%) of the tests were undertaken at pump capacity, indicating a high permeability.

For 17 of the 19 tests, the results range from 0 (tight) to 19 Lu, indicating the bedrock is generally tight throughout. However, two tests in Drill Hole G-0047 were conducted with the maximum pump capacity (i.e., >100 L/min).

High Lugeon values (at pump capacity) were encountered in borehole G-0047 at tests performed between depths along the hole of 3.0 to 6.0 m (vertical depths of 2.12 to 4.24 m below ground surface) and 6.0 to 9.0 m (vertical depths of 4.24 to 6.36 m below ground surface). Broken core or core loss was not noted in the core and RQD values over the test intervals were greater than 80%, but numerous open or party opened joints are noted within these zones. It appears that the results within the upper bedrock at borehole G-0047 may represent a localized area of higher Lugeon values, with test results over the underlying length of hole showing no take. It is also recognized that borehole G-0047 was drilled approximately 200 m east of the axis of principal structures and 25 m south of the discharge channel as part of the overall investigation program in the area and the high Lugeon values should not be considered to be representative of the overall site based upon all test results as indicated in Figure 11. The high Lugeon values at this borehole may also be attributed to possible loss of water due to inadequate packer sealing within the borehole or localized connections between the joints and ground surface; however observation of either of these conditions was not noted.

2003 Summer Investigation

Three drill holes (BH 03-027, 03-028 and 03-037) totaling 98.58 m of bedrock drilling were advanced during the 2003 summer exploration program in the Spillway Area, along the currently planned axis for the Principal Structures. A total of 20 WPT were conducted in these boreholes, on 105.46 m of bedrock (including the overlap of the test zones). The test stage lengths range from approximately 4.3 to 6.2 m, averaging 5.3 m.

Out of the 20 WPT conducted, 10 (50%) tests indicate that the rock is practically impermeable (0 Lu). In addition, nine (45%) tests indicate that the rock has a low permeability (Lugeon value 1 to 5) and one (5%) of the tests indicated a medium permeability. In summary, 19 (95.0%) of the 20 tests conducted indicate that the bedrock permeability ranges from low to practically impermeable.

The results range from 0 (tight) to 6 Lugeons, and are generally relatively tight throughout the holes. Higher water takes, resulting in Lugeon values greater than 10, were not encountered during the 2003 Summer Investigation in the Spillway Area.

Combined Investigations

A total of eight drill holes totaling 292.67 m of bedrock drilling were advanced in the Axis GR-4 Spillway Area. A total of 39 WPT were conducted in these eight drill holes, on 175.87 m of bedrock (including the overlap of the test zones). The stage length ranges between 2.0 m and 20.41 m, averaging 4.5 m.

A breakdown of the WPT in the Spillway Area is shown in Figure 9. Out of the 39 WPT conducted, 25 (64%) of the tests indicate that the rock is practically impermeable (0 Lu). In addition, nine (23%) tests indicate that the rock has a low permeability (Lugeon value 1 to 5) and three (8%) of the tests indicate a medium permeability. In summary, 34 (87%) of the 39 tests indicate that the bedrock permeability ranges from low to practically impermeable. Figures 10 and 11 show the Lugeon values with depth and elevation, respectively. Typically, higher water takes, resulting in Lugeon values greater than 10, are associated with broken and/or core loss zones, and partly open joint features recorded on the Geological Detail Fracture Logs.

High Lugeon values were measured within the upper bedrock of borehole G-0047 which may be attributed to open and partially opened joints. However, the hole is not located within the area of the Spillway structure and is not believed to represent the conditions encountered near the structure in which testing indicated low permeability to impermeable rock.

A breakdown of the interpreted flow characteristics for all WPT conducted in the Spillway Area is shown in Table 4.4.

4.6 Evaluation of Jointing Trends

Typically the joints in the bedrock in the Spillway Area are moderately spaced, tight, with little or no alteration. Those open joints which are present are typically widely to very widely spaced, slight to faintly altered and may be infilled with clay. Carbonate, chlorite and limonite coatings were frequently observed on joint surfaces.

In the Spillway Area, two major and two minor joint sets were identified from a total of 364 oriented core measurements, not including discontinuities described as healed. Jointing trends for the Spillway Area are summarized in Table 4.5, and are based on those holes listed in Table 4.1.

A polar density plot derived from the oriented core measurements taken from boreholes drilled in the Spillway Area is presented in Appendix B, Figure B1. In addition, stereonet projections of the dominant joint sets J1 through J4 are presented in Figure B2.

The following describes the open joints, slickensides, and clay coated joints based on the analysis from the oriented core measurements.

Open Joints

A total of 90 joints, or 25% of all measurements recorded within the Spillway Area, are identified as open, partly open or ground. Generally open joints are subhorizontal and not confined to a particular joint set.

Slickensides

A total of 19 joints were noted to be slickensided. Based on the information available, it appears that the movements which produced these slickensides are not confined to a particular joint set.

Clay Coated Joints

A total of 9 joints were noted as having clay or kaolinite coatings. Based on the information available, it appears that these coatings are not confined to a particular joint set.

As Table 4.2 indicates, a number of broken core zones, lost core zones, and broken and lost core zones have been recorded in the geological and detailed fracture logs; therefore, the joint orientations could not be measured due to the condition of these zones.

5 General Rock Mass Classification

5.1 Geological Strength Index

Hoek's Geological Strength Index (GSI) was used to establish the properties of the rock mass as an aid in determining the preliminary rock support guidelines [Ref 20]. Hoek's GSI is now commonly accepted for general rock mass classification, particularly for surface slopes and foundations. The GSI can be used to compute the rock mass strength parameters; cohesion and friction angle, as well as the modulus of deformation. The GSI consists of Bieniaski's 1976 Rock Mass Rating (RMR) computation without groundwater and joint orientation adjustments. These adjustments are not necessary because the actual groundwater conditions and joint orientations can be directly accounted for in the stability analyses.

Bieniawski's RMR system incorporates geological, geometry and engineering parameters in determining a quantitative value of rock mass quality, which can then be used in rock support design. The following six parameters are used to classify a rock mass using Bieniawski's RMR system:

1) Uniaxial Compressive Strength of the rock material
2) Rock Quality designation (RQD)
3) Spacing of discontinuities
4) Condition of discontinuities
5) Groundwater conditions
6) Orientation of discontinuities.

The RMR system provides rating for each of the six parameters listed above, and is shown in Figure 12. Each of the parameters is assigned a numeric value, which is dependant on site the specific properties present, and then summed to provide a total RMR value for the rock mass.

The GSI can be computed from Bieniaski's 1989 RMR classification [Ref 18] with the following provisions:

1) The first four parameters of the 1989 RMR are assessed as usual taking into account the site specific properties.
2) The rock mass is assumed to be completely dry, and the groundwater rating is assigned a value of 15.
3) The joint orientations are assumed to be "very favorable" and the "adjust for joint orientation" rating is assigned a value of zero.
4) The resulting RMR classification can be used to compute the GSI using the equation GSI = $RMR_{89} - 5$.

Within the Spillway Area at Keeyask GS, the analysis of the joint trends indicates that the major/minor joint sets will generally dip into the excavation on the north side of the channel, and away from the excavation on the south side. For a thorough discussion of the possible instabilities due to toppling, planar sliding, and/or wedge failures, and treatment considerations, the reader is referred to Memorandum GN-4.2.2.8, Rock Support and Temporary Drainage [Ref 22].

Bieniaski's 1989 RMR value and the GSI for the Spillway Area are outlined in Table 5.1.

5.2 Analysis of Rock Strength

The values for cohesion and friction angle within the rock mass can be computed using the RocScience software entitled RocLab, which includes an alternative way to measure GSI using generalized rock classification tables.

Table 5.2 summarizes the typical properties of the rock types encountered in the Spillway area.

Rock slope stability will be controlled by the joint orientations and characteristics, as they relate to the configuration of the different excavated wall faces. A kinematic assessment of potential failure along the dominant joint sets was conducted for each wall within the Spillway Structure and associated channels. A detailed discussion of the analysis is provided in a separate memorandum entitled "Rock Support and Temporary Drainage", Memorandum GN-4.2.2.8.

5.3 Further Considerations

Geotechnical engineering requires the exploration and analysis of a wide variety of earth and rock materials. These materials must be considered for adequacy as foundations and for use in earth and rockfill structures. Since overburden and bedrock are created by natural process, unlike other engineering materials such as steel or concrete, they seldom exhibit uniform properties. There is risk in every project that unexpected conditions will be encountered. The inability of subsurface exploration programs to detect, in advance, all potential significant properties and conditions in the rock mass, requires designers to make assumptions and generalizations that may be at variance with the field conditions encountered during excavation. Therefore, it will be prudent to review the rock support requirements as construction progresses.

Due to the complexity of the geology at the Keeyask GS, significant changes in discontinuity spacing or characteristics within the same rock type, or with a change in rock type, may necessitate the division of the rock mass into a number of smaller structural regions.

For excavation of the Spillway Structure area and its associated channels, good blasting techniques using pre-split blasting should result in a clean face. The pre-split face will also be more stable than a normally blasted excavation, and will consequently result in a lower cost for rock support.

6 Conclusions

The bedrock lithology encountered in the Spillway Area drill holes consists of greywacke gneiss, iron formation, granitic intrusions and diabase dykes, which is consistent with the regional bedrock geologic interpretation.

Core losses during drilling were generally less than 70 mm at any single location within the drill holes, and were associated with drill action and/or closely spaced joints.

The rock quality of the bedrock is considered to be good to excellent as indicated by average RQD values of 90%. Local zones of low RQDs are associated with narrow zones of closely spaced jointing.

The average Lugeon value determined by the WPT was typically below 3, indicating that the bedrock generally exhibits low permeability. Local zones of medium permeability, generally with Lugeon values less than 20 Lu, are associated with open or partly open joints. The bedrock is generally tight throughout the drill holes.

Two major and two minor joint sets have been identified in the Spillway Area.

RMR and GSI values were determined to assist with rock classification and were used to establish rock strength parameters for use in rock support design. The bedrock encountered in the Spillway Area is classified as fair to good quality rock.

Prepared By

P.R. Pantel

Attach
References
Photos 1 to 12
Appendices A & B
Figures B1 & B2
Figures 1 to 12

PRP: spa

References

1. Acres Manitoba Limited, Memorandum GN-1.1.19, “Gull Generating Station, Stage IV Investigation Program, Proposed Additional Investigation for GR-4 Axis Alignment”, Manitoba Hydro File 00195-11600-0238.

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5. Geo-Physi-Con Co. Ltd, December 1988, “Geophysical Exploration Program 1988, Gull and Birthday Rapid Sites, Northern Manitoba”, Report No. C88-36.

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Tables

Table 2.1
Keeyask GS – Stage IV Studies, Axis GR-4
Summary of Explorations

Date	Summary of Subsurface Exploration Programs at the Keeyask Sites									Purpose of Explorations
	Borrow Area			Dyke Lines				Principal Structures	Other	
	Auger Holes	Sonic Holes	Test Pits	Auger Holes	Sonic Holes	Test Pits	Diamond Holes	Diamond Holes		
1962 – 1963	-	-	-	-	-	-	-	-	(a) Air photo study (b) Borrow reconnaissance survey (c) Reconnaissance seismic survey (d) River bank mapping	Initial reconnaissance level investigations along the Nelson River
Aug 1987	2 (hand auger)	-	49 (shovel)	-	-	3 (shovel) 3(1)	-	-	(a) Shoreline mapping	Reconnaissance level construction material investigations in the Keeyask and Birthday areas
June-Sept 1988	-	-	-	-	-	-	2	19 (BQ) 25* (BQ)	(a) Geophysical surveys - refraction seismic - electromagnetic (EM 31/34, VLF-EM) - magnetic (b) Bedrock mapping (c) Overburden mapping (shoreline)	Investigation of foundation conditions in the area of the Principal Structures for the Keeyask sites (GR-1, GR-3, GR-4 and GR-5) and the Birthday sites (BR-2, BR-6 and BR-3A/5A)
July-Sept 1990	-	-	-	16 (minute man)	-	-	-	-	(a) Geophysical surveys - refraction seismic - marine seismic - electromagnetic (EM 31/34) (b) Terrain mapping (dyke) (c) Air photo study	Initial investigations of the foundation conditions along the dyke lines
Jan-April 1991	-	19	71 (backhoe)	68 (hollow stem)	41	189 (backhoe)	4 (NQ-bedrock only)	-	-	Investigate overburden conditions along the proposed dyke lines

Date	Summary of Subsurface Exploration Programs at the Keeyask Sites									Purpose of Explorations
	Borrow Area			Dyke Lines				Principal Structures	Other	
	Auger Holes	Sonic Holes	Test Pits	Auger Holes	Sonic Holes	Test Pits	Diamond Holes	Diamond Holes		
May-Sept 1991	-	-	296 (shovel and hand auger)	-	-	-	-	98 (NQ, HQ)	(a) Geophysical surveys - refraction seismic - marine seismic - electromagnetic (VLF-EM, HL-EM) - magnetic (b) Bedrock mapping (c) Terrain mapping (dyke)	Investigate foundation conditions in the Axes GR-3, GR-4 and GR-5 Principal Structures area, and along dyke lines located on the islands.
Jan-Apr 1992	-	158	337 (backhoe)	-	-	-	-	-	-	Impervious and granular borrow material investigations
Sept-Oct 1999	-	-	-	-	-	-	-	11	-	Investigate foundation conditions in the North Abutment of GR-3
Jan-Apr 2000	328	-	299 (backhoe)	68	-	7	-	-	-	Impervious and granular borrow material investigation. Investigated foundation conditions along dyke lines, at a proposed Fuse Plug dyke, and a creek diversion channel
July-Sept 2003	-	-	1 (shovel)	7	-	-	7	49 (NQ)	- Bathymetry	Investigate foundation conditions along the GR-4 axis, Principal Structures Area and along the new alignments of the North and South Dykes
2003-2004	-	-	-	-	-	-	-	-	- Bedrock mapping - Structural data	Investigate the Keeyask Rapids Area to better define the geology.

Note:

(1) Explorations at the Birthday sites

Table 4.1
Keeyask GS - Stage IV Studies, Axis GR-4
Spillway Area Drilling Summary

Exploratory Hole No.	Years	Location		Collar El (m)	Orientation (deg)		Depth (m - along core axis)			Approximate Elevation (m)		
		Northing	Easting		Dip from Horizontal	Azimuth	GWT (4)	B/R	E.O.H.	GWT (4)	B/R	E.O.H.
03-027 (1, 2)	2003	6245787.31	363065.72	148.16	70	315	2.66	0.00	34.79	145.66	148.16	115.47
03-08 (1, 2)	2003	6245887.41	363005.79	149.29	70	315	4.36	3.02	36.53	145.19	146.45	114.96
03-037(1, 2)	2003	6245626.55	363155.33	146.01	70	315	1.06	2.80	33.08	145.01	143.38	114.93
G-0043 (3)	1991	6245931.47	363164.20	150.69	45	270	0.00	2.25	42.06	150.69	149.10	120.95
G-0045 (3)	1991	6245902.03	363190.19	149.65	45	207	5.78	2.13	45.39	145.56	148.14	117.55
G-0047 (3)	1991	6245807.86	363272.63	149.04	45	257	4.22	1.46	40.91	146.06	148.01	120.11
G-0049 (3)	1991	6245862.14	363219.29	144.93	45	320	0.00	4.04	42.49	144.93	142.07	114.89
G-0051 (3)	1991	6245894.13	363109.43	149.00	45	185	5.60	7.96	41.08	145.04	143.37	119.95

Notes:

(1) Permanent Hole No. is not available at this time.

(2) Coordinates presented are based on the Universal Transverse Mercator Projection, Zone 15 North, North American Datum (NAD) 1983.

(3) Drill hole coordinates were converted from NAD 27 to NAD 83.

(4) Depth to GWL based on measured water level in open drill hole at time of drilling.
Water level may not represent actual GWLs in either overburden or bedrock.

(5) Elevations reported are based on the Canadian Geodetic Vertical Datum 1928.

(6) N/R - Not Recorded

Table 4.2
Keeyask GS – Stage IV Studies, Axis GR-4
Spillway Area – Summary of Core Losses

Drill Hole	Depth (m along core axis)		Detailed Fracture	Description
	From	To		
03-027	1.08	1.11	LCZ	Core loss assumed to occur at contact between granite and diabase. Upper contact is at 90 degrees to the core axis, irregular, semi-rough, moderately weathered, ground, some ferrous oxide. Lower contact is irregular, semi- rough, moderately weathered, partly ground, some calcite, some ferrous oxide. Core loss estimated to be 30 mm.
	28.92	28.95	BLCZ	Pieces vary in size between 5 to 30 mm, angular, ground, faintly to moderately weathered, and consist mostly of black mafic material. Upper contact is at 75 degrees to the core axis, irregular, semi-rough, weathered, partly ground, some calcite, some chlorite. Lower contact is at 45 degrees to the core axis, irregular, semi-rough, weathered, some calcite, some pyrite. Core loss estimated to be 10 mm.
	29.07	29.09	BLCZ	Pieces vary in size between 5 to 20 mm, are angular to ground, faintly to moderately weathered, and consist mostly of black mafic material. Upper contact is at 90 degrees to the core axis, irregular, rough, weathered. Lower contact is at 55 degrees to the core axis, irregular, rough, moderately weathered, some clay. Core loss estimated to be 10 mm.
	31.05	31.06	LCZ	Upper contact is at 60 degrees to the core axis, irregular, rough, ground, faintly weathered. Lower contact is at 90 degrees to the core axis, irregular, rough, ground, faintly weathered. Core loss estimated to be 10 mm.
	31.48	31.50	BLCZ	Pieces vary in size between 5 to 20 mm, are angular to ground, fresh to moderately weathered, some calcite. Upper contact is at 55 degrees to the core axis, subplanar, semi-rough, moderately weathered, partly ground. Lower contact is at 50 degrees to the core axis, irregular, rough, faintly weathered, ground. Core loss estimated to be 10 mm.
	33.29	33.50	BLCZ	Pieces vary in size between 5 to 40 mm, are angular to ground, faintly to moderately weathered, and commonly ferric oxide, some calcite, some chlorite coatings. Upper contact is at 30 degrees to the core axis, irregular, rough, weathered, some chlorite, trace calcite. Lower contact is at 20 degrees to the core axis, subplanar, rough, moderately weathered, some chlorite, some quartz. Core loss estimated to be 60 mm.
	34.76	34.79	LCZ	Core loss due to 30 mm left down hole.
03-028	36.47	36.53	LCZ	Core loss due to 60 mm left down hole.
03-037	3.70	3.73	LCZ	Upper contact is irregular, rough, ground and faintly weathered. Lower contact is irregular, rough, ground and faintly weathered. Core loss estimated to be 30 mm.
	33.06	33.08	LCZ	Core loss due to 20 mm left down hole.
G-0043	24.93	25.09	BLCZ	Pieces are angular, rough, chlorite coated. Zone possibly due to drill action on joints. Upper contact is at 55 degrees to the core axis, planar, rough, carbonate. Lower contact is at 90 degrees to the core, irregular. Core loss estimated to be 50 mm.

Drill Hole	Depth (m along core axis)		Detailed Fracture	Description
	From	To		
G-0045	7.53	7.84	BLCZ	Pieces are strong, and have been redrilled and ground. Upper and lower contacts are machine breaks. Core loss is assumed to be due to grinding. Core loss estimated to be 90 mm.
	20.87	21.33	BLCZ	Pieces are strong and have been redrilled and ground. Some surfaces have a chlorite coating, most are fresh. Inspector note "due to bit blocking". Suspect that zone is due to core catcher not working properly. Core loss estimated to be 100 mm.
	36.25	37.34	BLCZ	Pieces are angular, strong to moderately strong, slightly altered, some clay, some limonite, some chlorite. Normal drill water return. Upper contact is a joint at 10 degrees to the core axis, chlorite coated, some clay. Lower contact is a joint at 30 degrees to the core axis, clay coated. Core loss estimated to be 100 mm.
G-0047	16.41	17.03	BLCZ	The zone is due to drill action on core left down hole. Core loss estimated to be 240 mm.
	28.85	28.88	LCZ	The zone is due to drill action, pieces appear to be missing. Core loss estimated to be 30 mm.
	30.62	30.72	BLCZ	The zone is due to drill action on core left down hole. One piece is ground. Core loss estimated to be 50 mm.
	37.45	37.50	LCZ	The zone is due to drill action at the end of run. Core loss estimated to be 50 mm.
G-0049	10.86	10.96	BLCZ	Core loss is assumed to be due to drill action on closely spaced joints. Pieces are angular, rough, carbonate coated. Core loss estimated to be 100 mm.
	11.43	11.91	BLCZ	Pieces consist of clay and several pieces of core. Clay is light grey (dry) and contains medium to coarse sand and fine gravel. Largest piece of core is 95 mm in length. Core loss is attributed to washing out of a large clay seam. Core loss estimated to be 140 mm.
	42.00	42.49	LCZ	Core loss due to 490 mm left down hole.
G-0051	23.48	23.55	LCZ	Core loss assumed to be due to grinding. Upper contact is a machine break at 90 degrees to the core axis, fresh. Lower contact is a joint, at 50 degrees to the core axis, carbonate coating, chlorite coated, ground. Core loss estimated to be 70 mm.
	40.85	41.08	LCZ	Core loss due to 230 mm left down hole.

Notes:

(1) LCZ Lost Core Zone

(2) BLCZ Broken Lost Core Zone

Table 4.3
Keeyask GS - Stage IV Studies, Axis GR-4
Spillway Area – Water Pressure Test Summary

Drill Hole	Test Interval Depth[1] from Ground Surface (m)			Lugeon Value			Interpreted		Significant Features[3]
				Stage 1	Stage 2	Stage 3	Lugeon Value	Flow Characteristics[2]	
03-027	1.94	-	6.28	-	0	-	0	N/A	4O, 2PO, 7HJT
	5.76	-	10.85	0	0	0	0	No Take	2O, 2PO, 4HJT
	10.37	-	15.48	0	0	0	0	No Take	2O, 2HJT
	14.95	-	20.03	0	0	0	0	No Take	1O, 1HJT
	19.53	-	24.61	0	1	0	1	Laminar	1O, 2PO
	24.11	-	29.39	7	6	6	6	Laminar	2BLCZ, 1O, 1PO, 3HJT
	28.63	-	34.79	3	2	2	2	Laminar	4BLCZ, 1LCZ, 1O, 3PO, 8HJT
03-028	4.35	-	9.60	0	0	0	0	No Take	1BCZ, 4O, 12PO, 1HJT
	8.99	-	13.91	0	0	0	0	No Take	1O, 5PO, 1HJT
	13.54	-	18.49	0	0	0	0	No Take	1BCZ, 1PO
	18.07	-	23.31	2	1	1	1	Laminar	2O, 1PO, 2HJT
	22.68	-	27.96	1	0	2	1	Laminar	4PO, 2HJT
	27.20	-	32.46	1	1	1	1	Laminar	1O, 7PO, 3HJT
	31.84	-	36.53	0	1	1	1	Laminar	4PO
03-037	4.27	-	9.73	0	0	0	0	No Take	1BCZ, 2O, 3PO, 1HJT
	8.74	-	14.31	0	0	0	0	No Take	6O, 6PO
	13.38	-	18.94	0	0	0	0	No Take	6O, 8PO
	17.88	-	23.50	1	1	1	1	Laminar	2O, 8PO, 3HJT
	22.56	-	28.07	4	3	3	3	Laminar	1BCZ, 8O, 13PO, 3HJT
	27.07	-	33.08	2	1	1	1	Laminar	1BCZ, 5O, 2PO
G-0043	4.80	-	7.80	0	0	0	0	No Take	1BCZ, 2O, 1PO
	7.80	-	10.80	0	0	0	0	No Take	-
	17.50	-	20.50	0	0	0	0	No Take	2BCZ (1CJZ), 1O
	33.00	-	36.00	0	0	0	0	No Take	2BCZ, 1O, 1PO
G-0045	35.50	-	38.50	25	18	20	19	Turbulent	1BLCZ, 3O, 1HJT
G-0047	3.00	-	6.00	*	*	*	101 [4]	Pump Capacity	11PO
	6.00	-	9.00	*	*	*	101 [4]	Pump Capacity	2O, 10PO
	9.00	-	12.00	0	0	0	0	No Take	1BCZ (CJZ), 2O, 5PO
	15.50	-	18.50	0	0	0	0	No Take	1BLCZ
	20.50	-	40.91	0	0	0	0	No Take	1BLCZ, 2CLZ, 1O, 10PO

Drill Hole	Test Interval Depth[(1)] from Ground Surface (m)			Lugeon Value			Interpreted		Significant Features[(3)]
				Stage 1	Stage 2	Stage 3	Lugeon Value	Flow Characteristics[(2)]	
G-0049	10.00	-	13.00	0	0	0	0	No Take	2BLCZ (1CJZ), 2BCZ (1CJZ), 1O, 1PO
	13.00	-	16.00	0	0	0	0	No Take	2BCZ, (1HJT), 2O, 1PO
	16.00	-	19.00	0	0	0	0	No Take	2O
	26.50	-	29.50	0	0	0	0	No Take	1O, 2PO
	35.00	-	38.00	17	10	10	11	Void Filling	1BCZ (1HJT), 2O, 2PO
G-0051	8.00	-	10.00	0	0	0	0	No Take	2O, 1HJT
	25.00	-	27.00	0	0	0	0	No Take	2BCZ (2CJZ), 1HJT
	31.56	-	33.56	0	0	0	0	No Take	-
	37.00	-	39.00	0	0	0	0	No Take	2O

Notes:

(1) Depths listed are measured along the central axis of the core.

(2) Flow types are based on Houlsby (1976) rules.

(3) BCZ - Broken Core Zone
BLCZ - Broken Lost Core Zone
LCZ - Lost Core Zone
CJZ - Closely Jointed Zone
O -- Open Joint
PO - Partly Open Joint
HJT- Healed Joint
FOL - Foliation
SHEAR - Shear Zone, usually brittle
N/A Not Applicable. Flow pattern unassigned.
* - - No reading, flow exceeding pump capacity.

(4) WPT exceeding pump capacity were assigned a value of 101.

Table 4.4
Keeyask GS - Stage IV Studies, Axis GR-4
Interpreted Flow Characteristics

Interpreted Flow Characteristics	1991 Investigations	2003 Investigations	Total Number of Tests
Tight (i.e., no take)	15	9	24
Laminar	0	10	10
Turbulent	1	0	1
Dilation	0	0	0
Void Filling	1	0	1
N/A (2)	0	1(1)	1
Pump Capacity	2	0	2
Total Number of Tests	**19**	**20**	**39**

Notes:
(1) Only one step was conducted. "No take" was recorded.
(2) N/A - Not Applicable, flow pattern not assigned.

Table 4.5
Keeyask GS – Stage IV Studies, Axis GR-4
Summary of Joint Trend Measurements in Spillway Area

Spillway Joint Set	Orientation			Description
	Strike (deg)	Dip (1) (deg)	Dip Direction (deg)	
J1	25	32	115	Major
J2	126	30	216	Major
J3	210	25	300	Minor
J4	103	72	193	Minor

Note:

(1) Dip from horizontal. Dip direction is 90 deg right of the strike.

Table 5.1
Keeyask GS - Stage IV Studies, Axis GR-4
Spillway Area – RMR_{89} and GSI Values

Parameter	Spillway Area	
	Value	**Rating**
Point Load Index	7.6 MPa	12
RQD	89%	19
Spacing of discontinuities	286 mm	10
Condition of discontinuities	Note (1)	22
Groundwater (2)	Dry	15
Adjustment for joint orientation	Very favorable	0
RMR_{89} (3)		**78**
Rock Mass Class		**III**
Description of Rock Mass		**Good Rock**
GSI (4)		**73**

Notes:

(1) Figure 12, Section E was used to obtain a more refined rating

(2) During rock excavation, it is assumed that sidewalls and foundation conditions will be dry.

(3) This value is based on in situ rock foundations and assumes no stability treatment(s) (such as rock bolting) has been undertaken to prevent possible planar sliding, toppling, and/or wedge failure, due to the orientation of joint sets. Treatment recommendations and a through analysis of major/minor joint sets are discussed in Memorandum GN-4.2.2.8, Rock Support and Temporary Drainage [Ref 22].

(4) $GSI = RMR_{89} - 5$.

Table 5.2
Keeyask GS - Stage IV Studies, Axis GR-4
Summary of Analysis of Rock Strength Parameters using RocLab

Properties	Rock Types			
	Greywacke Gneiss	Iron Formation	Granite and Pegmatite	Diabase/Gabbro Dykes
Hoek-Brown Classification				
Intact Uniaxial Compressive Strength (1) (MPa)	175	250	250	175
Geological Strength Index (GSI)	73	73	73	73
Intact Rock Parameter (mi)	28	7	32	27
Disturbance Factor (D) (2)	0.7	0.7	0.7	0.7
Hoek-Brown Generalized Failure Criterion				
m_b (material constant) (3)	6.35	1.59	7.26	6.13
s (material constant) (4)	0.02	0.02	0.02	0.02
a (variable coefficient) (5)	0.5	0.5	0.5	0.5
Mohr-Coloumb Fit				
Cohesion (MPa)	13.67	14.24	20.21	13.54
Friction Angle	42	29.7	43	41.55
Rock Mass Parameters				
Tensile Strength (MPa)	-0.55	-3.146	-0.69	-0.57
Uniaxial Compressive Strength (MPa)	24.63	35.19	35.19	24.63
Global Strength (MPa)	61.22	49.05	93.02	60.21
Modulus of Deformation (MPa)	35075	52494	40563	30065

Notes:

(1) Based on field estimates

(2) Disturbance Factor for slopes using good blasting techniques

(3) mb is a reduced value of the material constant mi, which is based on the rock type and texture, where: mb= mi exp[(GSI-100)/ (28-14D)]; mi is material constant, obtained from Hoek 2006 – see Appendix C

(4) s = 1 for intact rock, as per Hoek

(5) $a = 1/2 + 1/6 (e^{-GSI/15} - e^{-20/3})$

Photographs

Photo 1: View looking west (upstream), showing Spillway and Central Dam Areas. Dash lines outline the Spillway location and its associated channels.

Photo 2: View looking southwest, showing Spillway Area and Discharge Channel.

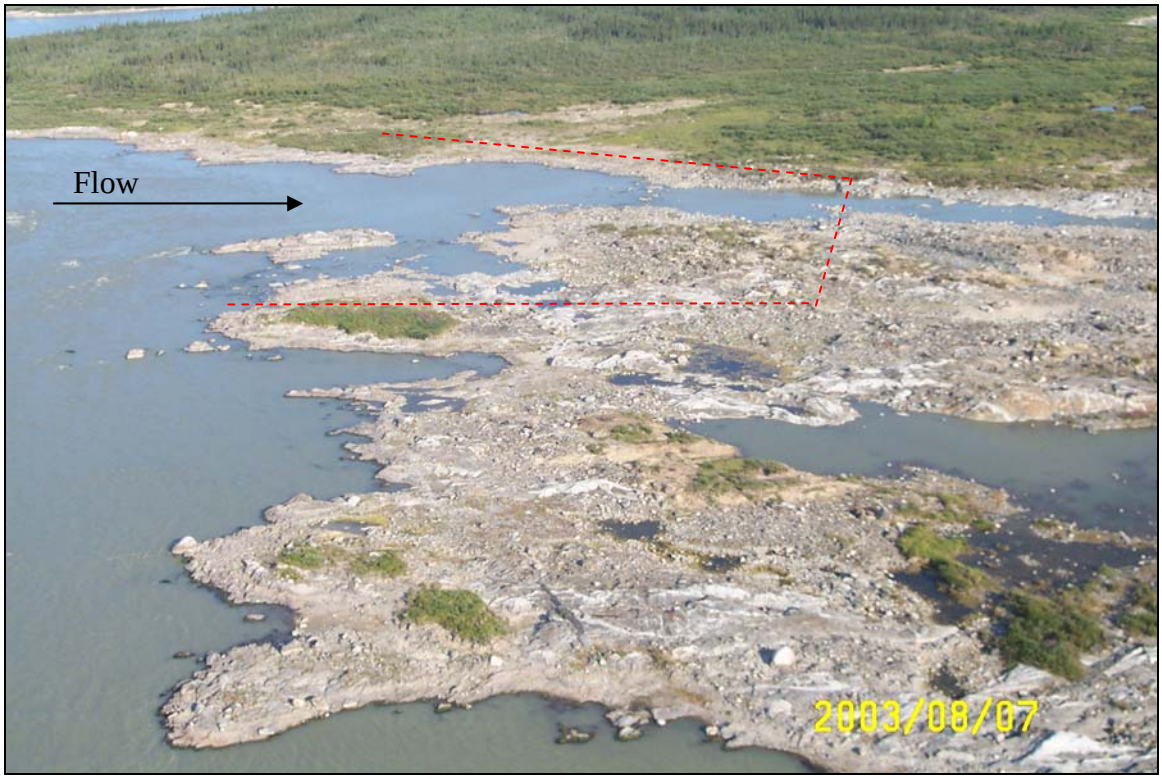


Photo 3: View looking northwest, showing Spillway Area and Approach Channel.

Photo 4: View looking northwest, showing Spillway Area.

Photo 5: View looking south, showing Spillway Area and South Channel.

Photo 6: View looking north, showing east end of Discharge Channel. To the top right of the photo is Stephens Lake.

Photo 7: View looking downstream of Spillway Structure at Discharge Channel.

Photo 8: View looking upstream of Spillway Structure at Approach Channel. Note the diabase (Gabbro) dyke intrusion into the host rock.

Photo 9: View looking north, showing location of Borehole 03-027 and the intrusion of a diabase (Gabbro) dyke into the host rock.

Photo 10: View looking downstream towards Stephens Lake from Spillway Area.

Photo 11: View looking downstream at the Spillway Discharge Channel from Axis GR-4 (near borehole 03-028).

Photo 12: View looking upstream from the Discharge Channel towards Axis GR-4. The diamond drill rig (on the right) is set up on borehole 03-028.

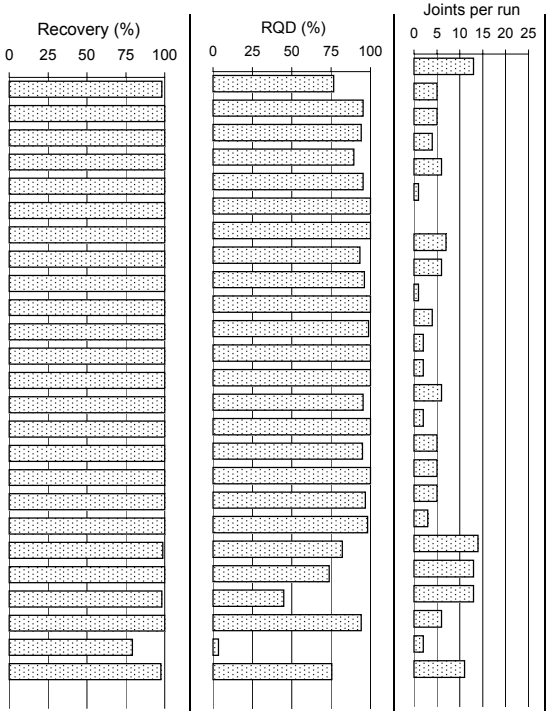
Appendix A

Appendix A
Gull Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Spillway Area
(For notes, see page 8)

Drill Hole: 03-027
Date: Sept. 9/03

Dip: 70 deg.
Azimuth: 315 deg.
Grd. Elev.: 147.17 m
Depth: 34.79 m

Geological Description [3]	Drill Run Depth (m - along core axis) From	To	(m)	Recovery Length (m)	(%)	RQD Length (m)	(%)	Jts per run		Average [3] Spacing per Jt. (mm)
0.00-1.08 Greywacke gneiss: dark grey, fine to medium grained, distinct foliation at 60 to 80 degrees to the core axis, strong, moderately spaced jointing, good to excellent rock quality, low permeability.	0.00	1.62	1.62	1.59	98	1.24	77	13	+	114
	1.62	3.13	1.51	1.51	100	1.44	95	5		252
	3.13	4.68	1.55	1.55	100	1.46	94	5		258
	4.68	6.28	1.60	1.60	100	1.43	89	4		320
	6.28	7.78	1.50	1.50	100	1.43	95	6		214
1.08-28.45 Diabase: dark green, very fine grained, no foliation evident, moderately spaced jointing, good to excellent rock quality, low permeability.	7.78	8.23	0.45	0.45	100	0.45	100	1		225
	8.23	9.36	1.13	1.13	100	1.13	100	0		1130
	9.36	10.85	1.49	1.49	100	1.39	93	7		186
	10.85	12.41	1.56	1.56	100	1.50	96	6		223
28.45-30.95 Greywacke gneiss: same as above, only weakly distinct foliation.	12.41	13.96	1.55	1.55	100	1.55	100	1		775
	13.96	15.48	1.52	1.52	100	1.50	99	4		304
	15.48	17.03	1.55	1.55	100	1.55	100	2		517
	17.03	18.52	1.49	1.49	100	1.49	100	2		497
	18.52	20.03	1.51	1.51	100	1.44	95	6		216
30.95-34.79 Granite: pink to light grey, medium to coarse grained, locally pegmatitic, strong to very strong, closely spaced jointing, good rock quality, low permeability.	20.03	21.43	1.40	1.40	100	1.40	100	2		467
	21.43	23.01	1.58	1.58	100	1.50	95	5		263
	23.01	24.61	1.60	1.60	100	1.60	100	5		267
	24.61	26.17	1.56	1.56	100	1.51	97	5		260
	26.17	27.77	1.60	1.60	100	1.57	98	3		400
	27.77	29.39	1.62	1.60	99	1.33	82	14	+	107
	29.39	30.69	1.30	1.30	100	0.96	74	13		93
	30.69	31.76	1.07	1.05	98	0.48	45	13	+	75
	31.76	33.28	1.52	1.52	100	1.43	94	6		217
	33.28	33.57	0.29	0.23	79	0.01	3	2	++	77
	33.57	34.79	1.22	1.19	98	0.92	75	11		99
	Totals =		34.79	34.63		31.71		141		
	Average =		1.39		99.5		91		6	245



Appendix A
Gull Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Spillway Area
(For notes, see page 8)

Drill Hole: 03-028
Date: Sept.5/03

Dip: 70 deg.
Azimuth: 315 deg.
Grd. Elev.: 148.79 m
Depth: 36.53 m

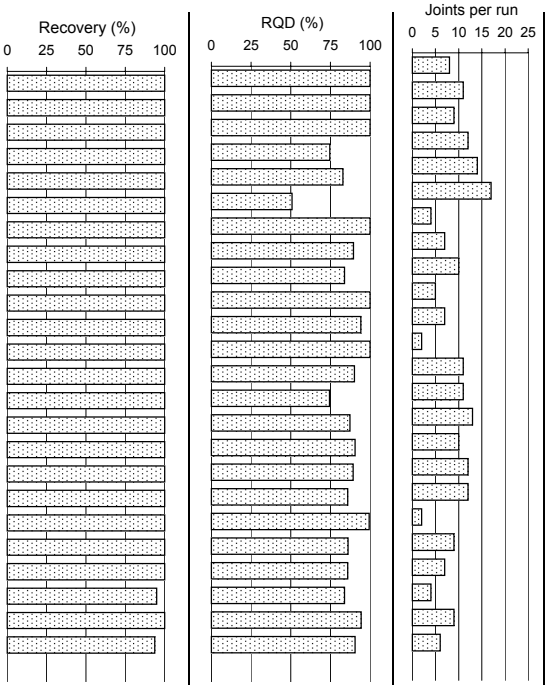
Geological Description [3]

3.02-11.00 Greywacke gneiss: dark grey, fine to medium grained, distinct foliation at 60 to 80 degrees to the core axis, moderately spaced jointing, good to excellent rock quality, low permeability.

11.00-13.90 Granite: light to medium grey, medium to coarse grained, strong, closely spaced jointing, excellent rock quality, low permeability.

13.90-36.47 Greywacke gneiss: as described above.

Drill Run Depth (m - along core axis)			Recovery Length		RQD Length		Jts per		Average [3] Spacing
From	To	(m)	(m)	(%)	(m)	(%)	run		per Jt. (mm)
3.02	3.83	0.81	0.81	100	0.81	100	8		90
3.83	5.19	1.36	1.36	100	1.36	100	11		113
5.19	6.53	1.34	1.34	100	1.34	100	9	+	134
6.53	8.03	1.50	1.50	100	1.12	75	12		115
8.03	9.60	1.57	1.57	100	1.30	83	14		105
9.60	10.82	1.22	1.22	100	0.62	51	17		68
10.82	12.39	1.57	1.57	100	1.57	100	4		314
12.39	13.91	1.52	1.52	100	1.36	89	7		190
13.91	15.46	1.55	1.55	100	1.30	84	10	+	141
15.46	16.95	1.49	1.49	100	1.49	100	5		248
16.95	18.49	1.54	1.54	100	1.45	94	7		193
18.49	19.09	0.60	0.60	100	0.60	100	2		200
19.09	20.60	1.51	1.51	100	1.36	90	11		126
20.60	21.81	1.21	1.21	100	0.90	74	11		101
21.81	23.31	1.50	1.50	100	1.31	87	13		107
23.31	24.88	1.57	1.57	100	1.42	90	10		143
24.88	26.39	1.51	1.51	100	1.35	89	12		116
26.39	27.96	1.57	1.57	100	1.35	86	12		121
27.96	29.40	1.44	1.44	100	1.43	99	2		480
29.40	30.98	1.58	1.58	100	1.36	86	9		158
30.98	32.46	1.48	1.48	100	1.27	86	7		185
32.46	34.01	1.55	1.47	95	1.30	84	4		294
34.01	35.58	1.57	1.57	100	1.48	94	9		157
35.58	36.53	0.95	0.89	94	0.86	91	6	+	127
Totals =		33.51	33.37		29.71		212		
Average =		1.40		99.6		89		9	157



Appendix A
Gull Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Spillway Area
(For notes, see page 8)

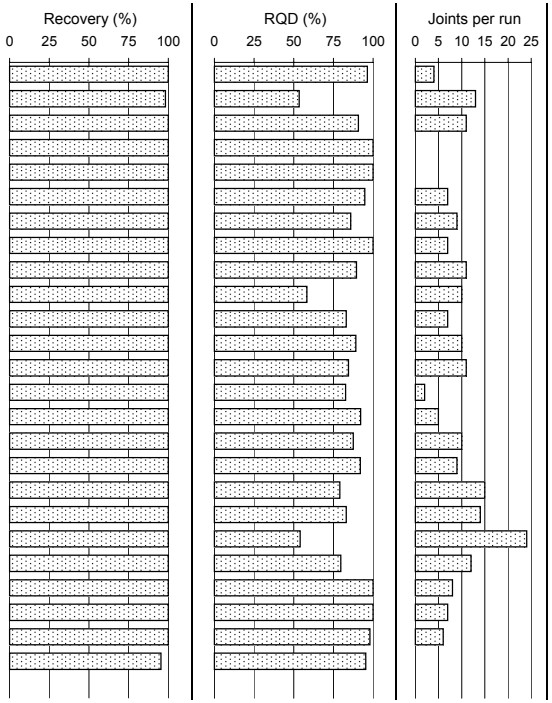
Drill Hole: 03-037
Date: Sept.5/03

Dip: 70 deg.
Azimuth: 315 deg.
Grd. Elev.: 146.01 m
Depth: 33.08 m

Geological Description [3]

2.80-33.08 Greywacke gneiss: dark grey to black, fine to medium grained, distinct to weakly distinct foliation at various angles to the core axis, generally between 65 to 85 degrees, strong, moderately spaced jointing, excellent rock quality, low permeability.

Drill Run Depth (m - along core axis)			Recovery Length		RQD Length		Jts per		Average [3] Spacing
From	To	(m)	(m)	(%)	(m)	(%)	run		per Jt. (mm)
2.80	3.62	0.82	0.82	100	0.79	96	4		164
3.62	5.19	1.57	1.54	98	0.84	54	13	+	110
5.19	6.59	1.40	1.40	100	1.27	91	11		117
6.59	6.66	0.07	0.07	100	0.07	100	0		70
6.66	6.70	0.04	0.04	100	0.04	100	0		40
6.70	8.25	1.55	1.55	100	1.47	95	7		194
8.25	9.73	1.48	1.48	100	1.27	86	9		148
9.73	11.29	1.56	1.56	100	1.56	100	7		195
11.29	12.82	1.53	1.53	100	1.37	90	11		128
12.82	13.54	0.72	0.72	100	0.42	58	10		65
13.54	14.31	0.77	0.77	100	0.64	83	7		96
14.31	15.86	1.55	1.55	100	1.38	89	10		141
15.86	17.41	1.55	1.55	100	1.31	85	11		129
17.41	17.93	0.52	0.52	100	0.43	83	2		173
17.93	18.94	1.01	1.01	100	0.93	92	5		168
18.94	20.46	1.52	1.52	100	1.33	88	10		138
20.46	21.93	1.47	1.47	100	1.35	92	9		147
21.93	23.50	1.57	1.57	100	1.24	79	15		98
23.50	25.03	1.53	1.53	100	1.27	83	14		102
25.03	26.55	1.52	1.52	100	0.82	54	24		61
26.55	28.07	1.52	1.52	100	1.21	80	12	+	117
28.07	29.61	1.54	1.54	100	1.54	100	8		171
29.61	31.14	1.53	1.53	100	1.53	100	7		191
31.14	32.64	1.50	1.50	100	1.47	98	6		214
32.64	33.08	0.44	0.42	95	0.42	95	0		420
Totals =		30.28	30.23		25.97		212		
Average =		1.21		99.8		86		8	142



Appendix A
Gull Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Spillway Area
(For notes, see page 8)

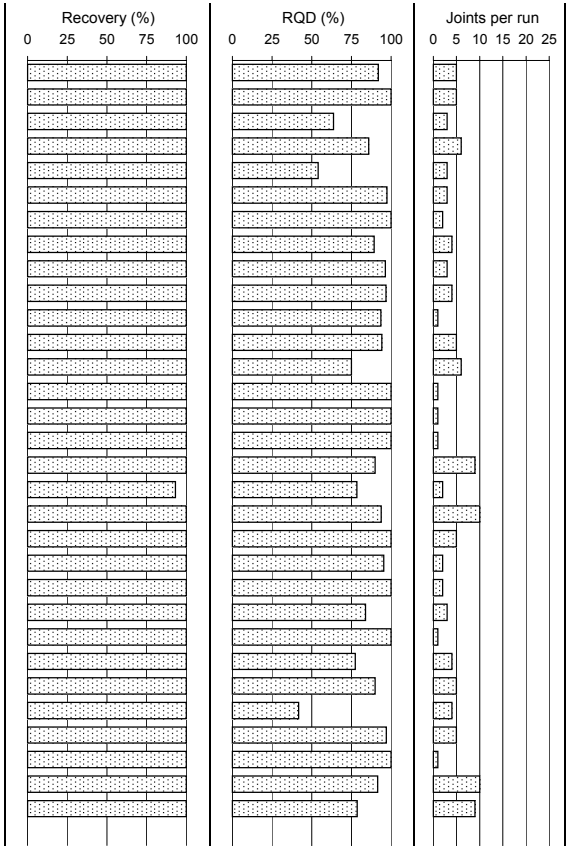
Drill Hole: G-0043
Date: Jul.26/91

Dip: 45 deg.
Azimuth: 270 deg.
Grd. Elev.: 150.69 m
Depth: 42.06 m

Geological Description [3]

2.25-42.25 Greywacke gneiss: dark grey, fine grained, strong, indistinct foliation, moderately spaced jointing, excellent rock quality, practically impermeable, granitic bands throughout. Granite bands are medium to light pink, medium to coarse grained, strong, no foliation evident.

Drill Run Depth (m - along core axis)			Recovery Length		RQD Length		Jts per		Average [3] Spacing
From	To	(m)	(m)	(%)	(m)	(%)	run		per Jt. (mm)
2.25	3.62	1.37	1.37	100	1.26	92	5	+	228
3.62	4.80	1.18	1.18	100	1.18	100	5		197
4.80	4.91	0.11	0.11	100	0.07	64	3		28
4.91	6.54	1.63	1.63	100	1.40	86	6	+	233
6.54	7.89	1.35	1.35	100	0.73	54	3	+	338
7.89	9.45	1.56	1.56	100	1.52	97	3		390
9.45	10.88	1.43	1.43	100	1.43	100	2		477
10.88	12.37	1.49	1.49	100	1.33	89	4		298
12.37	13.75	1.38	1.38	100	1.33	96	3		345
13.75	15.33	1.58	1.58	100	1.53	97	4		316
15.33	16.86	1.53	1.53	100	1.43	93	1	+	765
16.86	18.41	1.55	1.55	100	1.46	94	5	+	258
18.41	19.69	1.28	1.28	100	0.96	75	6	+	183
19.69	20.40	0.71	0.71	100	0.71	100	1		355
20.40	21.79	1.39	1.39	100	1.39	100	1		695
21.79	22.86	1.07	1.07	100	1.07	100	1		535
22.86	24.46	1.60	1.60	100	1.44	90	9		160
24.46	25.20	0.74	0.69	93	0.58	78	2	+	230
25.20	26.62	1.42	1.42	100	1.33	94	10		129
26.62	28.24	1.62	1.62	100	1.62	100	5		270
28.24	28.88	0.64	0.64	100	0.61	95	2		213
28.88	30.44	1.56	1.56	100	1.56	100	2		520
30.44	30.81	0.37	0.37	100	0.31	84	3		93
30.81	31.88	1.07	1.07	100	1.07	100	1		535
31.88	33.30	1.42	1.42	100	1.10	77	4	+	284
33.30	34.80	1.50	1.50	100	1.35	90	5		250
34.80	35.88	1.08	1.08	100	0.45	42	4	+	216
35.88	37.48	1.60	1.60	100	1.55	97	5	+	267
37.48	38.98	1.50	1.50	100	1.50	100	1		750
38.98	40.52	1.54	1.54	100	1.41	92	10	+	140
40.52	42.06	1.54	1.54	100	1.21	79	9		154
	Totals =	39.81	39.76		35.89		125		
	Average =	1.28		99.9		90		4	316



Appendix A
Gull Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Spillway Area
(For notes, see page 8)

Drill Hole: G-0045
Date: Jul.28/91

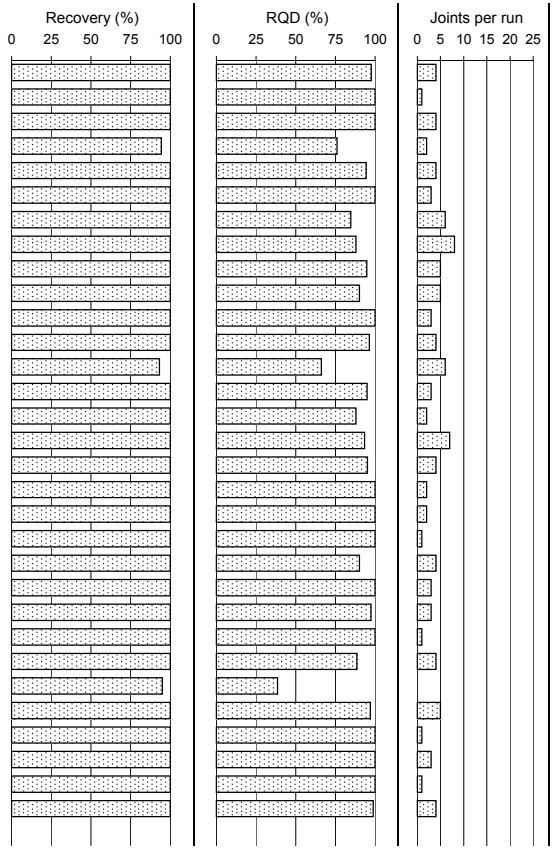
Dip: 45 deg.
Azimuth: 207 deg.
Grd. Elev.: 149.65 m
Depth: 45.39 m

Geological Description [3]

2.13-33.24 Greywacke gneiss: dark grey to black with light grey granitic material, fine grained, strong, distinct foliation at 35 degrees to the core axis, moderately to widely spaced jointing, good to excellent rock quality, low permeability. Contains a mixture of granite and greywacke gneiss.

33.24-45.38 Granite: light grey, medium to coarse grained, no foliation evident, moderately to widely spaced jointing, good to excellent rock quality, medium permeability.

Drill Run Depth (m - along core axis)			Recovery Length		RQD Length		Jts per		Average [3] Spacing
From	To	(m)	(m)	(%)	(m)	(%)	run		per Jt. (mm)
2.13	3.35	1.22	1.22	100	1.19	98	4		244
3.35	4.86	1.51	1.51	100	1.51	100	1		755
4.86	6.37	1.51	1.51	100	1.51	100	4		302
6.37	7.99	1.62	1.53	94	1.23	76	2	+	510
7.99	9.41	1.42	1.42	100	1.34	94	4	+	284
9.41	10.83	1.42	1.42	100	1.42	100	3		355
10.83	12.26	1.43	1.43	100	1.21	85	6		204
12.26	13.83	1.57	1.57	100	1.38	88	8		174
13.83	15.38	1.55	1.55	100	1.47	95	5		258
15.38	16.81	1.43	1.43	100	1.29	90	5		238
16.81	18.39	1.58	1.58	100	1.58	100	3		395
18.39	19.80	1.41	1.41	100	1.36	96	4		282
19.80	21.25	1.45	1.35	93	0.96	66	6	+	193
21.25	22.82	1.57	1.57	100	1.49	95	3	+	393
22.82	23.48	0.66	0.66	100	0.58	88	2		220
23.48	24.98	1.50	1.50	100	1.40	93	7		188
24.98	25.81	0.83	0.83	100	0.79	95	4		166
25.81	27.34	1.53	1.53	100	1.53	100	2		510
27.34	28.84	1.50	1.50	100	1.50	100	2		500
28.84	30.37	1.53	1.53	100	1.53	100	1		765
30.37	31.78	1.41	1.41	100	1.27	90	4		282
31.78	33.28	1.50	1.50	100	1.50	100	3		375
33.28	34.42	1.14	1.14	100	1.11	97	3		285
34.42	35.16	0.74	0.74	100	0.74	100	1		370
35.16	36.12	0.96	0.96	100	0.85	89	4		192
36.12	38.07	1.95	1.85	95	0.75	38	-	++	-
38.07	39.38	1.31	1.31	100	1.27	97	5		218
39.38	40.85	1.47	1.47	100	1.47	100	1		735
40.85	42.39	1.54	1.54	100	1.54	100	3		385
42.39	43.85	1.46	1.46	100	1.46	100	1		730
43.85	45.39	1.54	1.54	100	1.52	99	4		308
Totals =		43.26	42.97		39.75		105		
Average =		1.40		99.3		92		4	408



Appendix A
Gull Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Spillway Area
(For notes, see page 8)

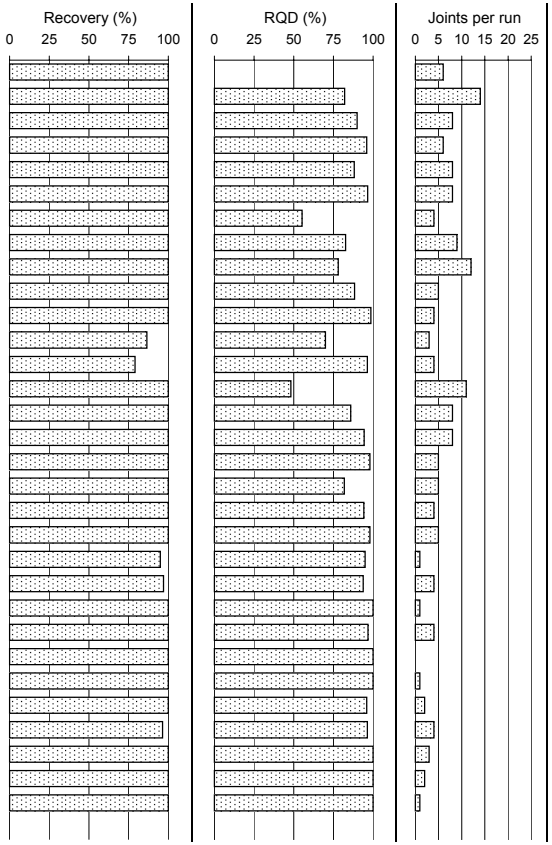
Drill Hole: G-0047
Date: Jul.30/91

Dip: 45 deg.
Azimuth: 257 deg.
Grd. Elev.: 149.04 m
Depth: 40.91 m

Geological Description [3]

1.46-40.91 Greywacke gneiss: dark grey, fine grained, strong, indistinct foliation at 40 to 50 degrees to the core axis, moderately spaced jointing, good to excellent rock quality, low permeability, granitic bands throughout. Granite bands are medium to light grey, medium to coarse grained, strong, no foliation evident.

Drill Run Depth (m - along core axis) From	To	(m)	Recovery Length (m)	(%)	RQD Length (m)	(%)	Jts per run		Average [3] Spacing per Jt. (mm)
1.46	1.80	0.34	0.34	100	0.00	0	6	+	49
1.80	3.47	1.67	1.67	100	1.37	82	14		111
3.47	4.86	1.39	1.39	100	1.25	90	8		154
4.86	6.34	1.48	1.48	100	1.42	96	6		211
6.34	7.85	1.51	1.51	100	1.33	88	8		168
7.85	9.30	1.45	1.45	100	1.40	97	8		161
9.30	9.68	0.38	0.38	100	0.21	55	4		76
9.68	10.89	1.21	1.21	100	1.00	83	9		121
10.89	12.30	1.41	1.41	100	1.10	78	12	+	108
12.30	13.84	1.54	1.54	100	1.36	88	5		257
13.84	15.35	1.51	1.51	100	1.49	99	4		302
15.35	16.91	1.56	1.35	87	1.09	70	3	+	338
16.91	18.56	1.62	1.28	79	1.56	96	4	+	256
18.56	19.91	1.35	1.35	100	0.65	48	11	+	113
19.91	20.98	1.07	1.07	100	0.92	86	8		119
20.98	22.56	1.58	1.58	100	1.49	94	8		176
22.56	24.12	1.56	1.56	100	1.53	98	5		260
24.12	25.71	1.59	1.59	100	1.30	82	5		265
25.71	27.09	1.38	1.38	100	1.30	94	4		276
27.09	28.55	1.46	1.46	100	1.43	98	5		243
28.55	29.14	0.59	0.56	95	0.56	95	1	+	280
29.14	30.76	1.62	1.57	97	1.52	94	4	+	314
30.76	31.86	1.10	1.10	100	1.10	100	1		550
31.86	33.45	1.59	1.59	100	1.54	97	4		318
33.45	34.35	0.90	0.90	100	0.90	100	0		900
34.35	34.91	0.56	0.56	100	0.56	100	1		280
34.91	36.17	1.26	1.26	100	1.21	96	2		420
36.17	37.56	1.39	1.34	96	1.34	96	4	+	268
37.56	38.99	1.43	1.43	100	1.43	100	3		358
38.99	40.30	1.31	1.31	100	1.31	100	2		437
40.30	40.91	0.61	0.61	100	0.61	100	1		305
Totals =		39.42	38.74		35.28		160		
Average =		1.27		98.3		89		5	245



Appendix A
Gull Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Spillway Area
(For notes, see page 8)

Drill Hole: G-0049
Date: Aug.1/91

Dip: 45 deg.
Azimuth: 320 deg.
Grd. Elev.: 144.93 m
Depth: 42.49 m

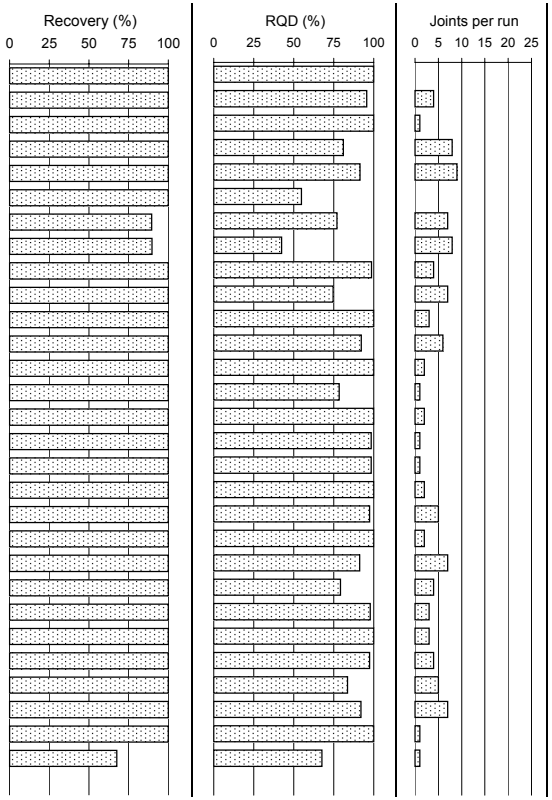
Geological Description [3]

4.04-7.87 Greywacke gneiss: dark grey, fine grained, strong, indistinct foliation, moderately to widely spaced jointing, good to excellent rock quality, low permeability, granitic bands throughout.

7.87-28.93 Granite: light grey, medium to coarse grained, strong, no foliation evident, moderately spaced jointing, good rock quality, low permeability, numerous healed joints throughout.

28.93-42.49 Greywacke gneiss: same as above.

Drill Run Depth (m - along core axis)			Recovery Length		RQD Length		Jts per		Average [3] Spacing
From	To	(m)	(m)	(%)	(m)	(%)	run		per Jt. (mm)
4.04	4.11	0.07	0.07	100	0.07	100	0		70
4.11	5.01	0.90	0.90	100	0.86	96	4		180
5.01	6.63	1.62	1.62	100	1.62	100	1		810
6.63	8.00	1.37	1.37	100	1.11	81	8		152
8.00	9.63	1.63	1.63	100	1.49	91	9		163
9.63	10.05	0.42	0.42	100	0.23	55	-	++	-
10.05	11.01	0.96	0.86	90	0.74	77	7	+	108
11.01	12.38	1.37	1.23	90	0.58	42	8	+	137
12.38	13.83	1.45	1.45	100	1.43	99	4		290
13.83	15.45	1.62	1.62	100	1.21	75	7	+	203
15.45	17.01	1.56	1.56	100	1.56	100	3		390
17.01	18.55	1.54	1.54	100	1.42	92	6		220
18.55	20.01	1.46	1.46	100	1.46	100	2		487
20.01	21.58	1.57	1.57	100	1.23	78	1	+	785
21.58	22.99	1.41	1.41	100	1.41	100	2		470
22.99	23.64	0.65	0.65	100	0.64	98	1		325
23.64	24.86	1.22	1.22	100	1.20	98	1		610
24.86	26.02	1.16	1.16	100	1.16	100	2		387
26.02	27.54	1.52	1.52	100	1.48	97	5		253
27.54	29.02	1.48	1.48	100	1.48	100	2		493
29.02	30.61	1.59	1.59	100	1.45	91	7		199
30.61	32.05	1.44	1.44	100	1.14	79	4		288
32.05	33.44	1.39	1.39	100	1.36	98	3		348
33.44	34.98	1.54	1.54	100	1.54	100	3		385
34.98	36.57	1.59	1.59	100	1.55	97	4		318
36.57	37.97	1.40	1.40	100	1.17	84	5	+	233
37.97	39.59	1.62	1.62	100	1.49	92	7		203
39.59	40.98	1.39	1.39	100	1.39	100	1		695
40.98	42.49	1.51	1.02	68	1.02	68	1		510
	Totals =	38.45	37.72		34.49		108		
	Average =	1.33		98.1		90		4	353



Appendix A
Gull Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Spillway Area
(For notes, see page 8)

Drill Hole: G-0051
Date: Aug.2/91

Dip: 45 deg.
Azimuth: 185 deg.
Grd. Elev.: 149 m
Depth: 41.08 m

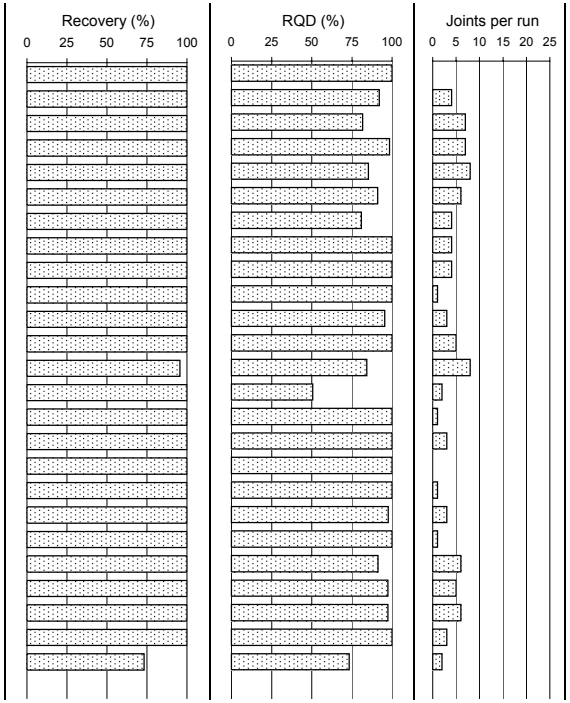
Geological Description [3]

7.96-26.53 Greywacke gneiss: dark grey to black, fine grained, strong, indistinct to distinct foliation at 20 to 30 degrees to the core axis, moderately spaced jointing, good to excellent rock quality, low permeability.

26.53-36.30 Granite: medium grey, medium grained, locally coarse grained, strong, no foliation evident, fresh, widely spaced jointing, excellent rock quality, practically impermeable.

36.30-41.08 Greywacke gneiss: dark grey to black, fine grained, strong, indistinct foliation at 30 degrees to the core axis, moderately spaced jointing, excellent rock quality, low permeability.

Drill Run Depth (m - along core axis)			Recovery Length		RQD Length		Jts per		Average [3] Spacing
From	To	(m)	(m)	(%)	(m)	(%)	run		per Jt. (mm)
7.96	8.29	0.33	0.33	100	0.33	100	0		330
8.29	9.43	1.14	1.14	100	1.05	92	4		228
9.43	10.91	1.48	1.48	100	1.21	82	7	+	185
10.91	12.86	1.95	1.95	100	1.92	98	7		244
12.86	14.35	1.49	1.49	100	1.27	85	8	+	166
14.35	15.81	1.46	1.46	100	1.33	91	6		209
15.81	16.44	0.63	0.63	100	0.51	81	4		126
16.44	17.42	0.98	0.98	100	0.98	100	4		196
17.42	18.95	1.53	1.53	100	1.53	100	4		306
18.95	20.42	1.47	1.47	100	1.47	100	1		735
20.42	21.96	1.54	1.54	100	1.47	95	3		385
21.96	23.48	1.52	1.52	100	1.52	100	5		253
23.48	25.07	1.59	1.52	96	1.34	84	8	+	169
25.07	26.53	1.46	1.46	100	0.74	51	2	++	487
26.53	26.91	0.38	0.38	100	0.38	100	1		190
26.91	28.39	1.48	1.48	100	1.48	100	3		370
28.39	29.58	1.19	1.19	100	1.19	100	0		1190
29.58	31.05	1.47	1.47	100	1.47	100	1		735
31.05	32.67	1.62	1.62	100	1.58	98	3		405
32.67	34.13	1.46	1.46	100	1.46	100	1		730
34.13	35.73	1.60	1.60	100	1.46	91	6		229
35.73	37.23	1.50	1.50	100	1.46	97	5		250
37.23	38.78	1.55	1.55	100	1.51	97	6		221
38.78	40.22	1.44	1.44	100	1.44	100	3		360
40.22	41.08	0.86	0.63	73	0.63	73	2		210
Totals =		33.12	32.82		30.73		94		
Average =		1.32		99.1		93		4	349



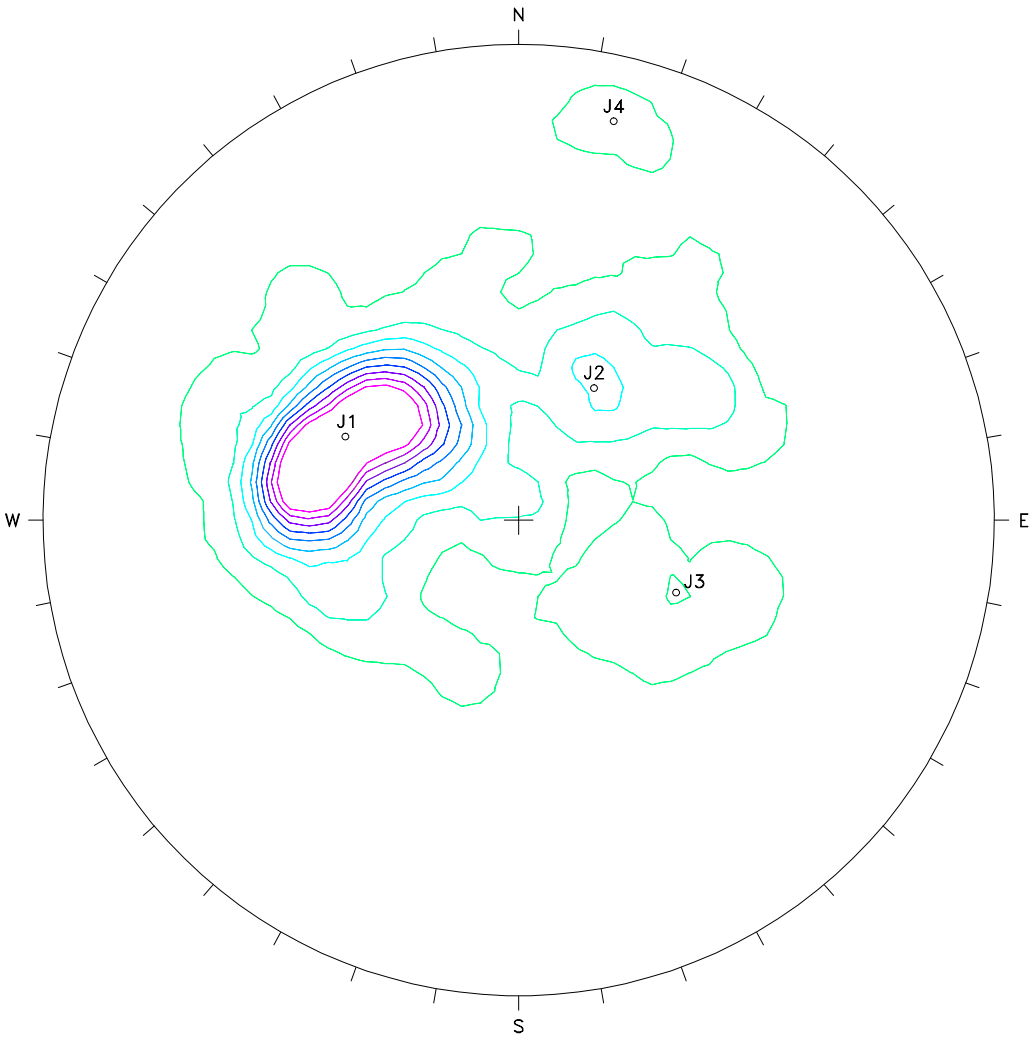
Notes:

(1) Chart Depths are approximate.
(2) Elevation is approximate.
(3) Refer to geological logs for a complete description.
(4) For barge hoes, elevation is the riverbed elevation.
+ Defines the minimum discontinuities counted in a core run, where missing or broken core is present.
++ Defines a core run with discontiinuities too numerous to count or the entire core run is broken or lost.

Appendix B

FIGURE B1

SHT.	REV.
0001	00



LEGEND:

o POLE REPRESENTATION OF JOINT SET

FISHER CONCENTRATIONS % OF TOTAL PER 1.0% AREA

	1.00 %
	2.00 %
	3.00 %
	4.00 %
	5.00 %
	6.00 %
	7.00 %
	8.00 %
	> 9.00 %

NO BIAS CORRECTION
MAXIMUM CONCENTRATION = 13.0771%

EQUAL AREA
LOWER HEMISPHERE
364 POLES
364 ENTRIES

NO.	DATE	REVISIONS	BY	CKD.	APP.
00	2009 04 06	ISSUED AS A FIGURE FOR MEMO REFERENCE GN-1.5.5			

ACRES MANITOBA LIMITED

ACRES

MANITOBA HYDRO

KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN
THE SPILLWAY AREA
POLAR DENSITY PLOT

DRAWN
CHECK
SCALE AS SHOWN
DATE

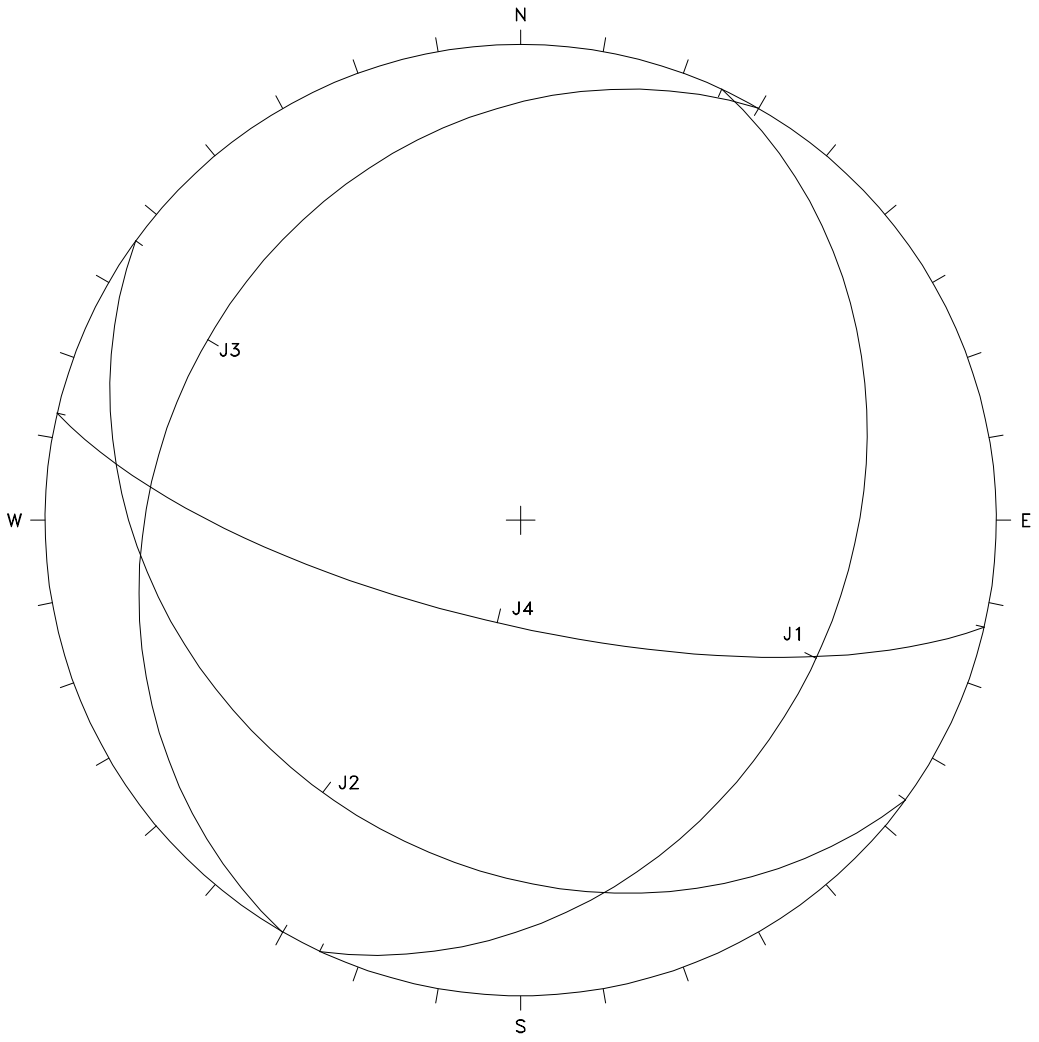
FIGURE B1

SHT.	REV.
0001	00

AUTOCAD ORIGINAL

FOR MICROFILM USE ONLY

FIGURE B2 | SHT. 0001 | REV. 00



ORIENTATIONS

ID	STRIKE/DIP (RIGHT HAND RULE) [DEGREES]
J1	025/32
J2	126/30
J3	210/25
J4	103/72

EQUAL AREA
LOWER HEMISPHERE
364 POLES
364 ENTRIES

NO.	DATE	REVISIONS	BY	CKD.	APP.
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STAGE IV STUDIES AXIS GR-4 REVIEW OF BEDROCK CONDITIONS IN THE SPILLWAY AREA DOMINANT JOINT SETS

DRAWN
CHECK
SCALE AS SHOWN
DATE

FIGURE B2 | SHT. 0001 | REV. 00

AUTOCAD ORIGINAL

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Appendix C

Appendix C
Keeyask Generating Station
Stage IV Studies, Axis GR-4
Rock Mass Properties

Values of the constant m_i for intact rock, by rock group. Note that values in parenthesis are estimates.
(Hoek E. Practical Rock Engineering, 2006, **www.rocscience.com**)

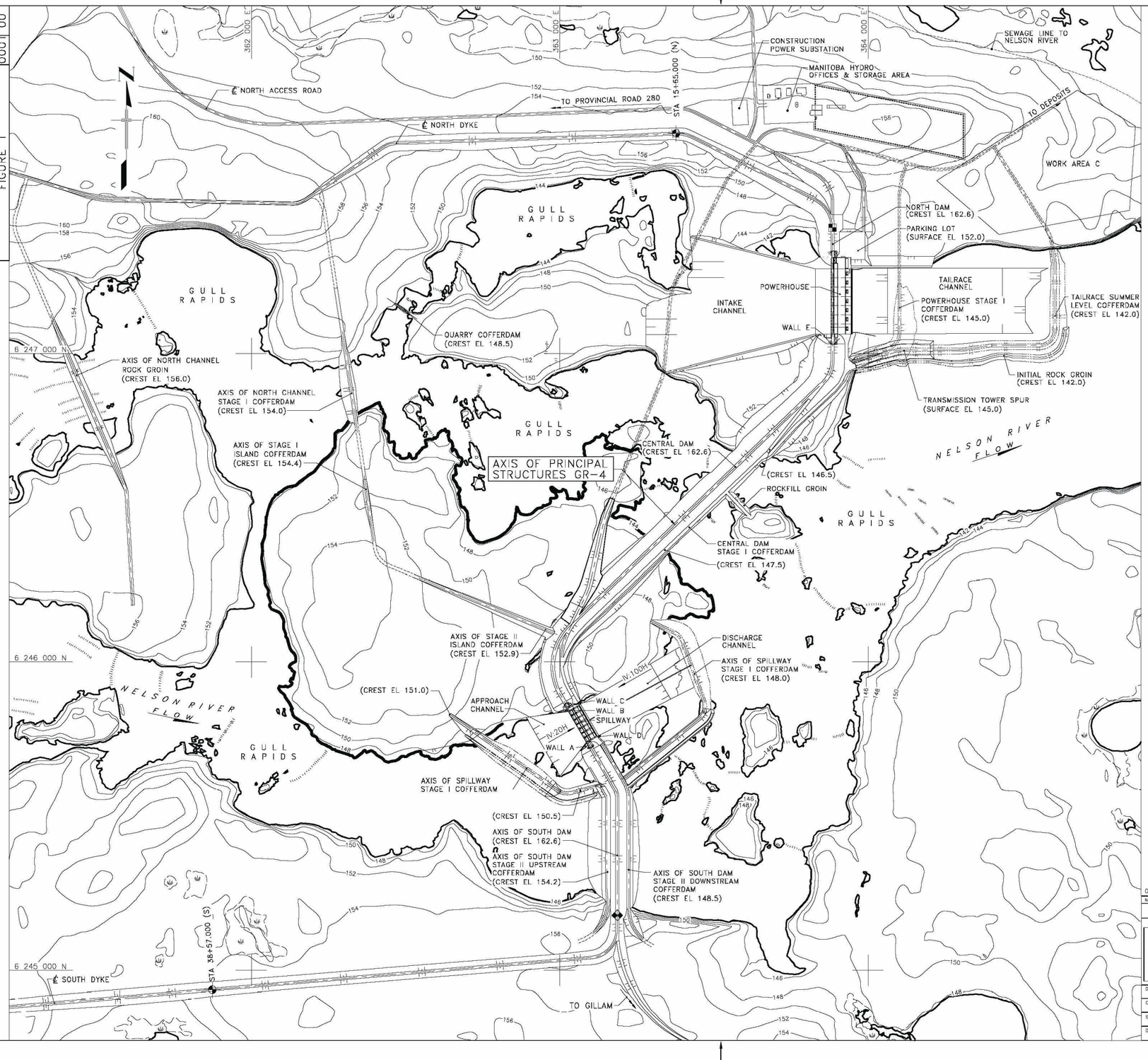
Rock Type	Class	Group	Texture			
			Coarse	**Medium**	**Fine**	**Very Fine**
Sedimentary	Clastic		Conglomerates[1] (21 ± 3) Breccias (19 ± 5)	Sandstones 17 ± 4	Siltstones 7 ± 2 Greywackes (18 ± 3)	Claystones 4 ± 2 Shales (6 ± 2) Maris (7 ± 2)
	Non-Clastic	Carbonates	Crystalline Limestone (12 ± 3)	Sparitic Limestones (10 ± 2)	Micritic Limestones (9 ± 2)	Dolomites (9 ± 3)
		Evaporites		Gypsum 8 ± 2	Anhydrite 12 ± 2	
		Organic				Chalk 7 ± 2
Metamorphic	Non Foliated		Marble 9 ± 3	Hornfels (19 ± 4) Metasandstone (19 ± 3)	Quartzites 20 ± 3	
	Slightly Foliated		Migmatite (29 ± 3)	Amphibolites 26 ± 6		
	Foliated[2]		Gneiss 28 ± 5	Schists 12 ± 3	Phyllites (7 ± 3)	Slates 7 ± 4
Igneous	Plutonic	Light	Granite 32 ± 3	Diorite 25 ± 5 Granodiorite (29 ± 30		
		Dark	Gabbro 27 ± 3	Dolerite (16 ± 5) Norite 20 ± 5		
	Hypabyssal		Porphyries (20 ± 5)		Diabase (15 ± 5)	Peridotite (25 ± 5)
	Volcanic	Lava		Rhyolite (25 ± 5) Andesite 25 ± 5	Dacite (25 ± 3) Basalt (25 ± 5)	Obsidian (19 ± 3)
		Pyroclastic	Agglomerate (19 ± 3)	Breccia (19 ± 5)		

Notes:

(1) Conglomerates and breccias may present a wide range of m_i values depending on the nature of the cementing material and the degree of cementation, so they may range from values similar to sandstone to values used for the fine grained sediments.

(2) These values are for intact rock specimens tested normal to bedding or foliation. The value of m_i will be significantly different if failure occurs along a weaknesses plane.

Figures



LEGEND:

- SHORELINE (SEE NOTE 6)
- 144 GROUND SURFACE CONTOUR (SEE NOTE 7)
- STREAM
- SWAMP
- RAPIDS
- TEMPORARY CONSTRUCTION ACCESS ROAD
- COORDINATE GRID MARKER (LOCATED AT 1000 METRE INTERVALS)
- COFFERDAM REMOVED
- REFERENCE POINT (SEE NOTE 10)
- REFERENCE POINT (SEE NOTE 11)
- REFERENCE POINT (SEE NOTE 12)

NOTES:

1. TOPOGRAPHY IS BASED ON MAPPING RECEIVED BY ACRES MANITOBA LIMITED FROM MANITOBA HYDRO MARCH, 2004.
2. MAPPING WAS PRODUCED USING PHOTOGRAMMETRIC METHODS BASED ON 1:20 000 SCALE PHOTOGRAPHY DATED OCTOBER, 1986.
3. COORDINATE GRID SHOWN IS BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 15, NORTH AMERICAN DATUM 1983.
4. COORDINATES AND ELEVATIONS ARE IN METRES.
5. ELEVATIONS ARE BASED ON CANADIAN GEODETIC VERTICAL DATUM 1928.
6. LOCATIONS OF SHORELINES ARE APPROXIMATE ONLY AND RELATE TO THE DATE OF PHOTOGRAPHY.
7. CONTOUR INTERVAL IS 2 METRES.
8. LOCATION AND PRESENTATION OF CONCRETE AND EARTHFILL STRUCTURES IS PRELIMINARY.
9. STATIONING IS BASED ON DISTANCE ALONG THE NORTH AND SOUTH BANK EARTH STRUCTURES' AXES AND CENTERLINES FOR AXIS GR-3 ALTERNATIVE ARRANGEMENT WITH FULL SUPPLY LEVEL AT EL 159.0 FOR THE NORTH BANK STATION 0+00 IS LOCATED AT COORDINATES 6 246 876.230 N AND 364 450.762 E. FOR THE SOUTH BANK STATION 0+00 IS LOCATED AT COORDINATES 6 246 476.050 N AND 364 543.280 E.
10. THE REFERENCE POINTS ARE LOCATED AT THE STATIONS WHERE THE NORTH AND SOUTH DYKE CENTERLINES FOR AXIS GR-4 INTERSECT WITH THE NORTH AND SOUTH DYKE CENTERLINES FOR AXIS GR-3 ALTERNATIVE ARRANGEMENT. FOR THE NORTH DYKE IT IS STA 15+65.000 (N) AND FOR THE SOUTH DYKE IT IS STA 38+57.000 (S).
11. THE REFERENCE POINT IS LOCATED AT THE INTERSECTION OF THE AXIS OF THE NORTH DAM AND THE CENTERLINE OF THE NORTH DYKE AND IS AT COORDINATES 6 247 407.573 N, 363 884.861 E.
12. THE REFERENCE POINT IS LOCATED AT THE INTERSECTION OF THE AXIS OF THE SOUTH DAM AND THE CENTERLINE OF THE SOUTH DYKE AND IS AT COORDINATES 6 245 178.480 N, 363 186.860 E.

SCALE 1:5000

100 0 100 200 300 400 500 METRES

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ACRES MANITOBA LIMITED

MANITOBA HYDRO

KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN THE SPILLWAY AREA
PRINCIPAL STRUCTURE

DRAWN
CHECK
SCALE AS SHOWN
DATE

FIGURE 1 — SHT. 0001 REV. 00

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AUTOCAD ORIGINAL

E SIZE - 471 x 862

SHT.	REV.
0001	00

FIGURE 2

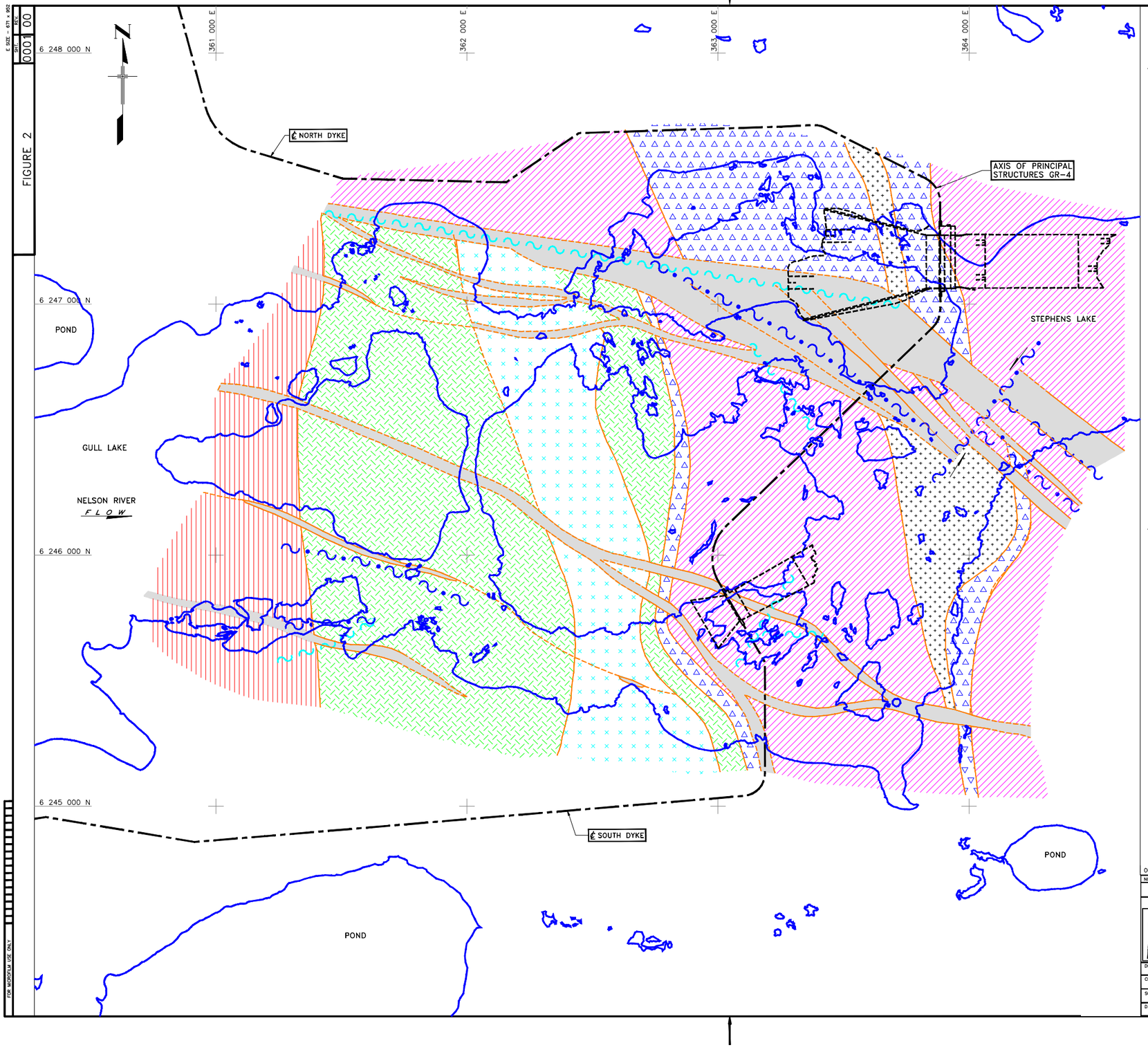

FIGURE 2

SHT.	REV.
0001	00

LEGEND:

AGE (SEE NOTE 6)		ROCK UNITS IDENTIFIED ON GEOLOGICAL PLAN (SEE NOTE 4)
PRECAMBRIAN	PALEO-PROTEROZOIC	MAFIC DYKES (DIABASE AND GABBRO) TYPICALLY IDENTIFIED ON DRILL LOGS AS DIABASE DYKES
	ARCHEAN FELSIC INTRUSIVE ROCKS	GRANITOID INJECTIONS AND PEGMATITE SUBUNITS INCLUDE LEUCOGRANITE, GRANODIORITE AND TONALITE TYPICALLY IDENTIFIED ON DRILL LOGS AS GRANITE/PEGMATITE
		GRANODIORITE AUGEN GNEISS TYPICALLY IDENTIFIED ON DRILL LOGS AS GRANITE/GRANITE GNEISS
		LEUCOGRANODIORITE AND DERIVED GNEISS TYPICALLY IDENTIFIED ON DRILL LOGS AS GRANITE/GRANITE GNEISS
		GRANODIORITE L-TECTONITE TYPICALLY IDENTIFIED ON DRILL LOGS AS GRANITE GNEISS
	ARCHEAN SUPRACRUSTAL ROCKS	METASEDIMENTARY ROCKS, METAGREYWACKE, INTERLAYERED PELITE AND PSAMMITE TYPICALLY IDENTIFIED ON DRILL LOGS AS GREYWACKE GNEISS
		MAFIC VOLCANIC ROCKS, AMPHIBOLITE INTERPRETED AS METABASALT, MASSIVE TO LAMINATED TYPICALLY IDENTIFIED ON DRILL LOGS AS AMPHIBOLITE
		GEOLOGICAL CONTACT (DEFINED, INFERRED)
		DUCTILE DEFORMATION ZONE (SHEAR, FAULT)
		BRITTLE DEFORMATION ZONE (INTENSE JOINTING AND FRACTURING)
		SHORELINE

NOTES:

1. LOCATIONS OF SHORELINES ARE APPROXIMATE AND WERE PRODUCED USING PHOTOGRAMMETRIC METHODS BASED ON 1:20 000 SCALE PHOTOGRAPHY DATED OCTOBER 1986.
2. THE COORDINATE GRID IS BASED ON UNIVERSAL TRANSVERSE MERCATOR SYSTEM, ZONE 15, NORTH AMERICAN DATUM 1983.
3. COORDINATES ARE IN METRES.
4. BEDROCK LITHOLOGIES IN LEGEND ARE BASED ON SURFACE BEDROCK MAPPING INVESTIGATIONS (SEE NOTE 5) AND AS BEDROCK LITHOLOGIES TYPICALLY IDENTIFIED ON DRILL LOGS.

   EXAMPLE:

   METASEDIMENTARY ROCKS, METAGREYWACKE, INTERLAYERED PELITE AND PSAMMITE BASED ON THE NOMENCLATURE FROM THE MANITOBA GEOLOGICAL SURVEY "REPORT OF ACTIVITIES 2004", MANITOBA INDUSTRY, ECONOMIC DEVELOPEMENT AND MINES MANITOBA GEOLOGICAL SURVEY, 2004, 171-189.

   TYPICALLY IDENTIFIED ON DRILL LOGS AS GREYWACKE GNEISS BASED ON THE NOMENCLATURE FROM MANITOBA HYDRO, JUNE 1995, "NELSON RIVER STUDIES, GULL GENERATING STATION, 1991 SUMMER SUBSURFACE INVESTIGATION PROGRAM", REPORT NO. PSPD 95-3.
5. THIS REGIONAL GEOLOGY MAP IS BASED ON FIGURE GS-13 FROM THE MANITOBA GEOLOGICAL SURVEY "REPORT OF ACTIVITIES 2004", MANITOBA INDUSTRY, ECONOMIC DEVELOPEMENT AND MINES MANITOBA GEOLOGICAL SURVEY, 2004, 171-189.
6. ARCHEAN RELATIVE AGES NOT IMPLIED.

SCALE 1:6000

100 0 100 200 300 400 500 600 METRES

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ACRES MANITOBA LIMITED

MANITOBA HYDRO

KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS
IN SPILLWAY AREA
REGIONAL BEDROCK GEOLOGY

FIGURE 2

SHT.	REV.
0001	00

DRAWN

CHECK

SCALE AS SHOWN

DATE

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AUTOCAD ORIGINAL

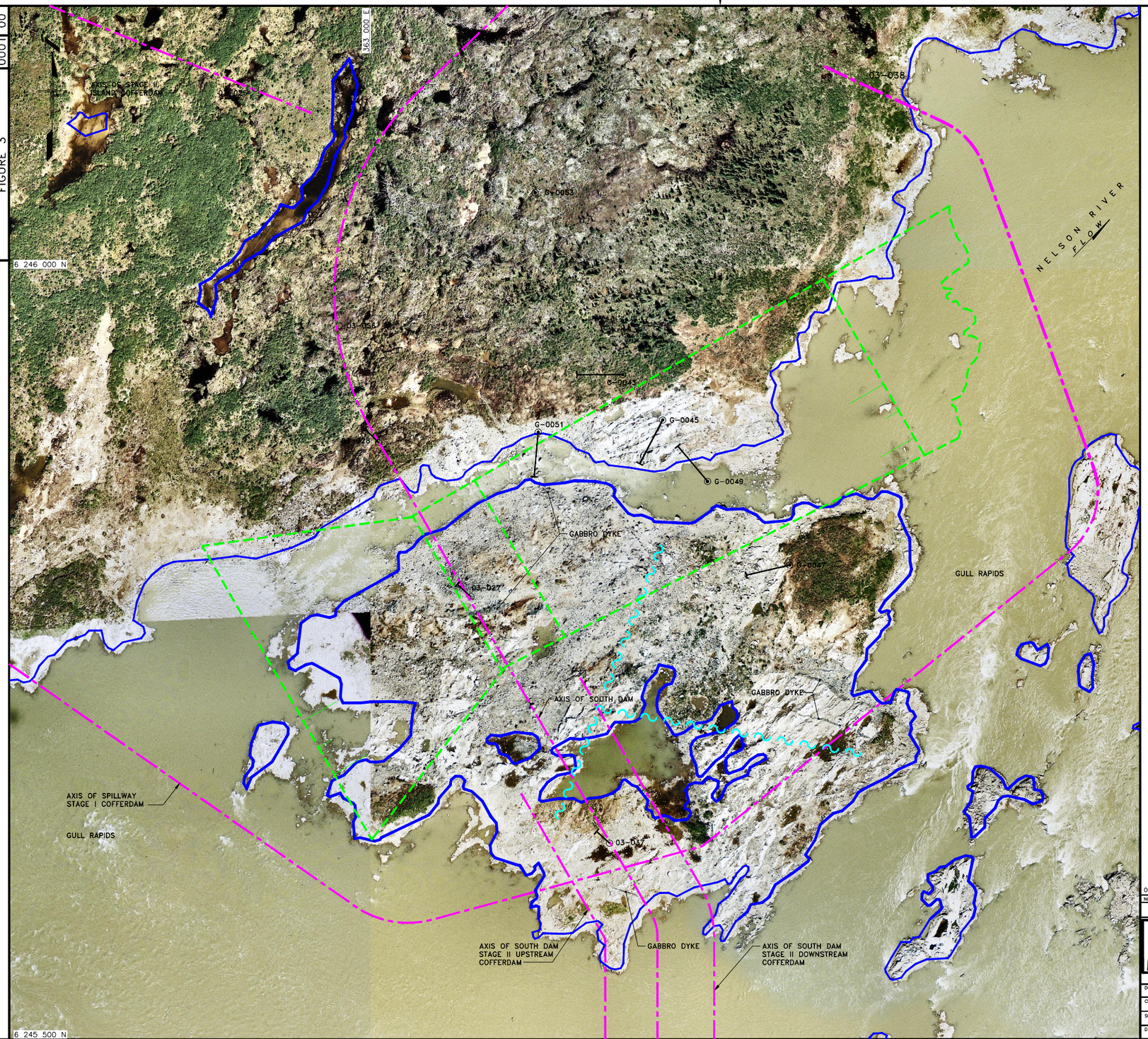

FIGURE 3 | SHT. 0001 | REV. 00

LEGEND:

- SHORELINE (SEE NOTE 2)
- OUTLINE OF SPILLWAY AND SPILLWAY CHANNELS
- FAULT
- DIAMOND DRILL HOLE, PRIOR TO SUMMER 2003 EXPLORATION (VERTICAL, INCLINED)
- EXPLORATION HOLE, SUMMER 2003 (VERTICAL, INCLINED) (SEE NOTE 7)
- G-0031 / 03-023 — EXPLORATION HOLE NUMBERS
- COORDINATE GRIDMARKER (LOCATED AT 500 METRE INTERVALS)

NOTES:

1. ORTHOGRAPHIC PHOTOGRAPHS ARE DATED JUNE 2003.
2. LOCATION OF SHORELINES ARE APPROXIMATE AND RELATE TO MAPPING PRODUCED USING PHOTOGRAMMETRIC METHODS BASED ON 1:20 000 SCALE PHOTOGRAPHY DATED OCTOBER 1986.
3. COORDINATE GRID SHOWN IS BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 15, NORTH AMERICAN DATUM 1983.
4. THE OVERBURDEN IN THE SPILLWAY AREA WAS REMOVED DURING ICE STAGING IN 2000.
5. BEDROCK IN THE SPILLWAY AREA CONSISTS OF METASEDIMENTARY ROCKS, META GREYWACKE, INTERLAYERED PELITE AND PSAMMITE. THE BEDROCK IS TYPICALLY IDENTIFIED ON THE DRILL LOGS AS GREYWACKE GNEISS. MAFIC DYKES (DIABASE AND GABBRO) ARE FOUND THROUGHOUT THE SPILLWAY AREA, AND ARE TYPICALLY IDENTIFIED ON THE DRILL LOGS AS DIABASE DYKES.
6. FOR THE REGIONAL BEDROCK GEOLOGY REFERENCE FIGURE 2.
7. SUMMER 2003 EXPLORATIONS ARE SHOWN AT THEIR PROPOSED LOCATION.

SCALE 1:1000 — 20 0 20 40 60 80 100 METRES

NO.	DATE	REVISIONS	BY	CKD.	APP.
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ACRES MANITOBA LIMITED

MANITOBA HYDRO

KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS
IN THE SPILLWAY AREA
ORTHOGRAPHIC PHOTOGRAPHS

DRAWN | CHECK | SCALE AS SHOWN | DATE

FIGURE 3 | SHT. 0001 | REV. 00

FOR MODRUM USE ONLY

E SIZE - 671 x 862 | SHT. 0001 | REV. 00

AUTOCAD ORIGINAL

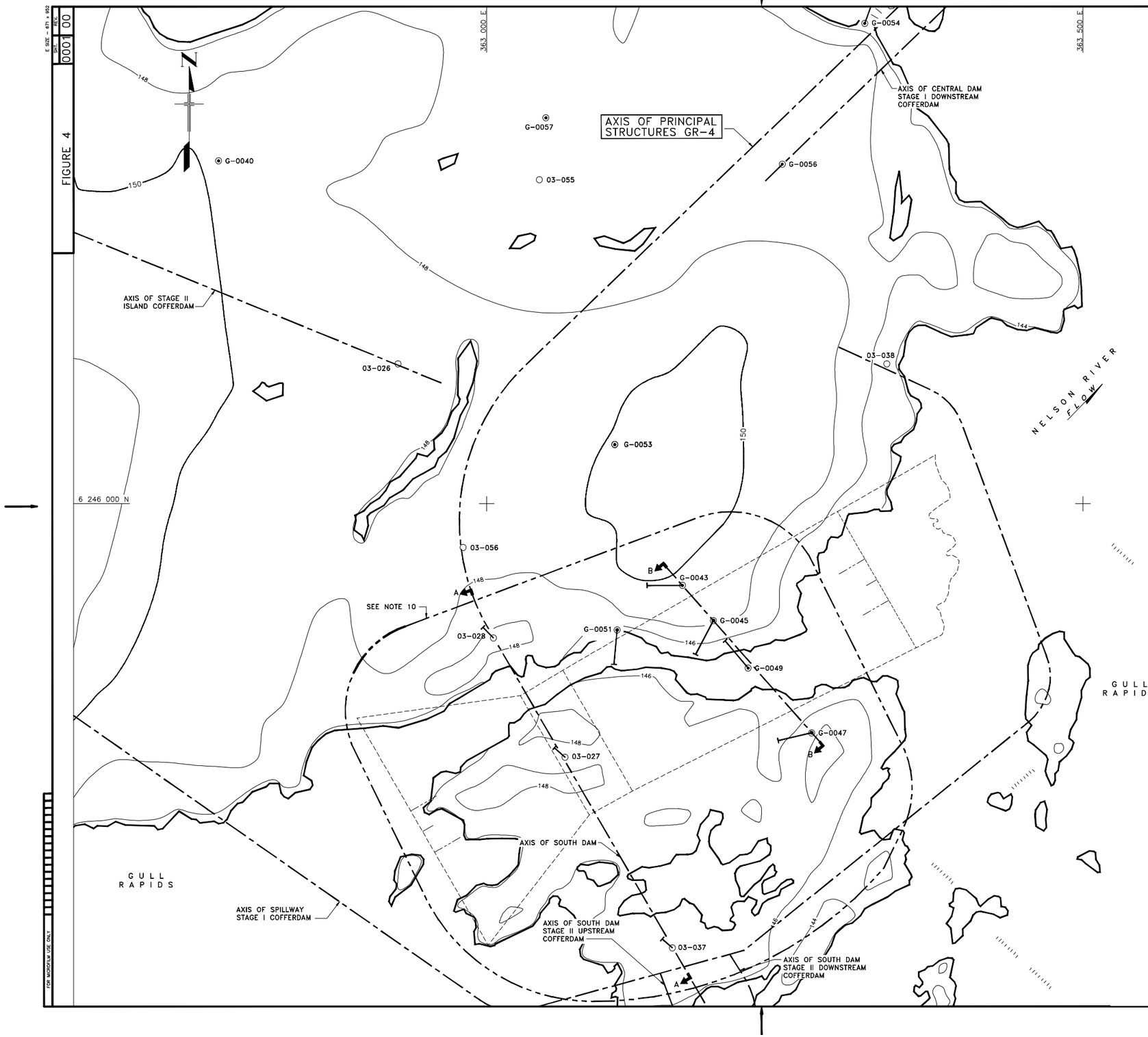

FIGURE 4 — SHT. 0001 REV. 00

LEGEND:

- SHORELINE (SEE NOTE 6)
- 144 — GROUND SURFACE CONTOUR (SEE NOTE 7)
- RAPIDS
- OUTLINE OF SPILLWAY AND SPILLWAY CHANNELS
- DIAMOND DRILL HOLE, PRIOR TO SUMMER 2003 EXPLORATION (VERTICAL, INCLINED)
- EXPLORATION HOLE, SUMMER 2003 (VERTICAL, INCLINED)
- G-0031 / 03-023 — EXPLORATION HOLE NUMBERS
- COORDINATE GRIDMARKER (LOCATED AT 500 METRE INTERVALS)

NOTES:

1. TOPOGRAPHY IS BASED ON MAPPING RECEIVED BY ACRES MANITOBA LIMITED FROM MANITOBA HYDRO MARCH 2004.
2. MAPPING WAS PRODUCED USING PHOTOGRAMMETRIC METHODS BASED ON 1:20 000 SCALE PHOTOGRAPHY DATED OCTOBER 1986.
3. COORDINATE GRID SHOWN IS BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 15, NORTH AMERICAN DATUM 1983.
4. COORDINATES AND ELEVATIONS ARE IN METRES.
5. ELEVATIONS ARE BASED ON CANADIAN GEODETIC VERTICAL DATUM 1928.
6. LOCATIONS OF SHORELINES ARE APPROXIMATE AND RELATE TO THE DATE OF PHOTOGRAPHY.
7. CONTOUR INTERVAL IS 2 METRES.
8. FOR GEOLOGICAL SECTION A–A AND B–B SEE FIGURES 5 AND 6 RESPECTIVELY.
9. TOPOGRAPHY HAS NOT BEEN ADJUSTED TO CONFORM TO TEST PIT OR DRILL HOLE INFORMATION.
10. ANALYSIS OF SPILLWAY AREA BEDROCK CONDITIONS ARE BASED ON EXPLORATION HOLES WITHIN THIS AREA.

SCALE 1:1250

25 0 25 50 75 100 125 METRES

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ACRES MANITOBA LIMITED

MANITOBA HYDRO

KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITION
IN THE SPILLWAY AREA
LOCATION OF EXPLORATION
& GEOLOGICAL SECTION

DRAWN
CHECK
SCALE AS SHOWN
DATE

FIGURE 4 — SHT. 0001 REV. 00

FOR MORPHUM USE ONLY

AUTOCAD ORIGINAL

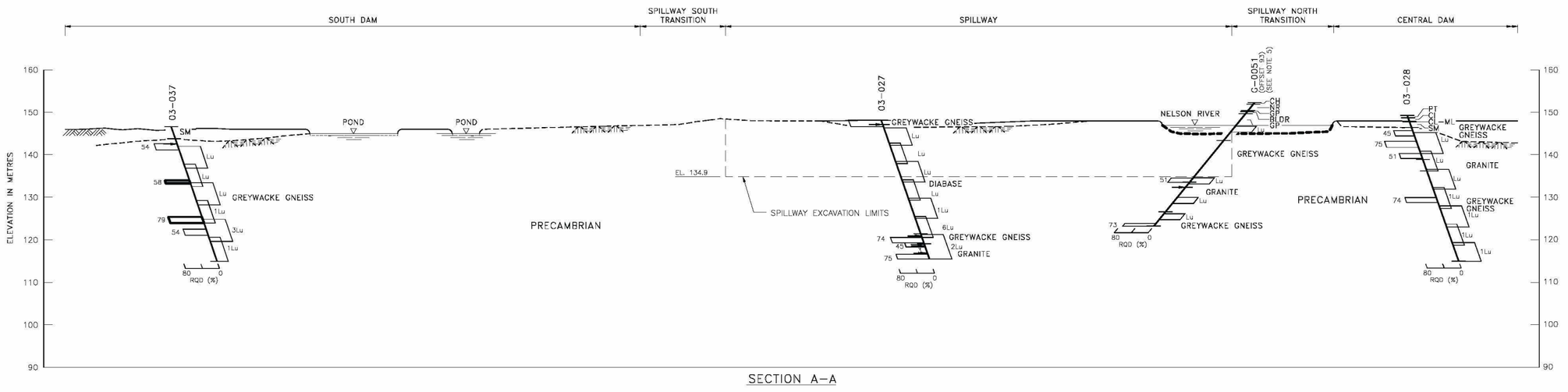
E SIZE - 671 x 892

SHT.	REV.
0001	00

FIGURE 5

FIGURE 5

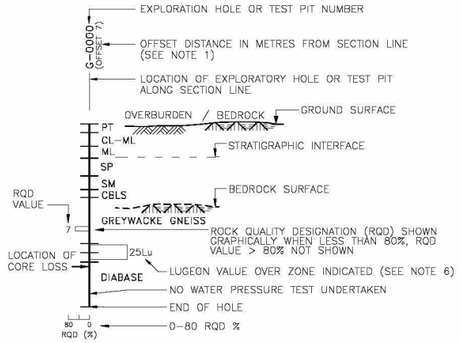
SHT.	REV.
0001	00



SECTION A–A

LEGEND:

EXPLORATION HOLE



CL–ML	UNIFIED SOIL CLASSIFICATION SYMBOL
CBLS	COBBLES
BLDR	BOULDER
GREYWACKE GNEISS, DIABASE	ROCK TYPE
NR	NO RECOVERY
▽	LAKE, RIVER OR POND WATER LEVEL

SOIL CLASSIFICATION SYMBOLS

BASED UPON THE UNIFIED SOILS CLASSIFICATION SYSTEM

PT	PEAT, MUSKEG, HIGHLY ORGANIC SOILS
OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY
CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
CI	INORGANIC CLAYS OF INTERMEDIATE PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS
OL	ORGANIC SILTS AND ORGANIC SILT–CLAYS OF LOW PLASTICITY
CL	INORGANIC CLAYS OF LOW PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS WITH SLIGHT PLASTICITY
SC	CLAYEY SANDS, POORLY GRADED SAND–CLAY MIXTURES
SM	SILTY SANDS, POORLY GRADED SAND–SILT MIXTURES
SP	POORLY GRADED SANDS, GRAVELLY SANDS; LITTLE OR NO FINES
SW	WELL GRADED SANDS, GRAVELLY SANDS; LITTLE OR NO FINES
GC	CLAYEY GRAVELS, POORLY GRADED GRAVEL–SAND–CLAY MIXTURES
GM	SILTY GRAVELS, POORLY GRADED GRAVEL–SAND–SILT MIXTURES
GP	POORLY GRADED GRAVELS, GRAVEL–SAND MIXTURES, LITTLE OR NO FINES
GW	WELL GRADED GRAVELS, GRAVEL–SAND MIXTURES; LITTLE OR NO FINES
CL–ML, GP–GC, SP–SM, ETC.	TYPICAL BORDER LINE CLASSIFICATION REQUIRING THE USE OF DUAL SYMBOLS

NOTES

1. OFFSET DISTANCE SHOWN IF GREATER THAN 5 METRES FROM SECTION LINE.
2. FOR LOCATION OF GEOLOGICAL SECTION A–A SEE FIGURE 4.
3. WHENEVER POSSIBLE THE GROUND SURFACE PROFILES WERE ADJUSTED TO CONFORM TO THE INFORMATION FROM THE DRILL HOLES OR TEST PITS WHICH ARE WITHIN 5 METRES FROM THE SECTION LINES AND THEREFORE THEY MAY DIFFER FROM THAT SHOWN BY THE CONTOURS ON FIGURE 4.
4. ELEVATIONS ARE BASED ON CANADIAN GEODETIC VERTICAL DATUM 1928.
5. THE OVERBURDEN IN THE SPILLWAY AREA WAS REMOVED DURING ICE STAGING IN 2000. THEREFORE, BOREHOLES DRILLED PRIOR TO 2000 IN THIS AREA MAY SHOW OVERBURDEN OVERLYING BEDROCK, WHICH HAS SUBSEQUENTLY BEEN REMOVED.
6. Lu REPRESENTS ZERO LUGEONS.

SCALE 1:400

10 0 10 20 30 40 METRES

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ACRES MANITOBA LIMITED

MANITOBA HYDRO

KEEYASK GENERATING STATION

STAGE IV STUDIES – AXIS GR–4
REVIEW OF BEDROCK CONDITIONS
IN THE SPILLWAY AREA
GEOLOGICAL SECTION A–A

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FIGURE 5

SHT.	REV.
0001	00

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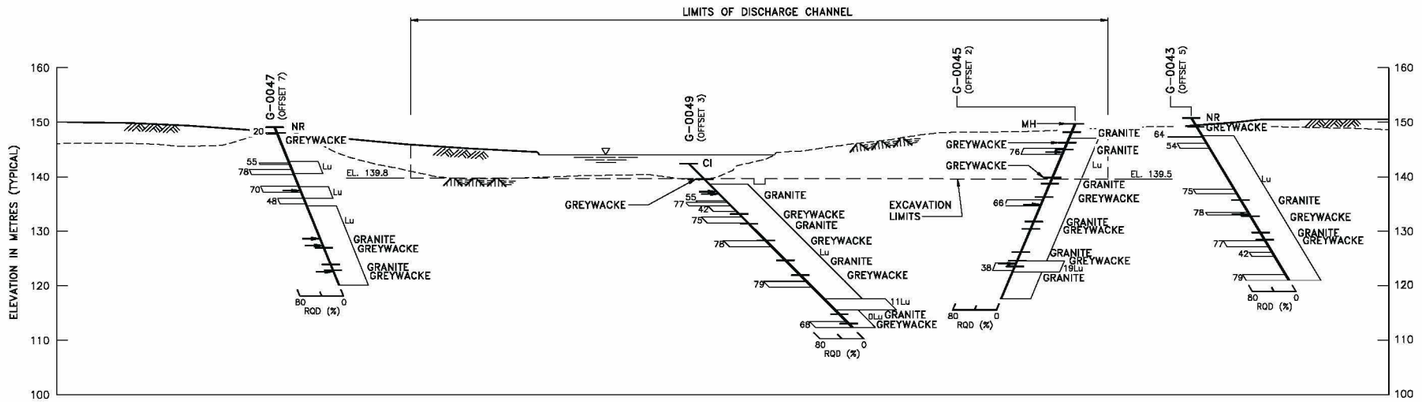
FIGURE 6 | SHT. 0001 | REV. 00



SECTION B–B

LEGEND:

EXPLORATION HOLE

- G-0273 (OFFSET 7): EXPLORATION HOLE OR TEST PIT NUMBER
- (OFFSET 7): OFFSET DISTANCE IN METRES FROM SECTION LINE (SEE NOTE 1)
- LOCATION OF EXPLORATORY HOLE OR TEST PIT ALONG SECTION LINE
- OVERBURDEN / BEDROCK — GROUND SURFACE
- PT, CL–ML, ML, SP, SM, CBLS — STRATIGRAPHIC INTERFACE
- BEDROCK SURFACE
- RQD VALUE: GREYWACKE GNEISS
- 65: ROCK QUALITY DESIGNATION (RQD) SHOWN GRAPHICALLY WHEN LESS THAN 80%, RQD VALUE > 80% NOT SHOWN
- LOCATION OF CORE LOSS: 25Lu — DIABASE — LUGEON VALUE OVER ZONE INDICATED (SEE NOTE 6)
- NO WATER PRESSURE TEST UNDERTAKEN
- END OF HOLE
- 80 / 0 RQD (%): 0–80 RQD %

CL–ML	UNIFIED SOIL CLASSIFICATION SYMBOL
CBLS	COBBLES
BLDR	BOULDER
GREYWACKE GNEISS, DIABASE GRANITE AMPHILBOLITE	ROCK TYPE
NR	NO RECOVERY
	LAKE, RIVER OR POND WATER LEVEL

SOIL CLASSIFICATION SYMBOLS:

BASED UPON THE UNIFIED SOILS CLASSIFICATION SYSTEM

PT	PEAT, MUSKEG, HIGHLY ORGANIC SOILS
OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY
CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
CI	INORGANIC CLAYS OF INTERMEDIATE PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS
OL	ORGANIC SILTS AND ORGANIC SILT–CLAYS OF LOW PLASTICITY
CL	INORGANIC CLAYS OF LOW PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS WITH SLIGHT PLASTICITY
SC	CLAYEY SANDS, POORLY GRADED SAND–CLAY MIXTURES
SM	SILTY SANDS, POORLY GRADED SAND–SILT MIXTURES
SP	POORLY GRADED SANDS, GRAVELLY SANDS; LITTLE OR NO FINES
SW	WELL GRADED SANDS, GRAVELLY SANDS; LITTLE OR NO FINES
GC	CLAYEY GRAVELS, POORLY GRADED GRAVEL–SAND–CLAY MIXTURES
GM	SILTY GRAVELS, POORLY GRADED GRAVEL–SAND–SILT MIXTURES
GP	POORLY GRADED GRAVELS, GRAVEL–SAND MIXTURES, LITTLE OR NO FINES
GW	WELL GRADED GRAVELS, GRAVEL–SAND MIXTURES; LITTLE OR NO FINES
CL–ML, GP–GC, SP–SM, ETC.	TYPICAL BORDER LINE CLASSIFICATION REQUIRING THE USE OF DUAL SYMBOLS

FROZEN GROUND SYMBOLS:

Frozen	SEASONAL FROST
Nf	POORLY BONDED OR FRIABLE ICE
Nbn	WELL BONDED, NO EXCESS ICE
Nbe	WELL BONDED, EXCESS ICE
Vx	INDIVIDUAL ICE CRYSTALS OR INCLUSIONS
Vc	ICE COATINGS ON PARTICLES
Vr	RANDOM OR IRREGULARLY ORIENTED ICE FORMATIONS
Vs	STRATIFIED OR DISTINCTLY ORIENTED ICE FORMATIONS
Ice + UNIFIED SOILS CLASSIFICATION	ICE WITH SOIL INCLUSIONS
Ice	ICE WITHOUT SOIL INCLUSIONS

NOTES:

1. OFFSET DISTANCE SHOWN IF GREATER THAN 5 METRES FROM SECTION LINE.
2. FOR LOCATION OF GEOLOGICAL SECTION B–B SEE FIGURE 4.
3. THE GROUND SURFACE PROFILE IS BASED ON MAPPING RECEIVED BY ACRES MANITOBA LIMITED FROM MANITOBA HYDRO MARCH 2004.
4. ELEVATIONS ARE BASED ON CANADIAN GEODETIC VERTICAL DATUM 1928.
5. THE OVERBURDEN IN THE SPILLWAY AREA WAS REMOVED DURING ICE STAGING IN 2000. THEREFORE, BOREHOLES DRILLED PRIOR TO 2000 IN THIS AREA MAY SHOW OVERBURDEN OVERLYING BEDROCK, WHICH HAS SUBSEQUENTLY BEEN REMOVED.
6. Lu REPRESENT ZERO LUGEONS.

SCALE 1:400 — 10 0 10 20 30 40 METRES

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ACRES MANITOBA LIMITED

MANITOBA HYDRO

KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR–4
REVIEW OF BEDROCK CONDITIONS
IN THE SPILLWAY AREA
GEOLOGICAL SECTION B–B

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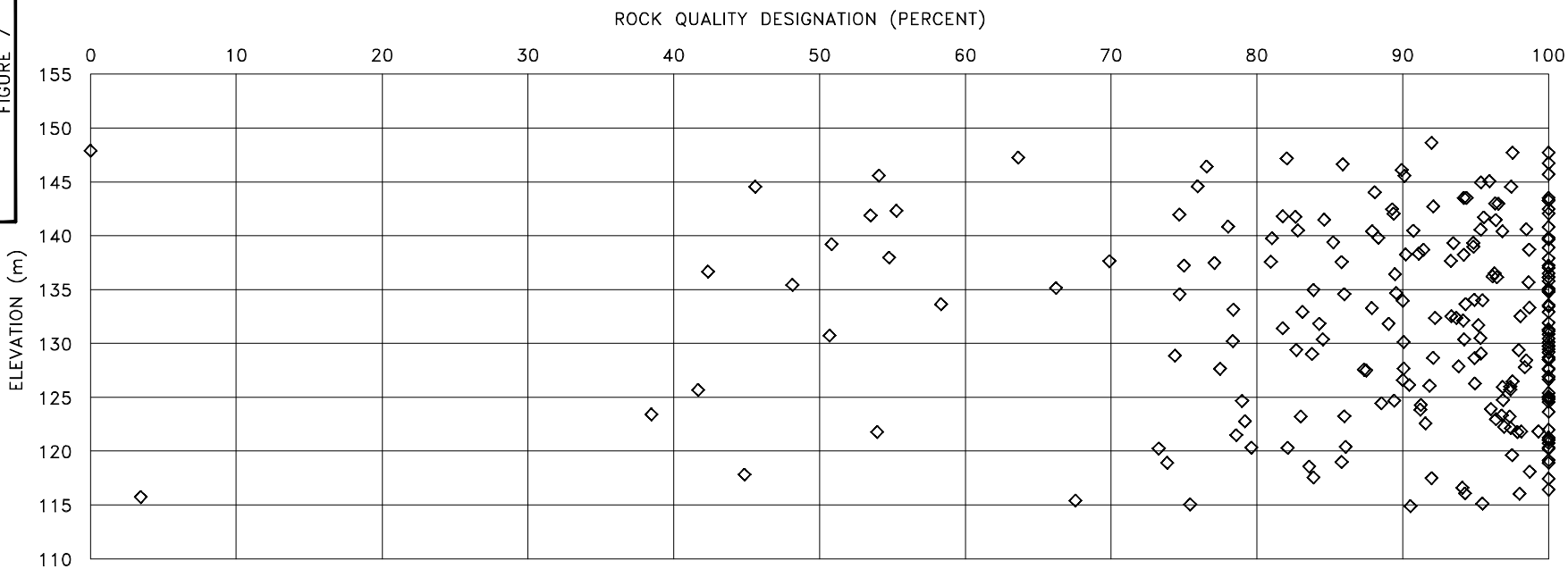
FIGURE 6 | SHT. 0001 | REV. 00

FIGURE 7 | SHT. 0001 | REV. 00



NOTES:

1. THE VERTICAL ELEVATION IS TO THE MIDDLE OF THE DRILL RUN.
2. ELEVATIONS ARE BASED ON CANADIAN GEODETIC VERTICAL DATUM 1928.
3. A TOTAL OF 221 RQD VALUES ARE SHOWN.
4. TWO DRILL RUNS WERE RECORDED WITH RQD VALUES < 10%. GENERALLY THESE OCCURED AT THE START OF A RUN WHEN THE DRILL BIT WAS BLOCKED. THE BLOCKED DRILL BIT WAS A RESULT OF CLOSELY SPACED JOINTS.

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KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN THE SPILLWAY AREA
RQD VALUES VS ELEVATION

FIGURE 7 | SHT. 0001 | REV. 00

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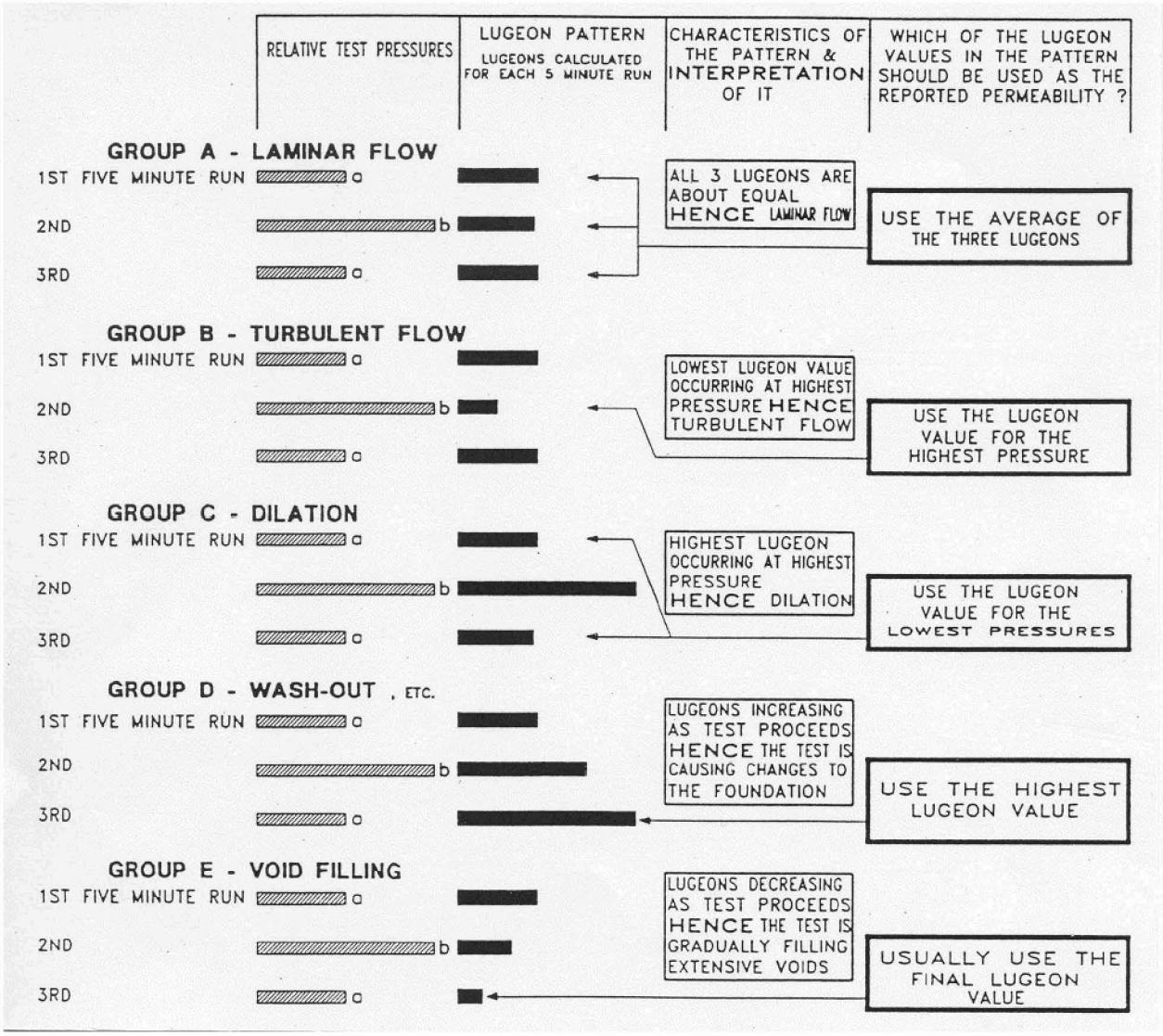

NOTES:

1. THIS TABLE GIVES GENERAL PATTERNS ONLY. DISCRETION HAS BEEN USED IN ADAPTING THESE TO THE INEVITABLE VARIATIONS MET IN PRACTICE.
2. MODIFIED AFTER HOULSBY, A.C. 1976. ROUTINE INTERPRETATION OF THE LUGEON WATER TEST. QUARTERLY JOURNAL OF ENGINEERING GEOLOGY, VOL. 9, 1976. PP.303–313.

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KETTLE GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN THE SPILLWAY AREA
2003 SUMMER EXPLORATION PROGRAM
PATTERNS FOR LUGEON WATER PRESSURE TEST INTERPRETATION

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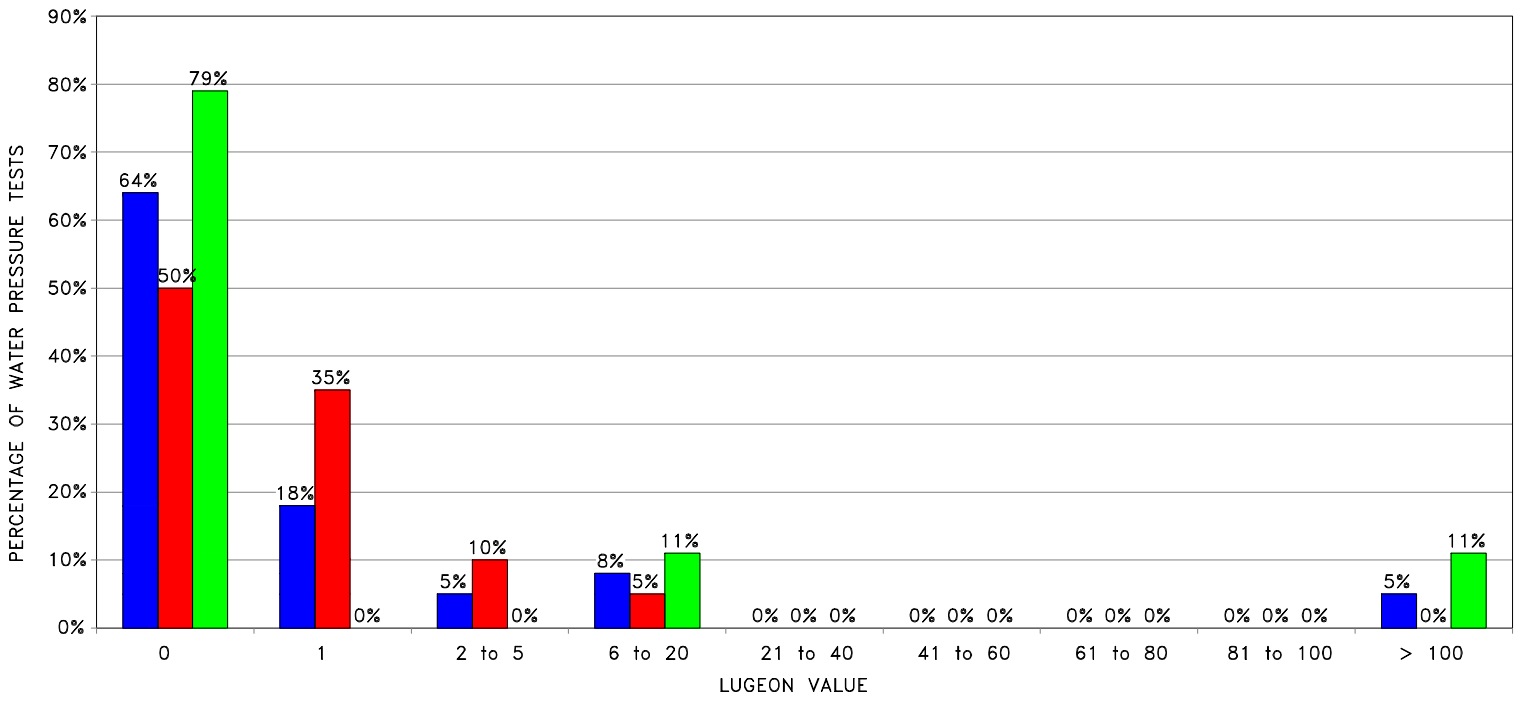
DATE

FIGURE 8 SHT. 0001 REV. 00

FIGURE 9 | SHT. 0001 | REV. 00



LEGEND:

- SUMMATION OF ALL EXPLORATION PROGRAMS
- 2003 EXPLORATION PROGRAM
- SUMMATION OF EXPLORATION PROGRAMS PRIOR TO 2003

NOTES:

1. A TOTAL OF 39 WATER PRESSURE TESTS WERE UNDERTAKEN IN THE SPILLWAY AREA.
2. A TOTAL OF 175.9 METRES OF ROCK WAS WATER PRESSURE TESTED, INCLUDING THE OVERLAP OF THE TEST ZONES.
3. WATER PRESSURE TESTS EXCEEDING PUMP CAPACITY OR GREATER THAN 100 LUGEONS ARE ASSIGNED A VALUE OF 101.
4. THE ADDITIVE SUM OF THE PERCENTAGES MAY NOT ADD UP TO 100% DUE TO ROUNDING.
5. 0 PRACTICALLY IMPERMEABLE
   1 TO 5 LOW PERMEABILITY
   6 TO 100 MEDIUM PERMEABILITY
   > 100 HIGH PERMEABILITY

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STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN THE SPILLWAY AREA
RANGE OF WATER PRESSURE TEST RESULTS

FIGURE 9 | SHT. 0001 | REV. 00

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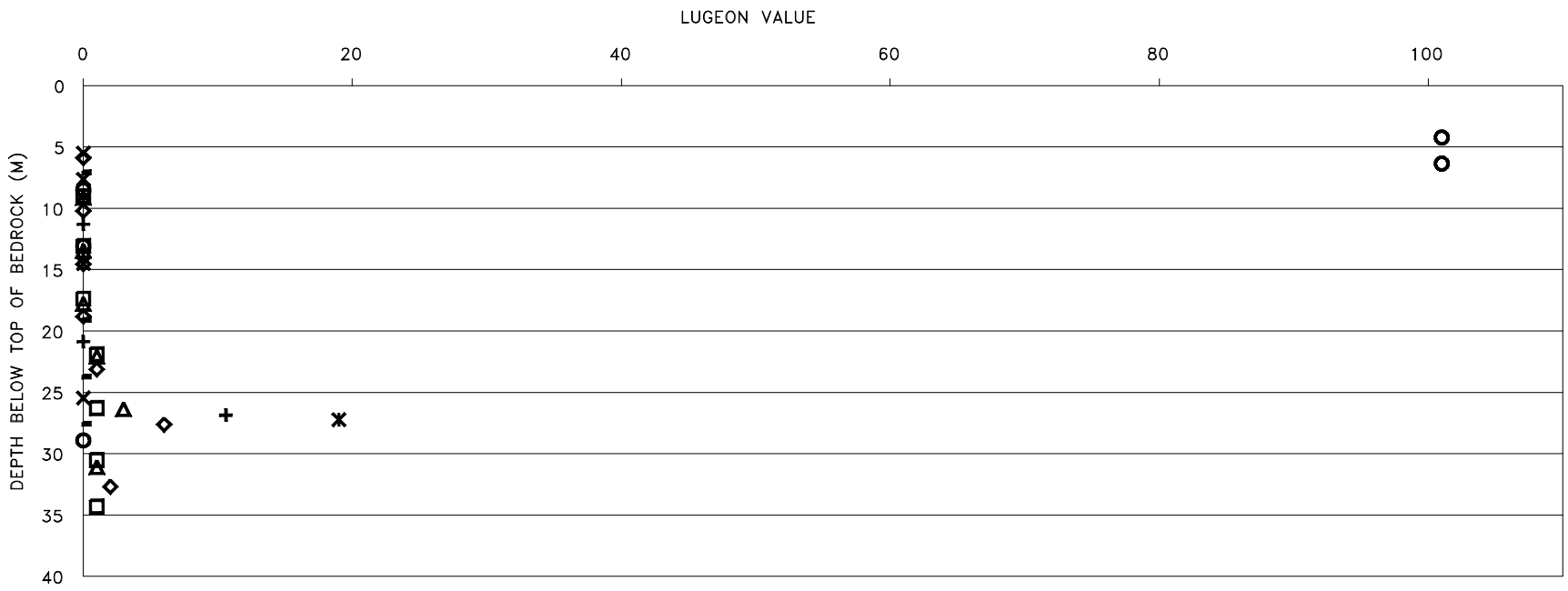
FIGURE 10 | SHT. 0001 | REV. 00



LEGEND:

◇ 03-027	✕ G-0043	+ G-0049
□ 03-028	✱ G-0045	▬ G-0051
△ 03-037	○ G-0047	

NOTES:

1. VERTICAL DEPTH TO MIDDLE OF TEST ZONES.
2. TEST ZONE LENGTHS ALONG CORE AXIS VARIES BETWEEN 2.0 AND 20.4 METRES, AVERAGING 4.5 METRES.
3. A TOTAL OF 39 WATER PRESSURE TESTS WERE UNDERTAKEN IN THE SPILLWAY AREA.
4. WATER PRESSURE TEST EXCEEDING PUMP CAPACITY, ARE ASSIGNED A VALUE OF 101.

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STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN THE SPILLWAY AREA
WATER PRESSURE TEST RESULTS
LUGEON VALUE VS DEPTH

FIGURE 10 | SHT. 0001 | REV. 00

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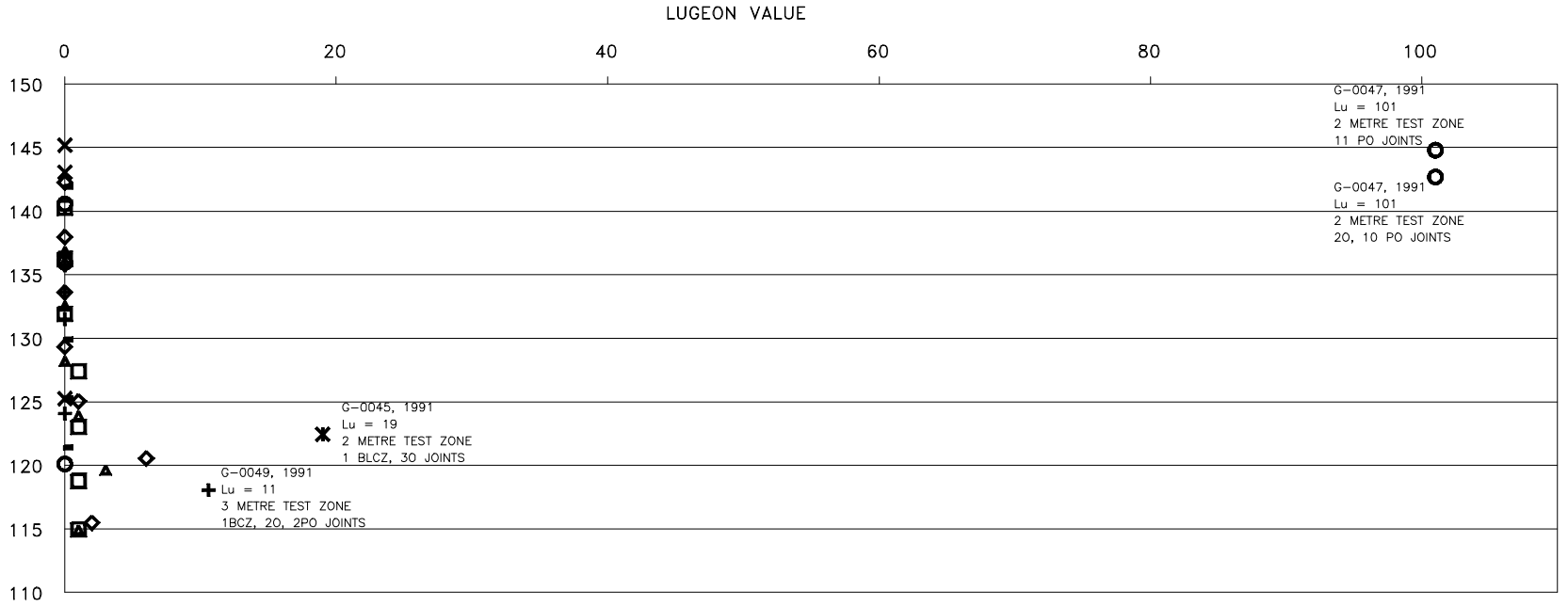
FIGURE 10 | SHT. 0001 | REV. 00

FIGURE 11 | SHT. 0001 | REV. 00



LEGEND:

03-027	G-0043	G-0049
03-028	G-0045	G-0051
03-037	G-0047	

NOTES:

1. ELEVATIONS ARE TO MIDDLE OF TEST ZONES.
2. ELEVATIONS ARE BASED ON CANADIAN GEODETIC VERTICAL DATUM 1928.
3. TEST ZONE LENGTHS ALONG CORE AXIS VARIES BETWEEN 2.0 AND 20.4 METRES, AVERAGING 4.5 METRES.
4. A TOTAL OF 39 WATER PRESSURE TESTS WERE UNDERTAKEN IN THE SPILLWAY AREA.
5. WATER PRESSURE TEST EXCEEDING PUMP CAPACITY, ARE ASSIGNED A VALUE OF 101.

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KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN THE SPILLWAY AREA
WATER PRESSURE TEST RESULTS
LUGEON VALUE VS ELEVATION

FIGURE 11 | SHT. 0001 | REV. 00

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AUTOCAD ORIGINAL

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FIGURE 12 — SHT. 0001 — REV. 00

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

Parameter			Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality *RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very favourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.

** Modified after Wickham et al (1972).

NOTES:

1. THIS TABLE USES SIX PARAMETERS TO CLASSIFY A ROCK MASS.

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KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN THE SPILLWAY AREA
ROCK MASS RATING SYSTEM
(AFTER BIENIAWSKI, 1989)

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FIGURE 12 — SHT. 0001 — REV. 00