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April 14, 2009
P10008(16).50.02

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 Powerhouse Area
Memorandum GN-1.5.4, Rev 0
Manitoba Hydro File 00195-11610-0017_02

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

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 H. Zbigniewicz
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-1.5.4
Rev. 0, April 14, 2009

Bedrock Geology
Review of Bedrock Conditions in the Powerhouse Area

Manitoba Hydro File 00195-11610-0017_02

Prepared by Phil Pantel (P. PANTEL) April 14, 2009
KGS Acres Ltd.

Checked by (W. Gendzelevich) April 14, 2009
KGS Acres Ltd.

Reviewed by (I.R. Dewar) April 14, 2009
KGS Acres Ltd.

Approved by (N.J. Smith) Apr 14, 2009
KGS Acres Ltd.

Accepted by Apr 22, 2009
Manitoba Hydro
P.S. MAGNUSSON

KGS Acres Ltd.
Winnipeg, Manitoba

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

Memorandum Name:	GN-1.5.4 Bedrock Geology - Review of Bedrock Conditions in the Powerhouse Area
Version / date:	Rev. 0 / April 14, 2009
Manitoba Hydro File:	00195-11610-0017_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 14, 2009
		File No.	P10008(16).50.02
From	P.R. Pantel, S.E. Nachtigall	**cc**	
Subject	**Keeyask Generating Station Stage IV Studies, Axis GR-4 Bedrock Geology Review of Bedrock Conditions In the Powerhouse Area Memorandum GN-1.5.4, Rev 0 Manitoba Hydro File 00195-11610-0017_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 eight diamond drill holes in the Powerhouse Area. Investigation of the bedrock in this area was undertaken in 1988, 1991, 1999 and 2003.

This memorandum discusses the preliminary results of the 2003 Powerhouse investigations, and the overall interpretation of the findings of all 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 investigation was 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.

(a) Material reconnaissance survey of Nelson River site, conducted in 1962 by Manitoba Hydro [Ref 2].

(b) Seismic survey conducted in 1962 by Geo-Recon Exploration [Ref 3].

(c) Geological mapping in 1963 between Birthday Rapids and downstream of Keeyask Rapids [Ref 4].

(d) 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].

(e) 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].

(f) Sonic drilling, hollow stem augering, diamond drilling and test pitting were conducted along the proposed dyke lines during the 1990/91 winter [Ref 12].

(g) 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].

(h) 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]. Geological mapping was also conducted in the Keeyask Rapids area.

(i) In the summer 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 north-eastern margin of the Superior Province in Manitoba. The Precambrian bedrock within the area consists of granite, amphibolite, greywacke gneiss and diabase. The greywacke gneiss contains bands or sills of granitic material throughout. Diabase occurs as continuous and discontinuous dikes, which have intruded the greywacke gneiss, amphibolite and granite rocks. The contacts between the diabase dikes 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 jointing. 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, 2003 and 2004 geological mapping programs, fracture/shear zones were observed within the bedrock outcrops to the south and west of the Powerhouse Area [Ref 13, 15, 16]. These zones are generally less than 0.5 m in width, inactive, and are typically healed or recrystallized and strong.

3.1 Geology of the Powerhouse Area

The Powerhouse Area consists of mafic volcanic and metasedimentary rocks (Archean Supracrustal rocks) with granitoid injections (Archean Felsic Intrusive rocks). In addition, mafic and ultramafic dykes (Paleoproterozoic rocks), have intruded into the mafic volcanic rocks and granitoid injections. A geological description of the rock types encountered in the Powerhouse Area is provided below.

Mafic Volcanic Rocks

Amphibolite interpreted as metabasalt, massive to laminated, composed of hornblende, plagioclase, epidote, chorite; interlayered with and intruded by medium to coarse grained

amphibolite (interpreted as metagabbro). The mafic volcanic rocks contain granitoid injections and mobilizate. The mafic volcanic rocks are identified in the drill hole logs as amphibolite.

Metasedimentary Rocks

Metagrewacke, 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.

Granitoid Injections and Pegmatite

Granitoid injections and pegmatite form intrusive veins and bodies in the mafic volcanic rocks. Granitic injection veins, sheets and bodies including leucocratic and locally contains 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.

Granodiorite and Derived Gneissic Rocks

Granodiorite augen gneiss injections, locally up to 25% biotite and amphibole. Observed in the granitoid injections. Granodiorite augen gneiss is identified in the drill hole logs as granite.

Mafic and Ultramafic Dykes

Diabase dykes, alphenitic to fine grained, occur up to a few metres wide. Gabbro dykes, medium to coarse grained, massive to weakly foliated, composed of amphibole, plagioclase and pyroxene, occur up to 50 m wide. Diabase and Gabbro are both identified in the drill hole logs as diabase.

Fault zones were not observed in the Powerhouse Area. However, a shear zone was identified in the south end of the Powerhouse Area. The shear zone is well healed, and strong.

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

4 Investigation Drilling Results for the Powerhouse Area

A total of nineteen drill holes were advanced in the Powerhouse Area. Fourteen of the nineteen drill holes were inclined holes, set at either a 45°, 60° or 70º angle to horizontal, to intercept bedrock joints in the Powerhouse Area. Thirteen holes were advanced down into the bedrock to about el 100 m, which is approximately 12 m below the lowest point of the proposed foundation of the Powerhouse structure. Some drill holes were drilled from a platform over shallow water in the north channel of the Nelson River.

Figures 3, 4 and 5 show the location of explorations and sections within the Powerhouse Area. A summary of the drilling data for those holes that have been used for the analyses contain 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 barrel rods will affect the quality of the sample obtained, with HQ and triple barrels typically producing samples with fewer machine-caused fractures.

4.1 Overburden

In the riverbed of the North Channel, the overburden consists of layers of sands and gravels, and till with occasional cobbles and boulders. The thickness of the overburden ranges from zero to 5.6 m.

4.2 Bedrock Lithology

The exploratory drill holes drilled within the Powerhouse Area encountered greywacke gneiss, amphibolite and granite. Diabase was also encountered in some of the holes drilled within the Powerhouse Approach Channel.

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

The amphibolite is typically described as being dark grey to black, very fine grained, strong, with distinct foliation.

The granite is typically described as being light grey/green to light pink/green, medium to coarse grained, 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 log in Appendix A.

In the Powerhouse Area, the percent recovery averaged 99% for all investigations. A core recovery percentage of 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 is classified as a core loss.

The zones where core loss occurred are summarized in Table 4.2. Individual core loss zones within the nineteen drill holes in the Powerhouse Area range between 10 mm to 260 mm (averaging 59 mm), excluding any core left the down 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 7.84 m to 8.20 m (360 mm length) in drill hole G-0016. The core loss within this zone is estimated to be 260 mm (72% of the zone). The zone is associated with drill action on closely spaced joints in faintly altered rock.

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 14 drill holes (73% of the holes), with lengths varying between 10 and 280 mm (averaging 105 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:

$$\text{RQD} = \frac{\sum \text{length of core pieces} > 10 \text{ cm length}}{\text{total length of core run}} \text{ x } 100\%$$

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 or 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 6.

The rock mass in the Powerhouse Area can be characterized as strong to very strong, with RQD values ranging from 37% to 100%, and averaging 90%. Generally the RQD values increase with depth. Below el 120 m, the RQDs for the subsequent runs are generally above 75%, indicating good to excellent rock quality.

There were four 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 bit was generally less than 10 mm in length, with two or more joints.

Out of 504 drill runs in the Powerhouse Area, 329 (65%) show that the bedrock is of excellent quality (RQD>90%). In addition, 124 (25%) show that the rock is of good quality, and 38 (8%) show that the rock is of fair quality. In summary, 453 (90%) of the drill runs show that the bedrock in the Powerhouse Area ranges between good to excellent quality.

The joint spacing is generally described as moderately spaced, averaging approximately 300 mm.

4.5 Water Pressure Tests

Water Pressure Testing (WPT) to determine the rock's permeability was undertaken, with the results being presented in terms of 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 lengths 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 7.

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 results greater than 100 Lu were 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 Powerhouse Area, are listed in Table 4.3. The following is a summary of the test results for the WPT conducted during the 1988, 1999 and 2003 investigation programs.

1988 and 1991 Investigations

Nine drill holes (BH G-0007, G-0008, G-0011 to G-0016 inclusive, and G-0204) totaling 376.10 m of bedrock drilling were advanced in the Powerhouse Area. A total of 66 WPT tests were conducted (in seven drill holes) on 148.0 m of bedrock (including the overlap of the test zones). The test stage lengths ranged between 2.0 to 3.0 m.

The results range from 0 (tight) to 74 Lu. Out of the 66 WPT tests conducted, 49 (74%) tests indicate that the rock is practically impermeable (0 Lu). In addition, 5 (8%) tests indicate that the rock has a low permeability (Lugeon value 1 to 5) and 11 (17%) of the tests indicate a medium permeability. In summary, 55 (83%) of the 66 tests conducted show that the bedrock permeability ranges from low to practically impermeable.

In general, the rock grades from relatively tight at depth to more permeable near the bedrock surface. However, one test in drill hole G-0008 (top of test zone 23.7 m) was conducted with the maximum pump capacity (i.e., >100 litres per minute). The significant features of this zone are three open joints and one partly open joint. Typically higher water takes, resulting in Lugeon values greater than 10, are associated with broken and/or core loss zones, or partly open joint features recorded on the Geological Detail Fracture Logs.

2003 Summer Investigation

Thirteen drill holes (BH 03-008 to 03-016 inclusive, and 03-022) totaling 299.86 m of bedrock drilling were advanced during the 2003 summer exploration program in the Powerhouse Area, along the currently planned axis for the Principal Structures. A total of 60 WPT were conducted on 319.69 m of bedrock (including the overlap of the test zones). The test stage length ranges from 3.2 to 8.9 m, averaging 5.3 m.

The results range from 0 (tight) to 18 Lu. Out of the 60 WPT conducted, 10 (17%) tests indicate that the rock is practically impermeable (0 Lu). In addition, 43 (72%) tests indicate that the rock has a low permeability (Lugeon value 1 to 5) and 7 (12%) of the tests indicate a medium permeability. In summary, 53 (88%) of the 60 tests conducted show that the bedrock permeability ranges from low to practically impermeable.

In general, the rock grades from relatively tight at depth to more permeable near the bedrock surface. Typically higher water takes, resulting in Lugeon values greater than 10, are associated with broken and/or core loss zones, or partly open joint features recorded on the Geological Detail Fracture Logs.

Combined Investigations

A total of 22 drill holes totaling 675.96 m of bedrock drilling were advanced in the Axis GR-4 Powerhouse Area. A total of 126 WPT were conducted in these 22 drill holes, within 467.69 m of bedrock (including the overlap of the test zones). The stage length ranges between 2.0 m and 8.9 m, averaging 3.7 m.

The range of the WPT results is shown in Figure 8. Out of the 126 WPT conducted, 59 (47%) tests show that the rock is practically impermeable (0 Lu). In addition, 48 (38%) tests show that the rock has a low permeability (Lugeon value 1 to 5) and 18 (14%) of the tests indicate a medium permeability. In summary, 107 (85%) of the 126 tests conducted show that the bedrock permeability ranges from low to practically impermeable. Figures 9 and 10 display the Lugeon values determined for all of WPT conducted in the Powerhouse Area with depth and elevation, respectively.

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

4.6 Evaluation of Jointing Trends

Typically the joints within the bedrock in the Powerhouse 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 Powerhouse Area, four major and two minor joints sets were identified from a total of 708 oriented core measurements, not including discontinuities described as healed. Jointing trends within the Powerhouse Area are summarized in Table 4.5 and are based on those holes listed in Table 4.1.

A polar density plot derived from oriented core measurements taken from boreholes drilled in the Powerhouse Area is presented in Appendix B, Figure B1. In addition, stereonet projections of the dominant Joint Sets J1 through J6 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 143 joints within the Powerhouse Area are identified as open, partly open or ground. Generally the open joints are subhorizontal and not confined to a particular joint set.

Slickensides

A total of 31 joints were noted to be slickensided. Based on the information available, it appears that movement which produced these slickensides is not confined to a particular joint set.

Clay Coated Joints

A total of 32 joints were noted as having clay or kaolinite coatings. Based on the information available, it appears that the clay coatings are not confined to a particular joint set.

As Table 4.2 indicates, a number of broken rock excavation, 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 conditions 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 Bieniawski'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 11. Each of the parameters is assigned a numeric value, which is dependant on the site 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 17] 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 Powerhouse Area at Keeyask GS, the majority of the joint sets will dip away from the excavations. For a thorough discussion of 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 Powerhouse 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 Powerhouse 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 Powerhouse 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 processes, unlike other engineering materials such as steel and 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 rock excavation. Therefore, it will be prudent to review the rock support requirement 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 the excavation of the Powerhouse 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 Powerhouse Area drill holes consist of greywacke gneiss, amphibolite, 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 an average RQD value of 90%. Local zones of low RQDs are associated with narrow zones of closely spaced jointing.

The average Lugeon value determined by the WPT is generally below 3, indicating that the bedrock has a low permeability. Local zones of medium permeability, generally with Lugeon values less than 20 Lu, are associated with open or partly open joints. The testing suggests tighter bedrock conditions exist at depth.

Four major and two minor joint sets have been identified in the Powerhouse 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 Powerhouse area is classified as fair to good quality rock.

Prepared By

P.R. Pantel

Attach
References
Tables 1 to 5.2
Photographs
Appendix A, B & C
Figures 1 to 11

PRP:spa

References

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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.

Table 2.1 Summary of Explorations Continued

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 Investigation Program, Axis GR-4
Powerhouse Area Drilling Summary

Exploratory Hole No.	Year	Location		Datum[4] (m)	Orientation (deg)		Depth (m - along core axis)			Approximate Elevation (m)		
		Northing	Easting		Dip from Horizontal	Azimuth	GWT [5]	B/R	E.O.H.	GWT [5]	B/R	E.O.H.
03-008 [1,2]	2003	6247318.18	363885.96	146.68	90	-	5.45	9.53	20.29	141.23	137.15	126.39
03-009 [1,2]	2003	6247197.78	364006.07	147.08	90	-	6.33	8.97	18.99	140.75	138.11	128.09
03-010 [1,2]	2003	6247251.96	363885.95	140.88	70	231	0.48	3.79	43.52	140.43	137.32	99.99
03-011 [1,2]	2003	6247197.86	363885.09	140.99	70	182	0.34	8.69	43.70	140.67	132.82	99.92
03-012 [1,2]	2003	6247196.75	363925.43	140.98	90	-	0.56	3.22	41.05	140.44	137.78	99.95
03-013 [1,2]	2003	6247157.44	363884.93	141.34	70	63	0.69	4.81	44.01	140.69	136.82	99.99
03-014 [1,2]	2003	6247137.86	363967.90	140.42	70	234	0.94	3.71	43.02	139.54	136.76	99.99
03-015 [1,2]	2003	6247116.58	363886.36	141.18	70	277	0.94	7.66	43.82	140.30	133.98	100.00
03-016 [1,2]	2003	6247097.05	363935.56	140.95	90	-	0.51	4.36	41.01	140.44	136.59	99.94
03-022 [1,2]	2003	6246995.98	363835.99	149.54	90	-	7.73	9.86	25.05	141.81	139.68	124.49
G-0007 [3]	1988	6247037.75	363927.70	140.19	45	13	N/R	3.86	28.94	N/R	137.46	119.73
G-0008 [3]	1991	6247317.44	363885.76	141.50	45	27	1.40	13.11	58.01	140.51	132.23	100.48
G-0011 [3]	1991	6247197.44	363885.65	140.05	45	195	0.00	0.94	55.44	140.05	139.39	100.85
G-0012 [3]	1991	6247197.40	363925.65	139.95	45	264	0.25	1.61	55.80	139.77	138.81	100.49
G-0013 [3]	1991	6247157.44	363885.62	136.91	60	270	-2.55	1.73	51.05	139.46	135.41	92.70
G-0014 [3]	1991	6247137.37	363965.59	140.11	60	206	0.00	4.03	46.10	140.11	136.62	100.19
G-0015 [3]	1991	6247117.44	363885.58	139.81	60	262	0.00	4.32	46.66	139.81	136.07	99.40
G-0016 [3]	1991	6247097.40	363935.56	139.76	60	12	0.00	4.73	42.36	139.76	135.66	103.08
G-0204 [3]	1999	6247194.62	363963.97	141.96	45	20	3.23	4.72	30.79	139.68	138.62	120.19

Notes:
(1) Permanent hole number 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) Datum varies: ground surface, barge platform or other.
(5) 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.
(6) Drill Holes 03-010 to 03-016 inclusive, were advanced from a drilling platform.
The elevation recorded is either the platform elevation or the top of the collar elevation.
(7) Elevations reported are based on the Canadian Geodetic Vertical Datum 1928.
(8) N/R Not Recorded.

Table 4.2
Keeyask GS -
Stage IV Investigation Program, Axis GR-4
Powerhouse Area – Summary of Core Losses

Drill Hole	Depth (m - along core axis)		Detailed Fracture	Description
	From	To		
03-008	9.91	9.92	LCZ	Core is grounded and fresh. Lower contact and upper contact are at 90 degrees to the core axis, subplanar, rough, fragmented across foliation. Core loss estimated to be 10 mm.
	11.54	11.60	BLCZ	Core loss is probably due to machine break and grinding. Core pieces are approximately 10 to 40 mm and grounded. Upper contact is at 80 degrees to the core axis, subplanar, semi-rough, ground, faintly weathered. Lower contact is at 90 degrees to the core axis, curved, semi-rough, partly ground, and fresh. Core loss estimated to be 10 mm.
	19.99	20.01	BLCZ	Core loss is probably due to machine break and grinding. Core pieces are approximately 10 to 40 mm and grounded. Upper contact is at 80 degrees to the core axis, irregular, semi-rough, ground, and fresh. Lower contact is at 70 degrees to the core axis, irregular, semi-rough, partly ground, fresh. Core loss estimated to be 10 mm.
	20.14	20.29	LCZ	Core loss due to 150 mm left down hole.
03-009	18.92	18.99	LCZ	Core loss due to 70 mm left down hole.
03-010	3.79	3.82	BLCZ	Core is grounded and faintly weathered. Lower contact is at 55 degrees to the core axis, subplanar, semi-rough, some limonite coating.
	5.45	5.53	BLCZ	Core loss is probably due to machine break and grinding. Core pieces are approximately 10 to 40 mm and grounded. Upper contact is at 80 degrees to the core axis, irregular, semi-rough, ground, and fresh. Lower contact is at 70 degrees to the core axis, irregular, semi-rough, partly ground, fresh.
	7.20	7.27	LCZ	Upper contact is at 50 degrees to the core axis, irregular, semi-rough, faintly weathered, some chlorite. Lower contact is at 75 degrees to the core axis, irregular, semi-rough, moderately weathered, partly ground, some chlorite. Core loss estimated to be 70 mm.
	8.39	8.44	BLCZ	Broken core pieces are angular to round and between 10 to 30 mm. Upper contact is irregular, rough, fresh, labeled as a machine break. Lower contact is irregular, rough, ground, fresh.
	9.09	9.25	LCZ	Upper contact is at 90 degrees to the core axis, irregular, rough, faintly weathered and partly ground. Lower contact is at 70 degrees to the core axis, irregular, rough, fresh, micaceous rich. Core loss estimated to be 160 mm.
	24.47	24.49	LCZ	Upper contact is at 90 degrees to the core axis, irregular, semi-rough, fresh and partly ground. Lower contact is at 80 degrees to the core axis, irregular, semi-rough, faintly weathered and partly ground. Core loss estimated to be 20 mm.

Table 4.2 Powerhouse Area – Summary of Core Losses Continued

Drill Hole	Depth (m - along core axis)		Detailed Fracture	Description
	From	To		
	32.82	32.84	LCZ	Upper contact is at 55 degrees to the core axis, subplanar, semi-rough, moderately weathered, trace ground, some epidote. Lower contact is at 80 degrees to the core axis, irregular, semi-rough, moderately weathered, partly ground, some epidote. Core loss estimated to be 20 mm.
03-011	10.52	10.78	BLCZ	Broken core zone probably a result of drill action on closely spaced joints. There is evidence of up to 9+ joints. Joints have a dark coating of epidote. The angle of the joints vary between 30 and 90 degrees to the core axis. Recovered pieces vary between 20 to 60 mm. Upper contact is at 65 degrees to the core axis, irregular, semi-rough, feature tightness is unknown due to grinding or other condition, moderately weathered, partly ground, some epidote, some chlorite, and trace ferrous oxide staining. Lower contact is at 75 degrees to the core axis, irregular, smooth, feature tightness is unknown due to grinding or other condition, moderately weathered, ground, some epidote, some chlorite. Core loss estimated to be 40 mm.
	43.69	43.70	LCZ	Core loss due to 10 mm left down hole.
03-012	5.49	5.58	BLCZ	Broken core zone due to coarse grained foliation in amphibolite. Recovered pieces are ground, 10 to 40 mm in diameter. Upper contact is at 80 degrees to the core axis, ground. Lower contact is at 90 degrees to the core axis, ground. Core loss estimated to be 90 mm.
	36.36	36.37	LCZ	Upper contact is at 90 degrees to the core axis, irregular, rough, faintly weathered and partly ground. Lower contact is at 80 degrees to the core axis, irregular, rough, fresh and partly ground. Core loss estimated to be 10 mm.
	41.01	41.05	LCZ	Core loss due to 40 mm left down hole.
03-013	7.27	7.29	LCZ	Upper contact is at 65 degrees to the core axis, irregular, rough, faintly weathered and ground. Lower contact is at 65 degrees to the core axis, irregular, rough, faintly weathered and ground. Core loss estimated to be 20 mm.
	12.06	12.08	BLCZ	Recovered 30 mm ground piece. Upper contact is at 90 degrees to the core axis, irregular, semi-rough, faintly weathered, ground, and trace limonite. Lower contact is at 60 degrees to the core axis, irregular, rough, faintly weathered and partly ground, some calcite, trace limonite. Core loss estimated to be 10 mm.
	12.15	12.18	BLCZ	Recovered 40 mm ground piece. Upper contact is at 85 degrees to the core axis, irregular, rough, fresh and ground. Lower contact is at 90 degrees to the core axis, subplanar, semi-rough, fresh and ground. Core loss estimated to be 10 mm.
	43.98	44.01	LCZ	Core loss due to 30 mm left down hole.

Table 4.2 Powerhouse Area – Summary of Core Losses Continued

Drill Hole	Depth (m - along core axis)		Detailed Fracture	Description
	From	To		
03-014	5.02	5.06	LCZ	Drill inspector reported the drill bit dropped at approximately this depth. Clay coatings on both the upper and lower contacts indicate a probable clay filled open joint. Upper contact is at 65 degrees to the core axis, irregular, semi-rough, feature tightness is unknown due to grinding or other condition, moderately weathered with clay coating. Lower contact is at 60 degrees to the core axis, irregular, semi-rough; feature tightness is unknown due to grinding or other condition, moderately weathered, with a clay coating. Core loss estimated to be 40 mm.
	24.79	24.81	LCZ	Upper contact is at 60 degrees to the core axis, irregular, rough, faintly weathered, trace pyrrhotite. Lower contact is at 45 degrees to the core axis, irregular, rough, partly ground, moderately weathered, some calcite, and some pyrite. Core loss estimated to be 20 mm.
	25.83	25.87	LCZ	Upper contact is at 80 degrees to the core axis, irregular, rough and fresh. Lower contact is at 90 degrees to the core axis, irregular, semi-rough and ground. Core loss estimated to be 40 mm.
03-014 cont	27.32	27.34	LCZ	Upper contact is at 80 degrees to the core axis, irregular, rough, partly ground and fresh. Lower contact is at 80 degrees to the core axis, irregular, rough, partly ground and faintly weathered. Core loss estimated to be 20 mm.
	27.57	27.58	LCZ	Upper contact is parallel to the foliation, at 60 degrees to the core axis, irregular, semi-rough, moderately weathered, some ferric oxide. Lower contact is parallel to the foliation at 60 degrees to the core axis, irregular, semi-rough, moderately weathered, slickensides, and some ferric oxide. Core loss estimated to be 10 mm.
	27.79	27.88	BLCZ	Recovered pieces are 5 to 40 mm, fresh, partly ground, some have calcite coated surfaces. Upper contact is at 75 degrees to the core axis, subplanar, trace ground, moderately weathered, some calcite. Lower contact is at 90 degrees to the core axis, subplanar, semi-rough, ground and fresh. Core loss estimated to be 50 mm.
	42.90	43.02	LCZ	Core loss due to 120 mm left down hole.
03-015	-	-	-	Core loss not encountered.
03-016	14.15	14.29	BLCZ	Upper and lower contacts are labeled as machine breaks, core loss probably due to grinding. Recovered pieces are 10 to 40 mm, angular and rounded. Upper contact is at 70 degrees to the core axis, irregular, rough, faintly weathered, some chlorite. Lower contact is at 90 degrees to the core axis, subplanar, ground.
	18.93	18.94	BLCZ	Recovered pieces are 20 mm. Upper contact is at 90 degrees to the core axis, irregular, semi-rough and ground. Lower contact is at 90 degrees to the core axis, irregular, semi-rough and ground. Core loss estimated to be 10 mm.
03-022	19.42	19.43	LCZ	Upper contact is at 80 degrees to the core axis, irregular, rough, faintly weathered, ground. Lower contact is at 85 degrees to the core axis, irregular, rough, moderately weathered, partly ground, with ferrous oxide stained. Core loss estimated to be 10 mm.

Table 4.2 Powerhouse Area – Summary of Core Losses Continued

Drill Hole	Depth (m - along core axis)		Detailed Fracture	Description
	From	To		
	20.03	20.05	BLCZ	Recovered pieces are 5 to 10 mm. Upper contact is at 80 degrees to the core axis, irregular, rough, faintly weathered and ground. Lower contact is at 90 degrees to the core axis, irregular, rough, faintly weathered and ground. Core loss estimated to be 10 mm.
G-0007	28.66	28.94	LCZ	Core loss due to 280 mm left down the hole.
G-0008	17.31	18.48	BLCZ	Closely jointed zone, at least 9 joints present, pieces range in size up to full diameter and 150 mm in length. Pieces are rough, angular, minor grinding, some chlorite coating, trace black coating (greasy feel, soft), minor carbonate. Core loss estimated to be 180 mm.
	22.79	22.92	BLCZ	Recovered pieces are angular, rough, and fresh. Possibly due to drill action on closely spaced joints. Core loss estimated to be 60 mm.
	26.30	26.36	BLCZ	Pieces are rough with minor carbonate and black (greasy feel, soft) coatings. Possibly due to drill action on closely spaced jointing. Core loss estimated to be 30 mm.
	35.06	35.53	BLCZ	Core is broken into three pieces (approximately 130 mm each) and is badly ground. Core loss estimated to be 70 mm.
	57.78	58.01	LCZ	Core loss due to 230 mm left down hole.
G-0011	3.65	4.01	BLCZ	Pieces are angular, strong, some surfaces chlorite coated, some iron staining, some slickensides, at least 4 joints. Core loss may be associated with an open and ground joint at 4.43 m. Core loss estimated to be 60 mm.
	13.74	13.90	BLCZ	The zone and core loss appears to be due to drill action and grinding. Pieces are angular, strong, some fresh surfaces, some chlorite coating. Lower contact is ground. Core loss estimated to be 150 mm.
	17.45	17.64	BLCZ	At least 3 joints at 20 to 25 degrees to the core axis, chlorite coated, some carbonate coating. Joints appear open. Core loss estimated to be 40 mm.
	18.61	18.73	BLCZ	Broken zone is due to drill action, core loss may be associated with numerous ground surfaces throughout the run. Appears only 1 joint present. Pieces are ground, strong, some chlorite coating. Core loss estimated to be 20 mm.
	55.40	55.44	LCZ	Core loss due to 40 mm left down hole.
G-0012	4.17	4.27	LCZ	Assumed clay seam, no sample but inspector noted seam 100 to 150 mm, water return brown. Core on either side of assumed seam does not match. Core loss estimated to be 100 mm.
	4.42	4.60	BLCZ	Possibly due to drill action on closely spaced joints. Pieces are angular, rough, and fresh. Core loss estimated to be 40 mm.
	36.80	37.26	BLCZ	Pieces are redrilled. Loss most likely due to redrilling of stub left down hole. Core loss estimated to be 90 mm.
G-0013	50.90	51.05	LCZ	Core loss due to 150 mm left down hole.
G-0014	46.02	46.10	LCZ	Core loss due to 80 mm left down hole.

Table 4.2 Powerhouse Area – Summary of Core Losses Continued

Drill Hole	Depth (m - along core axis)		Detailed Fracture	Description
	From	To		
G-0015	4.32	4.89	BLCZ	Core loss may be due to placing of the casing prior to drilling. At least 4 joints present. Pieces are strong, angular, some full diameter, some grinding, some redrilled. Core loss estimated to be 240 mm.
	6.62	6.73	LCZ	Core loss is assumed to be ground, open, machine break. Core loss estimated to be 110 mm.
	13.13	13.34	BLCZ	Three joints/machine breaks, 80 to 90 degrees to the core axis, and 1 joint at 30 degrees to the core axis. Pieces are full diameter with ground contacts. Assumed the core loss occurs at these ground contacts. Core loss estimated to be 70 mm.
	46.59	46.66	LCZ	Core loss due to 70 mm left down hole.
G-0016	7.84	8.20	BLCZ	Zone appears to be due to drill action on a closely jointed and faintly altered zone. Pieces are angular to sub angular, strong, some chlorite coating, some clay, some ground surfaces, some pieces faintly altered. Upper contact is a joint at 35 degrees to the core axis, planar, rough, chlorite coated, some clay, some limonite, and slight slickensides. Lower contact is a joint at 80 degrees to the core axis, planar, rough, some chlorite coating, some clay. Core loss estimated to be 260 mm.
	9.90	10.03	BLCZ	Pieces are angular, strong, some chlorite coating, some ground, some fresh surfaces. Upper contact is a joint at 30 degrees to the core axis, planar rough, some clay. Lower contact is a machine break at 85 degrees to the core axis, ground. Core loss estimated to be 70 mm.
	28.56	28.69	BLCZ	Piece of core is redrillled and ground, strong. Assumed core loss due to redrilling and grinding. Core loss estimated to be 40 mm.
	42.28	42.36	LCZ	Core loss due to 80 mm left down hole.
G-0204	30.67	30.79	LCZ	Core loss due to 120 mm left down hole.

Notes:
(1) LCZ Lost Core Zone
(2) BLCZ Broken Lost Core Zone

Table 4.3
Keeyask GS - Stage IV Investigation Program, Axis GR-4
Powerhouse Area – Water Pressure Test Summary

Drill Hole	Test Interval			Lugeon Value			Interpreted		Significant Feature[3]
	Depth[1] from Ground Surface (m)			Stage 1	Stage 2	Stage 3	Lugeon Value	Flow Characteristics[2]	
03-008	10.22	-	15.71	0	1	0	1	Laminar	1BCZ, 1BLCZ, 7PO, 8HJT
	15.00	-	20.29	3	4	2	3	Laminar	1BLCZ, 2PO, 10HJT
03-009	10.80	-	15.94	0	1	-	1	N/A	2BCZ, 14PO, 7HJT
	15.24	-	18.99	4	3	3	3	Laminar	1BCZ, 7PO, 7HJT
03-010	5.58	-	10.82	-	0	-	0	N/A	1BLCZ, 2LCZ, 1BCZ, 1O, 2HJT
	10.16	-	15.40	0	0	0	0	No take	-
	14.68	-	19.96	1	1	3	2	Laminar	1PO, 1HJT
	19.27	-	24.52	2	2	3	2	Laminar	1LCZ, 1O, 1PO
	23.83	-	29.09	3	2	2	2	Laminar	1LCZ, 1PO, 2HJT
	28.41	-	33.58	1	1	1	1	Laminar	1LCZ, 3PO, 4HJT
	32.98	-	38.10	1	1	0	1	Laminar	1PO
	37.54	-	43.52	1	1	1	1	Laminar	1O, 1PO, 1HJT
03-011	10.71	-	15.76	0	18	1	1	Dilation	1BLCZ, 5BCZ, 2O, 10PO, 16HJT, 1SHEAR
	15.14	-	20.07	6	6	6	6	Laminar	1O, 13PO
	19.55	-	24.82	3	3	2	3	Laminar	1FOL, 7PO
	23.98	-	29.32	0	0	0	0	No Take	1BCZ, 4PO
	28.63	-	34.05	0	0	0	0	No Take	1BCZ, 4PO
	33.30	-	38.66	0	1	0	0	Laminar	4PO
	37.77	-	43.70	1	1	1	1	Laminar	3BCZ, 1O, 10PO, 1HJT
03-012	5.01	-	11.02	-	16	-	16	N/A	1BLCZ, 2BCZ, 3O, 10PO, 3HJT
	10.33	-	15.61	2	2	2	2	Laminar	1O, 2PO, 1HJT
	13.93	-	20.14	0	1	0	1	Laminar	1BCZ, 1O, 9PO
	19.50	-	24.72	2	2	2	2	Laminar	2O, 8PO, 2HJT
	24.08	-	29.31	3	2	2	2	Laminar	5PO
	28.65	-	33.76	2	1	2	2	Laminar	4O, 5PO

Table 4.3 – Powerhouse Area Water Pressure Test Summary Continued

Drill Hole	Test Interval Depth[(1)] from Ground Surface (m)			Lugeon Value Stage 1	Stage 2	Stage 3	Interpreted Lugeon Value	Flow Characteristics[(2)]	Significant Feature[(3)]
	32.20	-	41.05	2	2	2	2	Laminar	1LCZ, 3O, 8PO
03-013	7.34	-	12.61	-	1	-	1	N/A	2BLCZ, 1O, 1PO, 2HJT
	11.84	-	17.26	9	14	11	11	Laminar	2BLCZ, 1O, 1PO, HJT's
	16.70	-	21.85	8	8	7	8	Laminar	2O
	21.40	-	26.48	7	5	5	6	Laminar	1O, 1PO
	25.93	-	30.98	4	3	3	3	Laminar	2PO
	30.46	-	35.53	2	1	1	1	Laminar	1O, 3HJT
	34.96	-	40.57	0	0	0	0	No Take	-
	39.62	-	44.01	1	0	1	1	Laminar	1O, 1PO
03-014	5.49	-	11.32	-	0	-	0	N/A	2BCZ, 4PO
	10.49	-	15.91	5	5	4	5	Laminar	3FOL, 4PO
	15.28	-	20.16	1	2	1	1	Laminar	2O, 8PO
	19.79	-	24.85	5	5	5	5	Laminar	1BCZ, 1LCZ, 1O, 1PO, 1HJT
	24.15	-	29.81	17	14	16	16	Laminar	2BCZ, 1BLCZ, 4LCZ, 2O, 6PO, 3HJT
	28.83	-	34.30	1	1	1	1	Laminar	5O, 3PO, 1HJT
	33.42	-	38.95	1	1	1	1	Laminar	1BCZ, 4O, 9PO
	38.00	-	43.02	1	0	0	1	Laminar	1BCZ, 3O, 9PO
03-015	9.27	-	14.22	-	0	-	0	N/A	5PO
	13.18	-	18.60	0	0	0	0	No Take	1O, 8PO
	17.77	-	23.20	17	15	10	14	Laminar	1BCZ, 5PO, 2FOL
	22.40	-	27.78	3	2	2	2	Laminar	1BCZ, 2PO, 1FOL
	27.13	-	32.50	1	1	1	1	Laminar	2BCZ, 6PO, 1HJT
	31.90	-	37.25	0	1	0	1	Laminar	3PO, 1HJT
	36.44	-	43.82	1	1	1	1	Laminar	1BCZ, 2PO
03-016	5.78	-	11.01	-	0	-	0	N/A	4PO, 1HJT
	10.32	-	15.59	5	5	5	5	Laminar	1BLCZ, 2O, 2PO, 2HJT
	14.88	-	20.17	3	3	3	3	Laminar	1BLCZ, 1O
	19.48	-	24.75	2	2	2	2	Laminar	1BCZ, 4PO, 2HJT

Table 4.3 – Powerhouse Area Water Pressure Test Summary Continued

Drill Hole	Test Interval			Lugeon Value			Interpreted		Significant Feature[3]
	Depth[1] from Ground Surface (m)			Stage 1	Stage 2	Stage 3	Lugeon Value	Flow Characteristics[2]	
	24.09	-	29.32	2	1	1	1	Laminar	2PO
	28.63	-	33.87	1	1	1	1	Laminar	3PO
	33.20	-	38.46	5	5	6	5	Laminar	1BCZ, 1HJT
	37.78	-	41.01	0	1	0	1	Laminar	-
03-022	11.42	-	15.87	2	0	0	1	Laminar	7PO, 2HJT
	15.13	-	20.35	2	2	2	2	Laminar	1BLCZ, 1LCZ, 2O, 4PO, 2HJT
	19.66	-	25.05	3	2	1	2	Laminar	1BLCZ, 1O
G-0008	14.40	-	16.40	0	0	0	0	No Take	4O, 3PO
	17.40	-	19.40	0	0	0	0	No Take	1BLCZ (CJZ), 1O, 3PO
	20.10	-	22.10	0	0	0	0	No Take	3O
	23.70	-	25.70	*	*	*	101 [5]	Pump Capacity	3O, 1PO,
	29.30	-	31.30	0	0	0	0	No Take	2O, 3PO
	31.50	-	33.50	16	13	16	13	Turbulent	3O, 2PO
	43.00	-	45.00	0	0	0	0	No Take	1BCZ (CJZ), 3O, 3PO
	50.50	-	52.50	0	0	0	0	No Take	1O, 1PO
G-0011	6.70	-	8.70	0	0	0	0	No Take	-
	12.10	-	14.10	0	0	0	0	No Take	1BLCZ
	14.70	-	16.70	0	0	0	0	No Take	1HJT
	17.50	-	19.50	0	0	0	0	No Take	2BLCZ
	21.30	-	23.30	0	0	0	0	No Take	-
	24.90	-	26.90	0	0	0	0	No Take	-
	29.50	-	31.50	42	-	-	42	N/A	1PO
	34.60	-	36.60	0	0	0	0	No Take	2O
	38.20	-	40.20	0	0	0	0	No Take	-
	41.02	-	43.02	3	3	3	3	Laminar	1BCZ (CJZ), 1O, 2HJT
	43.50	-	45.50	0	0	0	0	No Take	4O, 1PO
	45.50	-	47.50	0	0	0	0	No Take	3O

Table 4.3 – Powerhouse Area Water Pressure Test Summary Continued

Drill Hole	Test Interval			Lugeon Value			Interpreted		Significant Feature[3]
	Depth[1] from Ground Surface (m)			Stage 1	Stage 2	Stage 3	Lugeon Value	Flow Characteristics[2]	
G-0012	4.00	-	6.00	0	14	0	14	N/A	1LCZ, 1BLCZ (CJZ)
	6.80	-	8.80	0	0	0	0	No Take	1O, 1PO
	9.30	-	11.30	0	0	0	0	No Take	1O, 2PO
	16.20	-	18.20	-	74	-	74	N/A	2O, 3PO
	24.30	-	26.30	0	0	0	0	No Take	1O, 1PO
	29.50	-	31.50	6	6	6	6	Laminar	2O, 4PO
	36.80	-	38.80	0	0	0	0	No Take	1BLCZ, 1O
	43.60	-	45.60	0	0	0	0	No Take	1O, 2PO
	48.00	-	50.00	0	0	0	0	No Take	1O
G-0013	3.00	-	5.00	0	0	0	0	No Take	1O, 1PO
	5.50	-	7.50	0	0	0	0	No Take	-
	9.70	-	11.70	0	0	0	0	No Take	1O, 1PO
	12.40	-	14.40	0	0	0	0	No Take	2PO
	18.50	-	20.50	8	0	0	0	Dilation	1BCZ, 2O
	21.50	-	23.50	20	24	0	0	Void Filling	-
	26.30	-	28.30	0	0	0	0	No Take	3PO
	27.40	-	29.40	0	0	0	0	No Take	1BCZ, 2PO
	41.50	-	43.50	0	0	0	0	No Take	1O
G-0014	8.00	-	10.00	0	0	0	0	No Take	-
	10.03	-	12.03	0	0	0	0	No Take	1BCZ, 1PO, 1HJT
	13.30	-	15.30	0	0	0	0	No Take	1BCA, 1O, 1PO
	16.90	-	18.90	0	0	0	0	No Take	1BCZ, 1O
	19.20	-	21.20	0	0	0	0	No Take	1BCZ, 1O
	22.00	-	24.00	4	-	-	4	N/A	1BCZ, 1HJT
	24.50	-	26.50	0	0	0	0	No Take	3O, 2PO
	27.50	-	29.50	0	0	0	0	No Take	1BCZ (SHEAR), 2PO
	29.50	-	31.50	0	0	0	0	No Take	2BCZ (SHEAR)
	31.50	-	33.50	0	0	0	0	No Take	2BCZ (SHEAR), 1PO

Table 4.3 – Powerhouse Area Water Pressure Test Summary Continued

Drill Hole	Test Interval Depth[(1)] from Ground Surface (m)			Lugeon Value Stage 1	Stage 2	Stage 3	Interpreted Lugeon Value	Flow Characteristics[(2)]	Significant Feature[(3)]
	37.30	-	39.30	0	0	0	0	No Take	5O, 2PO
	40.20	-	42.20	0	0	0	0	No Take	1OP, 1HJT
G-0015	6.50	-	9.50	0	0	0	0	No Take	1LCZ, 1O, 2PO
	11.20	-	14.20	0	0	0	0	No Take	1LCZ, 1O
	16.50	-	19.50	0	0	0	0	No Take	1O
	21.00	-	24.00	0	0	0	0	No Take	3O
	25.00	-	28.00	1	2	-	2	N/A	3O, 2PO, 1HJT
	34.50	-	37.50	17	18	18	18	Laminar	2BCZ, 2O
	38.40	-	41.40	28	29	31	29	Laminar	2BCZ (1CJZ), 1O, 1PO, 1HJT
	41.80	-	44.80	0	0	0	0	No Take	5O,3PO, 1HJT
G-0016	6.00	-	9.00	-	38	-	38	N/A	1BLCZ (CJZ), 1BCZ (CJZ), 9O, 3PO
	11.20	-	14.20	0	0	0	0	No Take	4O, 3PO, 1HJT
	14.50	-	17.50	25	20	25	20	Turbulent	3O
	18.86	-	21.86	15	14	14	14	Laminar	4O, 1PO, 1HJT
	24.00	-	27.00	19	16	15	15	Void Filling	1O, 1PO
	29.50	-	32.50	0	0	0	0	No Take	1O, 1PO
	34.11	-	37.11	2	-	-	2	N/A	1PO
	37.16	-	40.16	5	4	4	4	Laminar	1O, 2PO, 1HJT

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.

(4) The depths recorded for borehole 03-011 have been adjusted.

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

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

Interpreted Flow Characteristics	1988 & 1991 Investigations	2003 Investigations	Total Number of Tests
Tight (i.e., no take)	47	5	52
Laminar	6	47	53
Turbulent	2	0	2
Dilation	1	1	2
Void Filling	2	0	2
N/A [2]	7	7[1]	14
Pump Capacity	1	0	1
Total Number of Tests	**66**	**60**	**126**

Notes:
[1] Less than three steps were conducted.
[2] N/A Not Applicable, flow pattern not assigned.

Table 4.5
Keeyask GS - Stage IV Investigation Program, Axis GR-4
Summary of Joint Trend Measurements in Powerhouse Area

Powerhouse Joint Set	Orientation			Description
	Strike (deg)	Dip [1] (deg)	Dip Direction (deg)	
J1	198	1	288	Major, subhorizontal joint set
J2	320	30	50	Major
J3	60	23	150	Major
J4	237	25	327	Major
J5	335	80	65	Minor, subvertical joint set
J6	65	53	155	Minor

[1]Note:
Dip from horizontal. Dip direction is 90 deg right of the strike.

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

Parameter	Powerhouse 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	Note (2)	15
Adjustment for joint orientation	-	0
RMR_{89} (3)	**-**	**78**
Rock Mass Class	**-**	**II**
Description of Rock Mass	**-**	**Good Rock**
GSI (4)	**-**	**73**

Notes:
(1) Figure 11, 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 conditions 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 thorough analysis of major/minor joint sets are discussed in Memorandum GN-4.2.2.8, Rock Support and Temporary Drainage [Ref 22].
(4) GSI = $RMR_{89} – 5$. Where RMR_{89} has the groundwater rating set to 15 and the adjustment for joint orientation set to zero.

Table 5.2
Keeyask GS - Stage IV Investigation Program, Axis GR-4
Summary of Analysis of Rock Strength Parameters Using RocLab

Properties	Rock Types			
	Greywacke Gneiss	Amphibolite	Granite	Diabase Dykes
Hoek-Brown Classification				
Intact Uniaxial Compressive Strength [(1)] (MPa)	175	175	250	175
Geological Strength Index (GSI)	73	73	73	73
Intact Rock Parameter (mi)	28	26	32	27
Disturbance Factor (slopes) [(2)]	0.7	0.7	0.7	0.7
Hoek-Brown Generalized Failure Criterion				
m_b (material constant) [(3)]	6.35	5.9	7.26	6.125
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	13.42	20.21	13.54
Friction Angle	42	41.22	43	41.55
Rock Mass Parameters				
Tensile Strength (MPa)	-0.55	-0.59	-0.69	-0.57
Uniaxial Compressive Strength (MPa)	24.63	24.63	35.19	24.63
Global Strength (MPa)	61.22	59.18	93.02	60.2
Modulus of Deformation (MPa)	35 075	30 064	40 563	30 065

Notes:
(1) Based on field estimates
(2) Disturbance Factor for slopes using good blasting techniques
(3) m_b is a reduced value of the material constant m_i, which is based on the rock type and texture, where: $m_b = m_i \exp[(GSI-100)/(28-14D)]$ mi is the material constant, obtained from Hoek 2006, see table in 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 east/northeast (downstream), showing Powerhouse location. Dash lines outline the Powerhouse area and its associated channels.

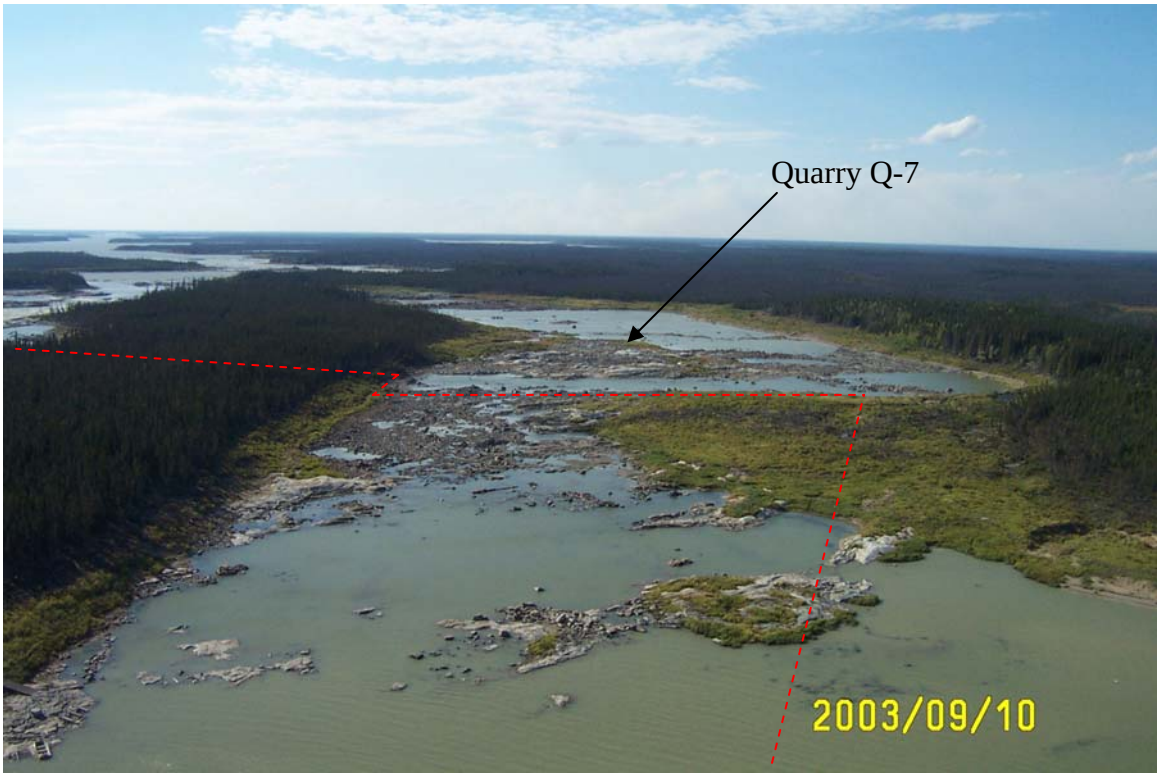


Photo 2: View looking west, showing Powerhouse Intake Channel Area and Rock Quarry Q-7.

Photo 3: View looking northeast/east, showing Powerhouse Intake Area.

Photo 4: View looking east (downstream), showing Intake Channel and Powerhouse Area.

Photo 5: View looking east (downstream), showing Tailrace channel Area.

Photo 6: View looking southwest, showing Intake Channel Area.

Appendix A

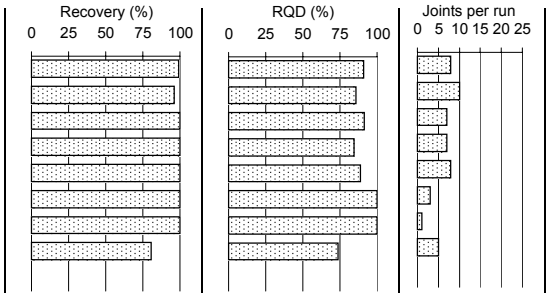
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: 03-008
Date: Jul. 24/03

Dip: 90 deg.
Azimuth: - deg.
Grd. Elev.: 146.68 m
Depth: 20.29 m

Geological Description[3]: Greywacke Gneiss: grey to dark grey, fine grained to very fine grained, strong, indistinct foliation at 0 to 30 degrees to the core axis, moderately spaced, good to excellent quality, low permeability.

Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
9.61	11.13	1.52	1.51	99	1.38	91	8 +	168
11.13	12.66	1.53	1.47	96	1.31	86	10 +	134
12.66	14.18	1.52	1.52	100	1.39	91	7	190
14.18	15.71	1.53	1.53	100	1.29	84	7	191
15.71	17.23	1.52	1.52	100	1.35	89	8	169
17.23	18.74	1.51	1.51	100	1.51	100	3	378
18.74	19.41	0.67	0.67	100	0.67	100	1	335
19.41	20.29	0.88	0.71	81	0.65	74	5 +	118
Total =		10.68	10.44		9.55		49	
Average =		1.34		97.8		89	6	214

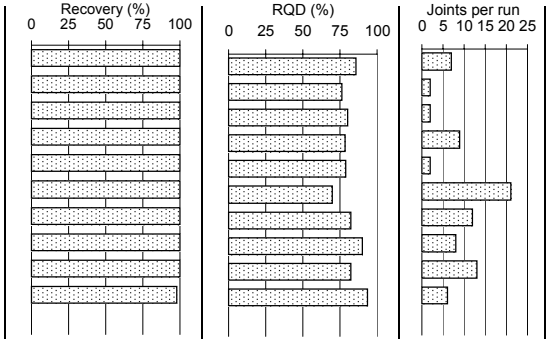


Drill Hole: 03-009
Date: Jul. 18/03

Dip: 90 deg.
Azimuth: - deg.
Grd. Elev.: 147.08 m
Depth: 18.99 m

Geological Description[3]: Greywacke Gneiss: grey to dark grey, very fine grained, strong, indistinct foliation at 10 to 15 degrees to the core axis, closely spaced, good quality, low permeability.

Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
8.97	9.74	0.77	0.77	100	0.66	86	7	96
9.74	9.91	0.17	0.17	100	0.13	76	2	57
9.91	10.31	0.40	0.40	100	0.32	80	2	133
10.31	10.91	0.60	0.60	100	0.47	78	9	60
10.91	11.29	0.38	0.38	100	0.30	79	2	127
11.29	12.87	1.58	1.58	100	1.10	70	21 +	72
12.87	14.40	1.53	1.53	100	1.26	82	12	118
14.40	15.94	1.54	1.54	100	1.39	90	8	171
15.94	17.46	1.52	1.52	100	1.25	82	13 +	109
17.46	18.99	1.53	1.50	98	1.43	93	6	214
Total =		10.02	9.99		8.31		82	
Average =		1.00		99.7		83	8	121



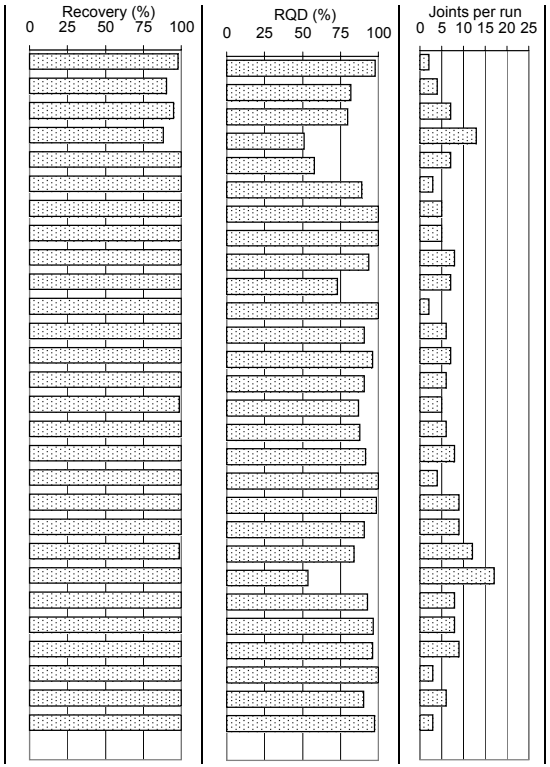
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: 03-010
Date: Jul. 27/03

Dip: 70 deg.
Azimuth: 231 deg.
Grd. Elev.: 138.16 m
Depth: 43.52 m

Barge Hole

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
3.79-32.44 Greywacke gneiss: light to medium greenish grey, coarse to very coarse grained, strong, distinct to indistinct planar to irregular foliation, closely to moderately spaced, good quality, low permeability, occasional granitic bands.	3.79	5.34	1.55	1.52	98	1.52	98	2 +	507
	5.34	6.16	0.82	0.74	90	0.67	82	4 +	148
	6.16	7.68	1.52	1.44	95	1.21	80	7 +	180
	7.68	9.27	1.59	1.40	88	0.81	51	13 +	100
	9.27	9.72	0.45	0.45	100	0.26	58	7	56
32.44-39.50 Granite: light to medium greenish grey, coarse to very coarse grained, strong, no distinct foliation, very closely spaced, good quality, low permeability.	9.72	10.82	1.10	1.10	100	0.98	89	3 +	275
	10.82	12.35	1.53	1.53	100	1.53	100	5	255
	12.35	13.87	1.52	1.52	100	1.52	100	5	253
	13.87	15.40	1.53	1.53	100	1.43	93	8	170
	15.40	16.91	1.51	1.51	100	1.10	73	7	189
39.50-43.52 Greywacke gneiss: light to medium greenish grey, coarse to very coarse grained, moderately strong, distinct to indistinct planar to irregular foliation, moderately spaced, excellent quality, low permeability, occasional granite intrusions.	16.91	18.44	1.53	1.53	100	1.53	100	2	510
	18.44	19.96	1.52	1.52	100	1.38	91	6	217
	19.96	21.48	1.52	1.52	100	1.46	96	7	190
	21.48	23.00	1.52	1.52	100	1.38	91	6	217
	23.00	24.52	1.52	1.50	99	1.32	87	5 +	250
	24.52	26.05	1.53	1.53	100	1.34	88	6	219
	26.05	27.57	1.52	1.52	100	1.39	91	8	169
	27.57	29.09	1.52	1.52	100	1.52	100	4	304
	29.09	30.49	1.40	1.40	100	1.38	99	9	140
	30.49	32.03	1.54	1.54	100	1.40	91	9	154
	32.03	33.58	1.55	1.53	99	1.30	84	12 +	118
	33.58	35.09	1.51	1.51	100	0.81	54	17	84
	35.09	36.62	1.53	1.53	100	1.42	93	8	170
	36.62	38.10	1.48	1.48	100	1.43	97	8	164
	38.10	39.66	1.56	1.56	100	1.50	96	9	156
	39.66	41.21	1.55	1.55	100	1.55	100	3	388
	41.21	42.74	1.53	1.53	100	1.38	90	6	219
	42.74	43.52	0.78	0.78	100	0.76	97	3	195
		Total =	39.73	39.31		35.28		189	
		Average =	1.42		98.9		89	7	209



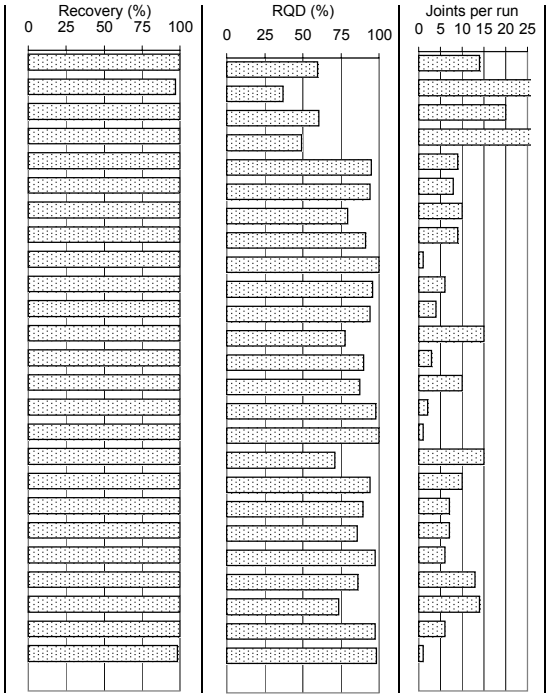
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: 03-011
Date: Jul. 31/03

Dip: 70 deg.
Azimuth: 230 deg.
Grd. Elev.: 136.31 m
Depth: 43.70 m

Barge Hole

Geological Description**	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery (%)	RQD Length (m)	RQD (%)	Jts per run	Average[3] Spacing per Jt. (mm)
8.69-19.58 Granite, light grey, medium to coarse grained, strong, closely spaced, good quality, low permeability, hard drilling, occasional amphibolite xenoliths.	8.69	9.85	1.16	1.16	100	0.69	59	14	77
	9.85	11.17	1.32	1.28	97	0.49	37	26 +	47
	11.17	12.66	1.49	1.49	100	0.90	60	20 +	71
19.58-24.62 Amphibolite: dark grey to black, very fine grained, strong, distinct foliation varies from 90 to 45 degrees to the core axis, moderately spaced, good to excellent quality, low impermeable.	12.66	14.20	1.54	1.54	100	0.76	49	32 +	47
	14.20	15.76	1.56	1.56	100	1.48	95	9 +	156
	15.76	17.27	1.51	1.51	100	1.42	94	8	168
	17.27	18.83	1.56	1.56	100	1.24	79	10	142
	18.83	20.07	1.24	1.24	100	1.13	91	9	124
24.62-41.16 Granite: white to light pink, fine to medium grained, strong, no foliation evident, closely spaced, good quality, practically impermeable.	20.07	20.28	0.21	0.21	100	0.21	100	1	105
	20.28	21.76	1.48	1.48	100	1.42	96	6	211
	21.76	23.29	1.53	1.53	100	1.44	94	4	306
	23.29	24.82	1.53	1.53	100	1.19	78	15	96
	24.82	26.30	1.48	1.48	100	1.33	90	3	370
41.16-43.70 Amphibolite: same as above, closely spaced, excellent quality, low permeability.	26.30	27.80	1.50	1.50	100	1.31	87	10 +	136
	27.80	29.32	1.52	1.52	100	1.49	98	2	507
	29.32	30.84	1.52	1.52	100	1.52	100	1	760
	30.84	32.36	1.52	1.52	100	1.08	71	15 +	95
	32.36	33.87	1.51	1.51	100	1.42	94	10 +	137
	33.87	35.40	1.53	1.53	100	1.37	90	7	191
	35.40	36.93	1.53	1.53	100	1.31	86	7	191
	36.93	38.49	1.56	1.56	100	1.52	97	6	223
	38.49	39.99	1.50	1.50	100	1.29	86	13 +	107
	39.99	41.57	1.58	1.58	100	1.16	73	14 +	105
	41.57	43.10	1.53	1.53	100	1.49	97	6 +	219
	43.10	43.70	0.60	0.59	98	0.59	98	1	295
		Total =	35.01	34.96		29.25		249	
		Average =	1.40		99.9		84	10	140



Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: 03-012
Date: Jul. 31/03

Dip: 90 deg.
Azimuth: - deg.
Grd. Elev.: 137.78 m
Depth: 41.05 m

Barge Hole

Geological Description[3]

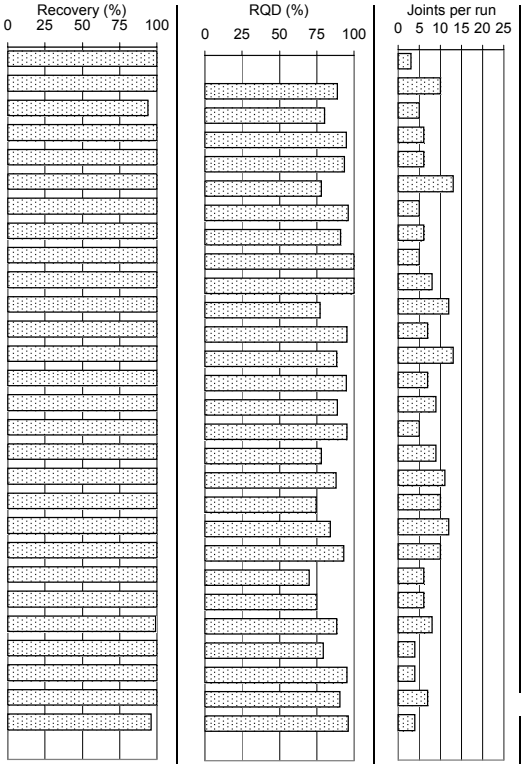
3.22-14.85 Amphibolite: dark grey to black, fine grained, moderately strong to strong, no distinct foliation, closely spaced, good quality, low permeability, contains fine to coarse-grained white to light grey granitic bands. Foliation and granitic bands varies from 30 to 45 degrees to the core axis. Granitic bands locally cross cut foliation.

14.85-21.05 Granite: light grey/green to light pink/green, medium to coarse grained, strong, no distinct foliation, closely spaced, good quality, low impermeability.

21.05-34.10 Amphibolite: same as above, strong, with granite intrusions.

34.10-41.05 Granite: same as above, greyish green, closely spaced, good quality, low impermeability.

Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
3.22	3.45	0.23	0.23	100	0.00	0	3	58
3.45	4.97	1.52	1.52	100	1.35	89	10	138
4.97	6.45	1.48	1.39	94	1.19	80	5 +	232
6.45	7.97	1.52	1.52	100	1.44	95	6	217
7.97	9.50	1.53	1.53	100	1.43	93	6	219
9.50	11.02	1.52	1.52	100	1.19	78	13	109
11.02	12.55	1.53	1.53	100	1.47	96	5	255
12.55	14.07	1.52	1.52	100	1.38	91	6	217
14.07	15.61	1.54	1.54	100	1.54	100	5	257
15.61	17.12	1.51	1.51	100	1.51	100	8	168
17.12	18.61	1.49	1.49	100	1.15	77	12	115
18.61	20.14	1.53	1.53	100	1.46	95	7	191
20.14	21.71	1.57	1.57	100	1.39	89	13	112
21.71	23.22	1.51	1.51	100	1.43	95	7	189
23.22	24.72	1.50	1.50	100	1.33	89	9	150
24.72	26.26	1.54	1.54	100	1.47	95	5	257
26.26	27.80	1.54	1.54	100	1.20	78	9	154
27.80	29.31	1.51	1.51	100	1.33	88	11	126
29.31	30.66	1.35	1.35	100	1.01	75	10	123
30.66	32.18	1.52	1.52	100	1.28	84	12	117
32.18	33.76	1.58	1.58	100	1.47	93	10	144
33.76	34.56	0.80	0.80	100	0.56	70	6	114
34.56	35.41	0.85	0.85	100	0.64	75	6	121
35.41	36.45	1.04	1.03	99	0.92	88	8 +	114
36.45	36.94	0.49	0.49	100	0.39	80	4	98
36.94	38.46	1.52	1.52	100	1.45	95	4	304
38.46	39.96	1.50	1.50	100	1.36	91	7	188
39.96	41.05	1.09	1.05	96	1.05	96	4	210
								0
	Total =	37.83	37.69		33.39		211	
	Average =	1.35		99.6		88	8	178



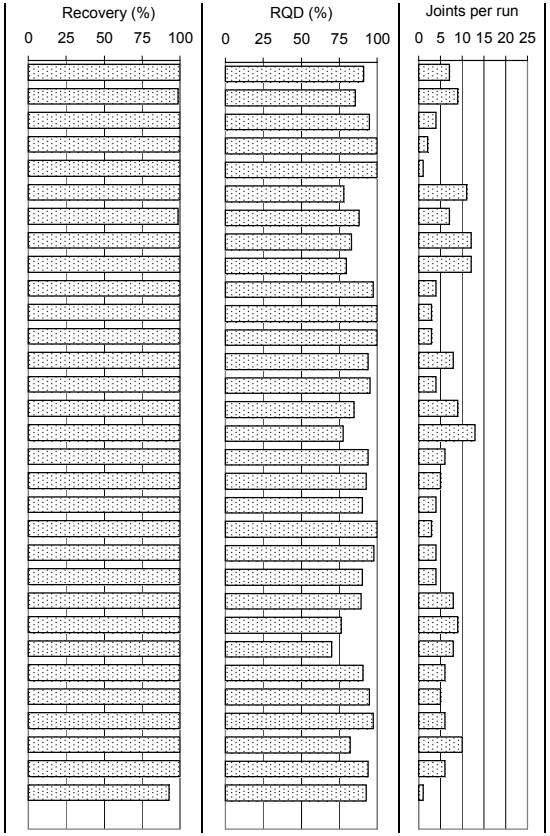
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: 03-013
Date: Aug. 5/03

Dip: 69 deg.
Azimuth: 63 deg.
Grd. Elev.: 137.32 m
Depth: 44.01 m

Barge Hole

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
4.75-14.45 Granite: white to light grey with some pink/green, medium to coarse grained, strong, good quality, medium permeability.	4.81	6.08	1.27	1.27	100	1.16	91	7	159
	6.08	7.67	1.59	1.57	99	1.36	86	9 +	157
	7.67	8.46	0.79	0.79	100	0.75	95	4	158
14.45-29.08 Amphibolite: black/dark green, fine grained, strong, good quality, medium permeability, occasional granite intrusions.	8.46	9.11	0.65	0.65	100	0.65	100	2	217
	9.11	9.52	0.41	0.41	100	0.41	100	1	205
	9.52	11.08	1.56	1.56	100	1.22	78	11	130
	11.08	12.61	1.53	1.51	99	1.35	88	7 +	189
	12.61	14.16	1.55	1.55	100	1.29	83	12	119
	14.16	15.69	1.53	1.53	100	1.22	80	12	118
29.08-44.01 Granite: same as above, low permeability.	15.69	17.26	1.57	1.57	100	1.53	97	4	314
	17.26	18.86	1.60	1.60	100	1.60	100	3	400
	18.86	20.36	1.50	1.50	100	1.50	100	3	375
	20.36	21.85	1.49	1.49	100	1.40	94	8	166
	21.85	23.39	1.54	1.54	100	1.47	95	4	308
	23.39	24.96	1.57	1.57	100	1.33	85	9	157
	24.96	26.48	1.52	1.52	100	1.18	78	13	109
	26.48	28.00	1.52	1.52	100	1.43	94	6	217
	28.00	28.84	0.84	0.84	100	0.78	93	5	140
	28.84	29.87	1.03	1.03	100	0.93	90	4	206
	29.87	30.98	1.11	1.11	100	1.11	100	3	278
	30.98	32.47	1.49	1.49	100	1.46	98	4	298
	32.47	33.38	0.91	0.91	100	0.82	90	4	182
	33.38	34.43	1.05	1.05	100	0.94	90	8	117
	34.43	35.53	1.10	1.10	100	0.84	76	9	110
	35.53	36.50	0.97	0.97	100	0.68	70	8	108
	36.50	37.48	0.98	0.98	100	0.89	91	6	140
	37.48	39.00	1.52	1.52	100	1.44	95	5	253
	39.00	40.57	1.57	1.57	100	1.53	97	6	224
	40.57	42.05	1.48	1.48	100	1.22	82	10	135
	42.05	43.60	1.55	1.55	100	1.46	94	6	221
	43.60	44.01	0.41	0.38	93	0.38	93	1 +	190
		Total =	39.20	39.13		35.33		194	
		Average =	1.26		99.8		90	6	201



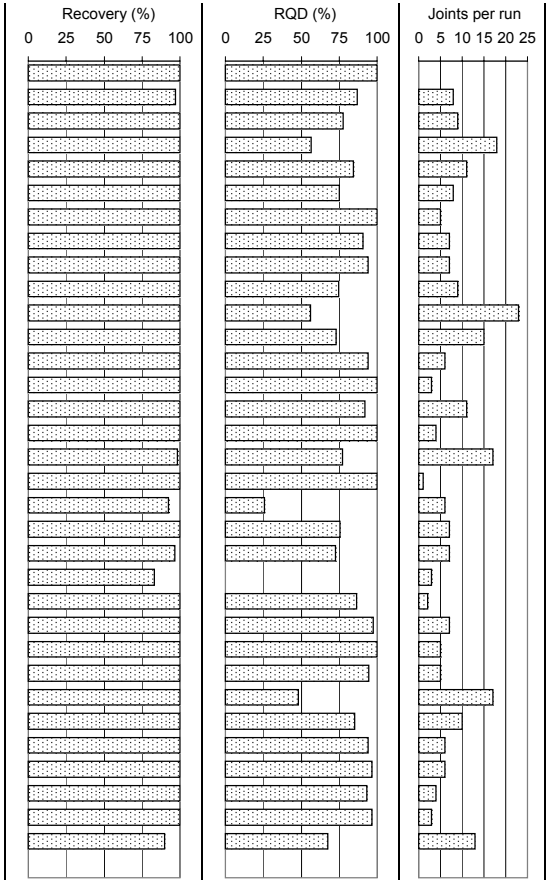
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: 03-014
Date: Aug. 19/03

Dip: 68 deg.
Azimuth: 231 deg.
Grd. Elev.: 137.52 m
Depth: 43.02 m

Barge Hole

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery (%)	RQD Length (m)	RQD (%)	Jts per run	Average[3] Spacing per Jt. (mm)
3.71-30.25 Greywacke gneiss: dark grey, medium to fine grained, strong, distinct foliation at 30 to 60 degrees to the core axis, closely spaced, low permeability, occasional granitic intrusions.	3.71	4.09	0.38	0.38	100	0.38	100	0	380
	4.09	5.48	1.39	1.35	97	1.21	87	8	154
	5.48	6.73	1.25	1.25	100	0.97	78	9	125
	6.73	8.27	1.54	1.54	100	0.87	56	18 +	81
	8.27	9.80	1.53	1.53	100	1.29	84	11 +	128
30.25-37.20 Granite: light pink to orange, coarse grained, strong, closely spaced, practically impermeable, dark inclusions.	9.80	10.36	0.56	0.56	100	0.42	75	8	62
	10.36	11.32	0.96	0.96	100	0.96	100	5	160
	11.32	12.85	1.53	1.53	100	1.39	91	7	191
	12.85	14.37	1.52	1.52	100	1.43	94	7	190
	14.37	15.91	1.54	1.54	100	1.15	75	9	154
	15.91	17.42	1.51	1.51	100	0.85	56	23	63
	17.42	18.97	1.55	1.55	100	1.13	73	15	97
	18.97	20.16	1.19	1.19	100	1.12	94	6	170
	20.16	20.66	0.50	0.50	100	0.50	100	3	125
	20.66	22.17	1.51	1.51	100	1.39	92	11	126
	22.17	23.75	1.58	1.58	100	1.58	100	4	316
	23.75	24.85	1.10	1.08	98	0.85	77	17 +	61
	24.85	25.33	0.48	0.48	100	0.48	100	1	240
	25.33	25.87	0.54	0.50	93	0.14	26	6 +	77
	25.87	26.73	0.86	0.86	100	0.65	76	7	108
	26.73	27.61	0.88	0.85	97	0.64	73	7 +	110
	27.61	27.91	0.30	0.25	83	0.00	0	3 +	75
	27.91	28.35	0.44	0.44	100	0.38	86	2	147
	28.35	29.81	1.46	1.46	100	1.42	97	7	183
	29.81	31.25	1.44	1.44	100	1.44	100	5	240
	31.25	32.76	1.51	1.51	100	1.43	95	5	252
	32.76	34.30	1.54	1.54	100	0.74	48	17	86
	34.30	35.85	1.55	1.55	100	1.32	85	10	141
	35.85	37.37	1.52	1.52	100	1.43	94	6	217
	37.37	38.95	1.58	1.58	100	1.53	97	6 +	226
	38.95	40.30	1.35	1.35	100	1.26	93	4	270
	40.30	41.82	1.52	1.52	100	1.47	97	3	380
37.20-43.02 Greywacke gneiss: dark grey, medium to fine grained, strong, distinct to weakly distinct foliation, closely spaced, practically impermeable.	41.82	43.02	1.20	1.08	90	0.81	67	13 +	86
		Total =	39.31	39.01		32.63		263	
		Average =	1.19		99.2		83	8	149



Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: 03-015
Date: Aug. 11/03

Dip: 70 deg.
Azimuth: 277 deg.
Grd. Elev.: 136.51 m
Depth: 43.82 m

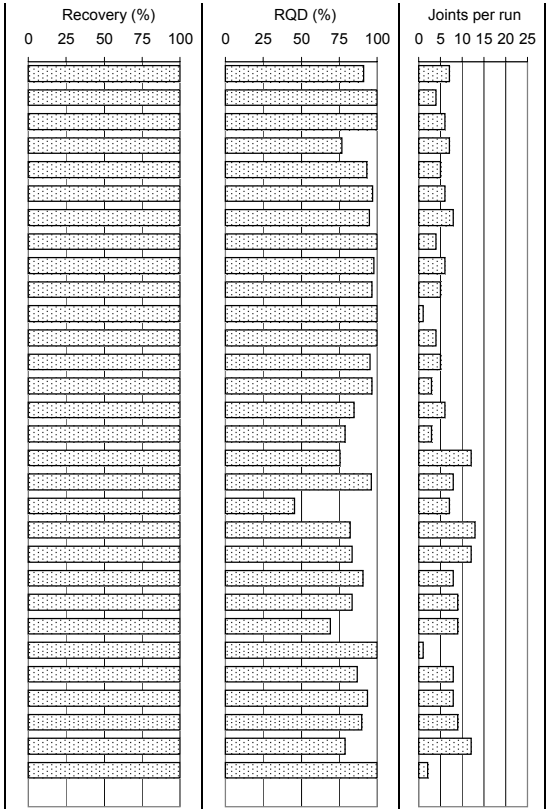
Barge Hole

Geological Description[3]

7.66-25.79 Amphibolite: black to dark green, fine to very fine grained, strong, indistinct to distinct foliation varying between 0 and 35 degrees to the core axis, moderately spaced, low permeability.

25.79-43.82 Granite: pink/grey to white, medium grained, moderately strong to strong, closely spaced, good quality, practically impermeable.

Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
7.66	8.57	0.91	0.91	100	0.83	91	7	114
8.57	10.05	1.48	1.48	100	1.48	100	4	296
10.05	11.63	1.58	1.58	100	1.58	100	6	226
11.63	12.70	1.07	1.07	100	0.82	77	7	134
12.70	14.22	1.52	1.52	100	1.42	93	5	253
14.22	15.59	1.37	1.37	100	1.33	97	6	196
15.59	17.11	1.52	1.52	100	1.44	95	8	169
17.11	18.60	1.49	1.49	100	1.49	100	4	298
18.60	19.90	1.30	1.30	100	1.27	98	6	186
19.90	21.45	1.55	1.55	100	1.50	97	5 +	258
21.45	21.72	0.27	0.27	100	0.27	100	1	135
21.72	23.20	1.48	1.48	100	1.48	100	4	296
23.20	23.87	0.67	0.67	100	0.64	96	5	112
23.87	24.73	0.86	0.86	100	0.83	97	3	215
24.73	26.25	1.52	1.52	100	1.29	85	6	217
26.25	26.44	0.19	0.19	100	0.15	79	3 +	48
26.44	27.78	1.34	1.34	100	1.01	75	12	103
27.78	29.05	1.27	1.27	100	1.22	96	8	141
29.05	29.62	0.57	0.57	100	0.26	46	7 +	71
29.62	30.98	1.36	1.36	100	1.12	82	13 +	97
30.98	32.50	1.52	1.52	100	1.27	84	12	117
32.50	34.01	1.51	1.51	100	1.37	91	8	168
34.01	35.46	1.45	1.45	100	1.21	83	9	145
35.46	36.27	0.81	0.81	100	0.56	69	9	81
36.27	37.25	0.98	0.98	100	0.98	100	1	490
37.25	38.77	1.52	1.52	100	1.32	87	8	169
38.77	40.16	1.39	1.39	100	1.30	94	8	154
40.16	41.57	1.41	1.41	100	1.27	90	9 +	141
41.57	43.14	1.57	1.57	100	1.24	79	12	121
43.14	43.82	0.68	0.68	100	0.68	100	2	227
Total =		36.16	36.16		32.63		198	
Average =		1.21		100.0		90	7	182



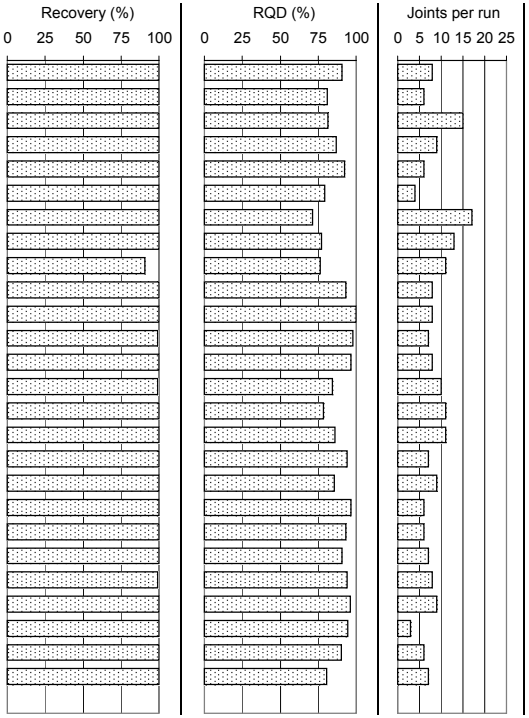
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: 03-016
Date: Jul. 22/03

Dip: 90 deg.
Azimuth: - deg.
Grd. Elev.: 137.30 m
Depth: 41.01 m

Barge Hole

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average** Spacing per Jt. (mm)
4.36-8.15 Greywacke gneiss: medium to dark grey, fine grained, moderately strong to strong, distinct to indistinct irregular and planar foliation, closely spaced, good quality.	4.36	5.87	1.51	1.51	100	1.37	91	8	168
	5.87	6.45	0.58	0.58	100	0.47	81	6	83
	6.45	7.97	1.52	1.52	100	1.24	82	15	95
	7.97	9.50	1.53	1.53	100	1.33	87	9	153
	9.50	10.28	0.78	0.78	100	0.72	92	6	111
8.15-19.45 Granite: pink to light grey, fine to coarse grained, strong, no foliation evident, closely spaced, good quality.	10.28	11.01	0.73	0.73	100	0.58	79	4	146
	11.01	12.54	1.53	1.53	100	1.09	71	17	85
	12.54	14.07	1.53	1.53	100	1.18	77	13	109
	14.07	15.59	1.52	1.38	91	1.16	76	11 +	127
	15.59	17.11	1.52	1.52	100	1.42	93	8	169
	17.11	18.64	1.53	1.53	100	1.53	100	8	170
	18.64	20.17	1.53	1.52	99	1.50	98	7 +	191
	20.17	21.69	1.52	1.52	100	1.47	97	8	169
	21.69	23.21	1.52	1.51	99	1.28	84	10 +	138
	23.21	24.75	1.54	1.54	100	1.21	79	11	128
	24.75	26.26	1.51	1.51	100	1.30	86	11	126
	26.26	27.80	1.54	1.54	100	1.45	94	7	193
	27.80	29.32	1.52	1.52	100	1.30	86	9	152
	29.32	30.84	1.52	1.52	100	1.47	97	6	217
	30.84	32.34	1.50	1.50	100	1.40	93	6	214
	32.34	33.87	1.53	1.53	100	1.39	91	7	191
	33.87	35.42	1.55	1.54	99	1.46	94	8 +	172
	35.42	36.95	1.53	1.53	100	1.47	96	9	153
	36.95	38.46	1.51	1.51	100	1.43	95	3	377
	38.46	39.99	1.53	1.53	100	1.38	90	6	219
	39.99	41.01	1.02	1.02	100	0.82	80	7	128
		Total =	36.65	36.48		32.42		220	
		Average =	1.41		99.5		88	8	166

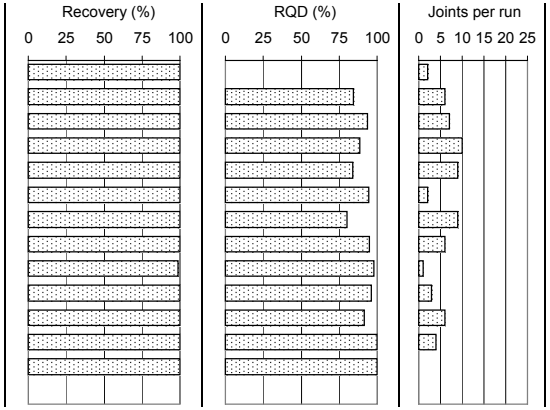


Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: 03-022
Date: Aug. 31/03

Dip: 90 deg.
Azimuth: - deg.
Grd. Elev.: 149.54 m
Depth: 25.05 m

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average** Spacing per Jt. (mm)
9.86-15.40 Amphibolite: black to dark green, medium to fine grained, distinct irregular foliation at various angles to the core axis, moderately strong to strong, closely spaced, good quality.	9.86	9.99	0.13	0.13	100	0.00	0	2	43
	9.99	11.28	1.29	1.29	100	1.09	84	6	184
	11.28	12.82	1.54	1.54	100	1.44	94	7	193
15.40-20.05 Granite: light grey to white, and pink, medium to very coarse grained (pegmatitic), strong, indistinct to locally weak foliation at various angles to core axis, closely spaced, good quality.	12.82	14.38	1.56	1.56	100	1.38	88	10	142
	14.38	15.50	1.12	1.12	100	0.94	84	9	112
	15.50	15.87	0.37	0.37	100	0.35	95	2	123
	15.87	17.42	1.55	1.55	100	1.24	80	9	155
	17.42	18.95	1.53	1.53	100	1.45	95	6	219
	18.95	20.35	1.40	1.38	99	1.37	98	1 +	700
	20.35	21.93	1.58	1.58	100	1.52	96	3	395
	21.93	23.46	1.53	1.53	100	1.40	92	6	219
	23.46	24.83	1.37	1.37	100	1.37	100	4	274
	24.83	25.05	0.22	0.22	100	0.22	100	0	220
		Total =	15.19	15.17		13.77		65	
		Average =	1.17		99.9		91	5	230

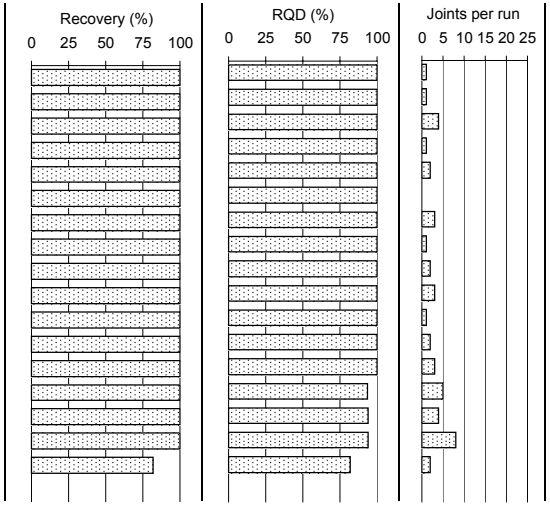


Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: G-0007
Date: Oct. 2/88

Dip: 45 deg.
Bearing: 19 deg.
Datum 140.19 m
Depth: 28.94 m

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
3.86-22.88 Granite: white to whitish grey, medium grained to coarse grained, strong, moderately spaced jointing, excellent rock quality.	3.86	4.56	0.70	0.70	100	0.70	100	1	350
	4.56	6.08	1.52	1.52	100	1.52	100	1	760
	6.08	7.66	1.58	1.58	100	1.58	100	4	316
22.88-23.39 Diabase: dark grey to green, very fine grained, slight foliation evident at 30 to 40 degrees to the core axis, strong, moderately spaced jointing, excellent rock quality.	7.66	9.15	1.49	1.49	100	1.49	100	1	745
	9.15	10.72	1.57	1.57	100	1.57	100	2	523
	10.72	12.23	1.51	1.51	100	1.51	100	0	1510
	12.23	13.75	1.52	1.52	100	1.52	100	3	380
	13.75	15.25	1.50	1.50	100	1.50	100	1	750
	15.25	16.80	1.55	1.55	100	1.55	100	2	517
	16.80	18.34	1.54	1.54	100	1.54	100	3	385
	18.34	19.85	1.51	1.51	100	1.51	100	1	755
	19.85	21.34	1.49	1.49	100	1.49	100	2	497
	21.34	22.88	1.54	1.54	100	1.54	100	3	385
	22.88	24.38	1.50	1.50	100	1.40	93	5	250
	24.38	25.91	1.53	1.53	100	1.44	94	4 +	306
	25.91	27.38	1.47	1.47	100	1.38	94	8	163
23.39-28.94 Granite: as described above, good to excellent rock quality.	27.38	28.94	1.56	1.28	82	1.28	82	2 +	427
		Total =	25.08	24.80		24.52		43	
		Average =	1.48		98.9		98	3	570

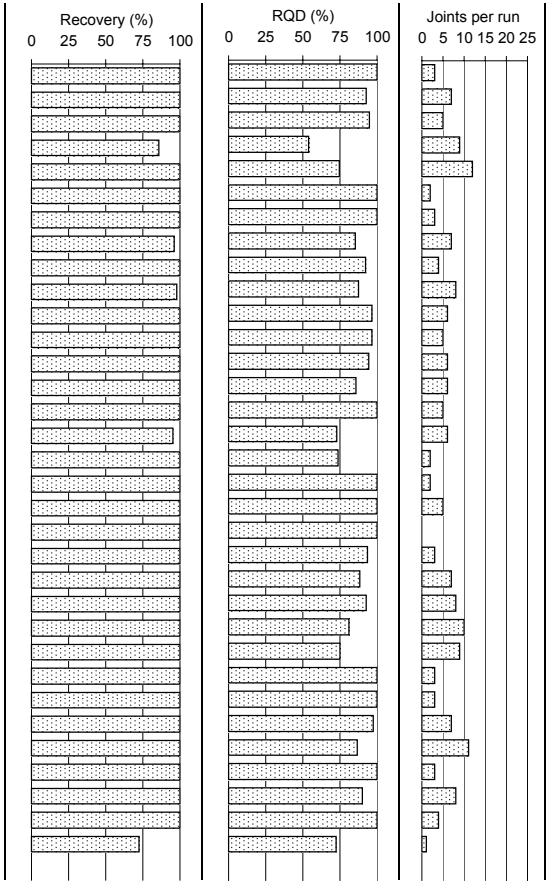


Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: G-0008
Date: Jun, 6/91

Dip: 45 deg.
Bearing: N28E
Datum 141.50 m
Depth: 58.01 m

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery (%)	RQD Length (m)	RQD (%)	Jts per run	Average[3] Spacing per Jt. (mm)
13.06-19.75 Greywacke gneiss: dark grey to greenish grey with pink to light grey granite bands throughout, fine grained, strong, distinct foliation at 35 to 45 degrees to the core axis. Closely to moderately spaced jointing, excellent rock quality, low permeability.	13.11	14.40	1.29	1.29	100	1.29	100	3	323
	14.40	15.73	1.33	1.33	100	1.23	92	7	166
	15.73	17.25	1.52	1.52	100	1.44	95	5	253
	17.25	18.53	1.28	1.10	86	0.69	54	9 +	110
	18.53	19.83	1.30	1.30	100	0.97	75	12	100
19.75-25.93 Granite: light pink, medium to coarse grained, strong, no foliation evident, hematitic stained, upper contact is intact, irregular and sharp, closely to moderately spaced jointing, excellent rock quality, low permeability.	19.83	20.64	0.81	0.81	100	0.81	100	2	270
	20.64	21.87	1.23	1.23	100	1.23	100	3	308
	21.87	23.49	1.62	1.56	96	1.38	85	7 +	195
	23.49	24.93	1.44	1.44	100	1.33	92	4	288
25.93-35.08 Greywacke gneiss: as descripbed above.	24.93	26.39	1.46	1.43	98	1.28	88	8 +	159
	26.39	27.88	1.49	1.49	100	1.44	97	6	213
35.08-40.66 Granite: as described above.	27.88	29.54	1.66	1.66	100	1.60	96	5	277
40.66-44.97 Greywacke gneiss: as described above.	29.54	30.93	1.39	1.39	100	1.31	94	6	199
	30.93	32.50	1.57	1.57	100	1.35	86	6	224
44.97-49.35 Granite: light grey, coarse grained, strong, no foliation evident, hematite staining throughout, upper contact is irregular, intact and sharp, closely to moderately spaced jointing, good to excellent rock quality, low permeability.	32.50	34.08	1.58	1.58	100	1.58	100	5	263
	34.08	35.55	1.47	1.40	95	1.07	73	6 +	200
	35.55	35.89	0.34	0.34	100	0.25	74	2	113
49.35-55.13 Greywacke gneiss: as described above.	35.89	37.32	1.43	1.43	100	1.43	100	2	477
	37.32	38.84	1.52	1.52	100	1.52	100	5	253
	38.84	39.14	0.30	0.30	100	0.30	100	0	300
	39.14	40.52	1.38	1.38	100	1.29	93	3	345
55.13-58.01 Granite: light grey, medium to coarse grained, strong, no foliation evident, hematite staining, possible containing garnet, upper contact is a joint, planar, rough, tight, black coating, minor carbonate, trace iron sulphides, slickensides and at 40 degrees to the core axis, moderately spaced jointing, excellent rock quality, low permeability	40.52	41.96	1.44	1.44	100	1.27	88	7	180
	41.96	43.47	1.51	1.51	100	1.40	93	8	168
	43.47	45.00	1.53	1.53	100	1.24	81	10 +	139
	45.00	46.48	1.48	1.48	100	1.11	75	9	148
	46.48	48.06	1.58	1.58	100	1.58	100	3	395
	48.06	49.23	1.17	1.17	100	1.17	100	3	293
	49.23	50.89	1.66	1.66	100	1.62	98	7	208
	50.89	52.48	1.59	1.59	100	1.38	87	11	133
	52.48	54.14	1.66	1.66	100	1.66	100	3	415
	54.14	55.63	1.49	1.49	100	1.34	90	8	166
	55.63	57.17	1.54	1.54	100	1.54	100	4	308
	57.17	58.01	0.84	0.61	73	0.61	73	1 +	305
		Total =	44.90	44.33		40.71		180	
		Average =	1.36		98.7		91	5	248



Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: G-0011
Date: Jun. 15, 91

Dip: 45 deg.
Bearing: S16W
Datum 140.05 m
Depth: 55.44 m

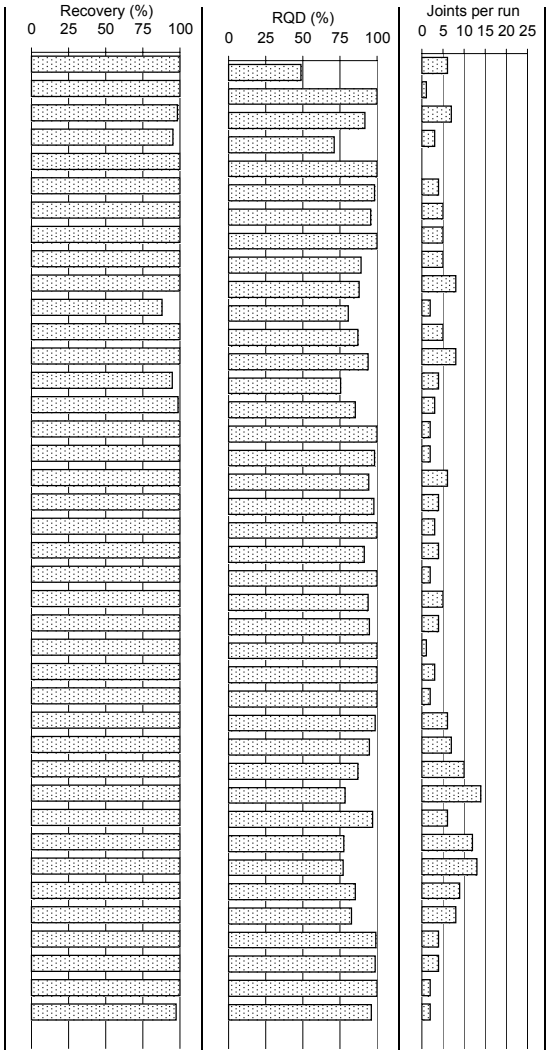
Barge hole

Geological Description[3]

0.94-43.87 Greywacke gneiss: medium to dark grey, fine grained, indistinct to strongly foliated at 30 to 45 degrees to the core axis, strong, moderately spaced jointing, excellent rock quality, with granitic stringers and intrusions.

43.87-55.44 Granite: light grey, coarse to medium grained, very strong, upper contact at 90 degrees, close to moderately close jointing, good to excellent rock quality.

Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
0.94	2.01	1.07	1.07	100	0.52	49	6 +	153
2.01	2.44	0.43	0.43	100	0.43	100	1	215
2.44	3.76	1.32	1.30	98	1.21	92	7 +	163
3.76	4.63	0.87	0.83	95	0.62	71	3 +	208
4.63	5.14	0.51	0.51	100	0.51	100	0	510
5.14	6.84	1.70	1.70	100	1.67	98	4	340
6.84	8.06	1.22	1.22	100	1.17	96	5	203
8.06	9.82	1.76	1.76	100	1.76	100	5	293
9.82	11.14	1.32	1.32	100	1.18	89	5	220
11.14	12.80	1.66	1.66	100	1.46	88	8	184
12.80	14.04	1.24	1.09	88	1.00	81	2 +	363
14.04	15.35	1.31	1.31	100	1.14	87	5	218
15.35	16.86	1.51	1.51	100	1.42	94	8	168
16.86	17.64	0.78	0.74	95	0.59	76	4 +	148
17.64	19.09	1.45	1.43	99	1.24	86	3 +	358
19.09	20.54	1.45	1.45	100	1.45	100	2	483
20.54	21.16	0.62	0.62	100	0.61	98	2	207
21.16	22.81	1.65	1.65	100	1.56	95	6	236
22.81	23.69	0.88	0.88	100	0.86	98	4	176
23.69	24.82	1.13	1.13	100	1.13	100	3	283
24.82	26.43	1.61	1.61	100	1.47	91	4	322
26.43	28.10	1.67	1.67	100	1.67	100	2	557
28.10	29.57	1.47	1.47	100	1.38	94	5	245
29.57	31.16	1.59	1.59	100	1.51	95	4	318
31.16	32.67	1.51	1.51	100	1.51	100	1	755
32.67	34.28	1.61	1.61	100	1.61	100	3	403
34.28	35.75	1.47	1.47	100	1.47	100	2	490
35.75	37.32	1.57	1.57	100	1.55	99	6	224
37.32	38.83	1.51	1.51	100	1.43	95	7	189
38.83	40.38	1.55	1.55	100	1.35	87	10	141
40.38	41.87	1.49	1.49	100	1.17	79	14 +	99
41.87	43.45	1.58	1.58	100	1.53	97	6	226
43.45	44.98	1.53	1.53	100	1.19	78	12	118
44.98	46.46	1.48	1.48	100	1.14	77	13	106
46.46	48.04	1.58	1.58	100	1.35	85	9	158
48.04	49.53	1.49	1.49	100	1.23	83	8 +	166
49.53	50.91	1.38	1.38	100	1.37	99	4	276
50.91	52.31	1.40	1.40	100	1.38	99	4	280
52.31	53.96	1.65	1.65	100	1.65	100	2	550
53.96	55.44	1.48	1.44	97	1.42	96	2 +	480
	Total =	54.50	54.19		49.91		201	
	Average =	1.36		99.4		92	5	270



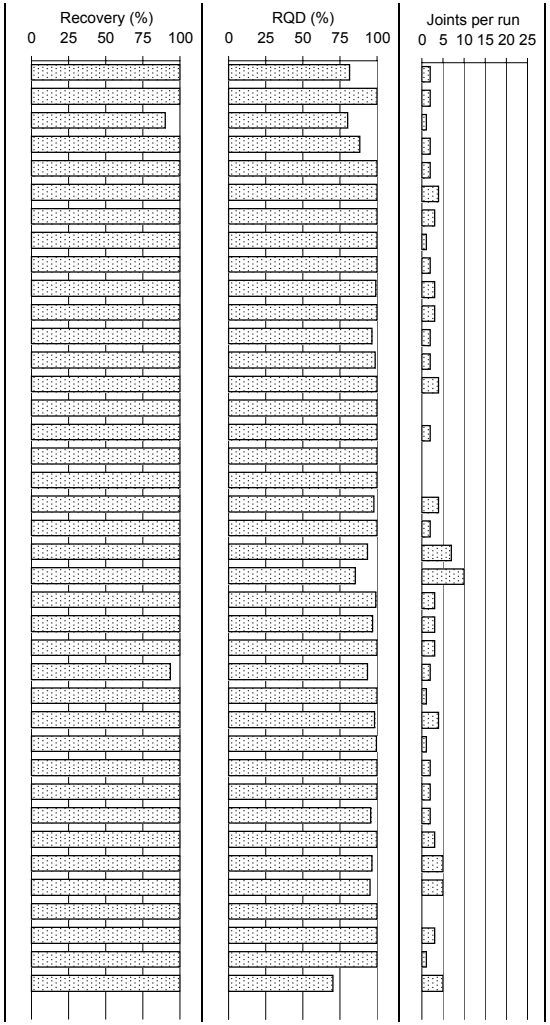
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: G-0012
Date: Jun. 18, 91

Dip: 45 deg.
Bearing: S85W
Datum 139.95 m
Depth: 55.80 m

Barge hole

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery (%)	RQD Length (m)	RQD (%)	Jts per run	Average[3] Spacing per Jt. (mm)
1.61-14.89 Greywacke gneiss: dark grey, with light grey granite, fine grained, strong, distinct foliation at 45 to 60 degrees to the core axis, moderately spaced jointing, excellent rock quality, medium permeability.	1.61	2.37	0.76	0.76	100	0.62	82	2 +	253
	2.37	4.00	1.63	1.63	100	1.63	100	2	543
	4.00	5.42	1.42	1.28	90	1.14	80	1 +	640
	5.42	6.96	1.54	1.54	100	1.36	88	2 +	513
14.89-44.06 Granite: medium grey, medium to coarse grained, strong, no foliation evident, moderately to widely spaced jointing, excellent rock quality, low permeability, upper contact is intact, planar, sharp and at 45 degrees to the core axis.	6.96	8.45	1.49	1.49	100	1.49	100	2	497
	8.45	9.99	1.54	1.54	100	1.54	100	4	308
	9.99	11.20	1.21	1.21	100	1.21	100	3	303
	11.20	12.61	1.41	1.41	100	1.41	100	1	705
	12.61	14.09	1.48	1.48	100	1.48	100	2	493
44.06-55.80 Greywacke gneiss: as described above, upper contact is intact, planar, sharp and at 55 degrees to the core axis.	14.09	15.62	1.53	1.53	100	1.52	99	3	383
	15.62	17.18	1.56	1.56	100	1.56	100	3	390
	17.18	18.69	1.51	1.51	100	1.46	97	2	503
	18.69	20.28	1.59	1.59	100	1.57	99	2	530
	20.28	21.78	1.50	1.50	100	1.50	100	4	300
	21.78	23.33	1.55	1.55	100	1.55	100	0	1550
	23.33	24.91	1.58	1.58	100	1.58	100	2	527
	24.91	25.63	0.72	0.72	100	0.72	100	0	720
	25.63	26.58	0.95	0.95	100	0.95	100	0	950
	26.58	28.11	1.53	1.53	100	1.50	98	4 +	306
	28.11	29.65	1.54	1.54	100	1.54	100	2	513
	29.65	31.03	1.38	1.38	100	1.29	93	7	173
	31.03	32.58	1.55	1.55	100	1.32	85	10	141
	32.58	33.66	1.08	1.08	100	1.07	99	3	270
	33.66	34.66	1.00	1.00	100	0.97	97	3	250
	34.66	35.87	1.21	1.21	100	1.21	100	3	303
	35.87	37.26	1.39	1.30	94	1.30	94	2 +	433
	37.26	38.55	1.29	1.29	100	1.29	100	1	645
	38.55	40.10	1.55	1.55	100	1.52	98	4	310
	40.10	41.67	1.57	1.57	100	1.56	99	1	785
	41.67	43.19	1.52	1.52	100	1.52	100	2	507
	43.19	44.61	1.42	1.42	100	1.42	100	2	473
	44.61	46.28	1.67	1.67	100	1.60	96	2	557
	46.28	47.87	1.59	1.59	100	1.59	100	3	398
	47.87	49.37	1.50	1.50	100	1.45	97	5	250
	49.37	51.03	1.66	1.66	100	1.58	95	5	277
	51.03	51.31	0.28	0.28	100	0.28	100	0	280
	51.31	52.70	1.39	1.39	100	1.39	100	3 +	348
	52.70	54.23	1.53	1.53	100	1.53	100	1	765
	54.23	55.80	1.57	1.57	100	1.10	70	5 ++	262
		Total =	54.19	53.96		52.32		103	
		Average =	1.39		99.6		97	3	521



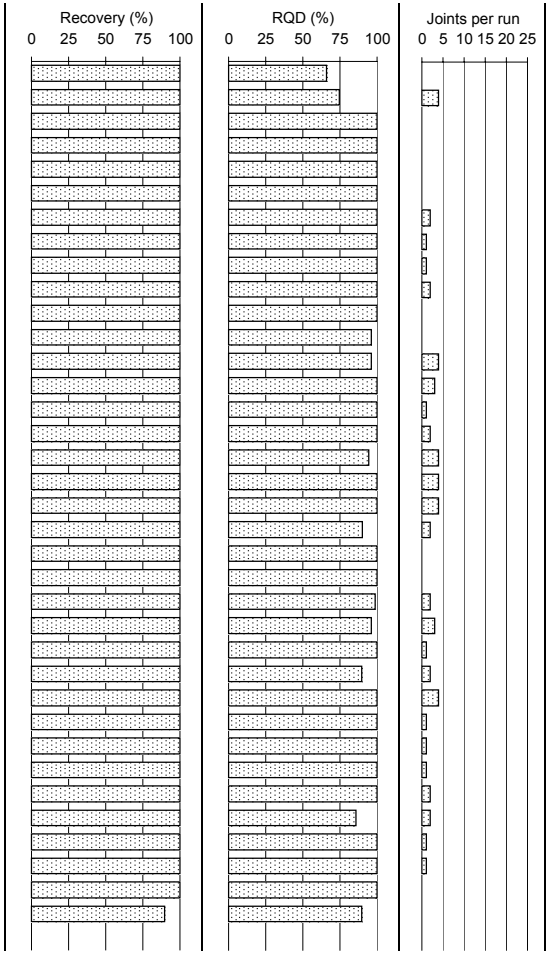
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: G-0013
Date: Jun. 21, 91

Dip: 60 deg.
Bearing: 270 deg.
Datum 140.00 m
Depth: 51.05 m

Barge hole

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
1.73-19.44 Granite: medium grey, medium to coarse grained, strong, no foliation evident, widely spaced jointing, excellent rock quality, low permeability, hematite staining throughout, minor biotite to chlorite alteration throughout.	1.73	2.38	0.65	0.65	100	0.43	66	0 +	650
	2.38	3.88	1.50	1.50	100	1.12	75	4 +	300
	3.88	5.33	1.45	1.45	100	1.45	100	0	1450
	5.33	6.69	1.36	1.36	100	1.36	100	0	1360
19.44-28.09 Greywacke gneiss: dark grey, medium to coarse grained, strong, widely spaced jointing, excellent rock quality, low permeability, upper contact is intact, irregular and gradational.	6.69	8.35	1.66	1.66	100	1.66	100	0	1660
	8.35	9.86	1.51	1.51	100	1.51	100	0	1510
	9.86	11.46	1.60	1.60	100	1.60	100	2	533
28.09-40.86 Granite: light pink, medium to coarse grained, strong, no foliation evident, widely spaced jointing, excellent rock quality, low permeability, upper contact is gradational.	11.46	12.93	1.47	1.47	100	1.47	100	1	735
	12.93	14.49	1.56	1.56	100	1.56	100	1	780
	14.49	16.05	1.56	1.56	100	1.56	100	2	520
	16.05	17.49	1.44	1.44	100	1.44	100	0	1440
40.86-44.87 Greywacke gneiss: dark grey with light grey granite, fine to medium grained, strong, no foliation evident, widely spaced jointing, excellent rock quality, low permeability, gneissic texture is not apparent from core surface but inspection of machine break surfaces shows a well developed gneissic texture, upper contact is intact, planar, sharp and at 75 degrees to the core axis.	17.49	18.97	1.48	1.48	100	1.42	96	0 +	1480
	18.97	20.54	1.57	1.57	100	1.51	96	4	314
	20.54	21.98	1.44	1.44	100	1.44	100	3	360
	21.98	23.60	1.62	1.62	100	1.62	100	1	810
	23.60	25.02	1.42	1.42	100	1.42	100	2	473
	25.02	26.65	1.63	1.63	100	1.54	94	4	326
	26.65	28.07	1.42	1.42	100	1.42	100	4	284
44.87-51.73 Granite: light grey, coarse grained, strong, no foliation evident, widely spaced jointing, excellent rock quality, upper contact is intact, planar, sharp and at 55 degrees to the core axis.	28.07	28.70	0.63	0.63	100	0.63	100	4	126
	28.70	29.83	1.13	1.13	100	1.02	90	2 +	377
	29.83	31.23	1.40	1.40	100	1.40	100	0	1400
	31.23	32.78	1.55	1.55	100	1.55	100	0	1550
	32.78	34.36	1.58	1.58	100	1.56	99	2	527
	34.36	35.91	1.55	1.55	100	1.49	96	3	388
	35.91	37.48	1.57	1.57	100	1.57	100	1	785
	37.48	38.17	0.69	0.69	100	0.62	90	2	230
	38.17	38.89	0.72	0.72	100	0.72	100	4	144
	38.89	40.51	1.62	1.62	100	1.62	100	1	810
	40.51	42.01	1.50	1.50	100	1.50	100	1	750
	42.01	43.58	1.57	1.57	100	1.57	100	1	785
	43.58	45.05	1.47	1.47	100	1.47	100	2	490
	45.05	45.47	0.42	0.42	100	0.36	86	2	140
	45.47	46.79	1.32	1.32	100	1.32	100	1	660
	46.79	48.13	1.34	1.34	100	1.34	100	1	670
	48.13	49.59	1.46	1.46	100	1.46	100	0	1460
	49.59	51.05	1.46	1.31	90	1.31	90	0	1310
		Total =	49.32	49.17		48.04		55	
		Average =	1.37		99.7		97	2	881



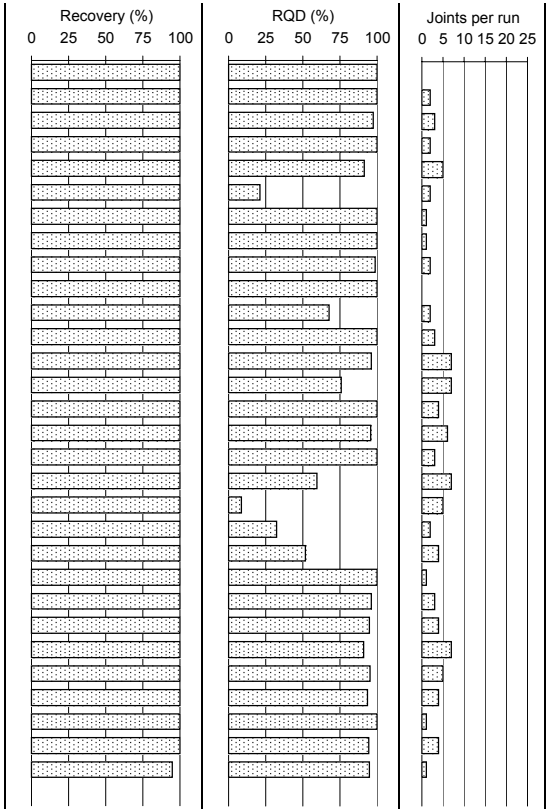
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: G-0014
Date: Jun. 25, 91

Dip: 60 deg.
Bearing: S26W
Datum 140.11 m
Depth: 46.10 m

Barge hole

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
4.03-12.82 Granite: light to medium grey, medium to coarse grained, strong, no foliation evident, widely spaced jointing, good to excellent rock quality, low permeability.	4.03	4.73	0.70	0.70	100	0.70	100	0	700
	4.73	6.31	1.58	1.58	100	1.58	100	2	527
	6.31	7.89	1.58	1.58	100	1.54	97	3 +	395
12.82-33.31 Greywacke gneiss: dark grey with light grey granite bands, fine grained, strong, distinct foliation at 25 to 35 degrees to the core axis, widely to moderately spaced jointing, good to excellent rock quality, low permeability, upper contact is intact sharp and irregular.	7.89	8.91	1.02	1.02	100	1.02	100	2	340
	8.91	10.44	1.53	1.53	100	1.40	92	5 +	255
	10.44	11.20	0.76	0.76	100	0.16	21	2 ++	253
	11.20	12.68	1.48	1.48	100	1.48	100	1	740
	12.68	14.00	1.32	1.32	100	1.32	100	1	660
33.31-37.41Granite: light grey, medium to coarse grained, strong, no foliation evident, widely spaced jointing, excellent rock quality, upper contact is intact, planar, sharp and at 50 degrees to the core axis.	14.00	15.50	1.50	1.50	100	1.48	99	2 +	500
	15.50	17.15	1.65	1.65	100	1.65	100	0	1650
	17.15	18.63	1.48	1.48	100	1.00	68	2 +	493
	18.63	20.14	1.51	1.51	100	1.51	100	3	378
37.41-46.10 Greywacke gneiss: dark grey, fine grained, strong, distinct foliation at 20 to 45 degrees to the core axis, moderately to widely spaced jointing, excellent rock quality, low permeability, upper contact is a joint, planar, rough, tight, carbonate coated and at 30 degrees to the core axis.	20.14	21.66	1.52	1.52	100	1.46	96	7 +	190
	21.66	23.15	1.49	1.49	100	1.13	76	7 +	186
	23.15	24.69	1.54	1.54	100	1.54	100	4	308
	24.69	26.25	1.56	1.56	100	1.49	96	6	223
	26.25	27.76	1.51	1.51	100	1.51	100	3	378
	27.76	29.22	1.46	1.46	100	0.87	60	7 +	183
	29.22	30.71	1.49	1.49	100	0.13	9	5 ++	248
	30.71	31.92	1.21	1.21	100	0.39	32	2 ++	403
	31.92	33.47	1.55	1.55	100	0.80	52	4 ++	310
	33.47	35.07	1.60	1.60	100	1.60	100	1	800
	35.07	35.58	0.51	0.51	100	0.49	96	3	128
	35.58	37.08	1.50	1.50	100	1.42	95	4	300
	37.08	38.50	1.42	1.42	100	1.29	91	7	178
	38.50	40.00	1.50	1.50	100	1.43	95	5	250
	40.00	41.55	1.55	1.55	100	1.45	94	4	310
	41.55	43.05	1.50	1.50	100	1.50	100	1	750
	43.05	44.60	1.55	1.55	100	1.46	94	4	310
	44.60	46.10	1.50	1.42	95	1.42	95	1 +	710
		Total =	42.07	41.99		36.22		98	
		Average =	1.40		99.8		86	3	425



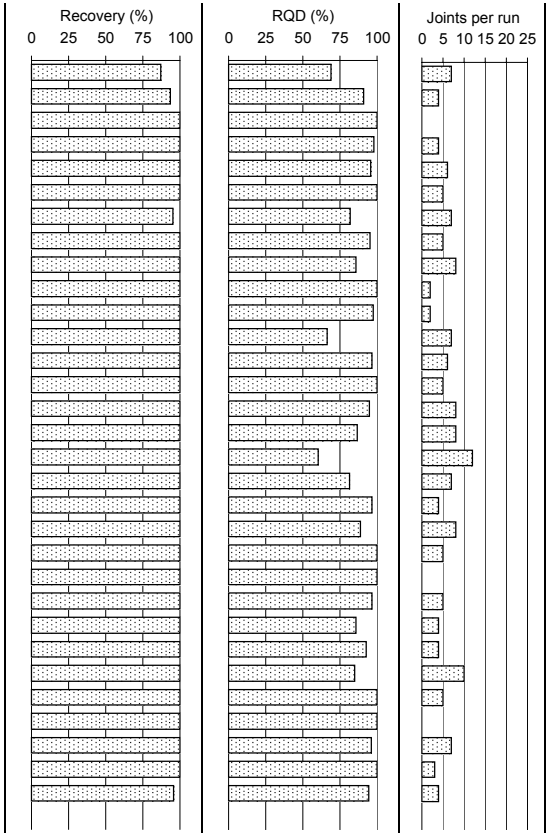
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: G-0015
Date: Jun. 27, 91

Dip: 60 deg.
Bearing: S82W
Datum 139.81 m
Depth: 46.66 m

Barge hole

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery Length (%)	RQD Length (m)	RQD Length (%)	Jts per run	Average[3] Spacing per Jt. (mm)
4..32-46.66 Greywacke gneiss: dark grey to black with light to medium grey granite, fine grained, strong, indistinct to distinct foliation at 30 to 40 degrees to the core axis, closely to moderately spaced jointing, good to excellent rock quality, low permeability.	4.32	6.15	1.83	1.59	87	1.26	69	7 +	199
	6.15	7.81	1.66	1.55	93	1.51	91	4 +	310
	7.81	8.08	0.27	0.27	100	0.27	100	0	270
	8.08	9.50	1.42	1.42	100	1.39	98	4	284
	9.50	10.85	1.35	1.35	100	1.29	96	6	193
	10.85	12.31	1.46	1.46	100	1.46	100	5	243
	12.31	13.76	1.45	1.38	95	1.19	82	7 +	173
	13.76	15.21	1.45	1.45	100	1.38	95	5	242
	15.21	16.75	1.54	1.54	100	1.32	86	8	171
	16.75	18.15	1.40	1.40	100	1.40	100	2	467
	18.15	19.61	1.46	1.46	100	1.42	97	2	487
	19.61	21.30	1.69	1.69	100	1.12	66	7 +	211
	21.30	22.50	1.20	1.20	100	1.16	97	6	171
	22.50	24.01	1.51	1.51	100	1.51	100	5	252
	24.01	25.57	1.56	1.56	100	1.48	95	8	173
	25.57	26.55	0.98	0.98	100	0.85	87	8	109
	26.55	28.04	1.49	1.49	100	0.90	60	12	115
	28.04	28.64	0.60	0.60	100	0.49	82	7 +	75
	28.64	30.15	1.51	1.51	100	1.46	97	4	302
	30.15	31.60	1.45	1.45	100	1.29	89	8	161
	31.60	33.15	1.55	1.55	100	1.55	100	5	258
	33.15	34.60	1.45	1.45	100	1.45	100	0	1450
	34.60	36.00	1.40	1.40	100	1.35	96	5 +	233
	36.00	37.54	1.54	1.54	100	1.32	86	4 +	308
	37.54	39.04	1.50	1.50	100	1.39	93	4 +	300
	39.04	40.57	1.53	1.53	100	1.30	85	10 +	139
	40.57	42.19	1.62	1.62	100	1.62	100	5	270
	42.19	42.33	0.14	0.14	100	0.14	100	0	140
	42.33	43.85	1.52	1.52	100	1.46	96	7	190
	43.85	45.09	1.24	1.24	100	1.24	100	3	310
	45.09	46.66	1.57	1.50	96	1.48	94	4 +	300
		Total =	42.34	41.85		38.45		162	
		Average =	1.37		98.8		91	5	260



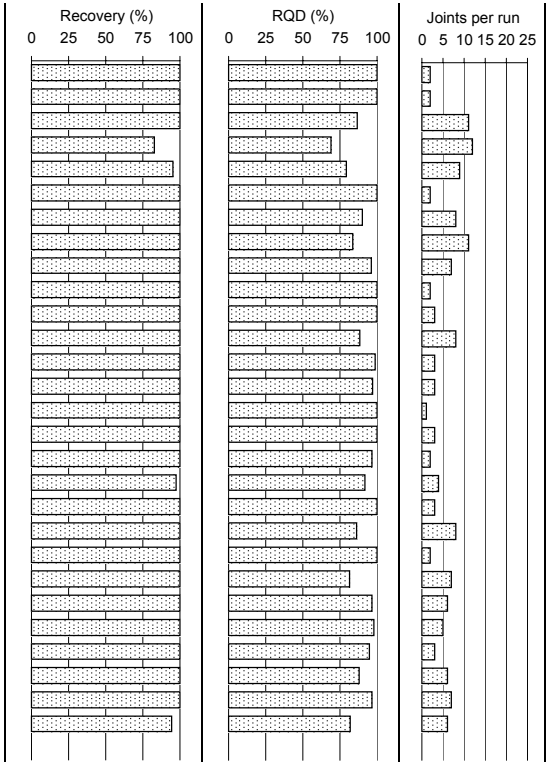
Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: G-0016
Date: Jun. 28, 91

Dip: 60 deg.
Bearing: N13W
Datum 139.76 m
Depth: 42.36 m

Barge hole

Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery (%)	RQD Length (m)	RQD (%)	Jts per run	Average[3] Spacing per Jt. (mm)
4.73-39.65 Granite: light grey to light brownish grey, medium to coarse grained, strong, no foliation evident, moderately spaced jointing, good to excellent rock quality, medium permeability, occasional mafic clot.	4.73	5.35	0.62	0.62	100	0.62	100	2	207
	5.35	5.93	0.58	0.58	100	0.58	100	2	193
	5.93	7.50	1.57	1.57	100	1.36	87	11	131
	7.50	8.99	1.49	1.23	83	1.03	69	12 +	95
39.65-42.36 Greywacke gneiss: dark grey to medium grey, fine to medium grained, occasionally coarse grained, strong, distinct foliation at 20 degrees to the core axis, moderately jointed, good rock quality, low permeability, contains some coarse quartz/feldspar grains, rounded and rotated, some angular fragments, upper contact is a joint, tight, sharp and at 20 degrees to the core axis.	8.99	10.44	1.45	1.38	95	1.15	79	9 +	138
	10.44	10.83	0.39	0.39	100	0.39	100	2	130
	10.83	12.37	1.54	1.54	100	1.39	90	8	171
	12.37	13.88	1.51	1.51	100	1.26	83	11	126
	13.88	15.40	1.52	1.52	100	1.46	96	7	190
	15.40	16.84	1.44	1.44	100	1.44	100	2	480
	16.84	18.13	1.29	1.29	100	1.29	100	3	323
	18.13	19.70	1.57	1.57	100	1.39	89	8	174
	19.70	21.16	1.46	1.46	100	1.44	99	3	365
	21.16	22.74	1.58	1.58	100	1.53	97	3	395
	22.74	24.13	1.39	1.39	100	1.39	100	1	695
	24.13	25.62	1.49	1.49	100	1.49	100	3	373
	25.62	27.07	1.45	1.45	100	1.40	97	2	483
	27.07	28.69	1.62	1.58	98	1.49	92	4 +	316
	28.69	30.03	1.34	1.34	100	1.34	100	3	335
	30.03	31.63	1.60	1.60	100	1.38	86	8	178
	31.63	33.08	1.45	1.45	100	1.45	100	2	483
	33.08	34.11	1.03	1.03	100	0.84	82	7	129
	34.11	35.63	1.52	1.52	100	1.47	97	6	217
	35.63	37.15	1.52	1.52	100	1.49	98	5	253
	37.15	37.93	0.78	0.78	100	0.74	95	3	195
	37.93	39.40	1.47	1.47	100	1.29	88	6	210
	39.40	40.93	1.53	1.53	100	1.48	97	7	191
	40.93	42.36	1.43	1.35	94	1.17	82	6 +	193
		Total =	37.63	37.18		34.75		146	
		Average =	1.34		98.8		92	5	256

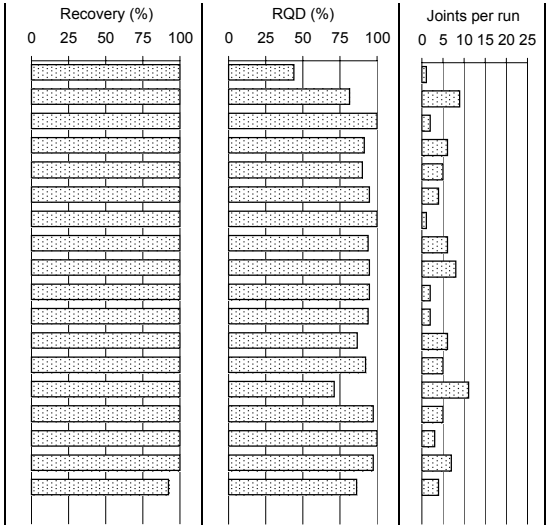


Appendix A
Keeyask Generating Station
Stage IV Investigation Program - Axis GR-4
Bedrock Summary Log: Powerhouse Area
(For notes, see page 18)

Drill Hole: G-0204
Date: Sept. 30/88

Dip: 45 deg.
Bearing: 230 deg.
Datum 141.96 m
Depth: 30.79 m

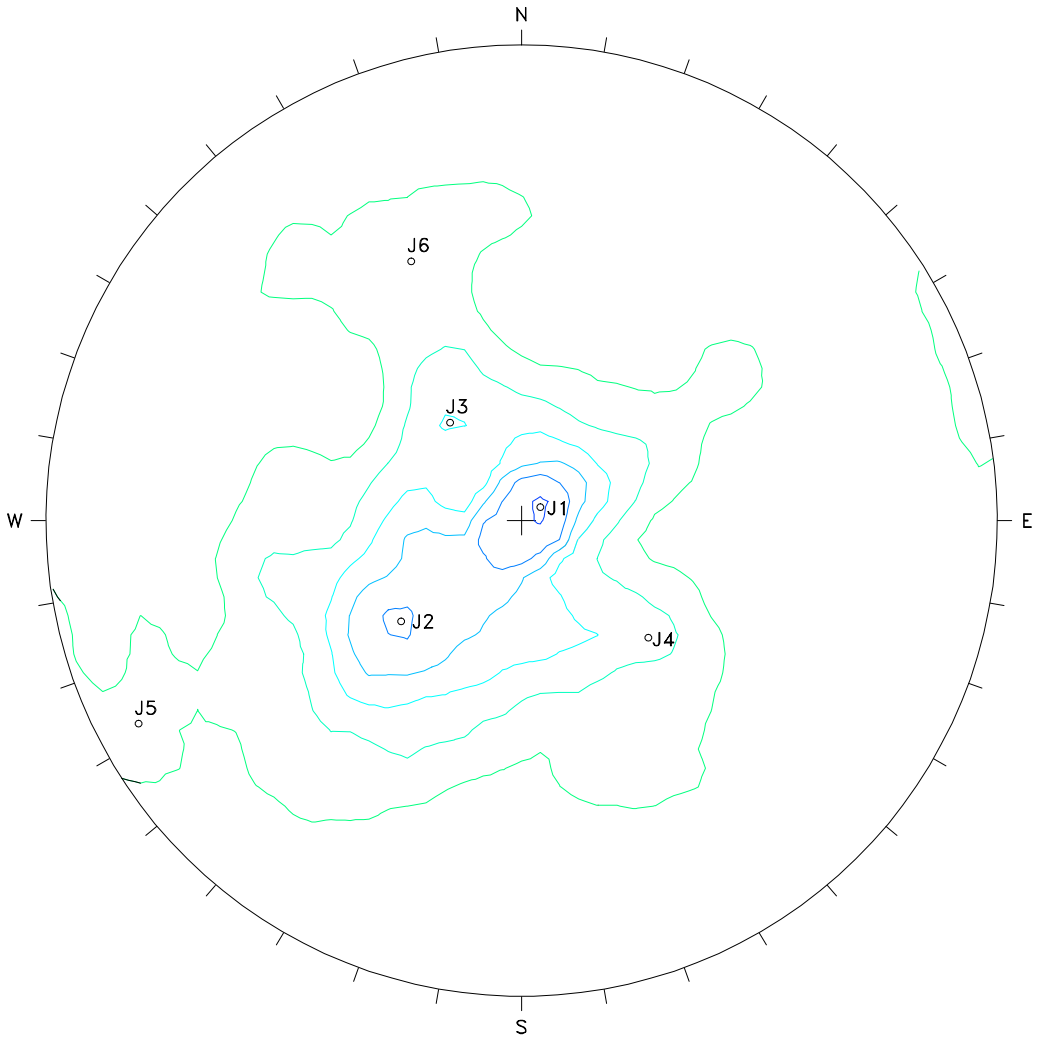
Geological Description[3]	Drill Run Depth (m - along core axis) From	To	Length (m)	Recovery Length (m)	Recovery (%)	RQD Length (m)	RQD (%)	Jts per run	Average[3] Spacing per Jt. (mm)
4.73-39.65 Granite: light grey to light brownish grey, medium to coarse grained, strong, no foliation evident, moderately spaced jointing, good to excellent rock quality, medium permeability, occasional mafic clot.	4.72	4.88	0.16	0.16	100	0.07	44	1	80
	4.88	6.40	1.52	1.52	100	1.24	82	9 +	152
	6.40	7.92	1.52	1.52	100	1.52	100	2	507
	7.92	9.44	1.52	1.52	100	1.39	91	6	217
39.65-42.36 Greywacke gneiss: dark grey to medium grey, fine to medium grained, occasionally coarse grained, strong, distinct foliation at 20 degrees to the core axis, moderately jointed, good rock quality, low permeability, contains some coarse quartz/feldspar grains, rounded and rotated, some angular fragments, upper contact is a joint, tight, sharp and at 20 degrees to the core axis.	9.44	10.97	1.53	1.53	100	1.38	90	5 +	255
	10.97	12.49	1.52	1.52	100	1.44	95	4 +	304
	12.49	14.00	1.51	1.51	100	1.51	100	1	755
	14.00	15.52	1.52	1.52	100	1.43	94	6	217
	15.52	17.05	1.53	1.53	100	1.45	95	8	170
	17.05	18.58	1.53	1.53	100	1.45	95	2	510
	18.58	20.11	1.53	1.53	100	1.44	94	2	510
	20.11	21.62	1.51	1.51	100	1.31	87	6 +	216
	21.62	23.14	1.52	1.52	100	1.40	92	5	253
	23.14	24.66	1.52	1.52	100	1.08	71	11 +	127
	24.66	26.20	1.54	1.54	100	1.50	97	5	257
	26.20	27.71	1.51	1.51	100	1.51	100	3	378
	27.71	29.27	1.56	1.56	100	1.52	97	7	195
	29.27	30.79	1.52	1.40	92	1.31	86	4 +	280
		Total =	26.07	25.95		23.95		87	
		Average =	1.45		99.5		92	5	296



Notes:
(1) Chart Depths are approximate.
(2) Elevation is approximate.
(3) Refer to geological logs for a complete description
(4) For barge holes, elevation noted 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 discontinuities too numerous to count, or the entire core run is broken or lost.

Appendix B

FIGURE B1 | SHT. 0001 | REV. 00



LEGEND:

○ 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 = 6.1269%

EQUAL AREA
LOWER HEMISPHERE
708 POLES
708 ENTRIES

NO.	DATE	REVISIONS	BY	CKD.	APP.
00	2009 04 06	ISSUED AS A FIGURE FOR MEMO REFERENCE GN-1.5.4			

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ACRES

DRAWN
CHECK
SCALE AS SHOWN
DATE

MANITOBA HYDRO

KEEYASK GENERATING STATION

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

FIGURE B1 | SHT. 0001 | REV. 00

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FIGURE B2

SHT. 0001 REV. 00

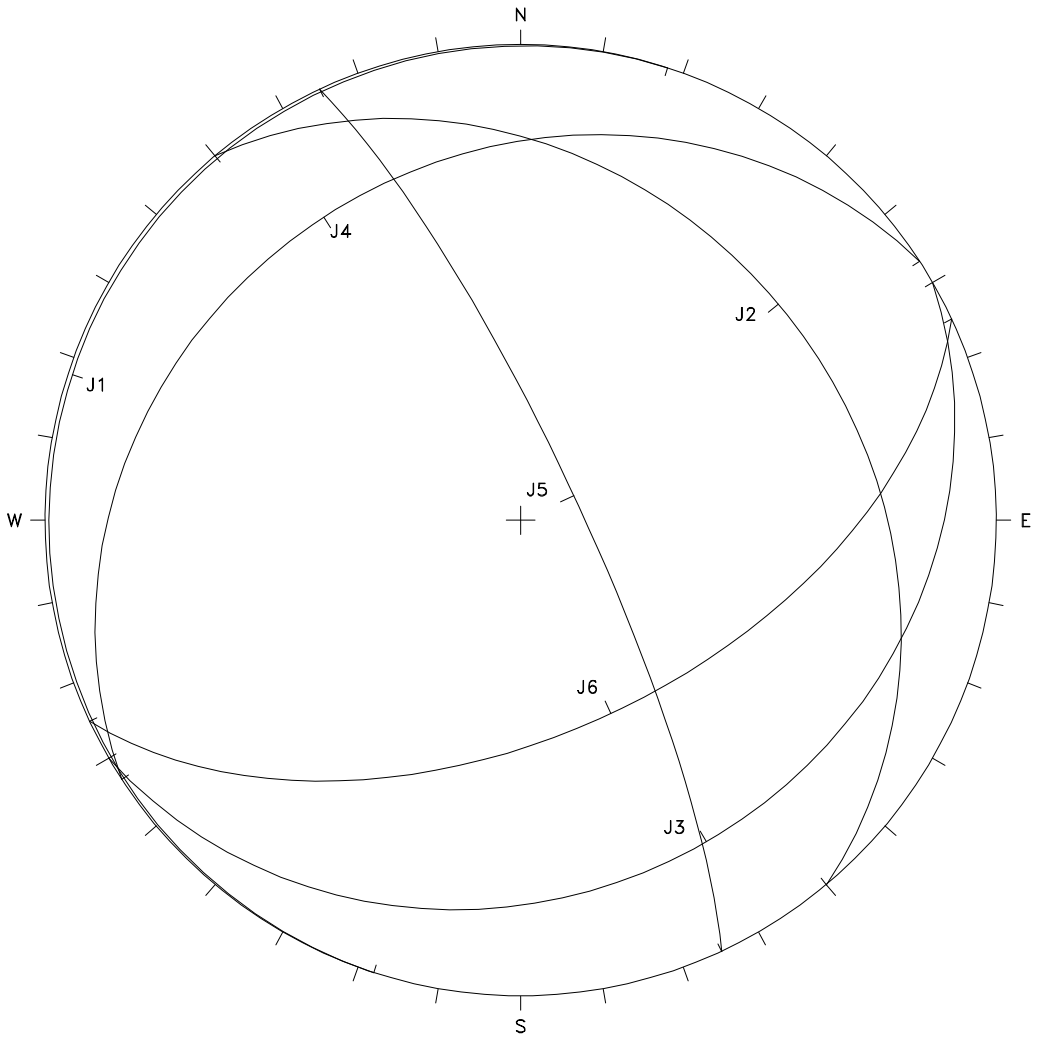

FIGURE B2 — SHT. 0001 REV. 00

ORIENTATIONS

ID	STRIKE/DIP (RIGHT HAND RULE) [DEGREES]
J1	198/01
J2	320/30
J3	060/23
J4	237/25
J5	335/80
J6	065/53

EQUAL AREA
LOWER HEMISPHERE
708 POLES
708 ENTRIES

NO.	DATE	REVISIONS	BY	CKD.	APP.
00	2009 04 06	ISSUED AS A FIGURE FOR MEMO REFERENCE GN-1.5.4			

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KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN
THE POWERHOUSE AREA
DOMINANT JOINTS SETS

DRAWN
CHECK
SCALE AS SHOWN
DATE

FIGURE B2 — SHT. 0001 REV. 00

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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

E SIZE - 671 x 950

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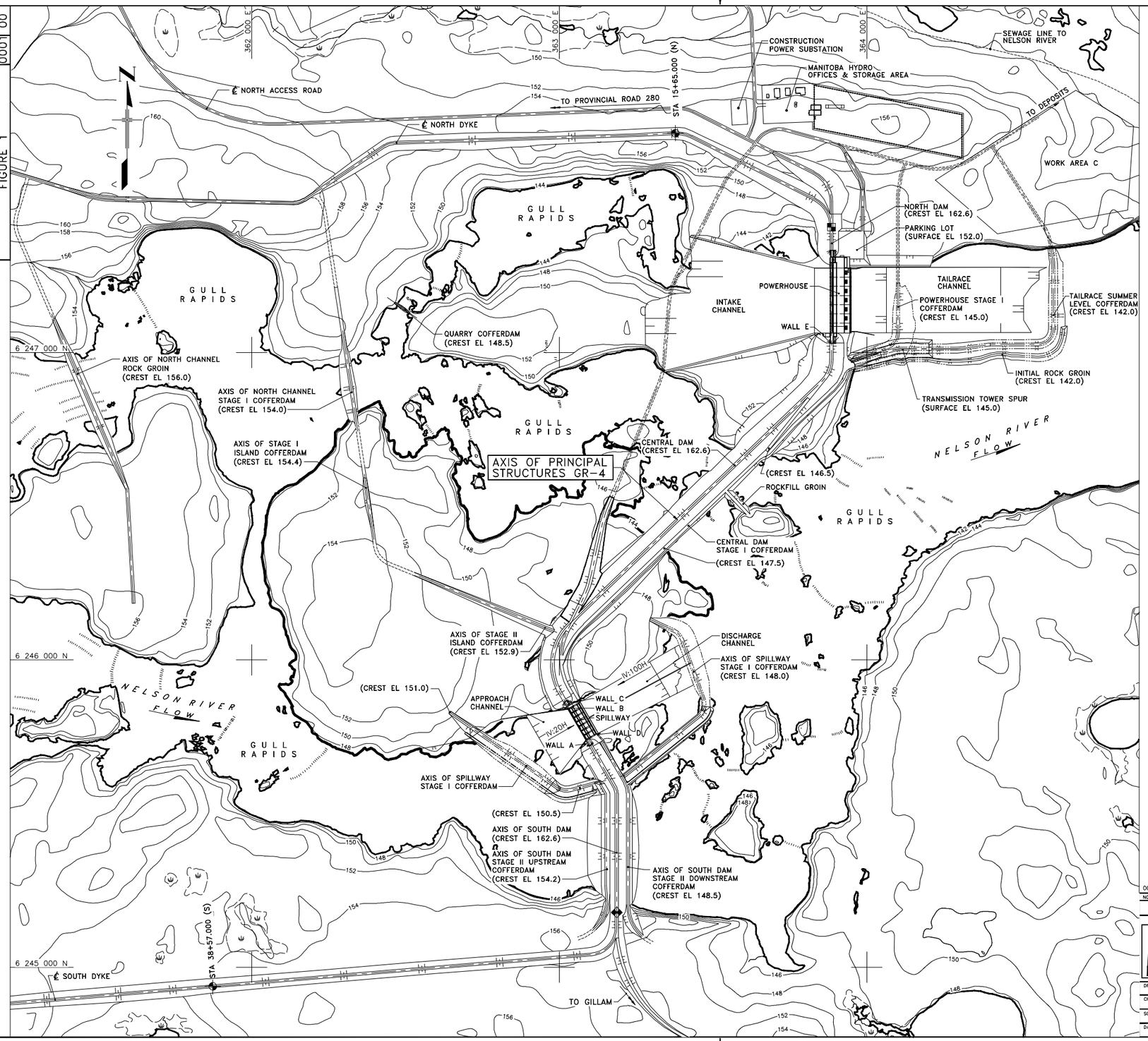
0001	00

FIGURE 1



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

NO.	DATE	REVISIONS	BY	CKD.	APP.
00	2009 04 06	ISSUED AS A FIGURE FOR MEMO REFERENCE GN-1.5.4			

ACRES MANITOBA LIMITED

MANITOBA HYDRO

KEEYASK GENERATING STATION

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

DRAWN	
CHECK	
SCALE	AS SHOWN
DATE	

FIGURE 1 — SHT. 0001 — REV. 00

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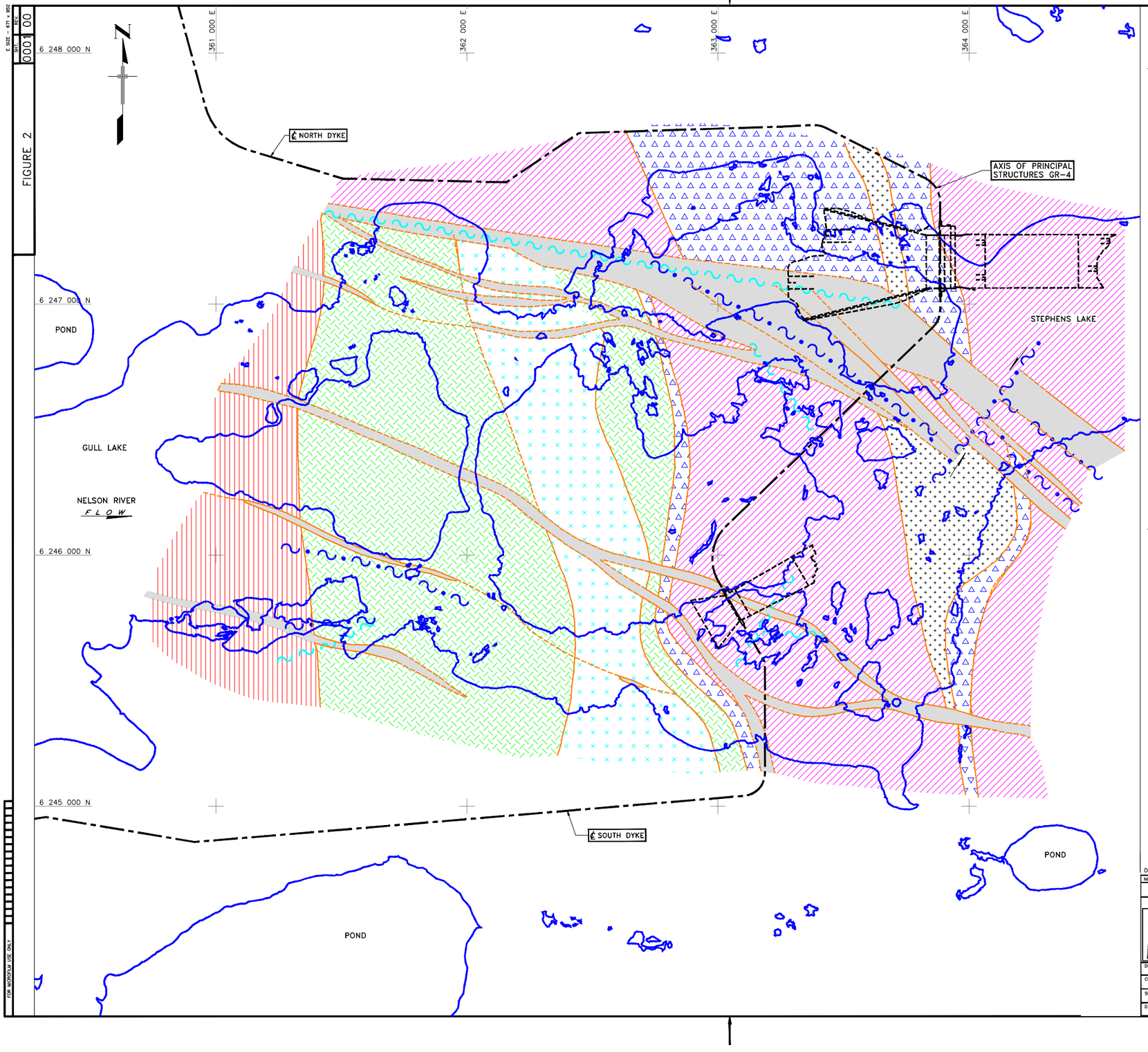

LEGEND:

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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KEEYASK GENERATING STATION

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

FIGURE 2 | SHT. 0001 | REV. 00

DRAWN | CHECK | SCALE AS SHOWN | DATE

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AUTOCAD ORIGINAL

E SIZE = 671 x 862

FIGURE 3

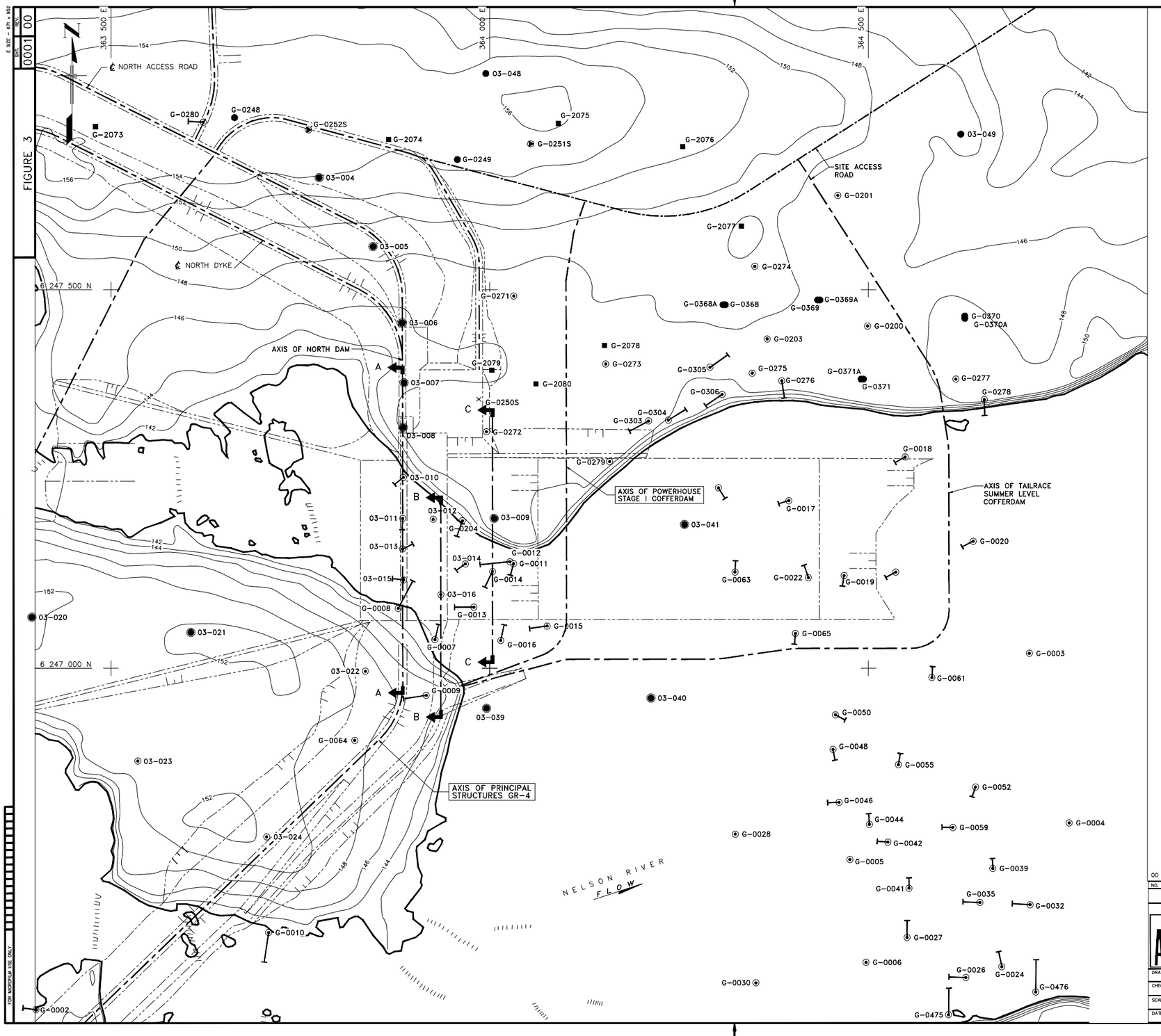
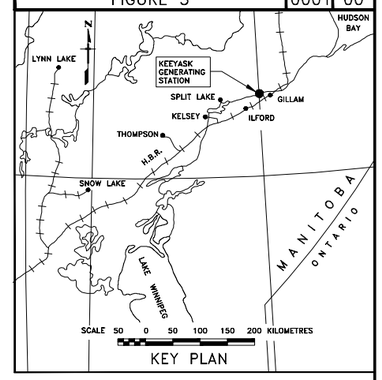


FIGURE 3



LEGEND:

- SHORELINE (SEE NOTE 6)
- 144 GROUND SURFACE CONTOUR (SEE NOTE 7)
- STREAM
- SWAMP
- RAPIDS
- DIAMOND DRILL HOLE (VERTICAL, INCLINED)
- SONIC/DIAMOND DRILL HOLE
- SONIC DRILL HOLE
- AUGER HOLE
- AUGER/DIAMOND DRILL HOLE
- TEST PIT
- × EXPLORATORY HOLE
- 03-004 2003 SUMMER EXPLORATION
- G-0031 EXPLORATION HOLE, TEST PIT NUMBER
- + COORDINATE GRID MARKER (LOCATED AT 1000 METRE INTERVALS)

NOTES:

1. TOPOGRAPHY IS BASED ON MAPPING RECEIVED BY ACRES MANITOBA LIMITED FROM MANITOBA HYDRO MAY 2000.
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, B–B, AND C–C SEE FIGURES 4 TO 5.

SCALE 1:2000 50 0 50 100 150 200 METRES

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KEEYASK GENERATING STATION

STAGE IV STUDIES AXIS GR–4
REVIEW OF BEDROCK CONDITIONS IN THE POWERHOUSE AREA – LOCATION OF EXPLORATIONS & GEOLOGICAL SECTION

FIGURE 3

SHT. 0001 REV. 00

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CHECK
SCALE AS SHOWN
DATE

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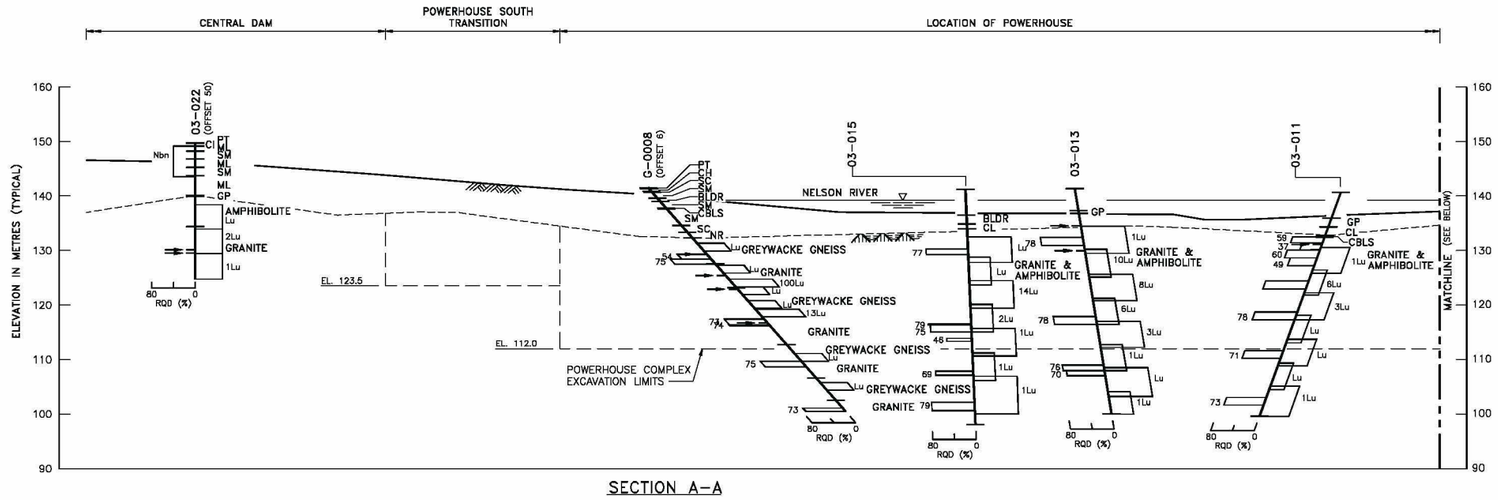
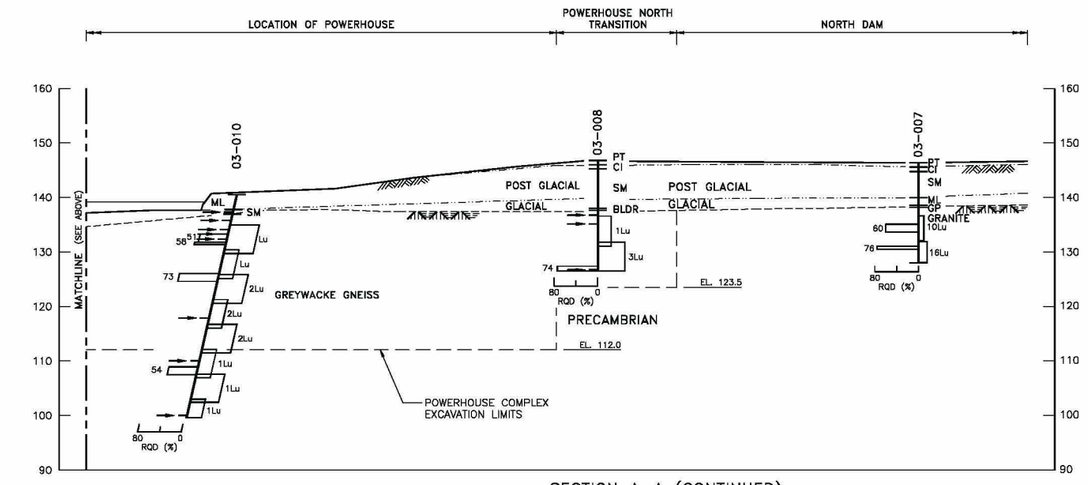
AUTOCAD ORIGINAL

E SIZE – 671 x 952



SECTION A–A



SECTION A–A (CONTINUED)

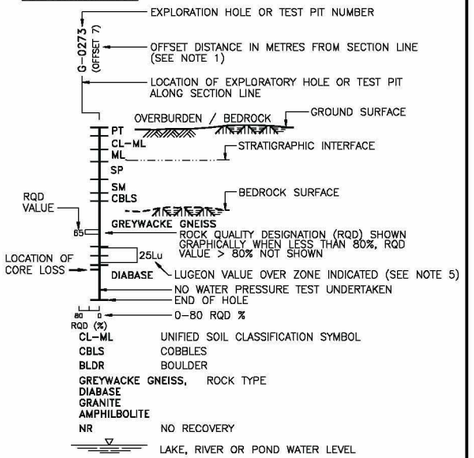
NOTES:

1. OFFSET DISTANCE SHOWN IF GREATER THAN 5 METRES FROM SECTION LINE.
2. FOR LOCATION OF GEOLOGICAL SECTION A–A SEE FIGURE 3.
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 3.
4. ELEVATIONS ARE BASED ON CANADIAN GEODETIC VERTICAL DATUM 1928.
5. Lu REPRESENTS ZERO LUGEON.

LEGEND:

FIGURE 4 — SHT. 0001 REV. 00

EXPLORATION HOLE



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

SCALE 1:400 — 10 0 10 20 30 40 METRES

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MANITOBA HYDRO
KEEYASK GENERATING STATION

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

DRAWN
CHECK
SCALE AS SHOWN
DATE

FIGURE 4 — SHT. 0001 REV. 00

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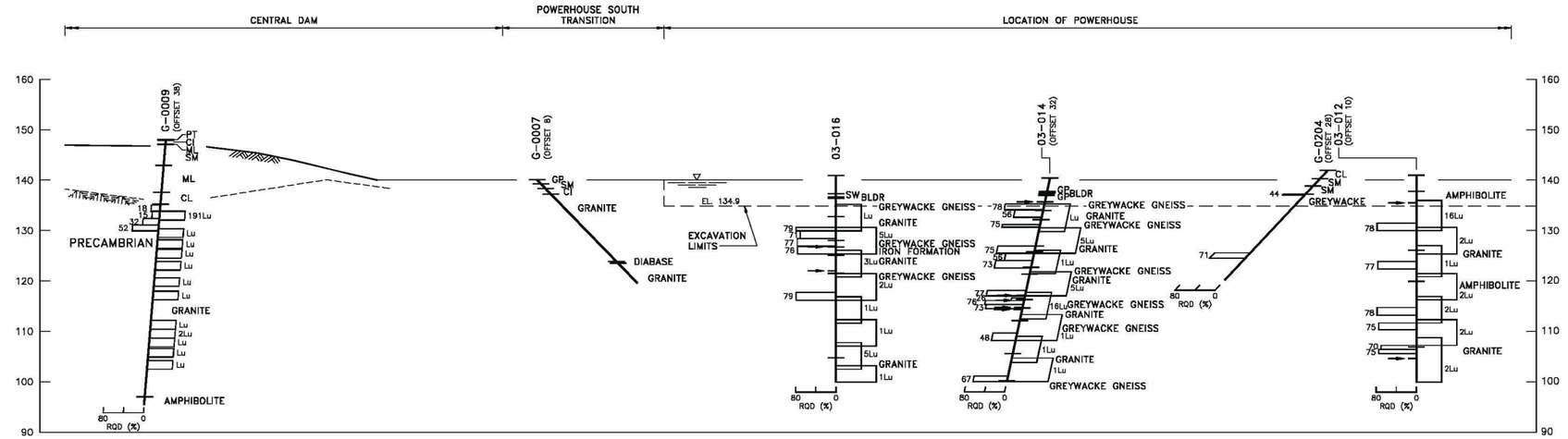
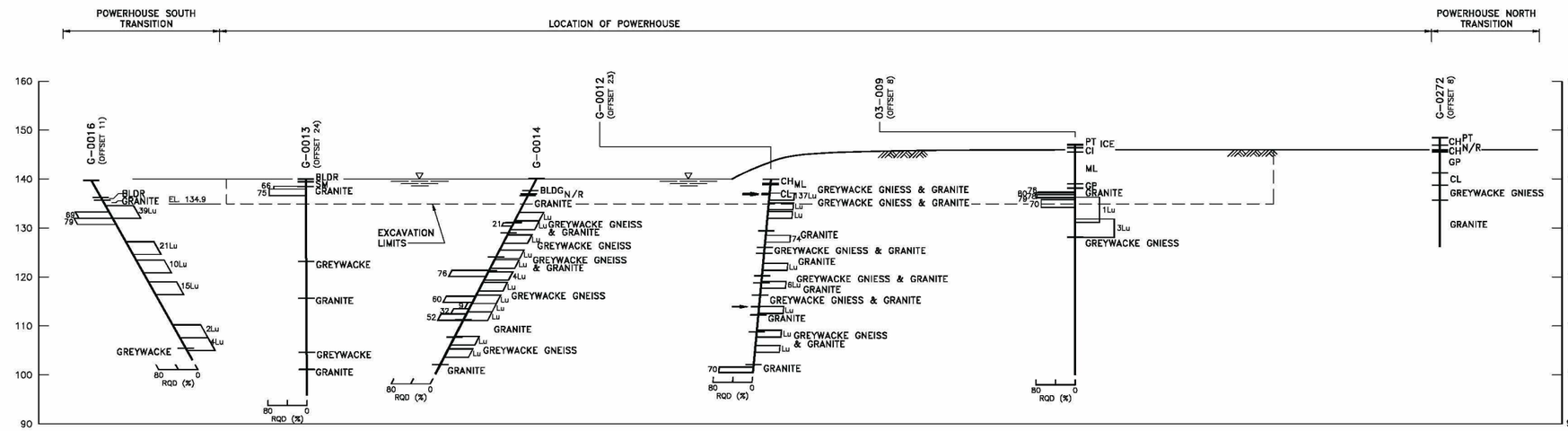


SECTION B–B



SECTION C–C

SCALE 1:400 — 10 0 10 20 30 40 METRES

NOTES:

1. FOR LEGEND AND NOTES SEE FIGURE 4.
2. FOR LOCATION OF GEOLOGICAL SECTIONS B–B AND C–C SEE FIGURE 3.

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KEEYASK GENERATING STATION

STAGE 4 STUDIES – AXIS GR–4
REVIEW OF BEDROCK CONDITIONS
IN THE POWERHOUSE AREA
GEOLOGICAL SECTION B–B AND C–C

FIGURE 5 | SHT. 0001 | REV. 00

DRAWN | CHECK | SCALE AS SHOWN | DATE

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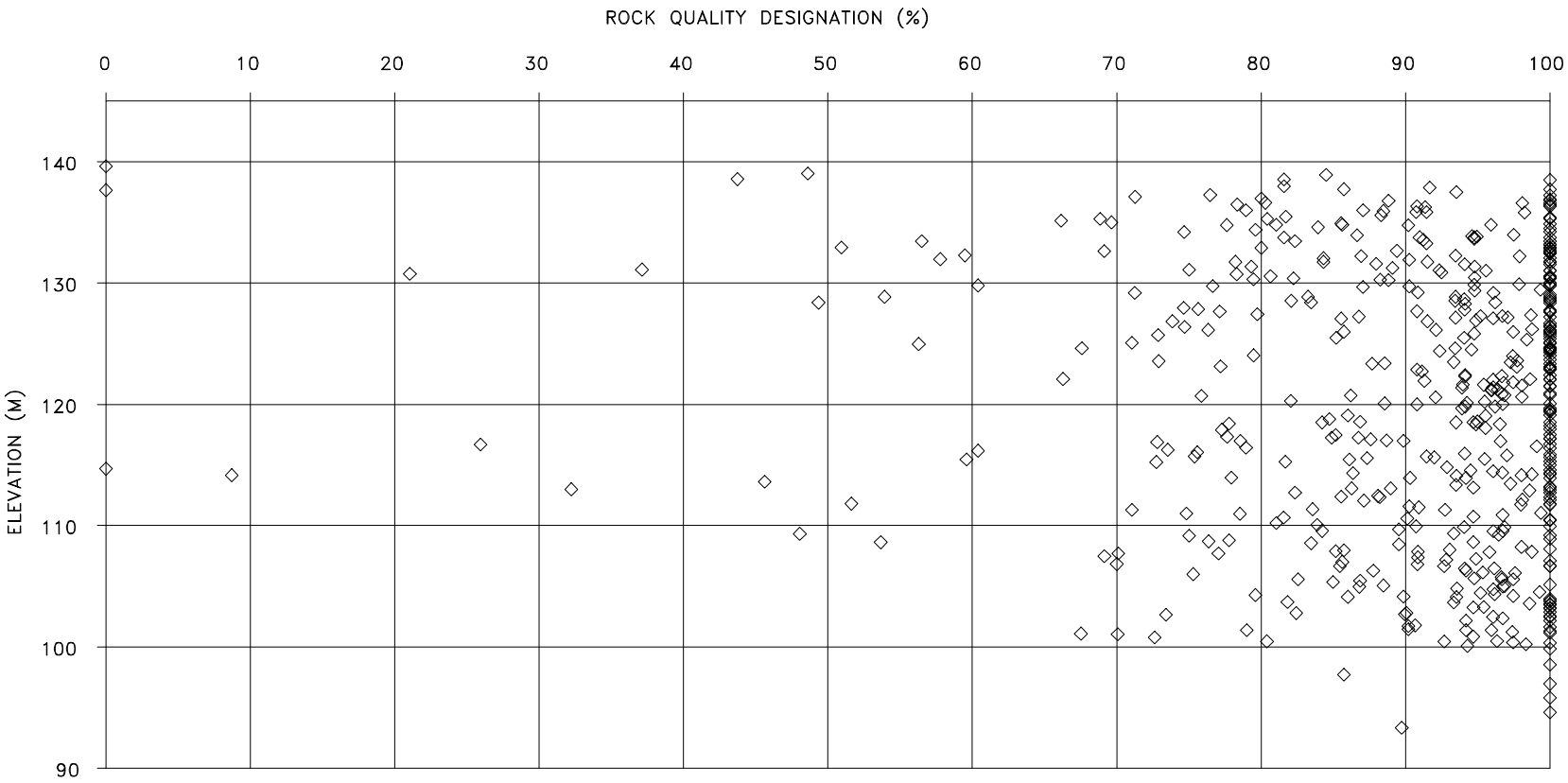
AUTOCAD ORIGINAL

E SIZE – 671 x 862 | SHT. 0001 | REV. 00 | FIGURE 5

FIGURE 6 | 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 504 RQD VALUES ARE SHOWN.
4. FOUR 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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STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN
THE POWERHOUSE AREA
RQD VALUES VS ELEVATION

FIGURE 6 | SHT. 0001 | REV. 00

AUTOCAD ORIGINAL

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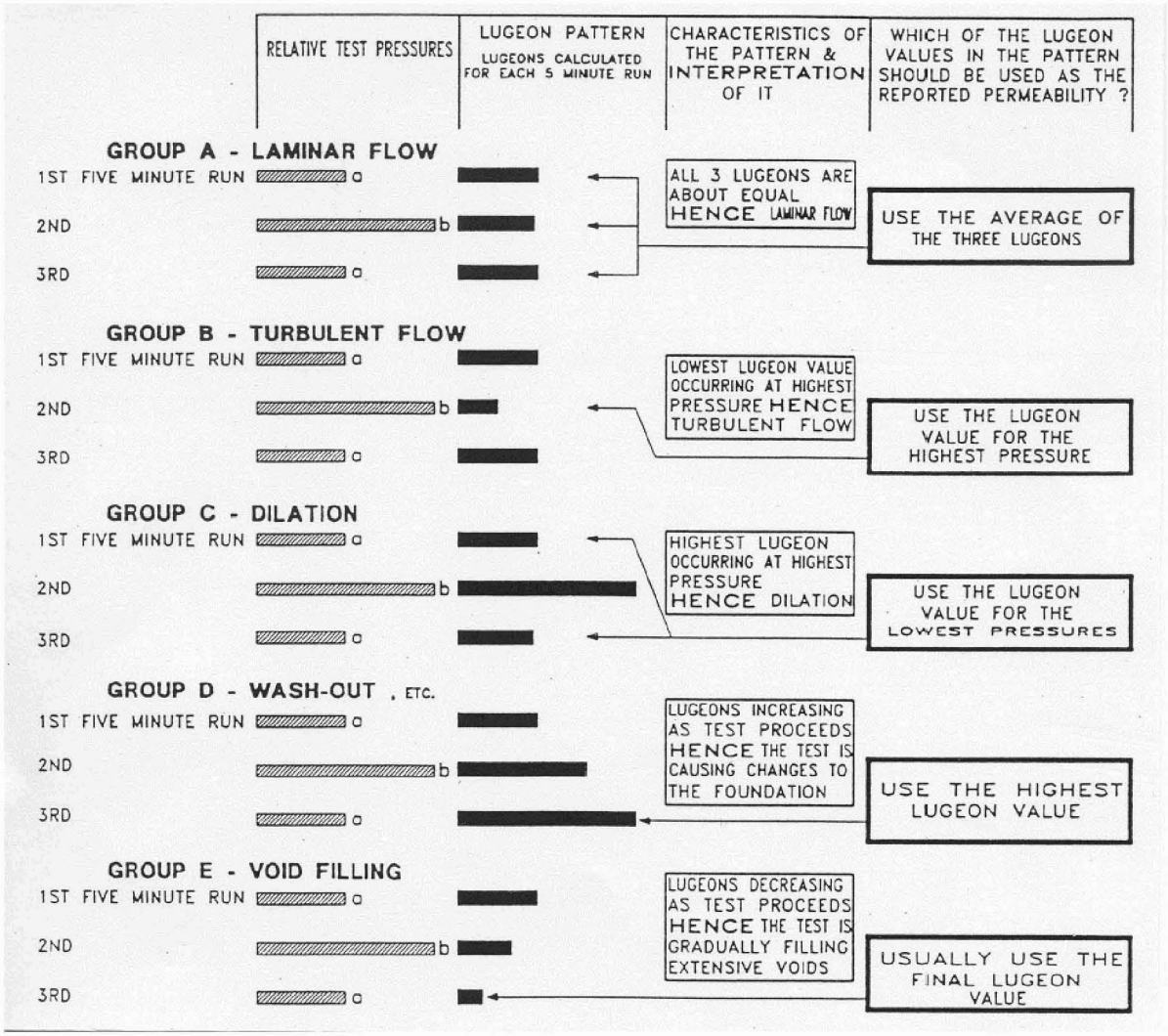
FIGURE 6 | SHT. 0001 | REV. 00

FIGURE 7 SHT. 0001 REV. 00



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

DRAWN
CHECK
SCALE AS SHOWN
DATE

FIGURE 7 SHT. 0001 REV. 00

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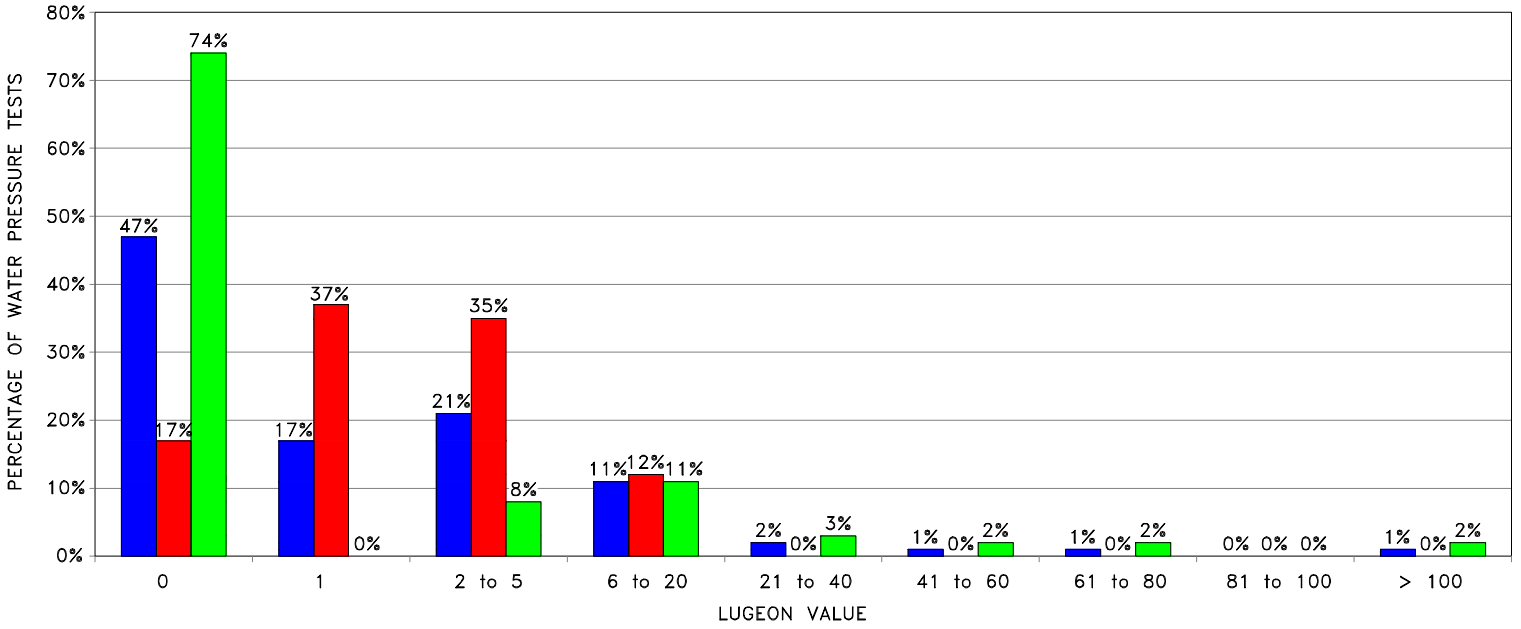
AUTOCAD ORIGINAL

FIGURE 8

SHT.	REV.
0001	00



LEGEND:

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

NOTES:

1. A TOTAL OF 126 WATER PRESSURE TESTS WERE UNDERTAKEN IN THE POWERHOUSE AREA.
2. A TOTAL OF 467.3 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 POWERHOUSE AREA
RANGE OF WATER PRESSURE
TEST RESULTS

FIGURE 8

SHT.	REV.
0001	00

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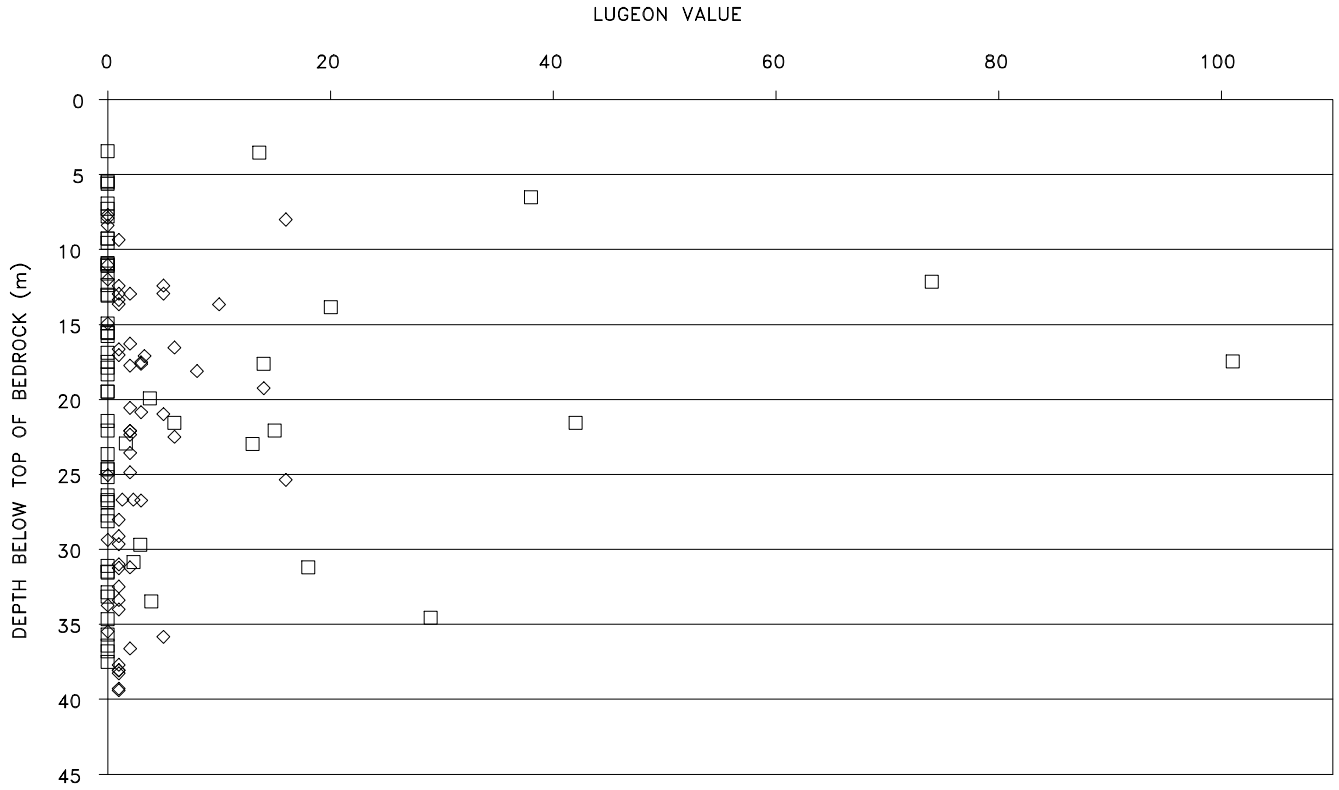
AUTOCAD ORIGINAL



LEGEND:

◇ 2003 INVESTIGATIONS

□ PREVIOUS INVESTIGATIONS

NOTES:

1. VERTICAL DEPTH TO MIDDLE OF TEST ZONES.
2. TEST ZONE LENGTHS ALONG CORE AXIS VARY BETWEEN 2.0 AND 8.9 METRES, AVERAGING 3.7 METRES.
3. A TOTAL OF 126 WATER PRESSURE TESTS WERE UNDERTAKEN IN THE POWERHOUSE 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 POWERHOUSE AREA
RANGE OF WATER PRESSURE
LUGEON VALUE VS DEPTH

DRAWN
CHECK
SCALE AS SHOWN
DATE

FIGURE 9 | SHT. 0001 | REV. 00

AUTOCAD ORIGINAL

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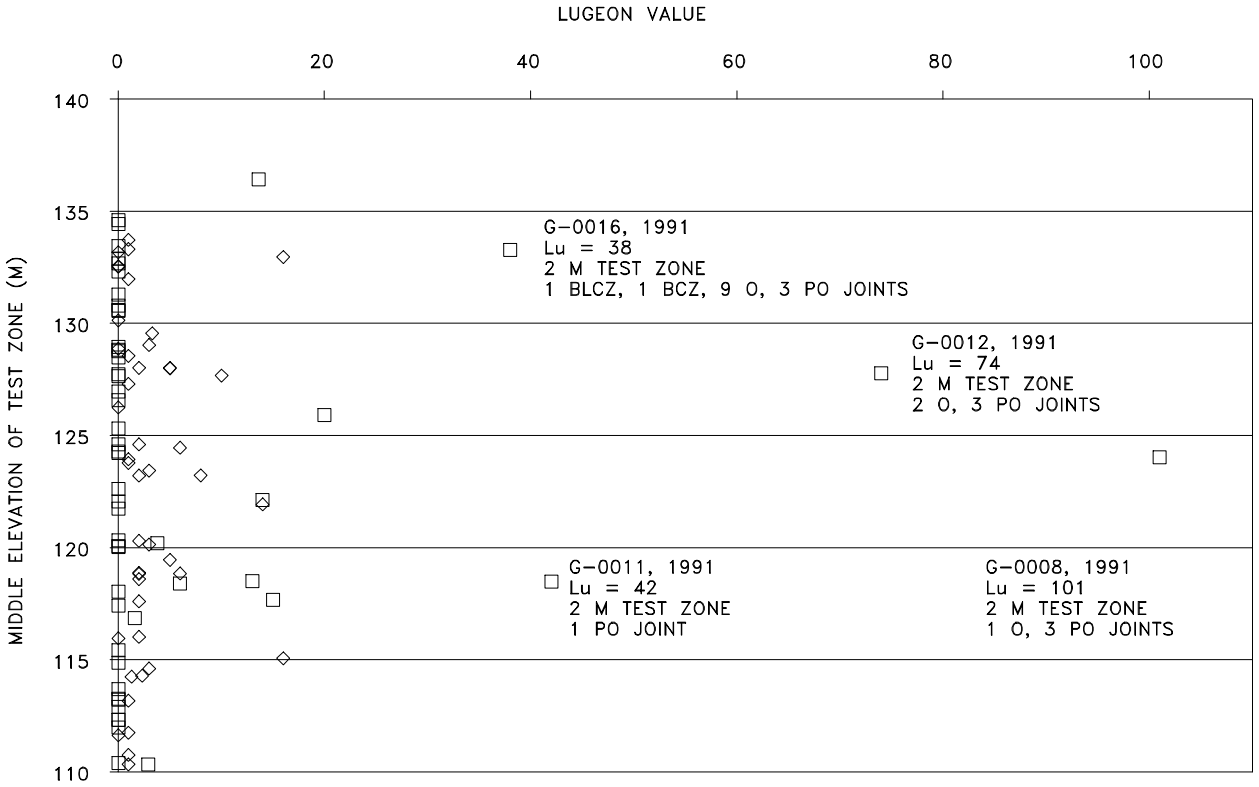
FIGURE 10 | SHT. 0001 | REV. 00



LEGEND:

◇ 2003 INVESTIGATIONS

□ PREVIOUS INVESTIGATIONS

NOTES:

1. ELEVATIONS 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 8.9 METRES, AVERAGING 3.7 METRES.
4. A TOTAL OF 126 WATER PRESSURE TESTS WERE UNDERTAKEN IN THE POWERHOUSE AREA.
5. WATER PRESSURE TEST EXCEEDING PUMP CAPACITY, ARE ASSIGNED A VALUE OF 101.

NO.	DATE	REVISIONS	BY	CKD.	APP.
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KEEYASK GENERATING STATION

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

FIGURE 10 | SHT. 0001 | REV. 00

DRAWN | CHECK | SCALE AS SHOWN | DATE

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AUTOCAD ORIGINAL

FIGURE 11 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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STAGE IV STUDIES AXIS GR-4
REVIEW OF BEDROCK CONDITIONS IN THE POWERHOUSE AREA
ROCK MASS RATING SYSTEM
(AFTER BIENIAWSKI, 1989)

DRAWN | CHECK | SCALE AS SHOWN | DATE

FIGURE 11 SHT. 0001 REV. 00

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