Appendix A - Methodology

1. Background Review of Existing Documentation

Review of background information included, but not limited to:

a) Ontario Geological Survey Mapping
   i. Aggregate resources inventory of Osprey Township, Grey County, southern Ontario Aggregate Resources Inventory Paper ARIP086
   ii. Paleozoic Geology of the Collinwood-Nottawasaga Area; Southern Ontario (Preliminary Map 954)
   iii. Geological series, Quaternary geology, Collingwood-Nottawasaga area, southern Ontario (Preliminary Map 919)
   iv. Bedrock topography series, Collingwood-Nottawasaga area, southern Ontario (Preliminary Map 926)
   v. Drift thickness series, Collingwood-Nottawasaga area, southern Ontario (Preliminary Map 925)

b) Ontario Geological Survey Reports
   i. Industrial Mineral Resources of Nottawasaga Town. OGS Open File Report 6011

c) Ministry of the Environment Water Well Records

d) Hydrogeological reports completed for the Duntroon Quarry
   i. Duntroon Quarry Expansion Geological Report and Level 2 Hydrogeological Assessment (September 2005)
   ii. Georgian Aggregates and Construction Inc.: Duntroon Quarry Permit to Take Water Number 01-P-1036 – Application to Amend (August, 2005)
   iii. Duntroon Quarry Groundwater and Surface Water Annual Monitoring Report (2001).

e) Published research papers
   i. Pratt and Miall, 1993. *Anatomy of a bioclastic grainstone megashoal (Middle Silurian, southern Ontario) revealed by ground-penetrating radar.* Geology.
   ii. Smith and Legault, 1985. *Preferred Orientations of Middle Silurian Guelph-Amabel Reefs of Southern Ontario*. Bulletin of Canadian Petroleum Geology.
   iii. Kunert, et al.,1998. *Controls and Age of Cavernous Porosity in Middle Silurian Dolomite, Southern Ontario.* Canadian Journal of Earth Science.
   iv. Stott and Von Bitter, 1999. *Lithofacies and Age Variation in the Fossil Hill Formation (Lower Silurian, Southern Georgian Bay Region, Ontario.* Canadian Journal of Earth Science.

f) Regional Ground Water Studies
   i. documentation on the AEMOT Ground Water Management Study (Greenland International Consulting Inc. (2001);

   ii. Grey and Bruce Counties Groundwater Study Final Report (Waterloo Hydrogeologic, 2003); and

A complete list is provided in the Reference section.

2. Drilling Program

A. Lithology / Formations

Lantech Drilling Services Inc. drilled twelve boreholes at the site in March and April 2004. The boreholes were drilled at 6 locations across the site (Figure 1-3). At each location, a well nest consisting of a deep well (up to approximately 53 m) and a shallow (up to approximately 26 m) well was drilled. In order to confirm the base of the Amabel, three of the deep boreholes were drilled into the underlying Cabot Head Formation. It was necessary to nest wells, as it was anticipated that several discrete fractures would be encountered. Therefore to monitor these locations, several monitoring wells would need to be installed. Each four-inch well can house two monitoring wells. Drilling two holes would allow for a total of four monitoring zones.

The boreholes were advanced using HQ coring equipment to obtain a four-inch hole that would allow for downhole geophysics to be completed and the installation of two monitoring wells. Core recovery was typically greater than 95% in all boreholes, which allowed for a completed stratigraphic log. Immediately after extracted from the core barrel, the core was photographed digitally, producing electronic logs of the core of the deep boreholes to aid in the identification of lithologic units. The core was then logged for lithology and fracture frequency. All breaks in the rock were identified as either mechanical or open (natural) fractures. The natural fractures were identified for the presences of infilling (generally calcite), and by evidence of weathering. The characteristics of the fractures can lead to the identification of potential flow zones. The details of the logging (i.e. electronic photos, fracture data) are incorporated into the M.A.Q. database for future reference.

Refer to Appendix C for site borehole logs.

3. Borehole Geophysics

The measurement of variation in the physical properties of geological units (including ground water) is the basis of all geophysical surveys. The objectives of using in situ physical property borehole measurements is to gain insight to the unique lithologic units and variation of rock characteristics with an overall goal to aid in quarry planning. The geophysical results provided confirmation of the geological interpretation based on core logging. Borehole geophysics sondes were collected in the four of the six deep boreholes on April 26 and 27, 2004 by DGI Geoscience Inc. The parameters surveyed included:

- Nuclear Logging - Natural Gamma Radiation
- Density
- 3 Arm Caliper
- Full Waveform Sonic
- Point Resistance
- Inductive Conductivity
- Neutron

Geophysics is controlled primarily by the porosity of the material. Porosity is the empty space within rock. Effective porosity is the amount of void space with interconnected pores that can transmit fluid or an electrical current. The neutron, density and sonic logs are often referred to as the "porosity logs". None of these directly measure porosity but each measures a different aspect of porosity. None of the "porosity logs, distinguish the type of porosity. Reduced porosity will cause an increase in the resistivity values and lower porosity values on the "porosity logs"

Permeability is the ability of fluids to move through connected pore space under unequal pressure. The more uniform particles, larger pore spaces and therefore more interconnected results in a greater the permeability. As the clay content in a formation increases the permeability will decrease.

i. Nuclear Logging

Nuclear logs are related to the measurement of the fundamental particles or radiations from the nucleus of an atom. The most common logs are natural gamma, neutron and gamma-gamma or density logs. Nuclear logs may run in a variety of downhole environments in either open or cased holes. Since radiation measures in nuclear logs is random in nature, minor fluctuations are present on all logs and the logs will not repeat exactly.

Gamma Ray

Natural gamma radiation is spontaneously emitted by some radioactive elements as they decay to a more stable state. There are many elements in geological materials that emit gamma radiation, including the following three most common gamma radiation emitting elements: uranium, thorium, and potassium (potassium being the most abundant). Clay particles tend to have a higher portion of potassium and therefore the level of gamma radiation emitted by a geological unit is usually directly related to the clay content (shales and argillaceous bedding partings contain high concentrations of clay). Gamma emissions vary with time and have a Poisson distribution characteristic of a geologic material. The measure of gamma radiation is expressed in units of counts per second (cps).

Density

The density log represents the electron density of the formation. By virtue of this the porosity can be determined with lithological identification. The density probe is similar to the gamma ray probe in that the downhole circuitry contains a gamma detector. In the case of a compensated density probe there are two detectors. This detector, with the use of a back up arm or spring is pushed against the borehole wall. A radioactive source, located some distance and on the same plane as the as the detector, bombards the formation with intermediate gamma ray energies. The phenomenon of Compton scattering takes place in which the back scattered gamma rays are received by the detector, or detectors. The degree of back scatter detected by the receiver is correlated to the density of the rock.

Density logs are more often used to derive the formation porosity, p, defined as the ratio of pore volume to total volume of the rock. The density log response is also used for mineral identification when run with other porosity devices. Each porosity device will respond to a particular mineral in quite a different way, which when cross plotted can often identify the mineral. If the density log is run alone it may be unclear in distinguishing a clay or shale from a sandstone since both have a similar density. The use of a gamma ray log should help with the definition. Like a neutron log, the density logs basically sees total porosity, where a false porosity would be derived if the rock where vugular. If a sonic log is available, the porosity can be corrected since sonic energy is thought to avoid the vugs and fractures, by travelling through the matrix instead (i.e. the path of least resistance).

Neutron

The neutron log, like the gamma ray measures radioactive properties. Unlike the gamma ray this log depends on the bombardment of the formation with neutron from a source and measures secondary results brought on by this bombardment. As a comparison the neutron log is like a resistivity log that measures the result of something being introduced into the formation while the gamma ray and Sp logs measure naturally occurring phenomena.

The heart of the neutron logging tool is the radioactive source that emits epithermal neutrons. Characteristically the source is made up of Americium 241-Berylium with a strength of 3 to 5 curries. The prime advantage of the neutron logs lies in the fact that it is a reliable indicator of porosity. It has been proven that the response of the neutron log is empirically related to the hydrogen content of the rocks and that the hydrogen content of the liquids in pore spaces can be accurately related to porosity in most cases.

ii. Three Arm Caliper

The caliper log is a mechanical measurement of borehole diameter. The probe consists of three independent spring-loaded arms. The movement of the arm is measured with variable resistors that provide a borehole diameter measurement using a calibration equation. The borehole diameter can vary for a number of reasons including: fracturing, vugs, voids, and drilling induced irregularities. The caliper log is oriented more for the potential detection horizontal and sub-horizontal fractures (i.e. "bumps" in the trace)(assuming a vertically drilled borehole). The caliper probe does not accurately measure deep narrow irregularities in the borehole wall due to the location of its measuring point.

iii. Full Wave Sonic

The sonic tool is designed to measure the time it takes for a pulsed compressional sound wave to travel one foot (interval transit time). The interval transit time for a formation depends on the elastic properties of the formation which are related to lithology and porosity. In general waves travel faster through denser formations. Therefore an increase travel time for a given type of material indicates increased porosity. The speed of sound is usually measured by how far the sound travels in one second. Travel time (delta T) which is the measurement used in sonic logging, is taken as the time it takes for sound to travel one foot, with the time being measured in micro seconds, one measurement is simple the inverse of the other.

iv. Point Resistance

Point resistance records the electrical resistance from points within the borehole to an electrical ground at land surface. In general, resistance increases with increasing grain size and decreases with increasing borehole diameter, fracture density, and dissolved-solids concentration of the water. Single-point resistance logs are useful in the determination of lithology, water quality, and location of fracture zones as identified as a sudden change in the resistivity profile.

v. Inductive Conductivity

The magnetic susceptibility (MS) of a volume of rock is a function of the amount of magnetic minerals, (mainly magnetite and pyrrhotite), contained within the rock. MS measurements can provide a rapid estimate of the ferromagnetism of the rock. These measurements can be interpreted to reflect lithological changes, degree of homogeneity and the presence of alteration zones in the rock mass. During the process of hydrothermal alteration, primary magnetic minerals (e.g. magnetite) may be altered (or oxidized) to weakly- or non-magnetic minerals (e.g. hematite). Anomalously low susceptibilities within an otherwise homogeneous high susceptibility (ferromagnetic) rock unit may be an indication of altered zones.

4. Horizontal and Vertical Fracture Mapping

Water movement through fractures is considered to be the primary means ground water flow at this site. All surrounding domestic wells depend upon obtaining a sufficient quantity of water via this regional fracture network. Therefore, an understanding of the fracture systems is fundamental in understanding the ground water regime.

Mapping of the horizontal fractures within the bedrock was completed as part of the field investigations. The horizontal fracture mapping was conducted in the field during the drilling program. The core removed from the borehole was logged in detail by noting the fracture depth, spacing, fracture type (i.e. mechanical vs natural). The characteristics of the natural fractures (i.e. weathering, mineral deposits, infilling, orientation) were noted and aided in the identification of potential high flow zones. This information is incorporated into the M.A.Q. database and the numerical ground water flow model

To relate the site specific fracture mapping into a more regional assessment which would be used to assist in the development of the geological conceptual understanding of the study area, Dr. Alexander Cruden, a professor of structural geology and tectonics at the University of Toronto was retained by M.A.Q. Aggregates. Dr. Cruden characterized the spatial statistics of lineaments and fractures, which assisted in quantifying the scale-dependence and interconnectivity of the fracture network.

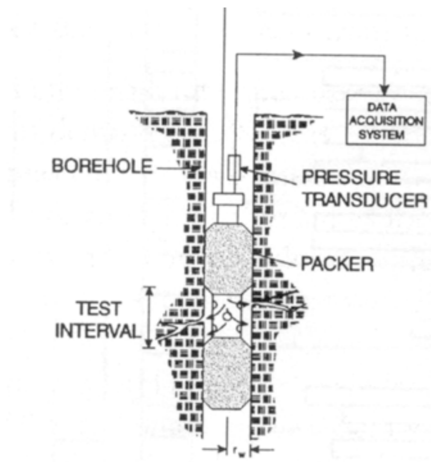
Borehole geophysical results are presented in Appendix D.

5. Hydraulic Testing Program

Unlike equivalent porous media (sand and gravel aquifers), determining the hydraulic characteristics of a fractured bedrock aquifer requires a hydraulic testing program designed to isolate and test discrete zones down the entire depth of the borehole as open fractures may interest a borehole at any depth. For the purpose of this investigation, the hydraulic testing program was developed from the preliminary conceptual model of the fracture network and ground water flow system. The hydraulic testing program involved transient testing techniques using a staddle-packer system (i.e. packer testing). Packer tests are preferred over the conventional “pumping tests” as the vertical distribution of transmissivity can be determined by systematically testing the length of the borehole in sections. Whereas pumping tests require pumping from an open hole, which draws water from all water bearing zones.

Shapiro and Hsieh (1998) determined that interpreting transient tests in fractured rock by using a homogeneous model of formation properties may be adequate in providing order of magnitude estimates of transmissivity in the vicinity of the borehole in most fractured rock terrains. However, caution should be used in applying the estimates of transmissivity from transient tests, because the transient tests stress only a small volume of the formation and thus can not be used to interpret formation heterogeneity or large-scale formation properties.

Packer testing consists of lowering inflatable rubber glands separated by a fixed distance down a borehole to test a selected zone. The rubber glands are inflated with compressed nitrogen, which seals the glands



against the borehole wall thus isolating the zone between the packer glands from the remainder of the borehole. The packed off interval and the wellbore annulus was instrumented so that the fluid pressure in each zone could be monitored at land surface by directly measuring a water level open to the atmosphere. By monitoring both the packed off zone and the annulus allowed for the detection of flow around the top packer (i.e. communication). The dataloggers were programmed to take fluid pressure readings (i.e. every three seconds).

Once the packers were inflated, the isolated zone was then taken out of equilibrium to determine the permeability of the test interval and if possible the static hydraulic head for the zone. The first test involved injecting compressed nitrogen into the closed off zone being tested. The increased pressure on the water level would exert a downward force and if the zone had permeability, this water level would lower, as water would be forced into the permeable zone. After a fixed pressure build up, the closed off interval pressure was opened to the atmosphere using a valve and the rate of response of the formation back to equilibrium was monitored. The second test involved poring a known volume of water into the isolated zone and recording the rate of response back to equilibrium. By measuring the rate of response of the water levels to these transient tests, the transmissivity of the zone was calculated using conventional transient analysis techniques [i.e. Cooper et al. (1967)].

As noted by Lapcevic et al. (1999) transient tests conducted in fracture rock frequently exhibits results, which deviate from the ideal porous media response. The deviation was attributed to the fracture network type response, which can yield a different type of response than that of porous media formations. Of note, fracture systems have little storativity and yield low values (i.e. as low as 10^{-20}). In cases where the Cooper method (1967) matched poorly (i.e. less than 50% match) the Hvorslev (1951) method was used to obtain an estimate of hydraulic conductivity using a straight-line evaluation technique.

The separation between the two rubber packers was set to be 1.2 m. This choice of test zone length will depend on the expected fracture spacing with depth. Too short of an interval would have lead to an unnecessarily large number of tests, while a too long of an interval would have averaged the transmissivity responses in the boreholes. To ensure full coverage of the borehole the packer system was only raised 0.9 m before another test event was conducted, thus there was a 0.3 m (1 foot) overlap. The packer testing completely covered the entire length of the borehole due to the use of the overlap strategy in the testing program.

For the Highland site, the selected packer spacing enabled the identification of distinct fracture zones (i.e. at an elevation 508 and 497 masl) of relatively high transmissivity separated by massive rock of low permeability within the geological formations. Packer testing results are presented in Appendix F.

6. Monitoring Well Construction

Based on the packer testing results, geophysics, hydrogeochemistry and detailed core logging, discrete fracture (or flow) zones were identified. These fractures were the target zones for the screened intervals in the monitoring wells. The screened interval isolates the discrete fractures through a permanently constructed monitoring system. Isolating these discrete intervals allows for the long-term monitoring of the hydraulic head and water quality. The construction details of the monitoring wells are provided in Table A-1. In addition, a detailed discussion on the water bearing fracture zones is presented in Section 5. Well construction is in compliance with Ontario Regulation 128/03.

Table A-1: Well Construction Details

Well No.	Ground Surface	Top of Casing	Monitoring Zone		UTMs (NAD83)		Geological Formation
			Bottom	Top			
	Metres Above Sea Level (m asl)				Northing	Easting	
OW1-I	512.22	513.29	506.2	507.7	638430	4749636	Amabel
OW1-II	512.22	513.29	501.6	503.1	638430	4749636	Amabel
OW1-III	512.18	513.21	485.5	487.0	638430	4749631	Amabel
OW1-IV	512.18	513.21	481.3	482.8	638430	4749631	Fossil Hill
OW2-I	522.24	523.42	510.7	512.2	638911	4749615	Amabel
OW2-II	522.24	523.42	501.6	503.1	638911	4749615	Amabel
OW2-III	522.14	523.18	498.8	500.3	638927	4749617	Amabel
OW2-IV	522.14	523.18	478.7	480.2	638927	4749617	Fossil Hill / Cabot Head
OW3-I	515.57	516.34	509.6	511.1	639172	4749929	Amabel
OW3-II	515.57	516.34	498.7	500.2	639172	4749929	Amabel
OW3-III	515.53	516.58	493.2	494.7	639167	4749928	Amabel
OW3-IV	515.53	516.58	485.0	486.5	639167	4749928	Amabel
OW4-I	518.87	519.76	511.9	513.4	639558	4749646	Amabel
OW4-II	518.87	519.76	509.3	510.8	639558	4749646	Amabel
OW4-III	518.85	519.72	496.8	498.3	639562	4749646	Amabel
OW4-IV	518.85	519.72	491.4	492.9	639562	4749646	Amabel
OW5-I	510.01	510.75	502.0	503.5	639570	4750150	Amabel
OW5-II	510.01	510.75	497.8	499.3	639570	4750150	Amabel
OW5-III	510.06	510.85	492.3	493.8	639573	4750151	Amabel
OW5-IV	510.06	510.85	480.3	481.8	639573	4750151	Fossil Hill / Cabot Head
OW6-I	526.28	527.01	513.1	514.6	638558	4750126	Amabel
OW6-II	526.28	527.01	501.6	503.1	638558	4750126	Amabel
OW6-III	526.21	526.98	480.9	482.4	638555	4750123	Amabel
OW6-IV	526.21	526.98	475.8	477.3	638555	4750123	Fossil Hill / Cabot Head

7. Hydrogeochemical Testing

i. General Water Quality

The proposed performance monitoring program outlined in Section 11.0 of the main report was implemented in late 2004. To date, a total of 53 ground water and 7 surface water samples have been collected (locations identified on Figure xx). Contemporary sampling protocols were used to acquire the samples. The parameters collected for each water quality sample are provided in Table A-2. The water quality data is provided in Appendix F. Hydrochemical assessment of these parameters characterize the water type and can be used to identify aquifer recharge areas, aquifer flow processes, and the degree of hydraulic connection between neighbouring aquifers.

The reliability of the major ion water quality data was assessed based on the ionic charge balance error (Mandel and Shiftan, 1981; Lloyd and Heathcote, 1985). The ionic charge balance error (C.B.E.) is defined as:

$$CBE = \frac{\sum cations - \sum anions}{\sum cations + \sum anions} x100$$

Where concentrations of cations and anions are expressed as meq/L. A CBE of less than 10% is commonly used as the criterion for acceptance of a water quality analysis. All of the CBE for the dataset used in this study are below 10%.

Table A-2: Water Quality Parameters

pH Alkalinity (as $CaCO_3$) Bicarbonate (as $CaCO_3$) Carbonate (as $CaCO_3$) Hydroxide Electrical Conductivity Fluoride Nitrate (as N) Nitrite (as N) Sulfate Calcium Magnesium Sodium Potassium Colour Turbidity	Bromide Total Organic Carbon Reactive Silica Ammonia (as N) Orthophosphate Aluminum Arsenic Barium Boron Cadmium Chromium Copper Iron Lead Manganese	Mercury Molybdenum Nickel Total Phosphorus Selenium Silver Strontium Thallium Tin Titanium Uranium Vanadium Zinc Total Dissolved Solids Total Hardness (as $CaCO_3$) Totol Suspended Solids (surface water only)

ii. Radioactive Isotope Analysis

Isotopic character of the waters was used to help address recharge mechanisms and recharge rates. This involved the collection and subsequent analysis of water samples from a monitoring well constructed in the Upper Amabel and one from the contact between the Amabel and the Fossil Hill Formation. The two samples collected for isotope analysis (enriched tritium) were shipped to the University of Waterloo Isotope Laboratory in Waterloo, Ontario.

8. Water Level Monitoring Program

There are currently 24 monitoring wells constructed on-site. Twelve of these have been equipped with pressure transducers (dataloggers), which are programmed to record the total pressure above the datalogger ever 2 hours. In addition, there is a barometric pressure transducer on-site which is programmed to read the atmospheric pressure at the same interval. This data allows for barometric correction to be applied to the pressure reading collected by the 12 dataloggers. In addition, manual water level readings are measured at all 24 monitoring wells. The data presented in this report covers the monitoring period from September 2004 to March 2006. This data is provided in Appendix E.

9. Dry Tracing Program

The most commonly used dyes are Rhodamine B and Rhodamine WT. For the purpose of this project, Rhodamine WT was used as Rhodamine B has the disadvantage of a greater tendency to absorb onto sediment and other water borne particles, which may not behave in the same hydraulic manner as the water under study. Rhodamine WT fluoresces when exposed to Ultra Violet light, emitting light in characteristic bands. It is this property that is used when measuring their concentration in the water. Detection techniques for dyes employ filter fluorometers, which have detection limits as low as a few parts per trillion (:g/m3).

Rhodamine WT (14 mL of solution: 20% strength) dye was introduced into Sinkhole #1 at outlet from the Central Wetland. Break out detection was measured at Seep #1 and Seep #2 (Figure xx). The sampling frequency was continuous to ensure that the recovered dye concentrations provided a higher data resolution during the rapidly rising or falling limb of the dye breakthrough curves. The monitoring of Seep #1 was terminated during the falling limb of the breakout curve in order to measure the peak concentration at Seep #2.

10. Vertical Fracture Mapping

Dr. Alexander Cruden was retained by M.A.Q. Aggregates, Inc. to complete an assessment of vertical fractures in the study area. This work was undertaken in November 2005. The analysis included reprocessing of fracture orientation data collected during an earlier study (Jaggar Hims Ltd., 2005), a site visit on Nov. 7 to observed fractures at the Duntroon Quarry and a number of outcrops (natural and abandoned quarries) in the area, photogeological interpretation of 1:20,000 scale aerial photographs, processing and interpretation of 10m digital elevation data, and interpretation of 1:1,000,000 scale aeromagnetic data.

Reprocessing of Jaggar Hims fracture data was carried out using Spheristat v2.2 (Pangaea Scientific). Aerial photographs were processed with Corel Photopaint v11 and lineaments were analysed using Image J v1.34 and Spheristat v2.2. Digital Elevation Models (DEM) and their derivatives were generated with Surfer v7.0. Interpretation of aeromagnetic anomalies was done using a published, hard copy shaded relief image of the total magnetic field (Gupta, 1991).