# Appendix 9B

## Hydrogeology/Groundwater Inflow Study (Itasca)

# PREDICTIONS OF GROUNDWATER INFLOW TO SUBLEVEL RETREAT MINING AT GUYANA GOLDFIELDS AURORA MINE GUYANA, SOUTH AMERICA

Prepared

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# TABLE OF CONTENTS

**Page**

## TABLE OF CONTENTS
## (continued)

**Page**

FIGURES

TABLES

## LIST OF FIGURES

## LIST OF TABLES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| 3-D | three dimensional |
| HSA | hydrologic study area |
| $K$ | hydraulic conductivity |
| $K_h$ | horizontal hydraulic conductivity |
| $K_x$, $K_v$, $K_z$ | hydraulic conductivity value along x, y, and z directions |
| L/s | liters per second |
| LOM | life of the mine |
| m | meters |
| $m^3$ | cubic meters |
| m/s | meters per second |
| m/day | meters per day |
| $m^3$/ day | cubic meters per day |
| mamsl | meters above mean sea level |
| mbgs | meters below ground surface |
| SLR | sublevel retreat |
| VWT | vibrating wire transducer |
| ZOR | zone of relaxation |

## EXECUTIVE SUMMARY
## (Page 1 of 2)

1) Itasca developed a three-dimensional (3D) finite element flow model of the Aurora Mine located 170 km west of Georgetown in Guyana, South America to predict groundwater inflows into the proposed Aurora pits and underground workings, and pore pressure distributions associated with open pit and underground mining.
2) Itasca first compiled and analyzed the hydrogeologic data from previous investigations and incorporated these data into a conceptual hydrogeologic model of the mine area. Then, based on this conceptual hydrogeologic model, a finite-element groundwater flow model of the Aurora Mine area was constructed. The model simulated the Cuyuni River within the model domain, the Aurora open pits, and the underground mine workings.
3) The hydrogeologic units incorporated into the model include the unconsolidated deposits, weathered bedrock, and fresh bedrock. The hydrologic properties of these geologic units were simulated based on the analysis of the packer test and pumping test data from field investigations provided by AMEC and SRK and refined through model calibration.
4) Based on the pumping test data analysis, Itasca hypothesizes that there likely exists a thin permeable unit within the weathered bedrock.
5) The shear zones were simulated in the model's sensitivity analysis.
6) A pre-mining steady-state simulation of the groundwater flow model was calibrated to the observed water levels in the mine area and subsequently the calibrated water levels were used as initial water levels for transient simulations of the pumping test and predictive simulations.
7) A transient simulation was performed based on the 53.5-hour pumping test conducted by AMEC in December 2010. The simulated drawdown values were compared to the measured drawdown values in the monitoring wells.
8) Four model scenarios were conducted; these scenarios include a base case scenario and three sensitivity analyses.
9) Pore pressure data files of 19 mining stages were transferred to SRK.
10) The volumes of water from both long-term and short-term rainfall events that report to SLR mine workings were calculated.
11) Based on the data analysis and numerical simulations, Itasca concludes the following:
    - The measured $K_h$ values of the fresh bedrock decreases with depth.

## EXECUTIVE SUMMARY
## (Page 2 of 2)

- For the weathered bedrock, the measured $K_h$ values of the areas closer to the Cuyuni River are generally greater than the $K_h$ values of the areas farther away from the Cuyuni River.
- The pumping test indicates that there is likely a thin permeable zone that lies between the Cuyuni River and the mining areas. This permeable zone is likely associated with the weathered bedrock.
- Under the base case scenario, the predicted maximum inflow rate to Rory's Knoll pit is about 600 $m^3$/day, to Aleck Hill is about 1,500 $m^3$/day, and to SLR workings is about 2,000 $m^3$/day.
- The predicted inflow is moderately sensitive to the horizontal anisotropy ratio of hydraulic conductivity. Assuming the horizontal anisotropy ratio of 1.0 will increase the predicted inflow rate to SLR workings from 2,000 $m^3$/day to about 4,000 $m^3$/day.
- The predicted inflow is highly sensitive to the permeable nature of the shear zones.
- Under the short term intensive storm event of 25 years return period, the volumes of water that report to SLR underground workings range from 20,000 to 32,000 $m^3$.

12) Based on Itasca's findings from this phase of the 3-D groundwater flow model, Itasca recommends the following:
    a) Conduct three shallow pumping tests in future investigations.
        - The first pumping test should be conducted in the alluvium/Saprolite unit. The purpose of this pumping test is to determine if the permeable zone observed during the 2010 pumping test exists within this unit.
        - The second pumping test should be conducted in the weathered bedrock unit to confirm if it is a permeable zone.
        - The third pumping test should be conducted in the shear zones. The well should be screened from the top of the shear zones (assumed to extend to the top of the bedrock) and 50 m below the top of the fresh bedrock. This test would provide data to evaluate the permeable nature of the shear zones.
    b) Locate or install multi-level piezometers at up to six locations for the pumping tests.
    c) Update the groundwater flow model after the completion of the recommended pumping tests.

## 1.0 INTRODUCTION

This report describes the groundwater flow model constructed by Itasca Denver, Inc., (Itasca) for Guyana Goldfields' planned Aurora Mine in Guyana, South America. The model was constructed with the geologic and hydrogeologic data collected from the mine area from past investigations. The purposes of this model were to:

1) simulate the open pit and sublevel retreat (SLR) mining,
2) predict potential flow rates into open pits and the SLR mining, and
3) provide predicted pore pressure distribution as input to geomechnic model.

Preliminary results of the groundwater flow model were provided to SRK Consulting (Canada) Inc., (SRK) in a technical memorandum dated 24 October 2012 (Itasca 2012). That memorandum was prepared without simulation of zone of relaxation (discussed in Section 3.4) and only presented the predicted inflow rates without detailed discussion of the data and groundwater flow model as described in this report.

# 2.0 BACKGROUND

## 2.1 SITE CONDITIONS

The Aurora mining project is located 170 km west of Georgetown in Guyana, South America. The project site is located adjacent to the Cuyuni River, one of Guyana's major rivers. Due to the proximity of the river to the proposed mine, three segments of berm structures (or man-made dykes) were proposed by Tetra Tech (email communication) to minimize the effects of potential flooding on the mining operations. Figure 1 shows the locations of the planned open pit and underground workings, Cuyuni River, and the proposed man-made dykes. Also shown in Figure 1 are the topography, borehole locations from past investigations, and the model domain.

A typical cross section of the area, as illustrated in Figure 2, consists of the unconsolidated deposits (alluvium followed by a residual soil and Saprolite) which overlays the weathered bedrock (also known as Saprock or transition rock) and finally the fresh bedrock. The residual soil, Saprolites and Saprock are derived from the weathering of basement rock which includes granites, meta-volcanic, tuffs and ultramafics. A more detailed description of the site conditions can be found in AMEC (2010). In Figure 2, alluvium and Saprolite were grouped and assigned as the unconsolidated deposits. The thickness of the unconsolidated deposits generally range from a few to 50 meters (m) and the thickness of the weathered bedrock ranges from a few to 20 m.

Several shear zones were identified in the mining vicinity. The locations of these shear zones are shown in Figure 1 and illustrated in Figure 2. The vertical extent of the shear zones was assumed to extend upward to the bottom of the weathered bedrock. More detailed descriptions of the geologic units are provided in Section 3.0 of this report.

## 2.2 PREVIOUS HYDROGEOLOGIC INVESTIGATIONS

Packer tests or pumping tests were conducted during field investigations in 2009, 2010, 2011, and 2012. The field investigations from 2009, 2010, and 2011 were conducted or supervised by AMEC (AMEC 2010; 2011; 2012) and the 2012 packer test was supervised by SRK.

Figure 1 shows the locations of boreholes drilled in 2009 (with prefix = "BH09-"), 2010 (with prefixes = "BH10-" or "TW-"), 2011 (with prefix = "BH11-"), and 2012 (with prefix = "BH12-"). Most of these holes are located within the mining area. The holes with measured water levels are summarized in Table 1. Table 1 also summarizes top and bottom elevations of the well screens or the elevations at which the vibrating wire transducers (VWT) were installed. For the open boreholes, the top and bottom elevations of the well screens refer to the top and bottom of the opening section.

### 2.2.1 Summary of Field Programs

*2009 Program*

In 2009, 373 packer tests from 34 different boreholes were performed by AMEC (AMEC 2010). The packer tests were conducted in the following areas:

1) Proposed River Dyke Site: BH09-01 through BH09-06
2) Proposed Open Pit Site: BH09-07 through BH09-12
3) Tailings Management Facility Site: BH09-14 through BH9-15
4) Proposed Tailings Management Area Site: BH09-19,BH09-21, BH09-22, BH09-24, BH09-25, and BH09-26
5) Proposed Water Management Pond Site: BH09-29, BH09-30, and BH29-32
6) Proposed Open Pit (Rock Mechanics Holes): BH09-RK-RMP-01 through BH09-RK-RMP-05, BH09-AH-RMP-06 through BH09-AH-RMP-09, BH09-WH-RMP-10, and BH09-WH-RMP-11

The results of the above tests are discussed in Section 2.2.2.

### *2010 Program*

The 2010 program was performed by AMEC (AMEC 2011a) to provide horizontal hydraulic conductivity ($K_h$) values in the area between the proposed pit and the Cuyuni River. The hydraulic testing in 2010 included both packer and pumping tests. Packer tests were conducted in the following locations:

- Along the stretch of the proposed berm structure (man-made dykes): BH10-01 (TW-1), BH10-02 (TW-2), BH10-03 (TW-3), BH10-04 (TW-4), BH10-05 (TW-5), BH10-06 (TW-6), TW-7 (Pumping Well), and TW-8
- In the vicinity of the proposed open pit: BH10-RK-RMU-05 and BH10-RK-RMU-06

Short-term pumping tests and flow profiling were conducted to determine the inflow zones in TW-2, TW-3, TW-4, TW-6, TW-7d, TW-8 and TW-8d. The short-term pumping tests were conducted by pumping from one of the test wells and monitoring water levels in the nearby monitoring wells for periods of up to 100 minutes (AMEC 2011a).

A longer 53.5-hour pumping test was also conducted by AMEC at TW-7 from December 10-12, 2010. The test well was pumped at an initial rate of 6.0 L/sec, and slightly decreased to 5.9 L/s after two hours of pumping, and remained at this rate until the final day of the test when the flow rate had decreased slightly to 5.8 L/s. The change in water levels during the TW-7 pumping test was monitored in a number of monitoring wells. The maximum drawdown value for each monitoring well is summarized in Table 2 and shown in Figure 3.

### *2011 Program*

In 2011, additional packer testing was conducted at the shaft hole and also at two locations between the Cuyuni River and the proposed mine (BH11-23 and BH11-24C); there was no information on the hydraulic conductivities of the bedrock below a depth of 300 m prior to the 2011 program.

The shaft hole is located on the southeast side of Rory's Knoll (Figure 1). The initial plan was to conduct packer tests through the entire hole at 50 m intervals, but due to the limitation of the testing equipment, packer tests were performed progressively at larger intervals below the depth of 252 m below ground surface (mbgs) (AMEC 2012).

BH11-23 and BH11-24(C) are located between the proposed mine and the Cuyuni River (Figure 1). According to AMEC (2012), BH-11-24 is located within the shear zones initially identified by SRK and BH11-23 is located between the shear zones and the Cuyuni River, north of the Rory's Knoll area (AMEC 2012).

***2012 Program***

The 2012 packer tests were conducted by SRK. The data from the packer tests were provided to Itasca for hydraulic conductivity analysis. Except for BH12-SLC-02 and BH12-SLC-03, all other holes are less than 50 m deep.

### 2.2.2 Analysis and Summary of Data from Previous Investigations

***Distribution of $K_h$ Values***

The measured $K_h$ values from all field investigations were analyzed to evaluate $K_h$ distribution vertically with depth and laterally from the Cuyuni River. Figures 4 through 7 show the $K_h$ distribution within the different geologic units. Also shown in the figures are the hydraulic conductivity values along the X (east-west) direction ($K_x$) used in the groundwater flow model which are discussed in Section 4.2.1 in this report. The $K_x$ and anisotropy values used in the model for all of the geologic units are discussed in Section 4.0 of this report. Figure 4 shows all measured $K_h$ values from the 2009-2012 field investigations. The data demonstrate a decreasing trend of the $K_h$ values with depth.

The measured $K_h$ values of different geologic units were then grouped according to the distance of the test hole from the Cuyuni River bank for every 200-m interval ("distance group") where data were available. Figure 5 shows the distribution of the measured $K_h$ values in the unconsolidated deposits with depth for different distance groups. Based on the available data, the $K_h$ values were divided into three groups according to their distance from the bank of the Cuyuni River:

- less than 200 m
- between 200 to 400 m
- between 400 and 1400 m

Figure 5 suggests that there is no clear spatial trend of $K_h$ in the unconsolidated deposits in relation to the distance from the Cuyuni River.

Figure 6 shows the distribution of measured $K_h$ values in the weathered bedrock unit from the bank of the Cuyuni River. Figure 6 shows that, except for one measured $K_h$ value in the 1400-m-distance group and large ranges of measured $K_h$ values in the 2000-m-distance group, the higher $K_h$ values are generally observed in the area that is closer to the Cuyuni River.

Figure 7a shows that, for the bedrock geologic units, there is no clear trend in the measured $K_h$ values at distances from the bank of the Cuyuni River; however, $K_h$ values generally decrease with depth, as shown in Figure 7b. Figure 7b also provides the $K_x$ value used in the model for these bedrock geologic units. As shown in Figure 7b, the $K_x$ values used in the model generally follow the distribution of the geometric mean values of the measured $K_h$ values for a specified depth interval.

### *Measured $K_h$ Value of the Shear Zones*

According to AMEC (2012), the purpose of conducting packer tests at BH-11-23 and BH-11-24 was to obtain the $K_h$ values of the shear zones. The locations of both holes are shown in Figure 1. Both holes were drilled to depths of approximately 500 mbgs. AMEC (2012) stated that BH-11-24 was drilled in the shear zones that were identified by SRK, and BH-11-23 is located between the identified shear zones and the Cuyuni River; however, AMEC (2012) later concluded that the geologic logs suggest that neither hole encountered the shear zones.

Therefore, there is no measured $K_h$ value from the shear zones. Nonetheless, the measured $K_h$ values from both holes are generally low with a majority value of $10^{-4}$ m/day.

### *Observations from Pumping Test*

In 2011, AMEC conducted several short-term pumping tests and one 53.5-hour pumping test (AMEC 2011a). AMEC also conducted flow profiling in seven boreholes listed in Table 2. The profiling results indicate that the water producing zone in most of the holes is between 15 to 60 mbgs. Based on AMEC's observation that "in test wells close to the river, the largest water producing zones were often located near the base of the casing, close to the bedrock contact with the Saprolite", Itasca postulates that the contact zone, which was simulated in the model as part of the weathered bedrock unit, could be more permeable than the other geologic units. This is further discussed in the following paragraphs.

As shown in Table 2, pumping well TW-7 is an open hole, as well as the majority of the monitoring wells. Subsequently, the pumping test was not a well-controlled test because it did not target specific geologic units; however, in combination with the flow profiling, the pumping test still provides valuable information regarding the groundwater flow conditions at the site.

Figure 8 shows that most of the monitoring wells reach equilibrium within a few hours after the pumping started. This indicates that there exists a relatively permeable zone within the vicinity of the pumping well. The possible ranges of the $K_h$ value and the thickness of this permeable zone are further evaluated with the classical Theis formula.

Figure 9 shows the estimated drawdown with distance from the pumping well from the Theis formula for two assumed thicknesses of the possible permeable units encountered during the pumping test. Figure 9a shows the calculated drawdown assuming the permeable unit is 2 m thick. As shown in Figure 9a, when the assumed $K_h$ value is approximately 50 m/day, the drawdown at approximately 1000 m from the pumping well is approximately 0.3 m, which is in the same range of the measured drawdown values. If the assumed $K_h$ value is less than 50 m/day, the estimated drawdown at approximately 1000 m from the pumping well would be smaller than the measured drawdown.

Figure 9b shows the calculated drawdown with distance from the pumping well assuming the permeable unit is 20 m thick. As shown in Figure 9b, using the Theis formula, the estimated drawdown at 1000 m from the pumping well would be smaller than the measured drawdown for all ranges of the $K_h$ values.

Though the combination of thicknesses of the permeable unit and the assumed $K_h$ value is not unique, Figure 9 demonstrates that, in order for the drawdown to propagate over 1000 m from the pumping well, the permeable unit is likely to be relatively thin with high $K_h$ values (in the range of 50 m/day). It is unlikely that all of these monitoring wells are connected by a permeable feature, such as regional fault or shear zone, because (1) there is no shear zone identified at the location of the pumping well, and (2) the flow profiling consistently shows that the water-producing zones occur at the contact between the weathered and fresh bedrock, which was penetrated by all the open boreholes.

## 3.0 CONCEPTUAL HYDROGEOLOGIC MODEL

The geologic setting (Figure 2) was briefly discussed in Section 2.1. Figure 2 illustrates the conceptual hydrogeologic model of the site along the north-south section. The major hydrogeologic components include recharge, rivers, distribution of different geologic units, the presence of shear zones, and hydraulic stresses induced by open-pit and underground mining. The conceptual hydrogeologic model was developed based on the analysis of the site conditions and data observed during the field investigation.

## 3.1 GENERAL HYDROGEOLOGIC SETTING

### 3.1.1 Climate

Aurora is located in a hot, humid, tropical environment with a high annual rainfall of approximately 2450 mm. The annual evaporation is 1342 mm (AMEC 2011b). The typical rainy seasons are from mid-April to mid-August and from mid-November to the end of January. There is no data available on the local aquifer recharge rate; however, the recharge to the low-permeability bedrock is expected to be low.

### 3.1.2 Topography, Drainage, and Vegetation

Aurora is located on the Cuyuni Greenstone Belt in north-western Guyana. The area has low relief with some hills near the Cuyuni River, one of Guyana’s major rivers. There are hills over 200 m high in the southwest part of the Aurora property. Several large creeks drain into the Cuyuni River and there are large swampy areas where the creeks flow into the river. The entire property is covered with dense rainforest on hummocky terrain derived from the erosion of deeply weathered rocks. Given the lack of data of the creeks and other surface water bodies, only the Cuyuni River was simulated in the groundwater flow model.

### 3.1.3 Hydrologic Study Area

Figure 1 shows the Hydrologic Study Area (HSA) defined for the groundwater model of the Aurora mine. The model boundaries were selected in such a way that the hydraulic stresses induced by mining operations will not propagate to the model boundary. The Cuyuni River is also located in the HSA. Several shear zones were identified within the HSA.

## 3.2 DESCRIPTION OF HYDROSTRATIGRAPHIC UNITS

The general stratigraphy of the site, from ground surface to below, consists of the following major units:

1) Unconsolidated Deposits: This unit consists of alluvium and Saprolite (rock weathered to a soil, but retaining the original structure of the parent rock)
2) Weathered Rock: This unit consists mostly of the Saprock geologic unit
3) Fresh Bedrock: This unit consists of granite and meta-volcanic rock

The alluvium is generally thin (approximately 2 to 4 m). In some local granite highland areas and the area between the proposed open pit mine and the Cuyuni River, the average thickness of the alluvium reaches 7.5 m.

Tropical weathering has transformed the upper portion of the bedrock into residual soil and Saprolite. Both alluvium and Saprolite were considered to have similar hydraulic properties and were designated as the unconsolidated deposits in both the conceptual model and the numerical model. This unit does not show a noticeable trend in the measured $K_h$ values versus distances from the bank of the Cuyuni River as discussed earlier and shown in Figure 5.

The weathered bedrock (Saprock) is a contact between the Saprolite and the bedrock. It varies in thickness from a few to 20 m. As discussed in Section 2 and shown in Figure 6, this unit is relatively thin. The $K_h$ value of this unit decreases with distance from the Cuyuni River. Furthermore, data from the pumping test suggest it is likely that a portion of the weathered bedrock contains a thin, high-permeability zone.

Fresh bedrock at the site comprises granite, meta-sedimentary and meta-volcanic rocks of the Cuyuni Formation. These different bedrock units were assumed to have similar hydraulic conductivity values and are considered as one geologic unit in the model.

## 3.3 GEOLOGIC STRUCTURES

Shear zones were identified at the site. Some of the shear zones will be encountered by open-pit and underground mining. As discussed in Section 2.2.2, no $K_h$ has been measured in the shear zones.

## 3.4 MINING ACTIVITIES

The Aurora open pits, other than Rory’s Knoll pit, and SLR mining will proceed simultaneously. SLR mining will only start after the completion of Rory’s Knoll pit. The SLR mining will cause the disturbance to the rock surrounding the Rory’s Knoll pit wall and SLR mine workings. This disturbance zone is defined in the groundwater flow model as the zone of relaxation (ZOR) and simulated as a more permeable zone than the in-situ rock. Because the inflow to open pits and underground mine workings occurs simultaneously, the excavation of open pits and underground mine working are simulated simultaneously in the model in order to realistically simulate the inflow to SLR mine workings and individual open pit.

## 4.0 GROUNDWATER FLOW MODEL

The groundwater flow model constructed for this investigation utilizes the commercial, numerical code *MINEDW*™ (Azrag et al. 1998) developed by Itasca, which solves 3-D groundwater flow problems with an unconfined (or phreatic) surface using the finite-element method. The modeling code has been verified by Sandia National Laboratory (1998) and is used at numerous mining hydrogeologic projects throughout the world.

### 4.1 MODEL DOMAIN AND DISCRETIZATION

The finite-element grid in plan view is shown in Figure 10. The finite-element discretization is the finest (20 m) in the pit area to represent the geometry of the pit and the hydrogeology in detail. The mesh gradually increases in size toward the boundaries of the model. For the base case scenario, the shear zones were simulated with the same hydrogeologic parameters as the in-situ rock. The impacts of these shear zones on the inflow rate was simulated in the sensitivity analysis. Therefore, the shear zones were represented as bands of finely discretized finite elements as shown in Figure 10.

The vertical discretization is also refined to simulate the open pit and underground geometry. The vertical discretization can be seen in cross section in Figure 11. (The location of the cross-section A-A' is also shown in Figure 10.) A total of thirty-six (36) model layers were created to simulate the various geologic units and mine levels. The thicknesses range from 25 m in the mining zone to 500 m below the mining zone.

The top of the model domain was assigned with ground surface elevations interpolated using LIDAR DEM data provided by Guyana (J. R. Sereneo, email communication). The bottom of the model domain is assumed to be -1800 mamsl.

The total number of nodes and elements in the model are 246,087 and 476,460, respectively. The groundwater model is approximately 7.7 km in the west-east direction and 7.5 km in the north-south direction.

## 4.2 SIMULATION OF HYDROGEOLOGIC SETTINGS

### 4.2.1 Simulation of Hydrogeologic Units

The hydrostratigraphic units simulated in the groundwater flow model were illustrated in the conceptual hydrogeologic model (Figure 2). The geologic models provided by Guyana and SRK were used as the basis for the model construction, specifically, the model-defined top elevation of the fresh bedrock. By assuming that the weathered bedrock has a uniform thickness of 5 m, Itasca then defined the thickness of the alluvium/Saprolite unit from the top of the weathered bedrock and ground surface.

The simulation of the hydrogeologic units is briefly summarized below:

**Unconsolidated Deposits:** This unit is a combination of alluvium and Saprolite. It is simulated with two model layers. As shown in Figure 10, this unit was laterally simulated with two zones of different hydraulic conductivity values (hereafter referred to as "hydrogeologic zones") based on the distance from the Cuyuni River bank. This simulation of two different hydrogeologic zones was mainly derived from the steady-state model calibration and from the limited measured $K_h$ values (as shown in Figure 5). The distance of 1400 m from the river bank is somewhat arbitrary and limited by the available data.

**Weathered Bedrock:** This unit was assumed to be 5 m thick and was simulated with two model layers. As discussed in Section 2.2.2 and shown in Figure 6, the $K_h$ values tend to decrease the farther they are from the river. Therefore, four hydrogeologic zones were simulated in the weathered bedrock unit. These hydrogeologic zones were defined based on the 200 m increment of the distance from the river bank, as shown in Figure 12.

**Fresh Bedrock:** The fresh bedrock unit is simulated in the model as one hydrogeologic zone for a given model layer. As discussed in Section 2.2.2 and shown in Figure 7a, there is no clear trend in the $K_h$ values versus the distance from the river bank. However, as shown in Figure 7b, the $K_h$ value reduces with depth, which was simulated in the model with four different hydrogeologic zones as shown in Figure 11.

**Shear Zones:** The shear zones were represented in the model to be present only in the fresh bedrock. For the base case scenario (discussed in Section 5.3 of this report), the shear zones were simulated with the same hydraulic properties as the in-situ fresh bedrock. A model representation of the shear zones in cross section is provided in Figure 11 with the assumption that the shear zones would extend laterally to the model boundary.

### 4.2.2 Simulation of Man-Made Dykes

The representation of the dykes in the model is shown in Figures 10 to 12. These dykes are assumed to extend from the ground surface to the top of the fresh bedrock. In the model, the dykes were assumed to be constructed with low-permeability material.

## 4.3 MODEL BOUNDARIES

### 4.3.1 Recharge from Precipitation

Two recharge zones with slightly different recharge values were simulated according to the ground surface elevation as shown in Figure 13. Based on the steady-state model calibration, the recharge value was assumed to be 0.0206 and 0.0263 mm/day, respectively for the model area that is lower and higher than 90 mamsl. In the predictive simulation, the recharge was assumed to be constant over the entire model simulation. Due to its low-permeability nature, no recharge was applied to the man-made dykes.

### 4.3.2 Variable-Flux Boundary Condition

In order to simulate the groundwater interaction between the model domain and the regional groundwater system, the nodes in the model boundaries, except for the river nodes, were assigned with a variable-flux boundary condition, as shown in Figure 13. The variable-flux boundary condition is a special feature of *MINEDW* that simulates an essentially infinite aquifer with the same hydraulic properties as those assigned to the elements at the model boundary.

### 4.3.3 Constant-Head Boundary Condition

The Cuyuni River within the model domain was simulated in the model as a constant-head boundary condition as shown in Figure 13. Because there is little variation in elevation along the river within the model domain, the nodes that correspond to the river were assigned with a constant head of 46 mamsl based on topographic data.

## 4.4 SIMULATION OF PRE-MINING CONDITIONS/STEADY-STATE CALIBRATION

Groundwater flow model simulations under steady-state conditions were conducted to establish baseline groundwater levels. The simulated groundwater levels are compared with the measured groundwater levels from various monitoring boreholes whose locations are shown in Figure 14. Figure 14 shows that groundwater flows from both the north and south toward the river.

A comparison between simulated and the limited measured water levels shows that the model generally matches the measured groundwater levels. The “quality line” in Figure 15 shows one method to compare between the measured and simulated groundwater levels. As shown in Figure 15, the trend in the measured groundwater levels generally agrees with that of the simulated values.

## 4.5 SIMULATION OF PUMPING TEST

As discussed in Section 2.2.2, the 53.5-hour pumping test conducted by AMEC in December 2010 was not a well-controlled pumping test, due to the fact that the pumping well and most of monitoring wells were open holes. In combination with the flow profiling information, however, the results of the pumping test provided valuable understanding of the hydrogeologic conditions for developing the conceptual hydrogeologic model.

Itasca simulated the pumping test to provide further understanding of the hydrogeologic conditions at the site. The analytical solution in Section 2.2.2 has demonstrated the probability of a thin, permeable unit at the site; however, the analytical solution is limited to an ideal one-dimensional, confined aquifer; therefore, it is useful to also simulate the pumping test using a 3-D model.

In simulating the pumping test, Itasca assumed that all 5.8 L/s of water is from the weathered bedrock zone. This assumption, though approximate, is reasonable, as the analytical solution demonstrated that only a thin permeable unit would allow the drawdown to propagate to approximately 1000 m from the pumping well. The simulated drawdown contours in the weathered bedrock model layer are shown in Figure 16. In general, the simulated drawdown follows the trend observed at the site. By assuming the thickness of the weathered bedrock is 5 m, however, the model could not produce a 0.2 to 0.3 m drawdown at approximately 1000 m from the pumping well as observed during the pumping test. No further attempt was made to reduce the layer thickness of the permeable unit for the following two reasons:

1) the objective of the model simulation was not to calibrate the model to the pumping test but rather to provide further understanding of the groundwater conditions at the site. This objective was judged to have been achieved; and
2) the analytical solution has already demonstrated that, by decreasing the thickness of the permeable zone, the estimated drawdown could reach about 0.3 m at approximately 1000 m from the pumping well. By assuming a thicker permeable zone than it could potentially be, the model would predict slightly more conservative inflow rates.

Based on the model simulations of the pumping test, Itasca observed the following:

1) There could be a thin permeable unit between the pit and the Cuyuni River. In the groundwater flow model, Itasca assumed that this permeable unit is located within 200 m north and south of the Cuyuni River with a thickness of 5 m and a hydraulic conductivity value of 50 m/day. Itasca also assumed that this permeable unit is part of the weathered bedrock unit.
2) There could be east-west preferential flow with the hydraulic conductivity along the east-west direction ($K_x$) being higher than the hydraulic conductivity value along the north-south ($K_y$) direction. Itasca assumed that the ratio of $K_x$ to $K_y$ is 10, in order to simulate the propagation of drawdown to the west of TW-7.

The hydraulic parameters derived from the simulations of the steady-state condition and the pumping test are summarized in Table 3. A comparison of the model's $K_x$ values to the global range shown in Figure 17 indicates that the modeled $K_x$ values of the fresh bedrock are greater than the global $K_h$ values of the competent rock.

## 4.6 SIMULATION OF MINING

### 4.6.1 Open Pit Mine

Figure 18 shows the open pits and underground mine development. Five open pits were simulated in the current model. Because there is no yearly pit plan, Itasca assumed that the open pits will be excavated linearly according to yearly pit bottom elevation provided by SRK (G. Carlson, email communication) which is summarized in Table 4.

Excavation of the open pit was simulated with drain nodes (or with a zero pore-pressure condition) according to the assumed schedule and the final configuration of the open pit. The purpose of simulating the pit excavation is to estimate the volume of groundwater that will seep into the pit over the life of the mine (LOM). Therefore, the drain nodes that represent pit excavation were turned 'on' according to the mining plan schedule.

Drain nodes were used to simulate the discharge of groundwater at the pit wall by the relationship:

$$Q = CL\,(H_s - H) \;\; if \;\; H > H_s$$

and

$$Q = 0 \;\; if \;\; H \le H_s$$

where

$Q$ = groundwater discharge to the drain nodes [m$^3$/day] (negative value indicates discharge from groundwater system),

$H_s$ = specified elevation of a pit wall node [m],

$H$ = calculated hydraulic head [m], and

$CL$ = the so-called leakance factor, assigned either with an assumed value or one estimated from

$$CL = \frac{f \cdot K \cdot D_2 \cdot D_3}{D_1}$$

where

$K$ = hydraulic conductivity of the drain node material [m/day],

$D_1, D_2, D_3$ = length related to the size of the individual element to which any particular drain is associated [m], and

$f$ = a factor that accounts for the effect of non-Darcian flow, the actual size of the excavation relative to the grid size, and the shape of the excavation. This value is generally calibrated to the measured inflow rate.

In *MINEDW*, the CL (leakance factor) can be calculated based on either the *K* value of the geologic units using the above equation, calibrated based on the observed inflow rate, or assigned with a large value. In predicting inflow to the Rory's Knoll open pit, a large leakance factor value was used, which essentially allows for groundwater from rocks to discharge freely to each drain node without considering the effects of non-Darcian flow. This assumption may lead to a slightly conservative prediction (i.e., an over estimate) of the seepage rate to the pit.

### 4.6.2 Simulation of Ramp

The ramp was assumed to start in Year 3. For each level of mining, ramp was assumed to be completed one year earlier than the start of SLR mining. The top and bottom elevations of the ramp are 75.8 and -1000 mamsl, respectively. The model assumes there is no grouting in the ramp to mitigate potential inflow. Because the detailed schedule was not available, Itasca assumed that the ramp was developed linearly with its elevation.

The ramp was simulated with drain nodes. The drain nodes corresponding to ramp locations were turned on at different time steps according to the assumed schedule. The mathematical representation of the drain nodes was described in Section 4.6.1.

### 4.6.3 Simulation of Underground Sublevel Retreat Mining

SLR mining begins in Year 5. Based on the SLR schedule provided by SRK and the extent of SLR, Itasca interpolated the schedule for each SLR mine level in the model to represent progressive mining over time. The top and bottom elevations of SLR mining are -70 and -970 mamsl, respectively. Underground mining was also simulated with drain nodes using the same approaches described in Section 4.6.1.

### 4.6.4 Simulation of Zone of Relaxation

The extent of ZOR was provided by SRK based on its geomechanic model simulations. Because the ZOR propagates both laterally and vertically as mining proceeds, SRK provides the ZOR extent for every 50 m SLR mining stage (J. Severin, email communication). The development of the ZOR over the LOM was simulated in the groundwater flow model by increasing the *K* value of the rock within the ZOR. In the groundwater flow model, the *K* value of ZOR was assumed to be 0.05 m/day (Table 3), which is one to two order(s) of magnitudes higher than the majority of fresh bedrock.

# 5.0 PREDICTIVE SIMULATIONS

## 5.1 DISCUSSION OF KEY SIMPLIFICATIONS/ASSUMPTIONS IN THE MODEL PREDICTION

The following are key simplifications regarding the model predictions:

1) Shear zones were simulated to have similar hydrogeologic properties as the in-situ bedrock. There are no measured data to demonstrate whether the shear zones are permeable or not. A permeable shear zone could significantly increase the inflow rates to both the open pit and the underground mine. Therefore, in the sensitivity analysis, the effect of shear zones on the predicted inflow was evaluated.
2) Based on the analysis of the pumping test, Itasca hypothesized that a thin permeable zone exists along the river band. The extent of this permeable zone is unknown. Based on the model simulations of the 53.5-hour pumping test, this thin, permeable zone was assumed to exist within 200 m along the river. This hypothesis requires further confirmation from future field investigations.
3) The effect of surface water runoff and direct precipitation from rain/storm events on the open pits and underground pumping requirements are not reflected in the predicted inflow rates. Direct precipitation over the foot print of the Rory's Knoll open pit and surface runoff to the pit will both report to the underground workings and require a higher pumping capacity than the predicted inflow rate from groundwater. For the same reason, higher pumping capacity than the predicted inflow rates from groundwater flow is required for other open pits.

## 5.2 SUMMARY OF MODEL SCENARIOS

The following predictive numerical simulations were conducted to estimate the inflow rates to the proposed open pit and underground workings:

**Scenario 1:** In this scenario, the hydraulic parameters were based on the model calibration to the limited field data. The shear zones were assumed to have a similar hydraulic conductivity as the in-situ rock. Scenario 1 is considered to be the base case scenario.

**Scenario 2:** This scenario evaluates the effect of the man-made dykes on the predicted inflow rates.

**Scenario 3:** This scenario evaluates the effect of anisotropy on the predicted inflow rates by assuming $K_x = K_y$.

**Scenario 4:** This scenario assumed that the $K_x$ value of the shear zones is 0.5 m/day, which is 10 times greater than the $K_x$ value of the upper bedrock in Scenario 1.

## 5.3 SUMMARY OF PREDICTED INFLOW RATES

### 5.3.1 Base Case Scenario

The predicted inflow rates to various open pits shown in Figure 19 leads to the following observations:

1) After Year 6, the inflow to Rory's Knoll pit will report to SLR mine workings.
2) Among all open pits, the Aleck Hill Pit would encounter the highest inflow rate with the maximum inflow rate of about 1,600 $m^3$/day because of its large footprint and depth.
3) The predicted inflow rates to other open pits are generally less than 200 $m^3$/day.

Figure 20 shows the estimated inflow rate to the SLR workings over time. After the initial increase due to the ramp development, the predicted inflow rate increases from 1,700 $m^3$/day in Year 6 to about 2,000 $m^3$/day by the end of mining.

### 5.3.2 Sensitivity Analysis

Figure 21 shows the sensitivity of predicted inflow rates to various parameters in Scenarios 2 through 4. Because of their low predicted inflow rate, the sensitivity analysis on the predicted inflow rate to Mad Kiss Pit, Walcott Hill Pit, and Aleck Hill North Pit are not presented in Figure 21. As shown in Figure 21a and Figure 21b, the predicted inflow rates to open pits are not sensitive to the man-made dykes, are moderately sensitive to the horizontal anisotropy ratio of $K_h$, and are very sensitive to the $K$ value of the shear zones.

Figure 21b shows that, by assuming $K_x$ equals to $K_y$, the predicted inflow to SLR workings almost doubles. The figure also shows that the predicted inflow rates are highly sensitive to the $K$

value of the shear zones. By arbitrarily assigning the $K_x$ value of the shear zones as 0.5 m/day, the maximum inflow rates increase by almost 10 times in comparison to the base case scenario.

## 5.4 EXPORT OF PORE PRESSURES FROM GROUNDWATER FLOW MODEL

The pore pressure was required by SRK for the domain and intervals as shown in the following table. The minimum and maximum coordinates refer to the lower and upper corner of the domain. The interval is the dimension of the blocks. Based on the block size and domain, the number of block segments was derived.

| Coordinates | Minimum (m) | Maximum (m) | Interval (m) | Number of Block Segments |
|---|---|---|---|---|
| x | 195143 | 197339.08 | 7.76 | 283 |
| y | 750352 | 752144.56 | 7.76 | 231 |
| z | -1800 | 108.96 | 7.76 | 246 |

The interpolated pore pressure for the above domain has a total of 16,274,336 records (or lines) (284 × 232 × 247). Each line has the format:

*x* *y* *z* pressure

Where, x, y, z refers to the center of the block, and pressure refers to the interpolated pore pressure as “meters (m) of water”. Furthermore, pore pressures for points above the water table were assigned as 0.0.

The model was shifted to new x, y coordinates for *FLAC3D* analysis. SRK requested that the pore pressures be reported in the new coordinates given in the table below. The shift was -200000 m and -750000 m in the x and y directions, respectively. The coordinates in the provided pore pressure files were in the converted coordinates.

| Coordinates | Minimum (m) | Maximum (m) |
|---|---|---|
| x | -4857 | -2661 |
| y | 352 | 2141 |
| z | -1800 | 108.96 |

The interpolated pore pressures from the groundwater flow model were provided to SRK for pre-mining, end of open pit, and 17 SLR stages. Each SLR stage covers the depth interval of 50 m.

## 5.5 ESTIMATED RAINFALL TO UNDERGROUND WORKINGS

The rainfall that reports to the underground workings is estimated based on the rainfall data provided by AMEC (2011b). Table 5 summarizes the potential rainfall that reports to the underground working area. The calculations were based on the average monthly precipitation and evaporation rate from the Timehri Climate Station (AMEC 2011b). As shown in the table, the rainfall to the underground workings contains both runoff from Rory's Knoll pit wall and direct precipitation to the underground workings. Table 5 did not include the runoff from the watershed catchment by assuming that engineering measures will be taken to avoid runoff from the catchment area.

The total rainfall was calculated based on the following assumptions:

1) Evaporation was assumed to occur on the pit wall.
2) Based on Itasca's project experience, 70% of the runoff from the pit wall was assumed to arrive to the underground workings with 30% being absorbed by the loose rock.
3) No evaporation and loss were assumed for the rainfall that is directly over the bottom of the pit.

The results in Table 5 indicate that for the normal rainfall:

1) The high rainfall that reports to the underground workings occurs in May, June, and July.
2) The estimated maximum total rainfall that reports to the underground workings is approximately 700 $m^3$/day.

Table 6 summarized the volume of water that will report to the underground workings for a short term rainfall with a return period of 25 years. Selection of 25 years return period is applicable to the Aurora mine because the LOM is about 18 years. As shown in Table 6, with short term intensive rain, the volume of water that reports to the SLR workings ranges from 20,000 to 32,000 $m^3$.

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

### 6.1 CONCLUSIONS

Based on the data analysis and model simulations, Itasca concludes the following:

1) The measured $K_h$ values of the fresh bedrock decreases with depth.
2) For the weathered bedrock, the measured $K_h$ values in the areas closer to the Cuyuni River are generally greater than those in the areas farther away from the Cuyuni River.
3) The pumping test indicates that there is likely a thin permeable zone that lies between the Cuyuni River and mining areas. This permeable zone is likely associated with the weathered bedrock.
4) Under the base case scenario, the predicted maximum inflow rate to Rory's Knoll pit is about 600 $m^3$/day, to Aleck Hill is about 1,500 $m^3$/day, and to SLR workings is about 2,000 $m^3$/day.
5) The predicted inflow is moderately sensitive to the horizontal anisotropy ratio of hydraulic conductivity. Assuming the horizontal anisotropy ratio of 1.0 will increase the predicted inflow rate to SLR workings from 2,000 $m^3$/day to about 4,000 $m^3$/day.
6) The predicted inflow is highly sensitive to the permeable nature of the shear zones.
7) Under the short term intensive storm event of 25 years return period, the volumes of water that report to SLR workings range from 20,000 to 32,000 $m^3$.

### 6.2 RECOMMENDATIONS

As discussed in 5.1, the two key factors that may affect the groundwater inflow rates to the open pit and underground mines are (1) the potential permeable zone between the Cuyuni River and the mine area as indicated from the pumping test, and (2) the hydraulic conductivity of the shear zones. Itasca recommends conducting three shallow pumping tests during future investigations:

1) The first pumping test should be conducted in the alluvium/Saprolite unit. The purpose of this pumping test is to determine if the permeable zone observed during the pumping test exists within this unit.

2) For the same reason as above, the second pumping test should be conducted in the weathered bedrock unit.
3) The third pumping test should be conducted in the shear zones. The well should be screened from the top of the shear zone (assumed to be the top of the bedrock) and 50 m below the top of the fresh bedrock. This test would provide data to evaluate the permeable nature of the shear zones.

Prior to these pumping tests, multi-level piezometers should be located and installed at five to six locations. The changes in water levels from these multi-level piezometers are valuable data in analyzing the groundwater conditions at the site. The locations of pumping wells and multi-level piezometers will be jointly decided by Guyana, SRK, and Itasca.

After the completion of the pumping tests, the groundwater flow model should be recalibrated to these pumping tests and, subsequently, used to simulate inflow rates to the mines.

## 7.0 REFERENCES

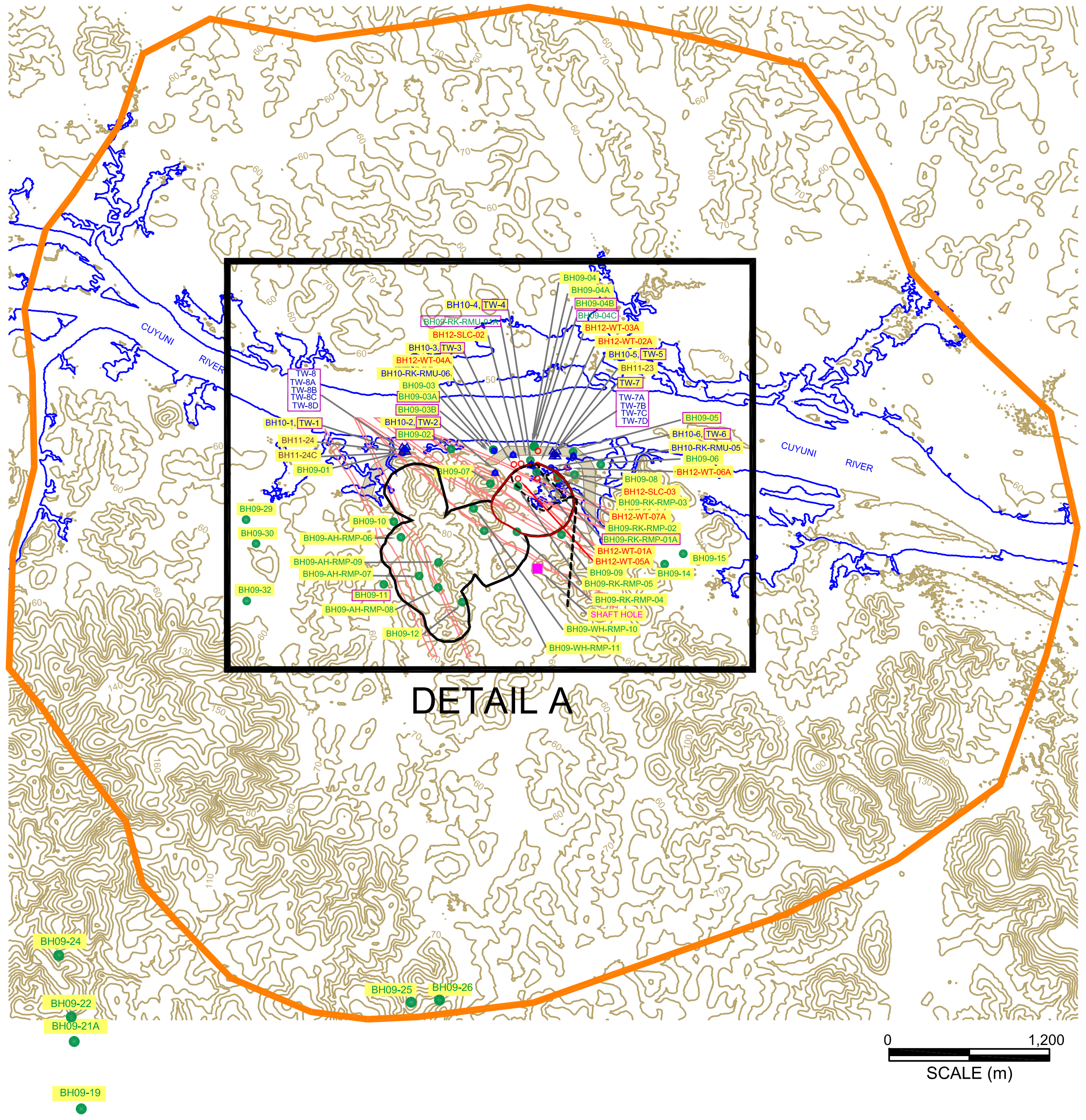
AMEC. 2010. Geotechnical Investigation for the feasibility study Aurora Gold Project, Guyana: Report submitted to Guyana Goldfields Inc. August 2010.

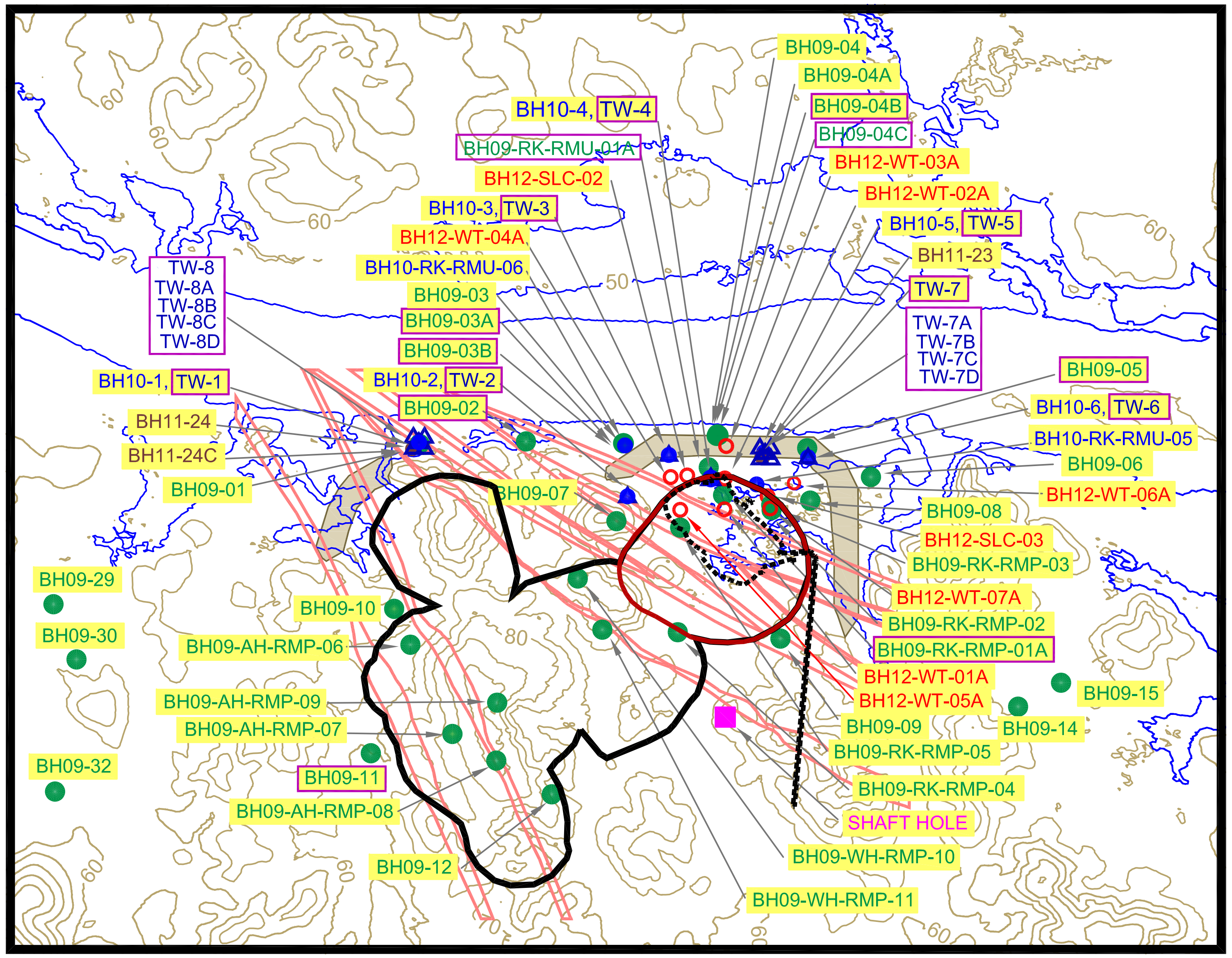
AMEC. 2011a. Pumping test results from the 2010 Testing program for Aurora Gold Project: Memorandum submitted to Guyana Goldfields Inc. April 2011.

AMEC. 2011b. Meteorological data update, Aurora feasibility study, Guyana Goldfields, Guyana. Draft memorandum submitted to Guyana Goldfields Inc. 4 October2011.

AMEC. 2012. Review of Phase 2 deep packer testing 2011 Aurora feasibility study, Guyana Goldfields, Guyana: Memorandum submitted to Guyana Goldfields Inc. February 2012.

Itasca. 2012. Predicted Inflow Rate to Sublevel Retreat Mining at Aurora Mine. Technical memorandum submitted to SRK Consulting (Canada) Inc., by Itasca Denver, Inc. 24 October.





DETAIL A

0 500
SCALE (m)

N

EXPLANATION

| | |
|---|---|
| BH09-08 ● | BOREHOLE DRILLED IN 2009 |
| BH10-RK-RMU-06 ● | BOREHOLE DRILLED IN 2010 |
| BH11-24 ● | BOREHOLE DRILLED IN 2011 |
| BH12-WT-01A ○ | BOREHOLE DRILLED IN 2012 |
| TW-7 △ | MONITORING BOREHOLE |
| ■ | SHAFT HOLE |
| 🟨 | INDICATES BOREHOLE FOR PACKER TESTING |
| ▭ | INDICATES BOREHOLE FOR PUMP TESTING |

| | |
|---|---|
| ━ | MODEL BOUNDARY |
| ▨ | MAN-MADE DYKE |
| ∼ | SHEAR ZONE |

FOOTPRINT OF PLANNED MINES

| | |
|---|---|
| ━ | AURORA OPEN PITS |
| ━ | RORY'S KNOLL PIT |
| - - - - | UNDERGROUND MINE |

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Engineers and Scientists

| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | BASEMAP |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | -- |

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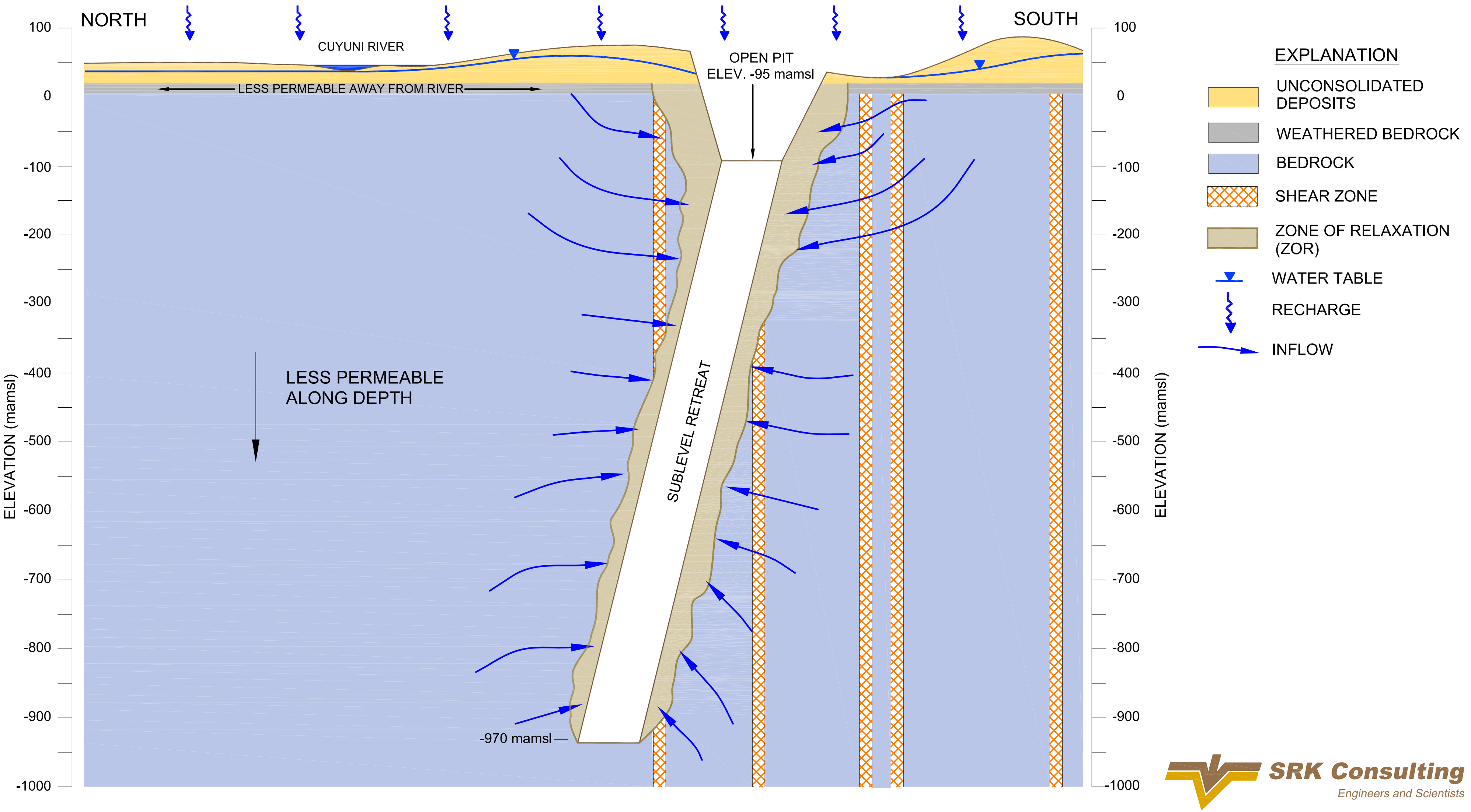
Base Map for Guyana Site

CLIENT:
SRK - Vancouver

FIGURE NO.
1



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Engineers and Scientists

0 400
SCALE (m)
2x VERTICAL EXAGGERATION

| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | CONCEPTUAL |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | -- |

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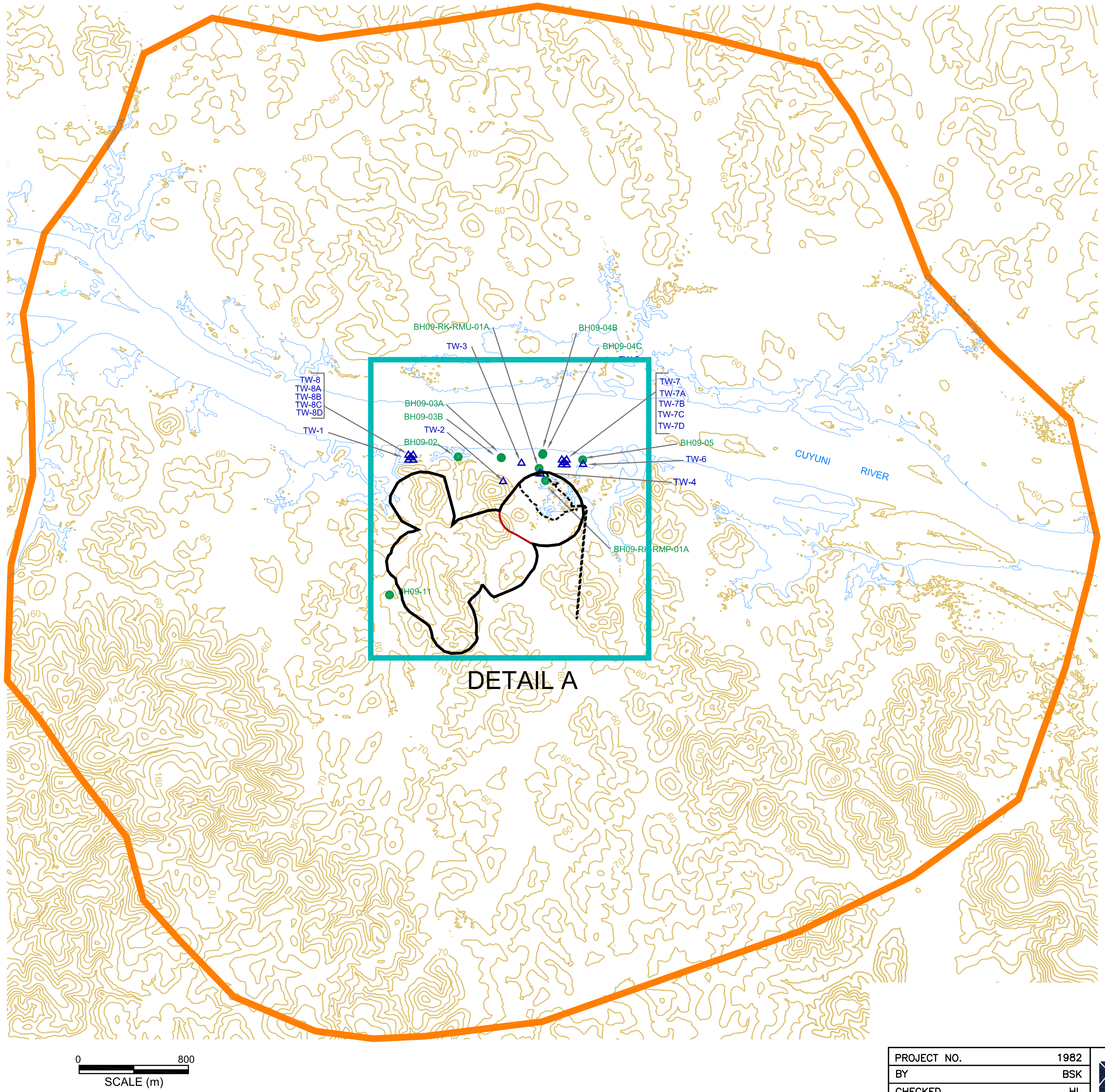
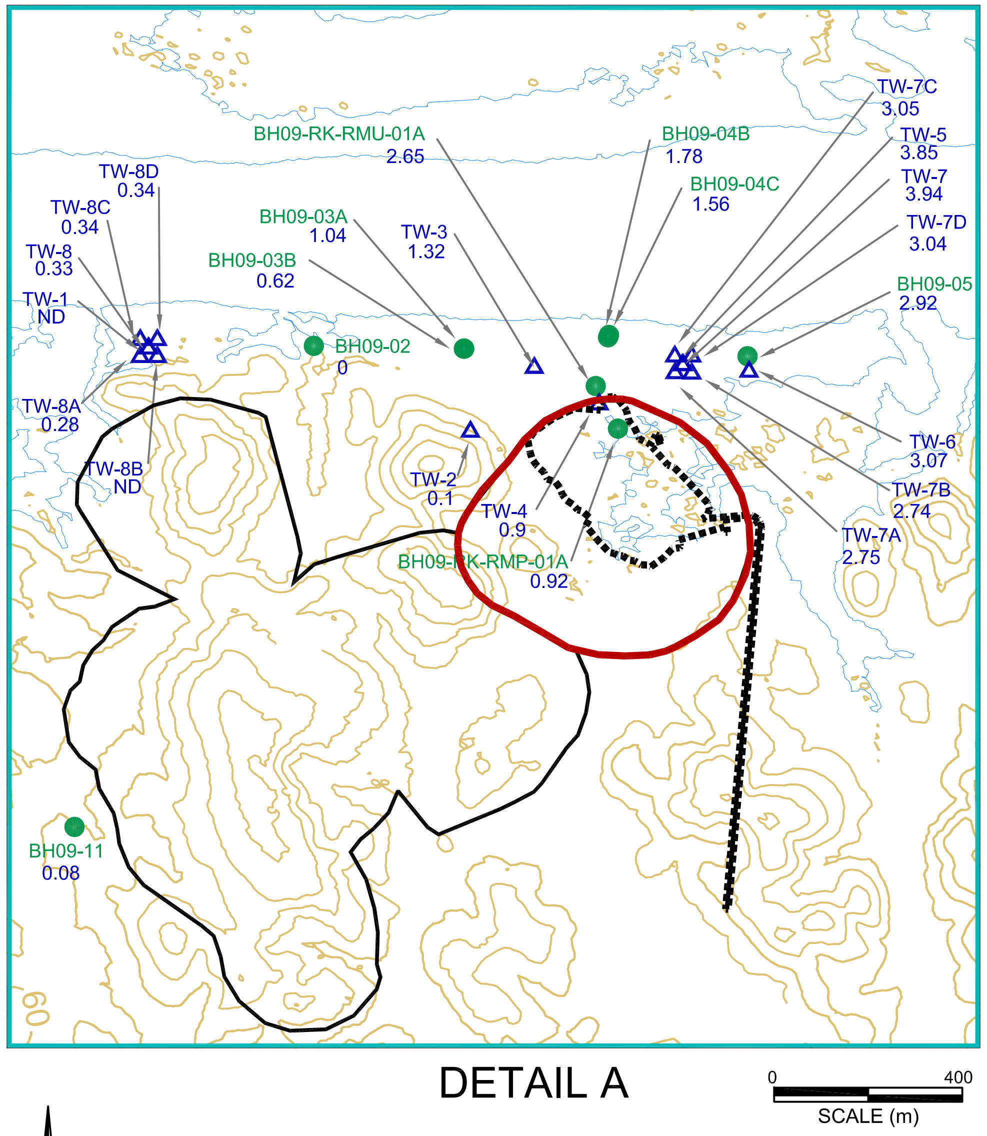
# Conceptual Hydrogeologic Model

CLIENT: SRK - Vancouver

FIGURE NO. 2





## EXPLANATION

| | |
|---|---|
| BH09-08 ● | BOREHOLE DRILLED IN 2009 |
| TW-4 △ | MONITORING BOREHOLE |
| 0.9<br>ND = NO DATA | MEASURED DRAWDOWN (m) |
| ▬ | MODEL BOUNDARY |

### FOOTPRINT OF PLANNED MINES

| | |
|---|---|
| ▬ | AURORA OPEN PITS |
| ▬ | RORY'S KNOLL PIT |
| - - - - | UNDERGROUND MINE |

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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | MEAS–DD |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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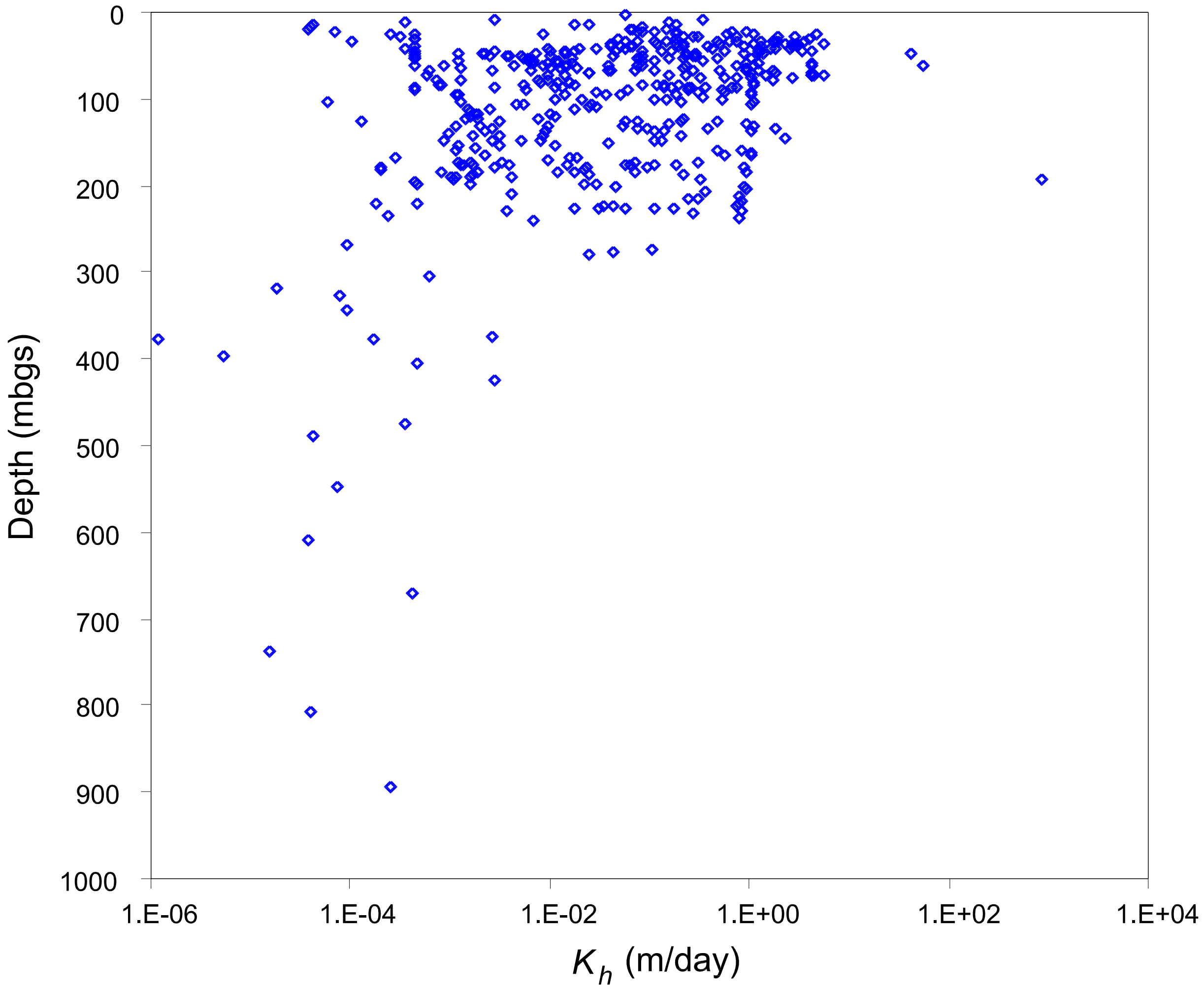
Measured Drawdown during
Pumping Test at TW-7

CLIENT:
SRK - Vancouver

FIGURE NO.
3



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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | MEASURED–K–DEPTH |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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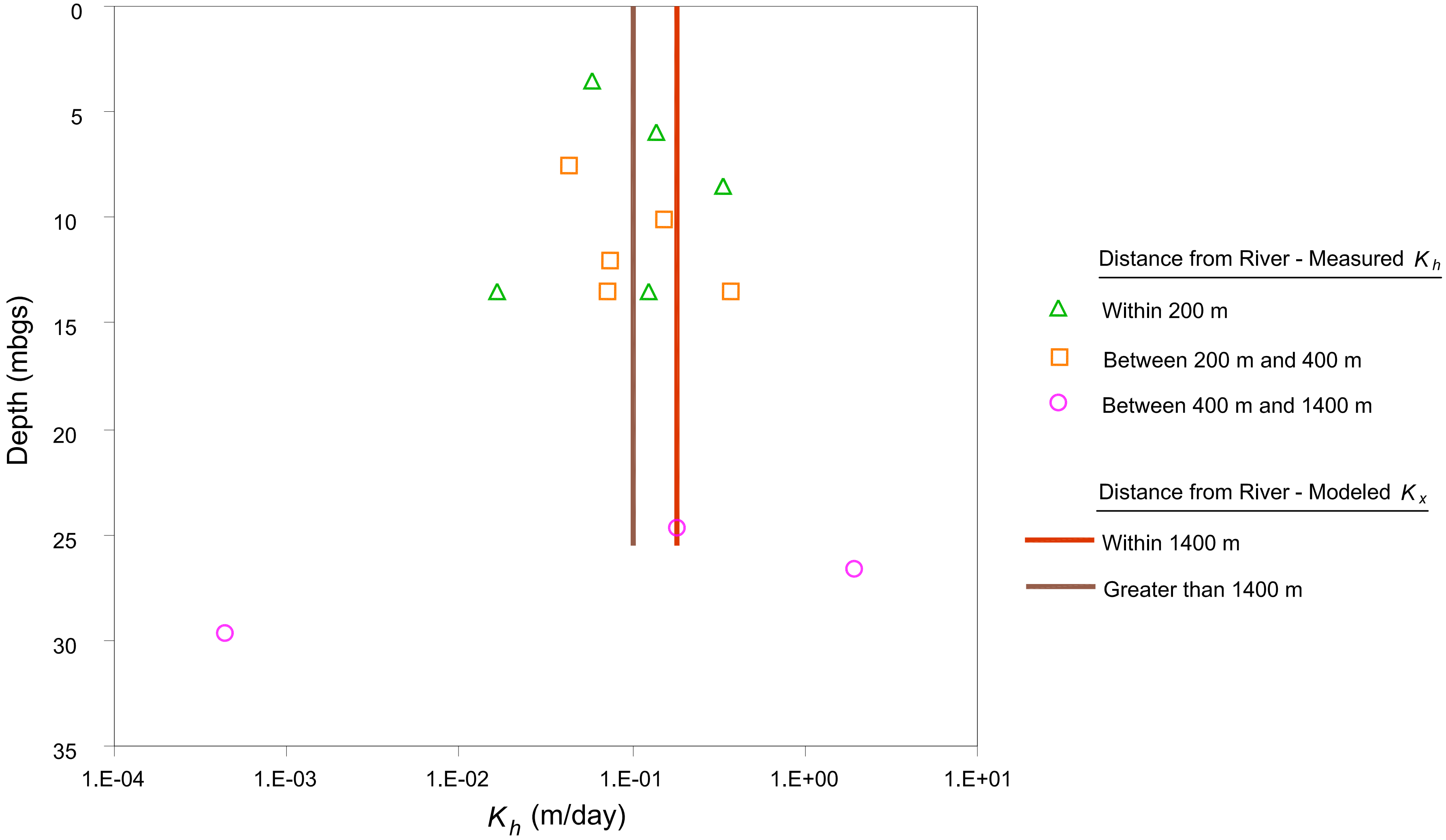
Measured $K_h$ vs. Depth
from 2008-2012 Field Programs

CLIENT: SRK - Vancouver

FIGURE NO. 4



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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | MEASURED–K–OVB |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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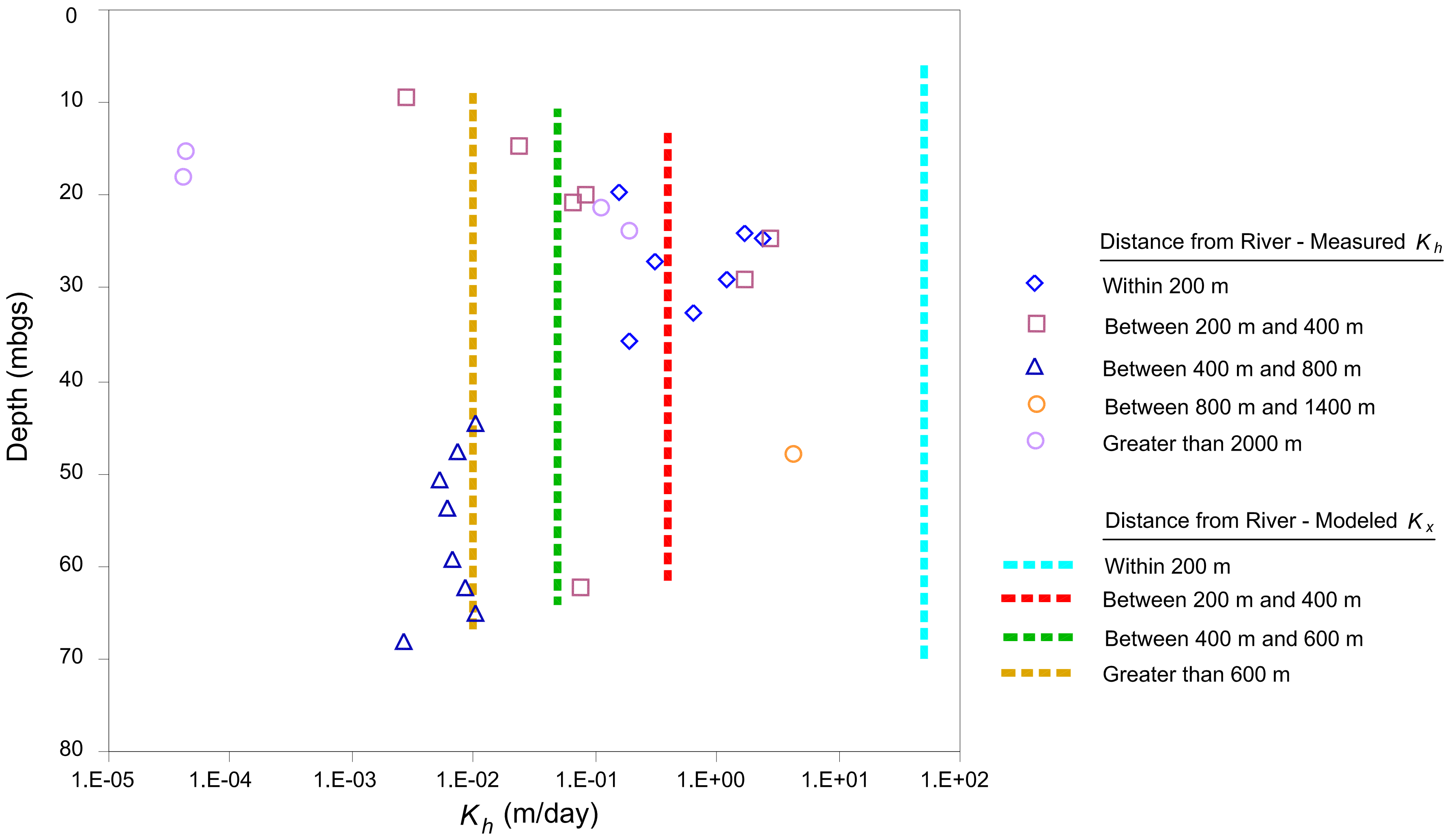
Measured $K_h$ and Modeled $K_x$
in Alluvium and Saprolite
Based on Distance from River

CLIENT: SRK - Vancouver

FIGURE NO. 5



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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | MEASURED-K-W-BDRK |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | -- |

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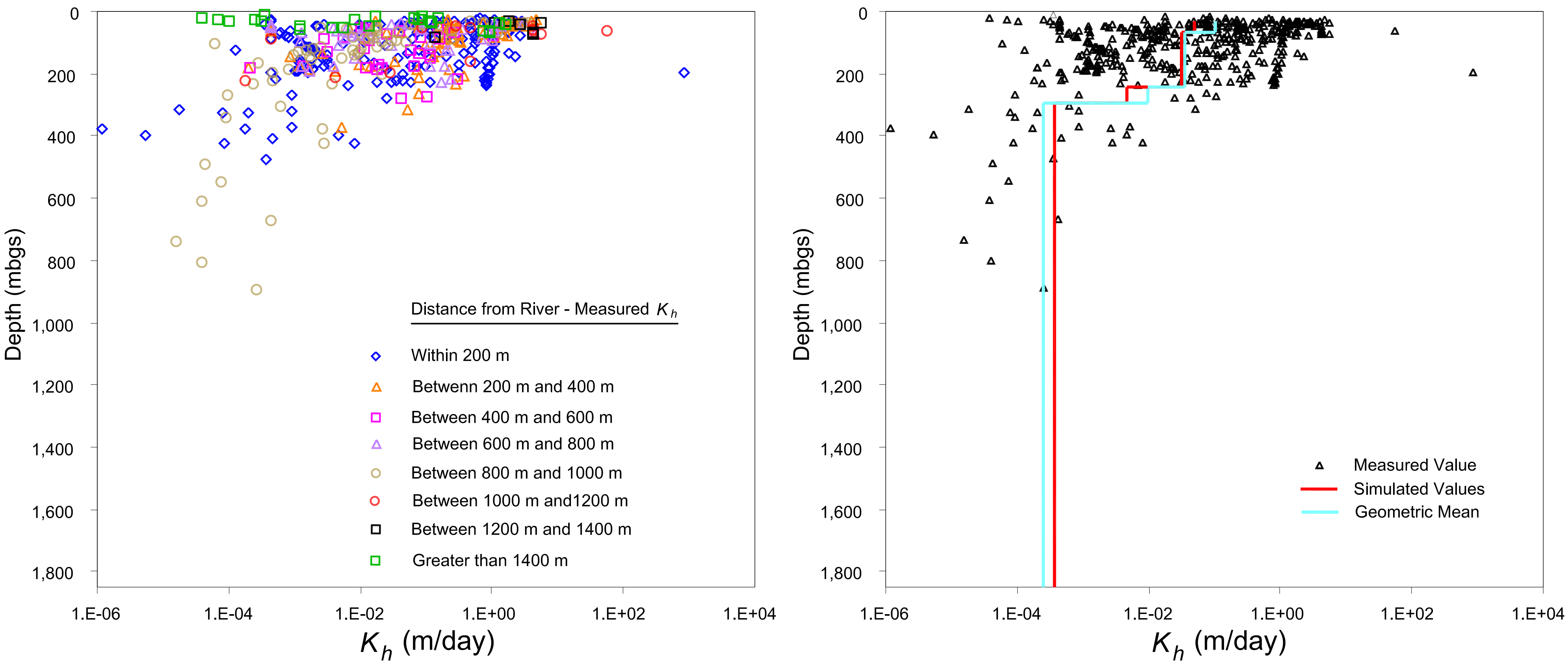
Measured $K_h$ and Modeled $K_x$
in Weathered Bedrock
Based on Distance from River

CLIENT: SRK - Vancouver

FIGURE NO. 6



a) Distance from River

b) Geometric Mean $K_h$ and Modeled $K_x$ vs. Depth

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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | MEASURED–K–BDRK |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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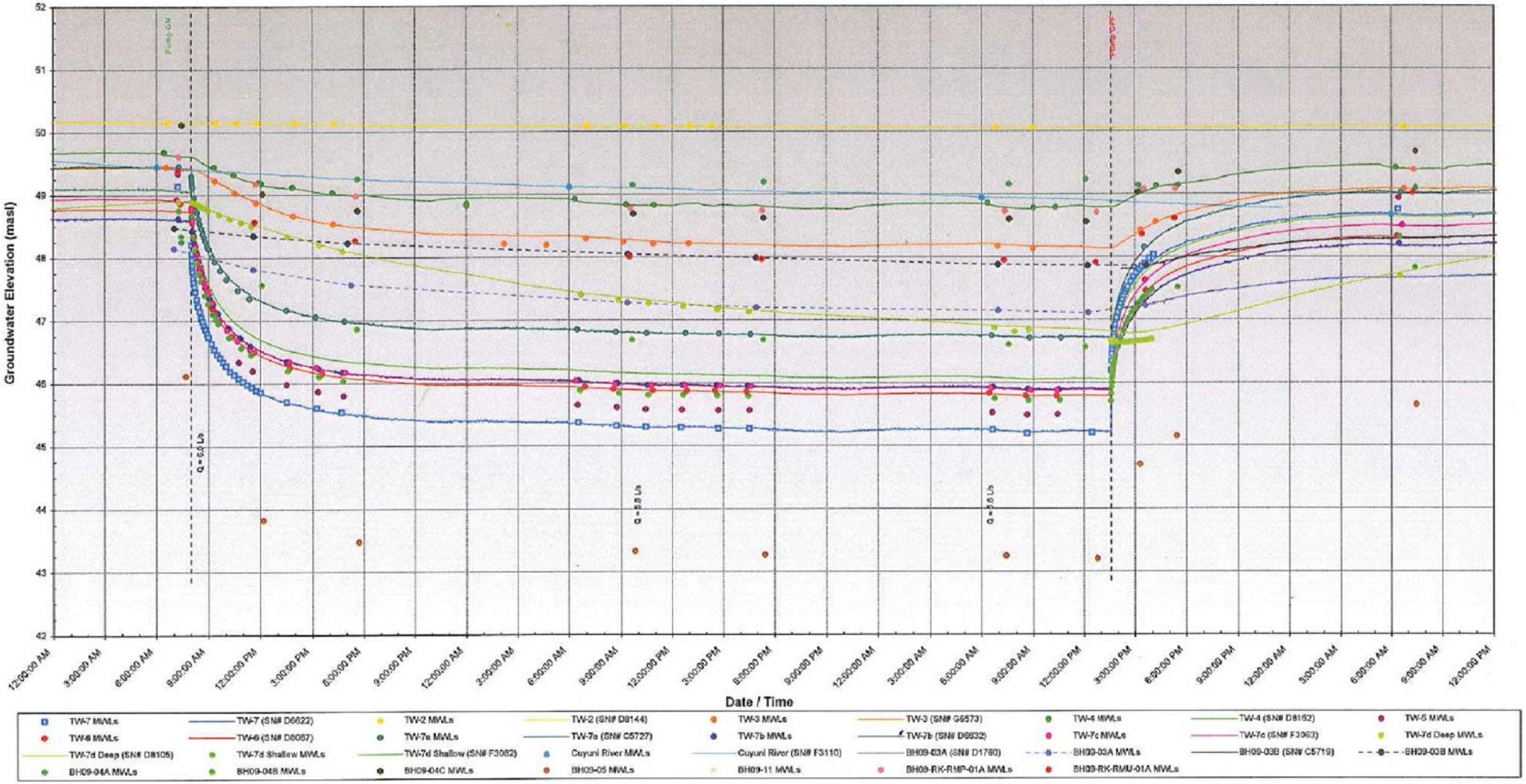
Measured $K_h$ and Modeled $K_x$
Values in Bedrock

CLIENT:
SRK - Vancouver

FIGURE NO.
7



SOURCE: AMEC, APRIL 2011

| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | OTHERS/BSK |
| CHECKED | HL |
| DRAWN | OTHERS/SAC |
| DRAWING NAME | MEAS–DD–AMEC |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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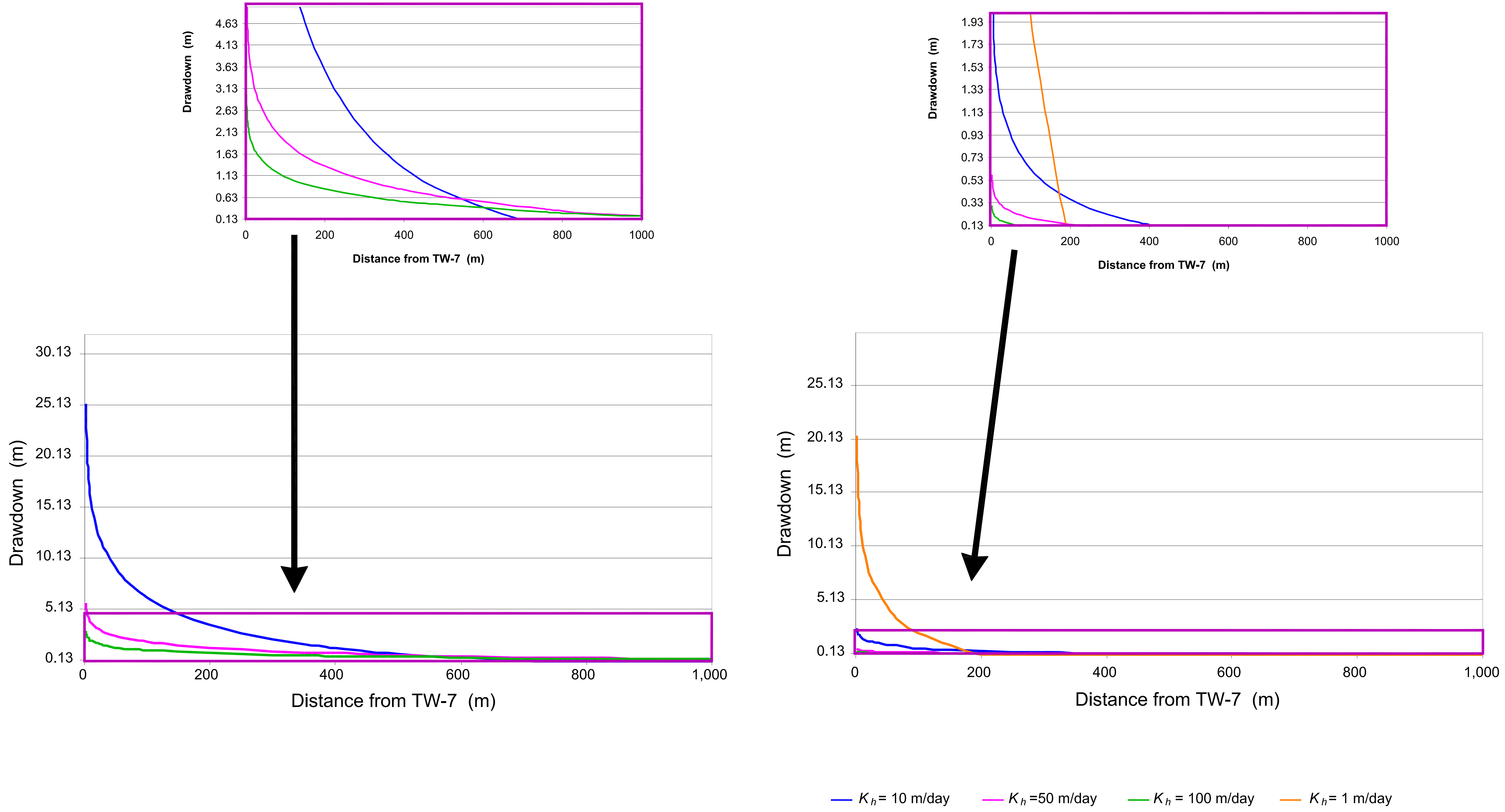
# Measured Groundwater Levels Over Time During Pumping Test

CLIENT:
SRK - Vancouver

FIGURE NO.
8

a) Assuming 2 m Thick Permeable Zone

b) Assuming 20 m Thick Permeable Zone



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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | HL |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | CALC–THEIS |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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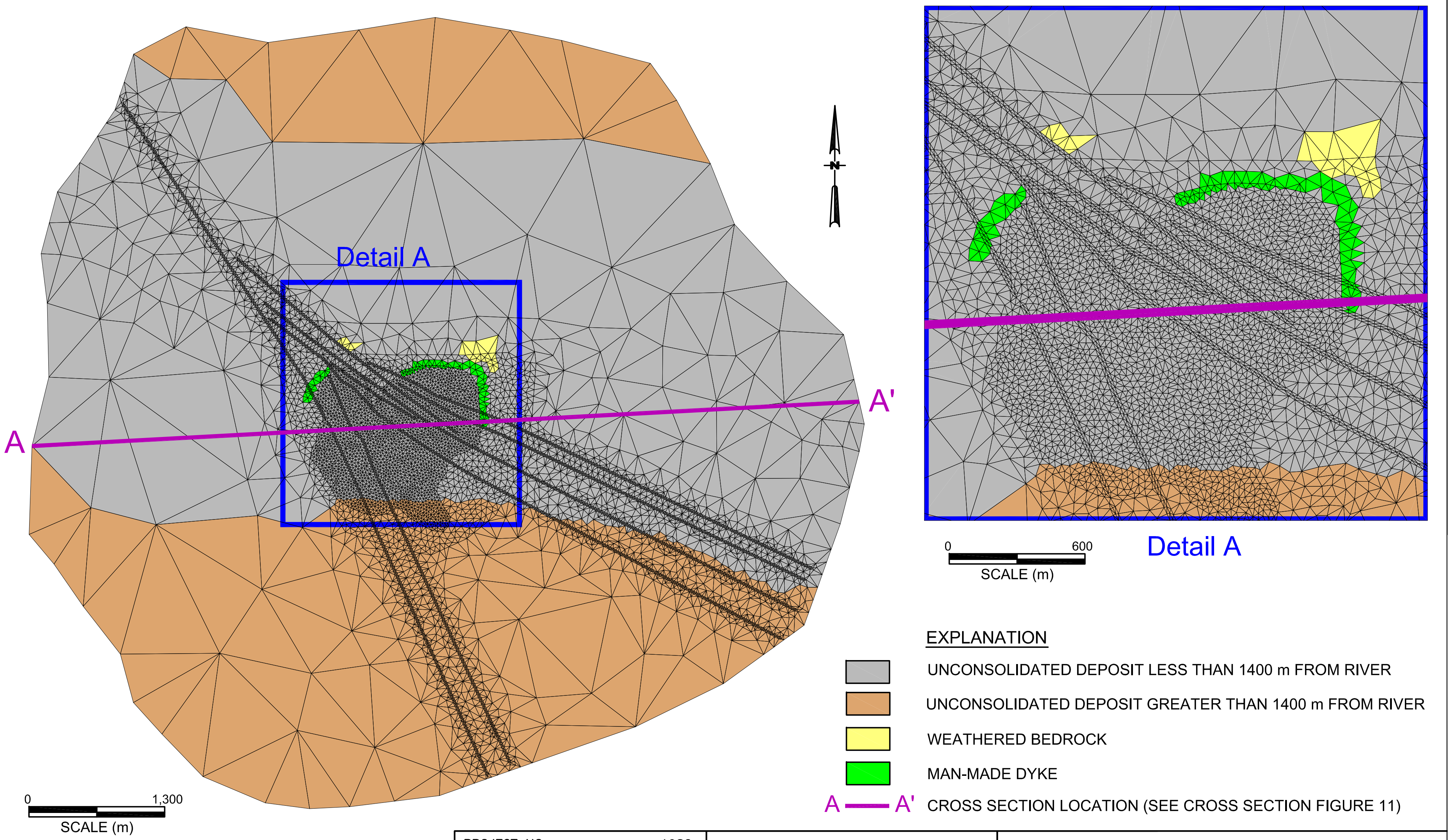
Calculated Drawdown at End of
Pumping Test for
Different Thicknesses of Assumed
Permeable Zones and $K_h$ Values

CLIENT:
SRK - Vancouver

FIGURE NO.
9



EXPLANATION

| | |
|---|---|
| ⬜ | UNCONSOLIDATED DEPOSIT LESS THAN 1400 m FROM RIVER |
| 🟧 | UNCONSOLIDATED DEPOSIT GREATER THAN 1400 m FROM RIVER |
| 🟨 | WEATHERED BEDROCK |
| 🟩 | MAN-MADE DYKE |
| A ― A' | CROSS SECTION LOCATION (SEE CROSS SECTION FIGURE 11) |

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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | HZ–UNCON–DEP |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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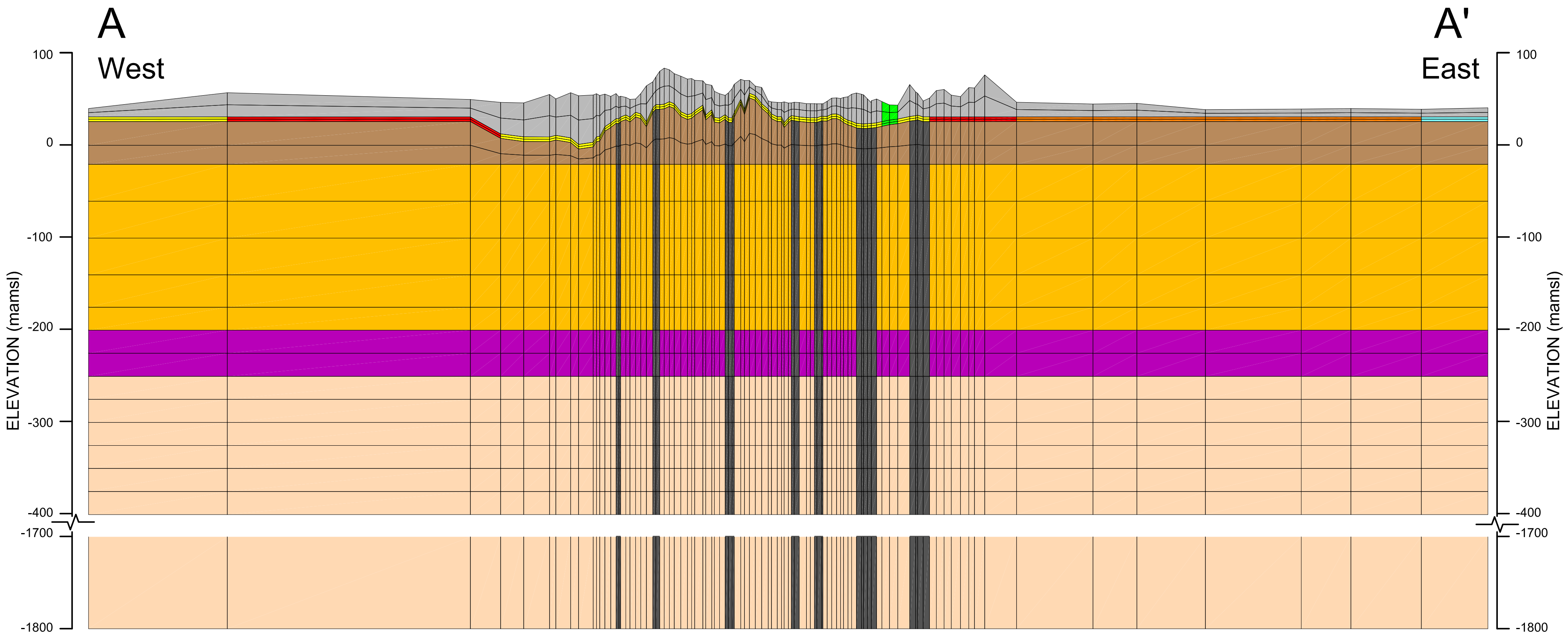
# Plan View of Simulated Hydrogeologic Zone of Unconsolidated Deposit

CLIENT: SRK - Vancouver

FIGURE NO. 10



EXPLANATION

▒ UNCONSOLIDATED DEPOSIT

🟥 HIGHLY PERMEABLE

🟨 MODERATELY PERMEABLE

🟧 LESS PERMEABLE

🟦 LEAST PERMEABLE

} WEATHERED BEDROCK

🟫 UPPER BEDROCK

🟧 MIDDLE BEDROCK

🟪 LOWER BEDROCK

⬜ DEEP BEDROCK

🟩 MAN-MADE DYKE

⬛ SHEAR ZONE

0 800

SCALE (m)

5x VERTICAL EXAGGERATION

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NOTE: CROSS SECTION LOCATION ON FIGURE 10

| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | XSEC–A–A |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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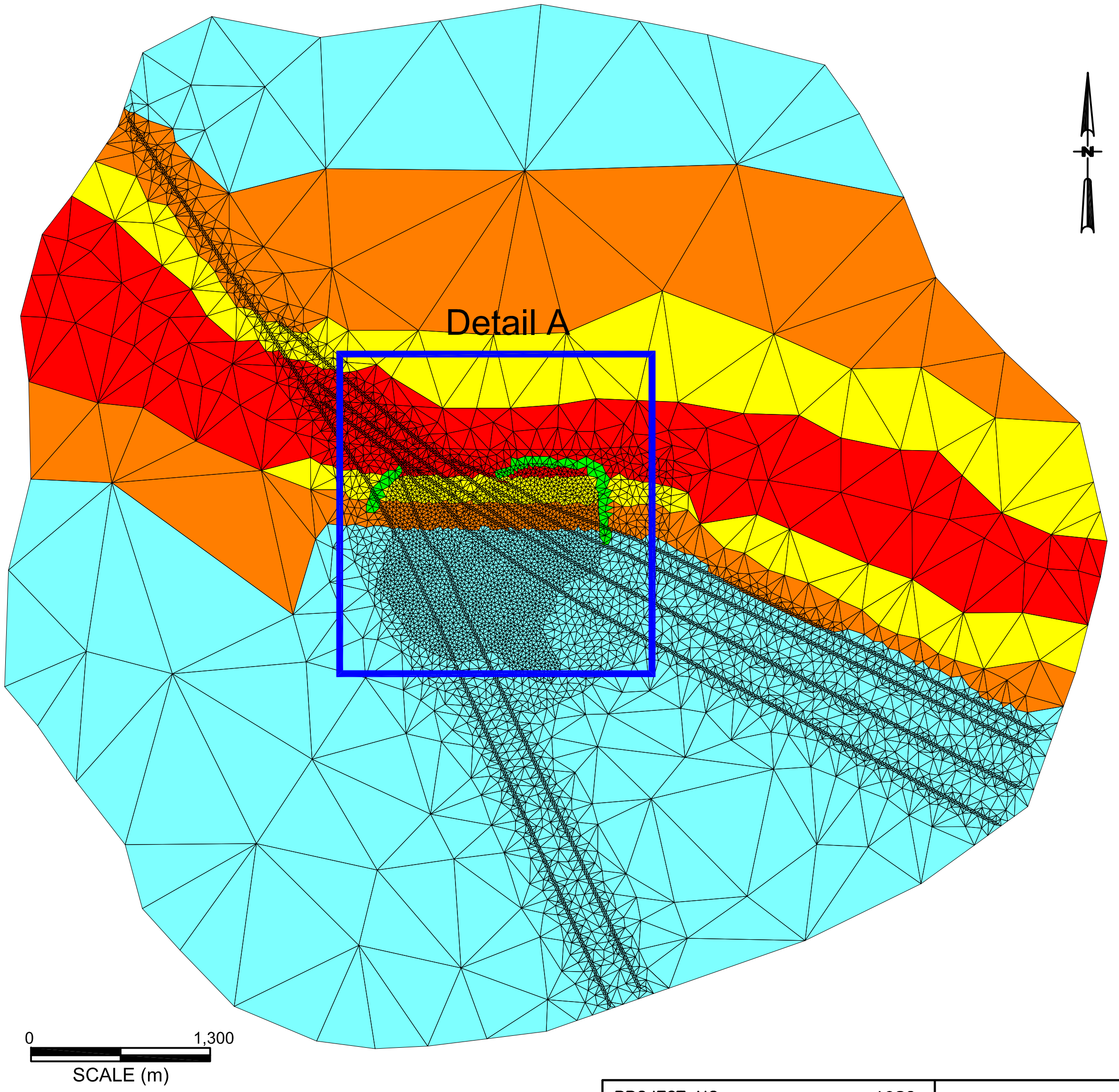
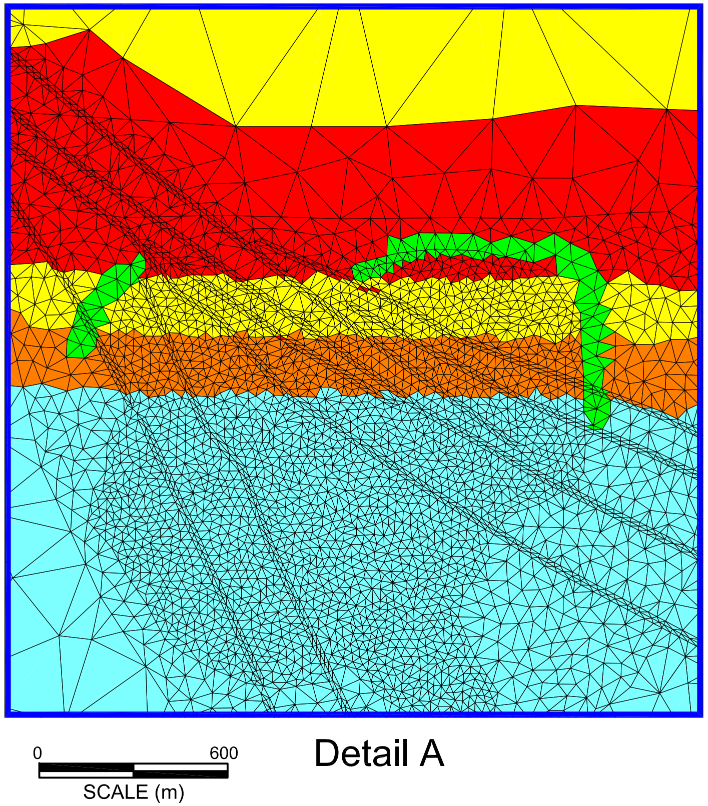
## Cross Section A-A' Showing Vertical Discretization of Model and Simulated Hydrogeologic Units

CLIENT: SRK - Vancouver

FIGURE NO. 11





Detail A

EXPLANATION

🟩 MAN-MADE DYKE

DISTANCE FROM RIVER

🟥 WITHIN 200 m

🟨 BETWEEN 200 m AND 400 m

🟧 BETWEEN 400 m AND 600 m

🟦 GREATER THAN 600 m

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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | W-BDRK-LAYER |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | -- |

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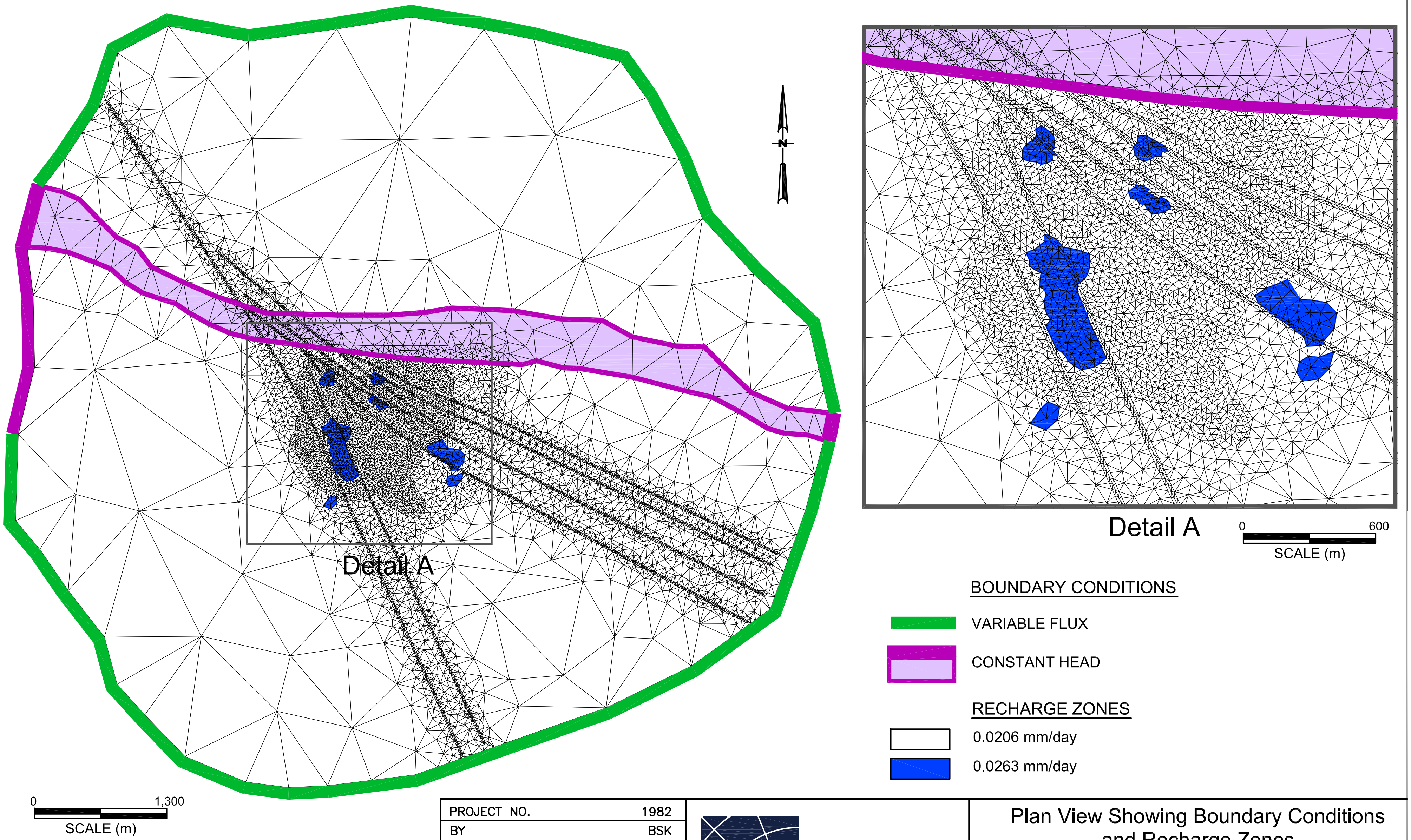
Plan View of Simulated
Hydrogeologic Zone of
Weathered Bedrock

CLIENT:
SRK - Vancouver

FIGURE NO.
12



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| PROJECT NO. | 1982 |
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| DRAWN | SAC |
| DRAWING NAME | MESH–BOUNDCOND |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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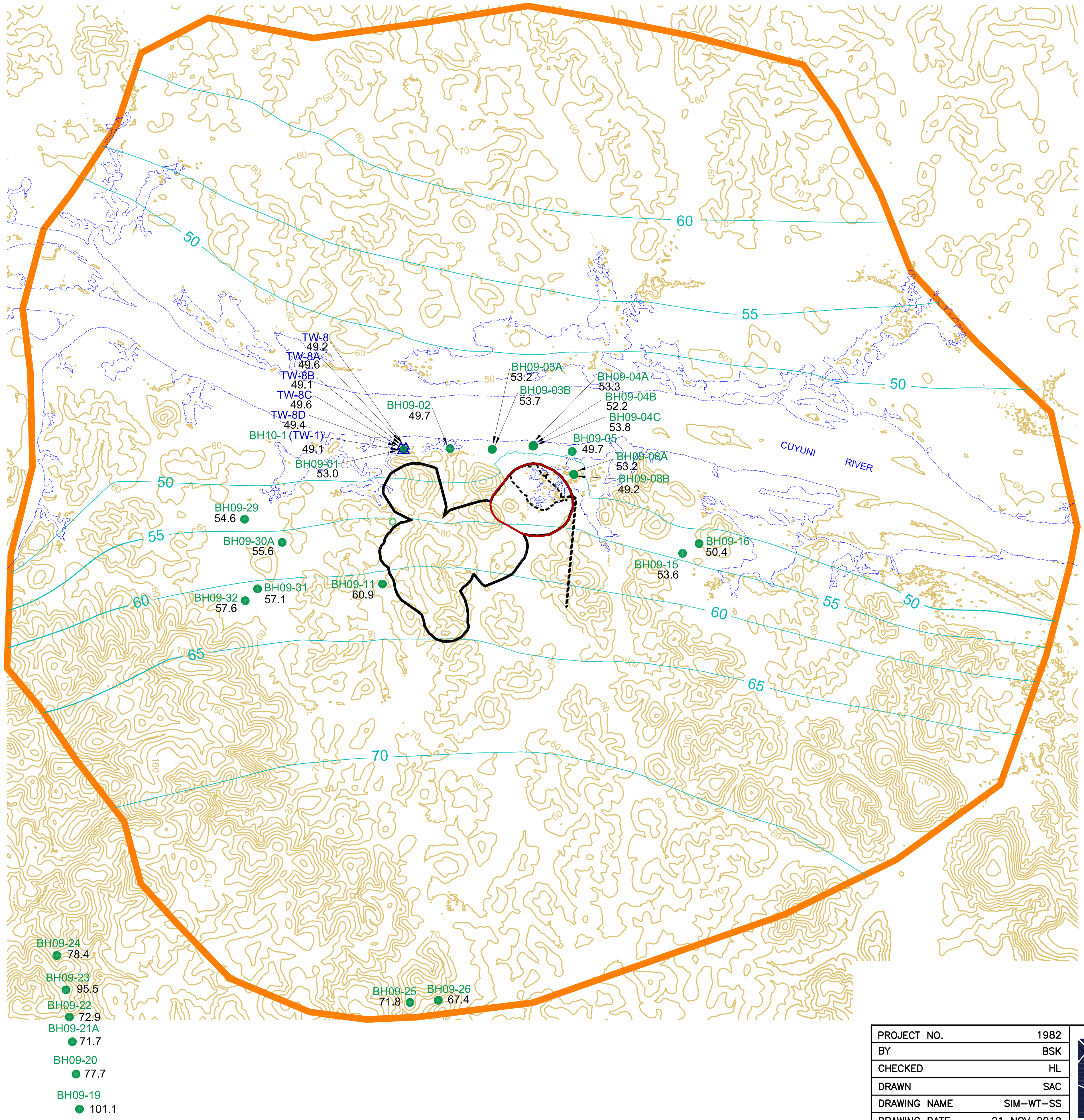
## Plan View Showing Boundary Conditions and Recharge Zones

CLIENT: SRK - Vancouver

FIGURE NO. 13



## EXPLANATION

| | |
|---|---|
| BH09-11 ● | BOREHOLE DRILLED IN 2009 |
| TW-8 △ | MONITORING BOREHOLE |
| 60.9 | WATER LEVEL (mamsl) |
| —50— | SIMULATED WATER TABLE CONTOUR (mamsl) |
| ▬ | MODEL BOUNDARY |

## FOOTPRINT OF PLANNED MINES

| | |
|---|---|
| — | AURORA OPEN PITS |
| — | RORY'S KNOLL PIT |
| ------- | UNDERGROUND MINE |

N

0 800
SCALE (m)

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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | SIM-WT-SS |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | -- |

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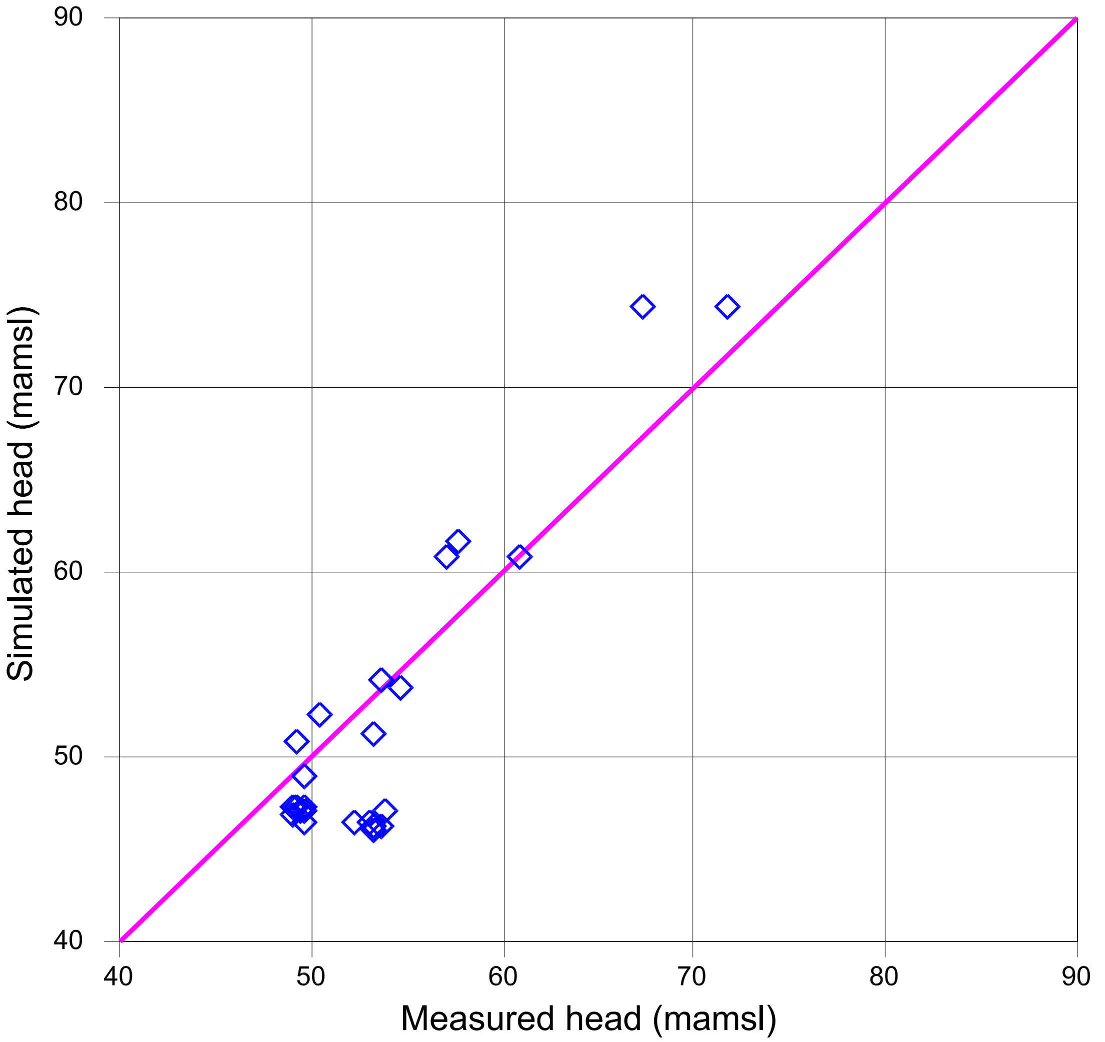
Simulated Water Table under
Steady-State Conditions

CLIENT:
SRK - Vancouver

FIGURE NO.
14



| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | QUAL–LINE |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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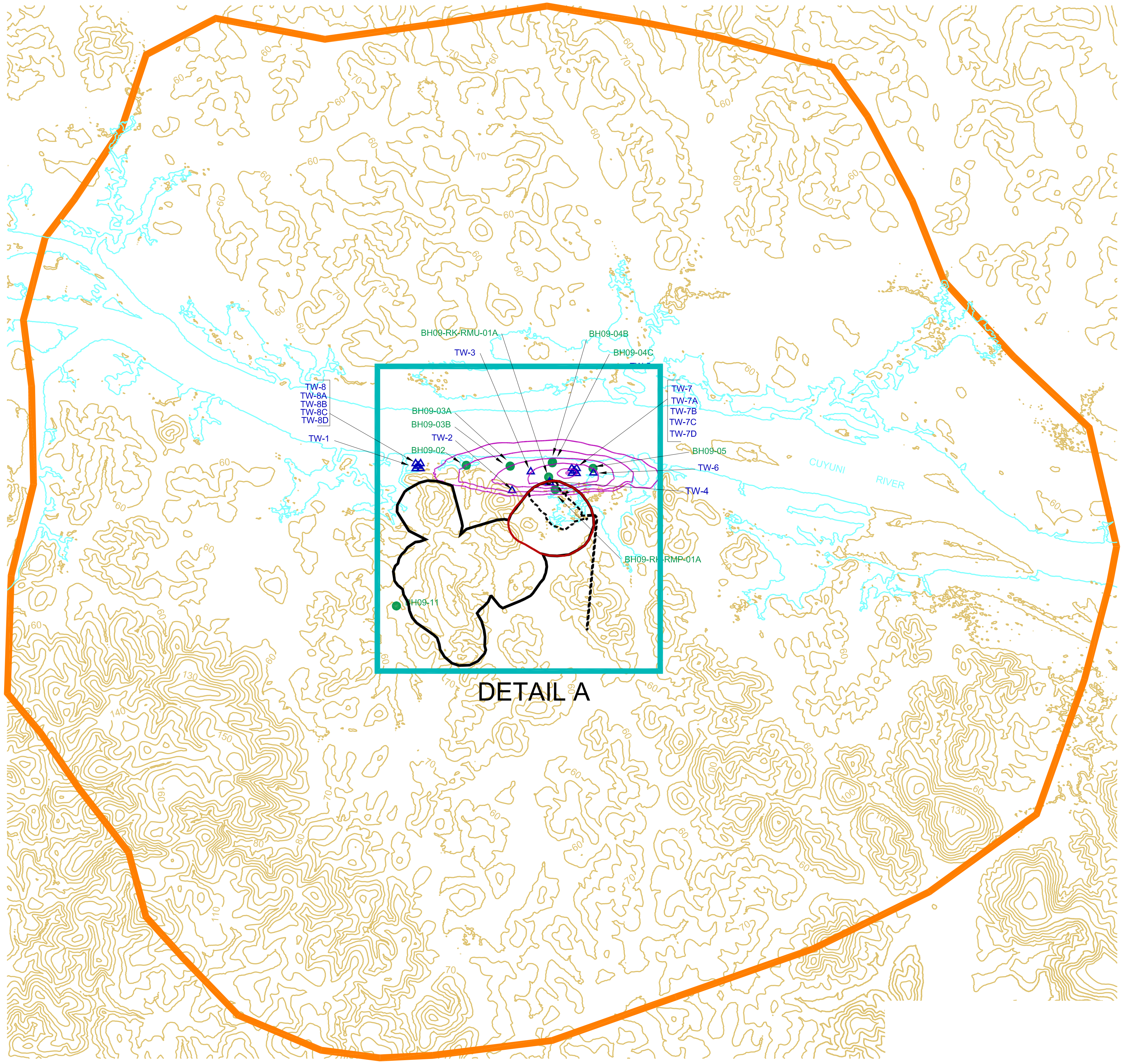
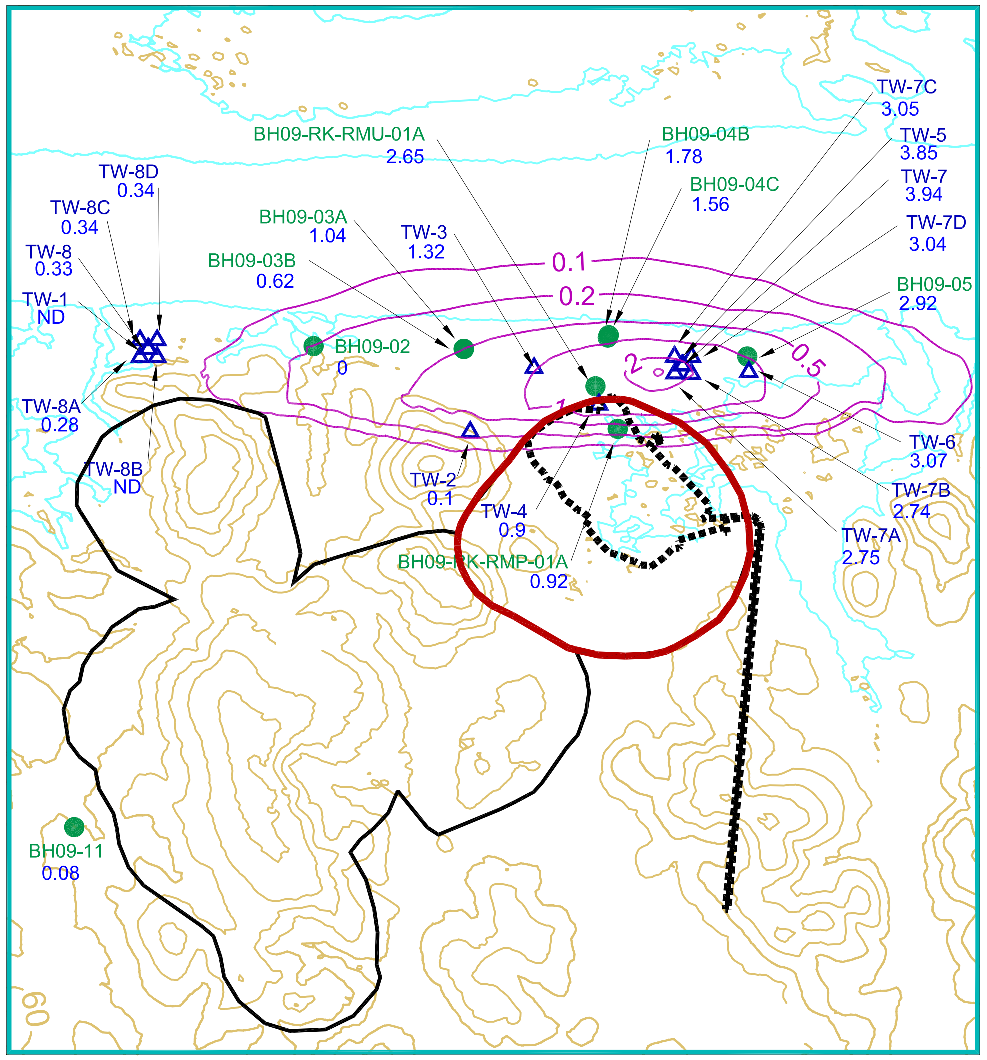
Quality Line for
Steady-State Conditions

CLIENT:
SRK - Vancouver

FIGURE NO.
15



0 800
SCALE (m)



## DETAIL A

N

0 400
SCALE (m)

### EXPLANATION

| | |
|---|---|
| BH09-08 ● | BOREHOLE DRILLED IN 2009 |
| TW-4 △ | MONITORING BOREHOLE |
| 0.9<br>ND | MEASURED DRAWDOWN<br>NO DATA |
| ▬ | MODEL BOUNDARY |
| — 2 — | SIMULATED DRAWDOWN CONTOUR (m) IN WEATHERED BEDROCK MODEL LAYER |

### FOOTPRINT OF PLANNED MINES

| | |
|---|---|
| — | AURORA OPEN PITS |
| — | RORY'S KNOLL PIT |
| ------ | UNDERGROUND MINE |

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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | SIM–VS–MEAS–DD |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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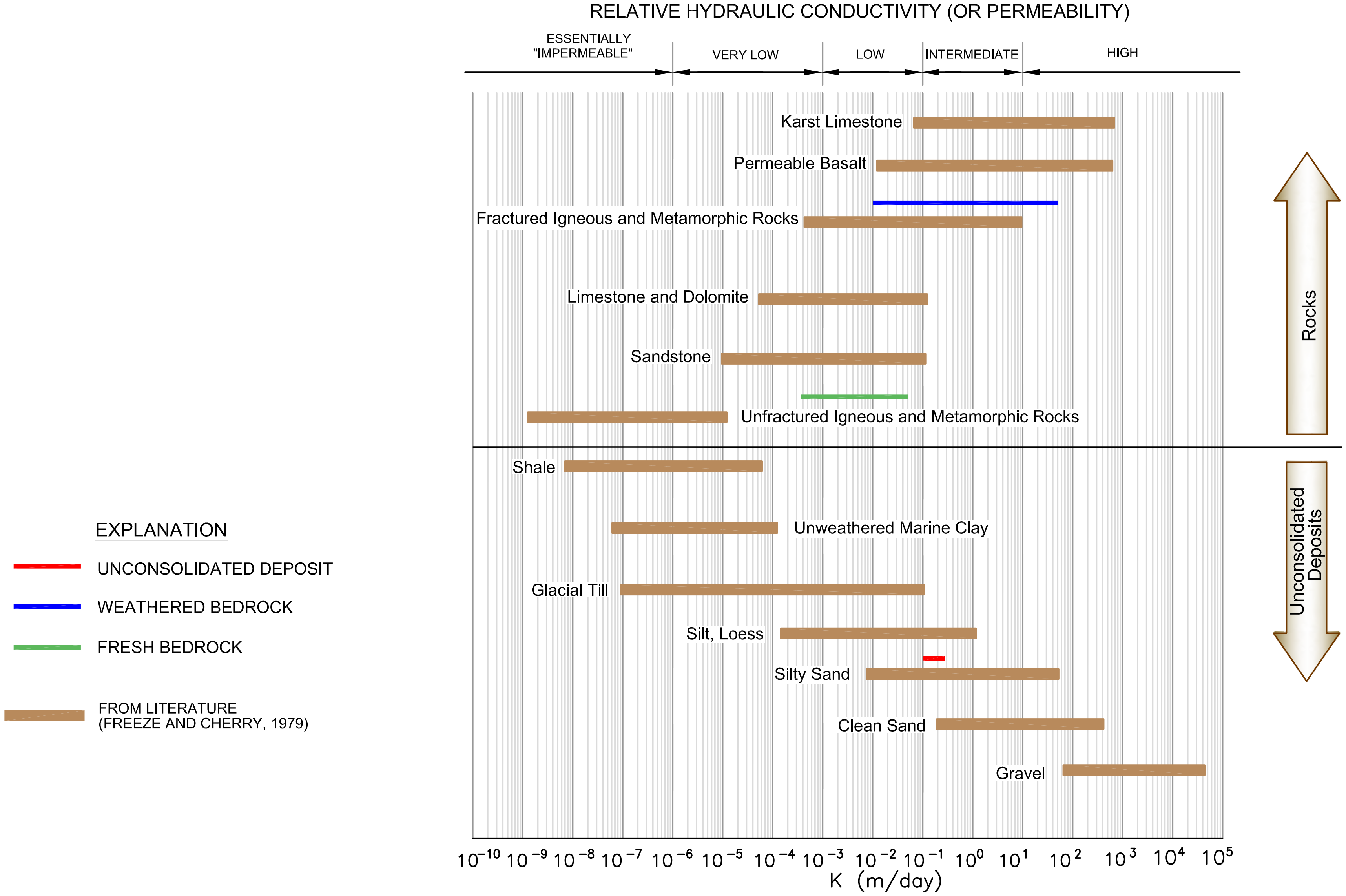
Measured and Simulated Drawdown
during Pumping Test at TW-7

CLIENT:
SRK - Vancouver

FIGURE NO.
16



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|  |  |
|---|---|
| PROJECT NO. | 1982 |
| BY | HL |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | K–VALUES |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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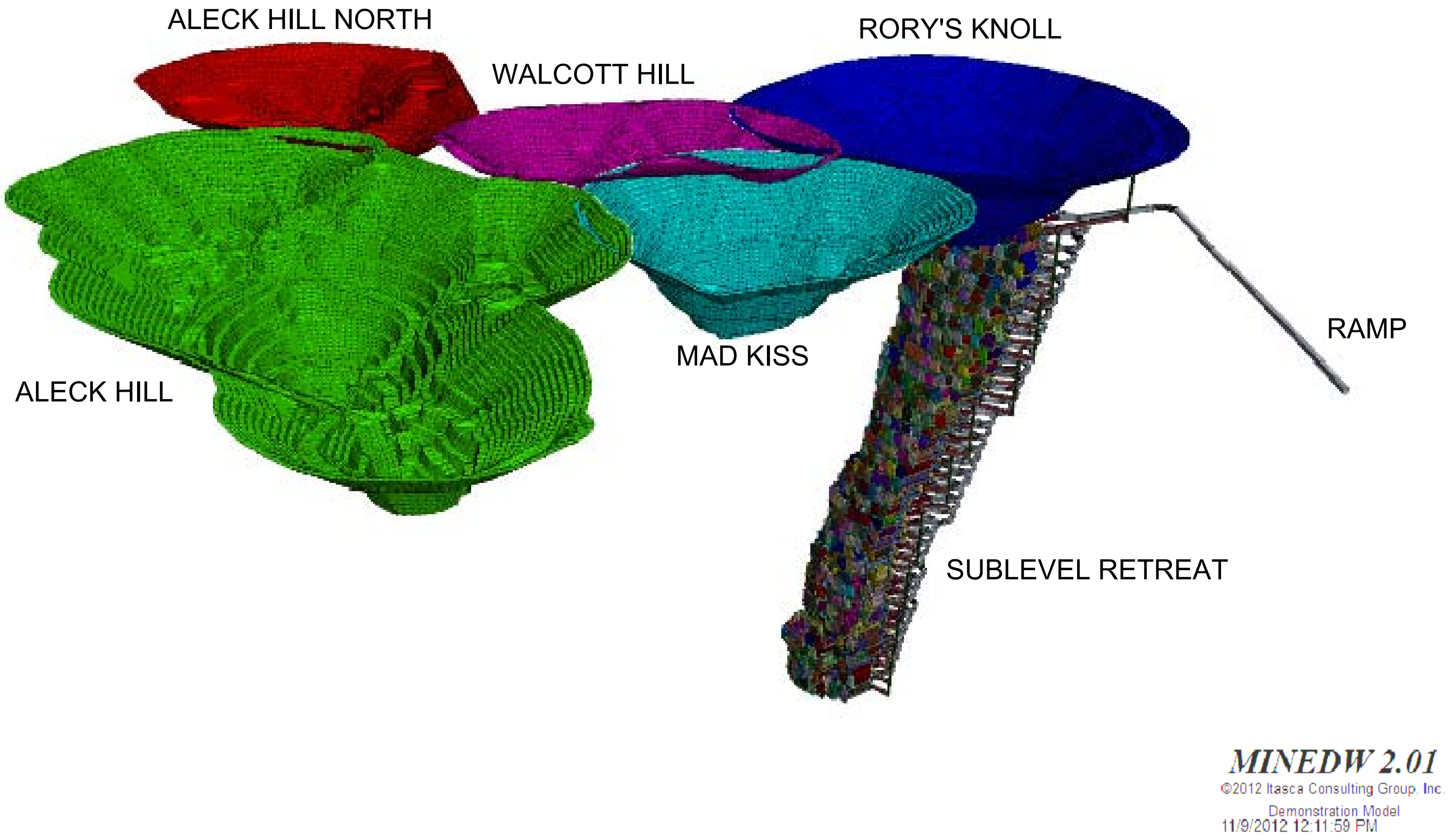
## Values of Hydraulic Conductivity Used in Groundwater Model

CLIENT: SRK - Vancouver

FIGURE NO. 17



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|  |  |
|---|---|
| PROJECT NO. | 1982 |
| BY | JX |
| CHECKED | HL |
| DRAWN | JX/SAC |
| DRAWING NAME | MINEDW–DIAGRAM |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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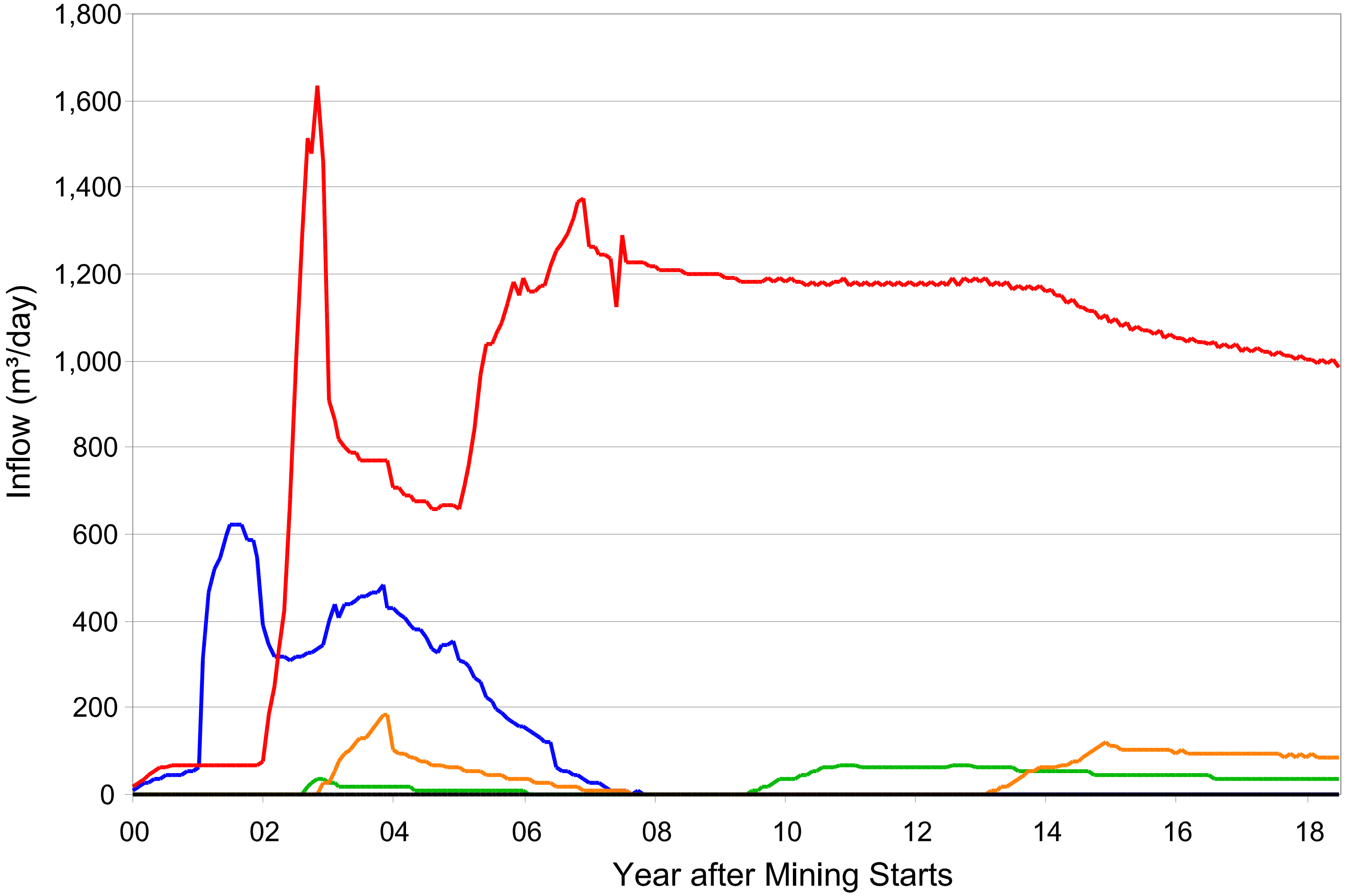
Simulated Open Pits and
Underground Mine Workings

CLIENT: SRK - Vancouver

FIGURE NO. 18



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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | SIM–INFLOW–RATES |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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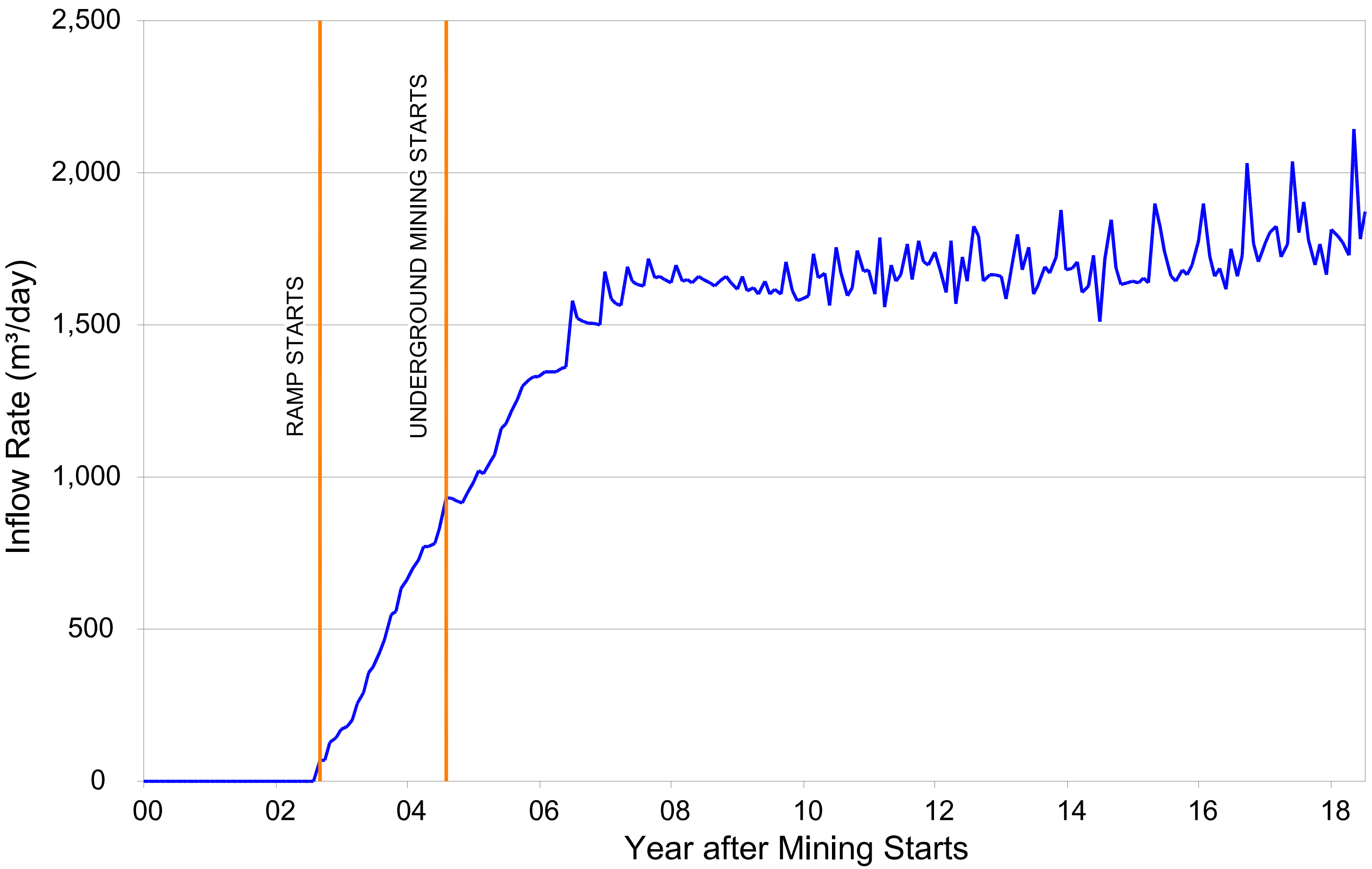
Scenario 1:
Simulated Inflow Rates to
Various Open Pits

CLIENT:
SRK - Vancouver

FIGURE NO.
19



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|  |  |
|---|---|
| PROJECT NO. | 1982 |
| BY | BSK |
| CHECKED | HL |
| DRAWN | SAC |
| DRAWING NAME | SIM–INFLOW–SLR |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | –– |

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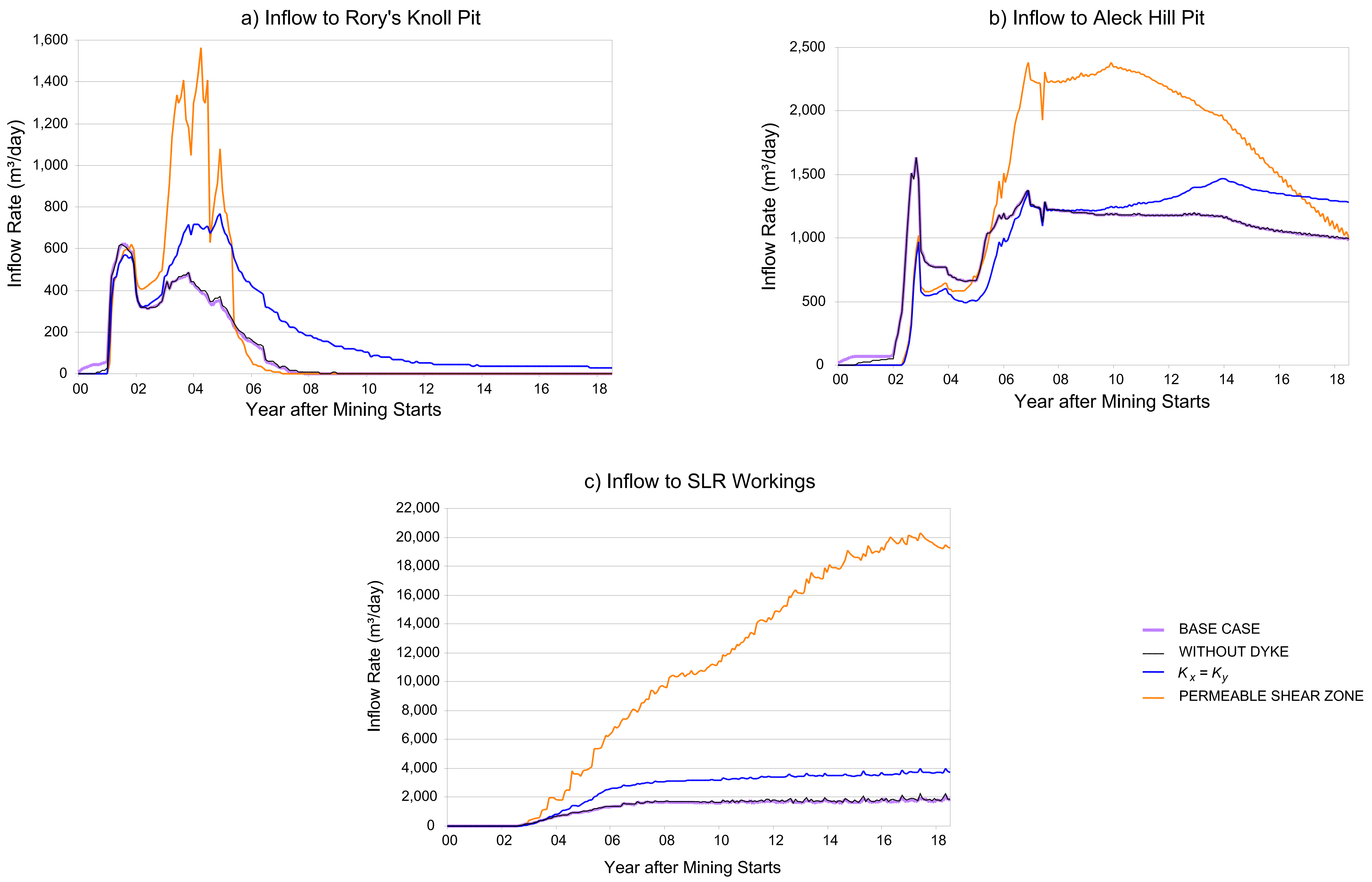
Scenario 1:
Simulated Inflow Rates to
SLR Workings

CLIENT: SRK - Vancouver

FIGURE NO. 20



a) Inflow to Rory's Knoll Pit

b) Inflow to Aleck Hill Pit

c) Inflow to SLR Workings

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| | |
|---|---|
| PROJECT NO. | 1982 |
| BY | HL |
| CHECKED | -- |
| DRAWN | SAC |
| DRAWING NAME | SENSITIVITY |
| DRAWING DATE | 21 NOV 2012 |
| REVISION DATE | -- |

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Sensitivity Analysis

CLIENT:
SRK - Vancouver

FIGURE NO.
21

## TABLE 1

## Water Levels Used for Steady-State Calibration

| Borehole ID | Easting (m) | Northing (m) | Ground Elevation (mamsl) | Bottom of Screen (mamsl) | Top of Screen (mamsl) | Screen Interval (m) | Water Level (mamsl) | Instrument Type | Geologic Unit |
|---|---|---|---|---|---|---|---|---|---|
| BH09-01 | 195742.5 | 751901.3 | 55.3 | 47.0 | | | 53.0 | VW | Ash Tuff and Tuff |
| BH09-02 | 196089.9 | 751909.4 | 54.9 | 45.7 | | | 49.7 | VW | Tuff/volvanic sediments |
| BH09-03A | 196408.8 | 751903.4 | 56.0 | 31.9 | 33.4 | 1.5 | 53.2 | Stand pipe | Saprolite w/rock |
| BH09-03B | 196407.4 | 751903.2 | 55.9 | 46.8 | 48.3 | 1.5 | 53.7 | Stand pipe | Alluvial w/Saprolite |
| BH09-04A | 196717.0 | 751929.1 | 56.5 | 52.3 | 53.8 | 1.5 | 53.3 | Stand pipe | Alluvial |
| BH09-04B | 196713.1 | 751932.0 | 56.4 | 38.1 | 44.2 | 6.1 | 52.2 | Stand pipe | Saprolite Weathered Bedrock |
| BH09-04C | 196714.2 | 751928.3 | 56.6 | 49.0 | | | 53.8 | VW | NA(1) |
| BH09-05 | 197006.0 | 751887.7 | 56.8 | 29.5 | | | 49.7 | VW | Volcanic sediments |
| BH09-08A | 197019.3 | 751714.3 | 53.5 | 42.7 | 44.2 | 1.5 | 53.2 | Stand pipe | Saprolite |
| BH09-08B | 197016.9 | 751716.0 | 53.4 | | | | 49.2 | VW | Fresh Bedrock |
| BH09-11 | 195583.5 | 750892.2 | 63.4 | -13.4 | | | 60.9 | VW | Fresh Bedrock |
| BH09-15 | 197834.0 | 751122.0 | 55.5 | 37.2 | 40.3 | 3.1 | 53.6 | Stand pipe | Saprolite |
| BH09-16 | 197958.9 | 751195.3 | 56.9 | 34.3 | 37.4 | 3.1 | 50.4 | Stand pipe | Saprolite |
| BH09-19 | 193313.4 | 746959.1 | 101.6 | 76.9 | 80.0 | 3.1 | 101.1 | Stand pipe | Weathered Bedrock |
| BH09-20 | 193284.5 | 747214.8 | 92.7 | 62.7 | | | 77.7 | VW | Fresh Bedrock |
| BH09-21A | 193259.2 | 747457.5 | 81.5 | 60.4 | 63.4 | 3.0 | 71.7 | Stand pipe | Saprolite |
| BH09-22 | 193234.3 | 747643.6 | 75.1 | 70.1 | 73.1 | 3.0 | 72.9 | Stand pipe | Saprolite w/rock |
| BH09-23 | 193209.4 | 747846.3 | 118.2 | 94.4 | 97.5 | 3.1 | 95.5 | Stand pipe | NA(1) |
| BH09-24 | 193135.8 | 748110.9 | 87.5 | 62.7 | | | 78.4 | VW | Fresh Bedrock |
| BH09-25 | 195794.7 | 747754.8 | 86.6 | 69.6 | 72.6 | 3.0 | 71.8 | Stand pipe | Saprolite w/rock |
| BH09-26 | 196004.3 | 747768.7 | 68.4 | 59.4 | 62.4 | 3.1 | 67.4 | Stand pipe | Saprolite |
| BH09-29 | 194548.0 | 751378.1 | 62.3 | 53.2 | 54.7 | 1.5 | 54.6 | Stand pipe | Saprolite |
| BH09-30A | 194630.3 | 751205.3 | 61.0 | 46.1 | | | 55.6 | VW | NA(1) |
| BH09-31 | 194646.7 | 750856.0 | 57.6 | 51.8 | 53.3 | 1.5 | 57.1 | Stand pipe | Saprolite |
| BH09-32 | 194553.0 | 750767.3 | 58.2 | 43.4 | | | 57.6 | VW | Saprolite |
| BH10-1 (TW 1) | 195740.1 | 751906.0 | 50.4 | -149.6 | 38.4 | 188.0 | 49.1 | Open Hole | Meta-volcanics |
| TW-8 | 195738.3 | 751904.3 | 50.4 | -171.6 | 35.4 | 206.0 | 49.2 | | Fresh Bedrock |
| TW-8a | 195722.4 | 751886.3 | 50.4 | -200.6 | 35.4 | 236.0 | 49.6 | | Fresh Bedrock |
| TW-8b | 195758.6 | 751886.4 | 49.7 | -202.3 | 37.7 | 240.0 | 49.1 | | Fresh Bedrock |
| TW-8c | 195722.3 | 751922.3 | 50.7 | -197.3 | 35.7 | 233.0 | 49.6 | | Fresh Bedrock |
| TW-8d | 195758.4 | 751922.4 | 50.6 | -201.4 | 35.6 | 237.0 | 49.4 | | Fresh Bedrock |

Note: 1) Geologic unit is not available.

## TABLE 2

### Summary of Maximum Drawdown After 53.5-hour Pumping Test

| Borehole ID | Easting (m) | Northing (m) | Distance from Pumping Well (m) | Measured Drawdown (m) | Top of Screen (mamsl) | Bottom of Screen (mamsl) | Instrument Type | Geologic Unit |
|---|---|---|---|---|---|---|---|---|
| BH09-02 | 196089.9 | 751909.4 | 779.2 | 0.0 | 45.7 | 45.7 | VW | Tuff/volvanic sediments |
| BH09-03A | 196408.8 | 751903.4 | 460.5 | 1.0 | 33.4 | 31.9 | Stand pipe | Saprolite w/rock |
| BH09-03B | 196407.4 | 751903.2 | 461.9 | 0.6 | 48.3 | 46.8 | Stand pipe | Alluvial w/Saprolite |
| BH09-04B | 196713.1 | 751932.0 | 167.2 | 1.8 | 44.2 | 38.1 | Stand pipe | Saprolite/weathered bedrock |
| BH09-04C | 196714.2 | 751928.3 | 164.8 | 1.6 | 49.0 | 49.0 | VW | NA(1) |
| BH09-05 | 197006.0 | 751887.7 | 139.1 | 2.9 | 29.5 | 29.5 | VW | Volcanic sediments |
| BH09-11 | 195583.5 | 750892.2 | 1613.9 | 0.1 | -13.4 | -13.4 | VW | Fresh Bedrock |
| BH09-RK-RMP-01A | 196732.4 | 751734.4 | 190.8 | 0.9 | NA(2) | NA(2) | Stand pipe | NA(1) |
| BH09-RK-RMU-01A | 196685.0 | 751824.5 | 187.9 | 2.7 | NA(2) | NA(2) | Stand pipe | NA(1) |
| TW-7 | 196868.1 | 751869.3 | 0.0 | 3.9 | 36.0 | -166.5 | Open Hole | Fresh Bedrock |
| TW-7a | 196852.9 | 751851.4 | 23.4 | 2.8 | 32.9 | -200.1 | | |
| TW-7b | 196888.4 | 751851.4 | 27.1 | 2.7 | 32.6 | -199.4 | | |
| TW-7c | 196852.4 | 751887.7 | 24.2 | 3.1 | 29.7 | -199.3 | | |
| TW-7d* | 196888.5 | 751887.6 | 27.4 | 3.0 | 33.0 | -200.0 | | |
| TW-8* | 195738.3 | 751904.3 | 1130.3 | 0.3 | 35.4 | -171.6 | | |
| TW-8a | 195722.4 | 751886.3 | 1145.8 | 0.3 | 35.4 | -200.6 | | |
| TW-8b | 195758.6 | 751886.4 | 1109.7 | | 37.7 | -202.3 | | |
| TW-8c | 195722.3 | 751922.3 | 1147.0 | 0.3 | 35.7 | -197.3 | | |
| TW-8d* | 195758.4 | 751922.4 | 1111.0 | 0.3 | 35.6 | -201.4 | | |
| TW-1 | 195740.4 | 751904.3 | 1128.2 | | 38.4 | -149.6 | | |
| TW-2* | 196420.3 | 751728.3 | 469.2 | 0.1 | 12.4 | -133.6 | | |
| TW-3* | 196555.8 | 751863.8 | 312.6 | 1.3 | 39.5 | -157.5 | | |
| TW-4* | 196692.9 | 751786.7 | 193.6 | 0.9 | 26.2 | -151.8 | | |
| TW-5 | 196870.0 | 751869.3 | 2.0 | 3.9 | 30.1 | -190.9 | | |
| TW-6* | 197009.7 | 751855.8 | 141.8 | 3.1 | 26.9 | -151.1 | | |

Notes: * Boreholes with flow profiling.

1) Geologic unit is not available.

2) Screen information is not available.

## TABLE 3

## Hydraulic Parameters of Geologic Units in Groundwater Flow Model

| Formation/Unit | | Hydraulic Conductivity (m/day) | | | Specific Storage ($m^{-1}$) | Specific Yield ( ) |
|---|---|---|---|---|---|---|
| | | $K_x$ | $K_y$ | $K_z$ | | |
| Unconsolidated Deposits | < 1400 m from the riverbank | 1.0E-01 | 1.0E-01 | 1.0E-02 | 1.0E-05 | 2.0E-01 |
| | > 1400 m from the riverbank | 1.8E-01 | 1.8E-01 | 1.8E-02 | 1.0E-05 | 2.0E-01 |
| Weathered Bedrock | < 200 m from the riverbank | 5.0E+01 | 5.0E+00 | 5.0E+00 | 1.0E-06 | 1.0E-02 |
| | between 200 and 400 m from the riverbank | 4.0E-01 | 4.0E-02 | 4.0E-02 | 1.0E-06 | 1.0E-02 |
| | between 400 and 600 m from the riverbank | 5.0E-02 | 5.0E-03 | 5.0E-03 | 1.0E-06 | 1.0E-02 |
| | > 600 m from the riverbank | 1.0E-02 | 1.0E-03 | 1.0E-03 | 1.0E-06 | 1.0E-02 |
| Fresh Bedrock | Upper Bedrock: above -15 mamsl | 5.0E-02 | 5.0E-03 | 5.0E-03 | 1.0E-06 | 5.0E-03 |
| | Middle Bedrock: between -15 mamsl and -195 mamsl | 3.2E-02 | 3.2E-03 | 3.2E-03 | 1.0E-06 | 5.0E-03 |
| | Lower Bedrock: between -195 mamsl and -245 mamsl | 4.7E-03 | 4.7E-04 | 4.7E-04 | 1.0E-06 | 5.0E-03 |
| | Deep Bedrock: below -245 mamsl | 3.6E-04 | 3.6E-05 | 3.6E-05 | 1.0E-06 | 5.0E-03 |
| Zone of Relaxation | for prediction only | 5.0E-02 | 5.0E-02 | 5.0E-02 | 5.0E-06 | 5.0E-03 |
| Dyke | for prediction only | 1.0E-05 | 1.0E-05 | 1.0E-05 | 1.0E-06 | 5.0E-03 |
| Shear Zone | for sensitivity analysis only | 5.0E-01 | 5.0E-02 | 5.0E-02 | 1.0E-05 | 5.0E-03 |

## TABLE 4

## Open Pits Excavation Schedule

| Pit Name | | Bottom Elevation (mamsl) | Excavation Schedule (Production Years) | |
|---|---|---|---|---|
| | | | Start | End |
| Rory's Knoll | SAP | 25 | 1 | 3 |
| | PB1 | -35 | 4 | 5 |
| | PB2 | -95 | 4 | 6 |
| Aleck Hill | SAP | 30 | 1 | 4 |
| | PB1 | -35 | 4 | 7 |
| | PB2 | -110 | 4 | 14 |
| Aleck Hill North | SAP | 45 | 2 | 3 |
| | PB1 | 0 | 8 | 13 |
| Mad Kiss | SAP | 40 | 4 | 4 |
| | PB1 | -60 | 11 | 15 |
| Walcott Hill | PB1 | 35 | 14 | 15 |

## TABLE 5

## Estimated Rainfall over Pit Area that Reports to Underground Workings

| Month | Precipitation | | Evaporation | | Rainfall to Underground Workings (m$^3$/day) | | |
|---|---|---|---|---|---|---|---|
| | Monthly (mm/month) | Daily (mm/day) | Monthly (mm/month) | Daily (mm/day) | Run-off [1, 2, 3] from Rory's Knoll Pit Wall over Area of 135,580 m$^2$ | Direct Precipitation to UG over Area of 7,800 m$^2$ | Total Rainfall |
| Jan | 207 | 6.80 | 85.4 | 2.81 | 379 | 53 | 432 |
| Feb | 102 | 3.35 | 89.3 | 2.93 | 40 | 26 | 66 |
| Mar | 134 | 4.40 | 105.1 | 3.45 | 90 | 34 | 124 |
| Apr | 172 | 5.65 | 112.1 | 3.68 | 187 | 44 | 231 |
| May | 317 | 10.41 | 118.3 | 3.89 | 620 | 81 | 701 |
| June | 337 | 11.07 | 138.8 | 4.56 | 618 | 86 | 704 |
| July | 286 | 9.40 | 98.6 | 3.24 | 584 | 73 | 658 |
| Aug | 219 | 7.19 | 86.7 | 2.85 | 412 | 56 | 469 |
| Sept | 132 | 4.34 | 141.4 | 4.65 | 0 | 34 | 34 |
| Oct | 137 | 4.50 | 144.4 | 4.74 | 0 | 35 | 35 |
| Nov | 174 | 5.72 | 96.8 | 3.18 | 241 | 45 | 285 |
| Dec | 233 | 7.65 | 124.9 | 4.10 | 337 | 60 | 397 |

Notes:
1) The area excludes the 7,800 m$^2$ of direct precipitation.
2) Evaporation was substracted from the precipitation.
3) Assumes that 70% of the runoff from the pit wall reports to the underground workings.

## TABLE 6

## Estimated Volume of Water over Pit Area that Reports to Underground Workings During a Storm Event with 25 Years Return Period

| Duration (Hours) | Rainfall Intensity (mm/hour) | Volume of Rainfall to Underground Workings During the Storm Event ($m^3$) |
|---|---|---|
| | | Rainfall[1, 2, 3] to Rory's Knoll Pit Perimeter Area of 140,000 $m^2$ |
| 3 | 40.3 | 16,926 |
| 6 | 25 | 21,000 |
| 12 | 15.5 | 26,040 |

Notes: 1) The area does not include any runoff catchment area.

2) Evaporation was not included in this short term event.

3) Assumes that all precipitation reports to the underground workings.