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## **1.0 INTRODUCTION**

The Mount Polley Mining Corporation (MPMC) has retained AMEC Environment and Infrastructure, a division of AMEC Americas Ltd. (AMEC), to provide a hydrogeological assessment of the Mount Polley mine site. The mine site is located approximately 60 km northeast of Williams Lake B.C. and approximately 20 km southwest of Likely B.C. The purpose of this assessment is to address concerns expressed by the British Columbia Ministry of Environment (MOE) regarding changes in groundwater quality at the mine site and to characterize the hydrogeologic setting at the mine site.

### **1.1 Objectives and Scope of Work**

The main objectives of the hydrogeological assessment are to:

- Provide a data gap analysis and attempt to resolve gaps in the available data;
- Characterize the local hydrogeological conditions at the mine site and develop a site specific conceptual model;
- Identify surface and/or groundwater quality changes related to mining activity, specifically acid rock drainage (ARD);
- Determine infiltration rates into the Springer Pit and identify potential groundwater impacts related to the Springer Pit development; and
- Identify areas of potential environmental concern and potential contaminants of concern.

The following work has been performed:

- An in-depth data review and compilation of relevant groundwater information collected by MPMC and from the public domain;
- Ten (10) monitoring wells at five locations have been installed to resolve identified data gaps;
- Development of a conceptual site model and the identification of wells exhibiting significant changes in either baseline static water levels and/or water quality;
- Hydrogeological mapping to define discharge and recharge areas; and
- Decommissioning of one (1) monitoring well.

The main text of this report provides a discussion of the regional setting, a summary of the field program, characterization of the hydrogeological setting, potential impacts and conclusions and recommendations. Supporting information is available in the accompanying figures, tables, and appendices.

## **2.0 REGIONAL SETTING**

The mine site is positioned on a ridge that separates Polley Lake and Bootjack Lake. The regional study area includes the Mount Polley mine site and the adjacent Bootjack Lake/

Morehead Creek drainage basin and the Polley Lake/ Hazeltine Creek drainage basin located southwest and northeast of the mine site respectively (Figure 1).

## 2.1 Physiography

The regional topographic relief and drainage networks are shown in Figure 2. The study area covers approximately 100 km<sup>2</sup>. The Mount Polley mine site is located within the geographic region known as the Fraser Plateau. This region is west of and adjacent to the Quesnel Highlands and the Cariboo Mountain Range. The topography of this area is bedrock controlled and the elevation ranges from approximately 915 masl to 1470 masl. The topographic highs in the area are Mount Polley which peaks at approximately 1470 meters above sea level (masl) and is located at the center of the mine site, Bootjack and Jacobie mountains are located east of Mount Polley with elevations of 1270 masl and 1310 masl, respectively. These topographic highs have volcanic origins. The terrain within the study area slopes towards the east with a total relief of approximately 680 meters, with the surface of Quesnel Lake at approximately 790 masl.

This area was glaciated during the last glaciation and the overburden in the area is mostly glacial and glacio-lacustrine sediments. The composition of the till is silty clay/clayey silt with varying amounts of gravel and boulders. The overburden thickness in the area ranges from less than 1 meter to greater than 25 meters and bedrock is typically not exposed within most of the site. Bedrock exposure is limited to steep slopes and cuts. The majority of the area is tree covered and supports an active logging industry.

## 2.2 Regional Climate

The climate in the area can be described as a humid, continental climate with warm summers, with spring being the driest season and the summer being the wettest season.

The climate data is from Environment Canada's Canadian Climate Normals (1971-2000) database. Climate data for Likely B.C. is available from 1974 to 1993 and the findings are summarized below:

- Precipitation rates range from a maximum monthly average of 81.8 mm in June to a minimum monthly average of 35.5 mm in March;
- The average yearly precipitation is 692.4 mm, with 215.2 mm occurring as snow;
- Temperatures range from a maximum daily average of 15.4 degrees Celsius in July to minimum daily average of -7.0 degrees Celsius in January.
- The average yearly daily temperature is 4.6 degrees Celsius.

The Likely B.C. meteorological station is located approximately 20 kilometres from the mine site.

## 2.3 Regional Geology

The mine site is located within the Quesnellia Terrane. The Quesnellia Terrane consists chiefly of west-facing Upper Triassic to Lower Jurassic (Karnian to Sinemurian) volcanic arc rocks (Nicola Group, Rossland Formation), coeval calc-alkalic and alkalic plutons, and laterally



equivalent clastic sedimentary rocks (Mortimer, 1987; Monger, 1989; Andrew and others, 1990; Parrish and Monger, 1992).

The mine site is located within Quesnellia on the eastern margin of the Intermontane Belt. This part of Quesnellia consists of a sequence of volcanic units that dip east to northeast 5 kilometers west of the property, and dip predominantly to the west or southwest 4 kilometres east of the property (Bailey, 1987).

The volcanic rocks include flows, breccias and tuffs. Volumetrically the most important are augite-porphyrific basalt to trachybasalts that locally form pillowed units. Less common are purple and maroon polymictic volcanic breccias, and green crystal and lapilli tuffs. An analcite-bearing flow and flow breccia are interpreted to be the youngest volcanic units in the area (Bailey, 1987).

### **3.0 PREVIOUS INVESTIGATIONS**

Drilling and well installations have been completed in multiple years beginning in 1981. Much of the information from these well investigations is lost other than some reference to their drilling and some flow measurements. A series of holes labelled R81-1 to R86-38 were drilled to depths ranging from 18 meters to 237 meters. Each of these boreholes has a reported groundwater yield from them ranging from 10 to 400 gallons per minute. There is no other information from these wells.

Another series of wells labelled MP89-107 to MP89-236 were drilled in the tailings area and in the Springer or Cariboo pit areas. All of these were 2 inch monitoring wells at one time but have since been destroyed. No drill logs or information from the monitoring wells is available.

In 1995, seven water wells were completed labelled 95-R1 to 95-R7. Two of these wells, 95-R4 and 95-R5 have been incorporated into the regular groundwater monitoring plan.

Fifteen new monitoring wells were installed in 1996, generally with a shallow and a deep installation at each site. Most of these wells have borehole logs and installation details in the database and most of them are in the current groundwater monitoring network.

In 2000 and 2011 several new installations were constructed in the tailings area.

All of these boreholes provide information on the general geology of the area, particularly overburden geology and they provide groundwater monitoring locations where wells have been retained.

Golder Associates produced a report on pit groundwater inflows and development of a pit lake. They predicted that at ultimate pit depth (820 masl), the groundwater inflows would be 1600 m<sup>3</sup>/day and that when the pit lake reaches spill elevation (1060 masl) the groundwater influx would be 100 m<sup>3</sup>/day.



#### **4.0 IDENTIFICATION OF DATA GAPS**

The available monitoring network from the previous investigations provides adequate coverage of the mine site. There are some installations that require modification or replacement as outlined below.

1. The monitoring well GW96-8a/8b was destroyed in the construction of a haul road. This monitoring well nest provided coverage for an area downgradient of the mill and required replacement. This well was replaced by Well #X.
2. Monitoring well 95-R-4 contained multiple screens at six different levels. This potentially connected separate aquifers. Interpretation of water quality results from these multiple screens was thus ambiguous. This well was grouted and replaced with Well #Y.
3. Monitoring well 95-R-5 also contained multiple screens creating the same potential to join multiple aquifers and mixing water quality. Two wells were installed on either side of this well to expand the monitoring network, wells Z1 and Z2. Water quality in 95-R-5 has shown a recent distinct increase in sulphate. This well will be retained in the monitoring network in the short term. Because of the multiple screens, this will eventually be replaced.
4. Groundwater level and quality monitoring in the tailings facility is well developed. Some water quality is starting to show a potential impact from mine operations. This will be monitored closely and expanded monitoring is warranted.

In general, none of these installations have been hydraulically tested through rising or falling head tests. This will be completed in a future field program. A copy of all available borehole logs is included in [Appendix I](#).

#### **5.0 FIELD PROGRAM METHODOLOGY**

The field program took place between November 14, 2012 and December 18, 2012 and involved borehole drilling, monitoring well installation, well development, and single well response tests.

##### **5.1 Monitoring Well Installation**

Monitoring wells were installed as pairs, with each pair having a shallow and deep monitoring well. Each well had its own borehole.

Drilling was completed with a Fraste Multidrill XL, air rotary, track mounted drill rig to advance a total of ten (10) boreholes at five locations. Rock chip samples were collected every 3.0 meters at each of the deep boreholes. These samples were submitted to the MPMC for analysis. At each location the shallow monitoring wells were installed at the first indication of persistent groundwater conditions and the deep monitoring wells were installed at or around 100 mbgs.

Installation of PVC monitoring wells and the well development was completed by the drilling contractor, GeoTech Drilling Ltd., with AMEC providing guidance. The monitoring wells were constructed using 5 cm diameter PVC pipe risers and slotted screens. Screen lengths were 3.0

meters and 6.1 meters for the shallow and deep wells respectively. A sand pack was placed around the slotted screen and approximately 0.3 to 1.0 meter above the PVC screen. Bentonite pellets were placed above the sand pack to create a hydraulic seal. The remainder of the borehole was grouted to surface and completed with an above ground protective casing. Monitoring well details are summarized in [Table 1](#).

Table 1: Monitoring Well Installation Details

Monitoring Well ID	Total Well Depth (m)	Ground Surface Elevation (masl)	Well Screen Interval (masl)	Screened Formation
GW12-1A	99.6	991.6	892.0 - 899.2	Bedrock
GW12-1B	24.4	991.4	967.0 - 970.7	Bedrock
GW12-2A	100.6	1035.4	934.8 - 941.5	Bedrock
GW12-2B	30.2	1035.4	1005.2 - 1008.9	Bedrock
GW12-3A	99.7	1039.1	939.4 - 946.4	Bedrock
GW12-3B	16.1	1039.2	1023.1 - 1026.4	Bedrock
GW12-4A	100.6	989.9	889.3 – 896.5	Bedrock
GW12-4B	36.3	990.1	953.8 – 957.3	Bedrock
GW12-5A	100.4	965.3	864.9 – 872.2	Bedrock
GW12-5B	12.7	966.2	953.5 – 957.6	Glacial Till

The completed monitoring wells were developed using air injection. Each monitoring well was developed by air lifting for at least 2 hours and/or until the purged water was clear and contained no sediments. Prior to well development, static water levels were taken and these are summarized in section [4.1.1](#).

## 5.2 Single Well Response Tests

Upon completion of the air development, water levels were taken to record the recovery in each well (rising head test). The rising head test data was used to calculate hydraulic conductivities of subsurface materials.

## 6.0 RESULTS

### 6.1 Hydrogeology and Conceptual Site Model

Groundwater in the Mount Polley area is mainly confined in a bedrock aquifer where flow is largely controlled by the orientation and frequency of fractures, faults and unconformities caused by volcanic events.

Localized overburden aquifers occur in topographic low areas, particularly in the tailings area, as these areas were not scraped/eroded during the last period of glaciation, thus glacial deposits (basal till) has remained intact in these locations. In general these glacial deposits do not contain significant outwash sands and gravels which can typically occur in glacial-fluvial deposits.

### 6.1.1 Groundwater Levels and Flow Directions

Groundwater measurements were recorded at all new well locations upon well installation. The groundwater level ranges from an elevation of 957.57 mbgs to 1036.25 mbgs.

Table 2. A summary of the measured groundwater levels is presented in the following table:

Monitoring well ID	Measured Groundwater Depth (m)	Ground Surface Elevation (m)	Groundwater Level Elevation (m)	Gradient
GW12-1A	4.98	991.59	986.61	Up
GW12-1B	5.12	991.37	986.25	
GW12-2A	21.42	1035.45	1014.03	Down
GW12-2B	21.39	1035.45	1014.06	
GW12-3A	3.15	1039.06	1035.91	Down
GW12-3B	2.99	1039.24	1036.25	
GW12-4A	21.95	989.87	968.17	Down
GW12-4B	12.81	990.12	977.06	
GW12-5A	7.71	965.28	957.57	Down
GW12-5B	5.31	966.22	960.91	

The strongest hydraulic gradients are downward at sites GW12-4 and 5. These are both adjacent to Polley Lake. The other gradients are also down, with the exception of GW12-1, but all are very slight. The downwards gradients adjacent to Polley Lake indicate that groundwater is recharged in the high ground between Polley and Bootjack Lakes and discharges into the lakes. GW12-1 is located at the toe of the Mount Polley and is thus expected to be a groundwater discharge area as well.

Bootjack Lake is approximately 63 meters in elevation above Polley Lake and imprints a deep seated flow direction from Bootjack to Polley Lake. The shallower flow paths report to both Bootjack and Polley lakes. **Figure 2** displays a cross section through the Mount Polley mine site that illustrates the conceptual groundwater flow paths.

**Figure 3** presents a map of hydraulic heads derived from water level measurements in monitoring wells, local ponds and pits, and topography. The figure illustrates the general mound of groundwater in the high ground around the mine and the steep groundwater contours surrounding the pits. Figures 2 and 3 represent our conceptual model of groundwater flow directions and approximate head distributions.

### 6.1.2 Hydraulic Conductivity

Single well response tests were performed on all new installations upon well completion. The well response test used was the rising head test and hydraulic conductivities were calculated based upon the results.

The Hvorslev mathematical solution was used to calculate the hydraulic conductivity. The solution assumes a homogeneous aquifer with infinite vertical extent. This solution is widely used and provides a straight-forward and well-documented approximation of hydraulic conductivity in the vicinity of the monitoring well screen. The results of the single well response tests are summarized in the following table.

Monitoring Well	Screened Formation	Ground Surface Elevation (masl)	Well Screen Interval (masl)	Hydraulic Conductivity (m/s)
GW12-1A	Bedrock	991.59	892.0 - 899.2	$2.2 \times 10^{-9}$
GW12-1B	Bedrock	991.37	967.0 - 970.7	$>10^{-4}$
GW12-2A	Bedrock	1035.45	934.8 - 941.5	$2.9 \times 10^{-8}$
GW12-2B	Bedrock	1035.45	1005.2 - 1008.9	$2.0 \times 10^{-7}$
GW12-3A	Bedrock	1039.06	939.4 - 946.4	$2.5 \times 10^{-7}$
GW12-3B	Bedrock	1039.24	1023.1 - 1026.4	$9.8 \times 10^{-6}$
GW12-4A	Bedrock	989.87	889.3 - 896.5	$3.7 \times 10^{-9}$
GW12-4B	Bedrock	990.12	953.8 - 957.3	$2.5 \times 10^{-5}$
GW12-5A	Bedrock	965.28	864.9 - 872.2	$>10^{-4}$
GW12-5B	Glacial Till	966.22	953.5 - 957.6	$2.7 \times 10^{-7}$

The hydraulic conductivities of all of the wells ranges from  $>10^{-4}$  to  $2.21 \times 10^{-9}$  m/s. The average hydraulic conductivity of the shallow wells is  $2.7 \times 10^{-5}$  m/s and the average hydraulic conductivity of the deep wells is  $4.9 \times 10^{-6}$  m/s. The difference in the average hydraulic conductivity between the shallow and deep wells is one order of magnitude and is similar to what is observed in monitoring well pairs GW12-2 and GW12-3. However in monitoring well pairs GW12-1, GW12-4 and GW12-5 the variation in hydraulic conductivity between the shallow and deep wells is three orders of magnitude, with shallow wells at GW12-1 and GW12-4 having the highest hydraulic conductivity. GW12-5 is the only monitoring well pair where the lower hydraulic conductivity was observed in the shallow well. Monitoring well GW12-5B was the only well screened within overburden/glacial till.

### 6.1.3 Groundwater Flow Velocities

Using the approximate distribution of hydraulic heads, Figure 5, the shallow general hydraulic gradient toward both Polley and Bootjack Lake is approximately 0.14 m/m. Around the dewatered Springer and Cariboo pits, the local gradient is much higher and it appears that in the vicinity of the tailings pond the gradients are much lower.

Using the average hydraulic conductivity for shallow wells is  $2.7 \times 10^{-5}$  m/s and an assumed porosity of 0.1, the average D'Arcy velocity is approximately 3 m/day.

### 6.1.4 Pit Groundwater Inflows

The actual groundwater inflows to Springer and Cariboo pits can be determined from a detailed water balance, which is not in this scope of work; MPMC is preparing the water balance. Using

the hydraulic head contours and estimates of bulk hydraulic conductivity, combined inflows to Springer and Cariboo pits may be as high as 2800 m<sup>3</sup>/day. This is likely a high estimate but within the range predicted by Golder Associates.

## **6.2 Groundwater Quality Trends**

Based on recent groundwater sampling programs, five wells appear to be showing evidence of influence by mine operations. Two are in the pit/waste rock area; 95-R4, 95-R5, and three are in the tailings facility area; GW96-2B, GW96-4B, and GW00-1B.

### **6.2.1 95-R4**

Monitoring well 95-R4 has shown elevated Sulphate and Selenium and decreased Molybdenum. There is a slight possibility of elevated copper. This well has multiple screens so the origin of this water quality is not known. This well was also significantly affected by the nearby sub-horizontal borehole that appeared to dramatically lower the water level in the well. Monitoring wells GW12-2A/B have replaced this well. Further monitoring should help to clarify these ambiguous results.

### **6.2.2 95-R5**

Monitoring well 95-R5 shows elevated concentrations of sulphate, cadmium, and possibly copper, as well as elevated hardness. There is also a slight decrease in molybdenum. This well also has multiple screens. Monitoring will continue on this well. Adjacent wells have been constructed, GW12-4A/B and GW12-5A/B, to expand coverage in this area.

Well 95-R5 is screened with four screens at 43ft, 164ft, 209ft, and 254ft. Discrete micro purge samples were collected at these four locations using a [redacted] pump. A total of [redacted] litres were purged from each sampling zone. The results of the sampling are not entirely conclusive; however the parameters with the greatest historic increases, sulphate and cadmium, were at the highest concentrations in the zone at 164 feet. This may suggest that this is the zone carrying the highest percentage of mine affected water.

### **6.2.3 GW96-2B**

Monitoring well GW96-2B, located on the northeast limb of the tailings facility, is constructed from 31 to 35 meters depth in a water bearing sand. Sulphate in this well is just beginning to show signs of change; no other parameters are showing any clear trends.

### **6.2.4 GW96-4B**

Monitoring well GW96-4B, located on the southwest limb of the tailings facility is showing a distinct trend of rising hardness, sulphate, and nitrate. This is a very shallow well, 3 to 7 meters, constructed in a sand lens.

### **6.2.5 GW00-11B**

This well is also on the southwest limb of the tailings facility and also shallow, 4 – 10 meters and constructed across a thin sand seam. This well shows several elevated parameters; hardness, sulphate, nitrate, cadmium, molybdenum, and selenium.



There are some common themes in this suite of results, sulphate is the commonly elevated parameter. Some wells also show elevated selenium, cadmium, or nitrate. Well GW00-11B includes all of them plus molybdenum.

The mechanisms for these changes are not fully known. A review of geochemistry data and analysis, which we understand is frequently updated with new kinetic data, will help explain some of these mechanisms. This is beyond the scope of this assignment.

## **7.0 GROUNDWATER QUALITY MONITORING PROTOCOL**

A groundwater monitoring protocol including sampling sites, frequency, and parameters has been proposed by MPMC. This proposal is appropriate for current conditions. Because there are initial indications of some mine affected water showing up in a couple of places, the monitoring program should remain adaptable to monitoring results. Additional monitoring sites may be required in future along with enhanced frequency.

## **8.0 SUMMARY**

Hydrogeological conditions at Mt. Polley are defined by boreholes and monitoring wells constructed across the site. This data set and interpretations are summarized below.

1. The area hydrostratigraphy consists of, from top down:
  - a. Generally thin but locally thick glacio-fluvial overburden
  - b. Weathered and/or fractured bedrock
  - c. Intact and competent bedrock
2. It is apparent that some permeable fractures can be present at depth.
3. Hydraulic heads are generally a subdued form of topography being high in the center of the mine area and lower at both lakes and lower south of the tailings pond.
4. Groundwater discharges to both Bootjack and Polley lakes.
5. Groundwater discharges southeast of the tailings pond.
6. Groundwater discharges to Springer and Cariboo pits.
7. Groundwater velocities are approximately 3 meters/year but with considerable variability.
8. Groundwater appears to have been impacted at a few sites in the tailings area and a couple of sites downgradient of mine facilities.
9. Monitoring is established across the mine site with appropriate frequencies and analytical protocols.

## **9.0 CONCLUSIONS AND RECOMMENDATIONS**

MPMC has an established monitoring program with some data records extending back to 1995. Recent possible detections have resulted in an expansion and modification to the monitoring program. MPMC will need to continue to be adaptive to changes in water chemistry and devise mitigation measures where necessary. Some recommendations moving forward are:



1. Conduct a study correlating changes in groundwater chemistry with the waste rock and tailings geochemistry data. Some sampling in the tailings would help define mechanisms there.
2. Continue to monitor 95-R5 for two more events but consider replacing this well with a nested pair.
3. Water quality results for the new wells GW12-4 and GW12-5 may indicate a need for expanded monitoring in this area.
4. A detailed water balance should be prepared to assess the groundwater volumes reporting to the pits. This will aid in calibrating a groundwater flow model that can be used for closure planning.