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RGC Project No: 201001

To:
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RE: Independent Third-Party Review - Hydrogeology of Red Chris Tailings Storage Facility, B.C.

1 Introduction

1.1 Terms of Reference

Red Chris Development Corporation ("RCDC"), a subsidiary of Imperial Metals Corporation ("IMC"), is currently in the process of developing the Red Chris Mine, a gold-copper project located near the town of Iskut in northwestern B.C.. The proposed mine development will include a 30,000 tonnes per day milling operation and related open pit mine. The Red Chris Project received an environmental assessment (EA) certificate in 2004 and a Mines Act Permit was issued by the Province of British Columbia in May 2012.

In response to concerns by local stakeholders (Thaltan First Nations or "TFN") about potential impacts from tailings seepage to nearby surface waters, RCDC made a commitment to commission an independent Third-Party Review of the hydrogeological studies submitted during the permitting process.

In consultation with members from the Tahltan Heritage Resource Environmental Assessment Team ("THREAT"), the B.C. Ministry of Environment ("MoE"), and the B.C. Ministry of Energy & Mining ("MEM"), RCDC appointed Dr. Christoph Wels from Robertson GeoConsultants Inc. to conduct this Third-Party hydrogeological review for the Red Chris Project.

This Third-party review was initiated with a kick-off meeting held on August 29, 2012 in Vancouver (in the RGC office) at which representatives from THREAT, MoE, MEM, RCDC and the reviewer participated.

1.2 Scope of Review

The scope of work for this hydrogeological review was developed by RCDC in consultation with the above-mentioned stakeholders and is summarized in a document entitled "Red Chris Mine – Third Party Review – Scope of Work Hydrogeology" which is attached in Appendix A of this review report.

According to this document, the scope of this Third-Party review is to:

- *assess the hydrogeological characterization work done to date for the Red Chris project; and*
- *Identify gaps in the data as required to assess the hydrogeological conditions for the site.*

The review should be based on the Tailings Storage Facility (TSF) footprint and predicted downstream seepage plumes and potential seepage return zones within the receiving environment.

Furthermore, the scoping document specified the following objectives:

- *Review available data (well(s), geotechnical, soil surveys, etc.) for the TSF footprint and potential seepage flowpath receiving environment areas to identify information gaps and potential deficiencies in the monitoring network.*
- *Provide an assessment of models run to date, with respect to parameterization, calibration, assumptions and overall representativeness of the related groundwater system. This includes information from the mill/processing plant predictive water quality work.*
- *Review proposed contingencies and mitigation measures for seepage management for the TSF footprint and potential seepage receiving environment.*

The remainder of this letter report summarizes the findings of this Third Party review by the reviewer (Dr. Christoph Wels). It should be emphasized that this review was completed independently by the author with no formal or informal review and/or approval by RCDC or any other stakeholders in the Red Chris Project.

1.3 Data Reviewed

A list of all materials (reports, figures, data) provided to Dr. Christoph Wels for the Third-Party Review is provided in Appendix B of this review report.

2 Key Findings of Review

Based on a review of the information provided I conclude the following:

- The hydrogeological studies completed in the TSF area to date are adequate for their primary intended purpose, i.e. to assess dam stability (geotechnical concern) and mine water supply (water management concern)
- However, the hydrogeological studies completed to date are not sufficiently detailed to fully assess/monitor potential environmental impacts due to seepage from the TSF on the downstream aquatic environment (specifically water quality impacts to Trail Creek and Quarry Creek) and/or to design contingency measures to mitigate any potential impacts
- Additional hydrogeological site characterization, groundwater monitoring and groundwater modeling is recommended to better understand the potential pathways and magnitude of seepage from the TSF and to design seepage interception systems

The following sections provide a detailed presentation of the review findings, including an overview of the key issues related to the Red Chris TSF, an assessment of information gaps, a review of proposed contingencies and mitigation measures, groundwater modeling studies, and the proposed monitoring plan, and recommendations for additional hydrogeological work.

3 Key Issues

3.1 Potential Impact of TSF Seepage on Surface Water Quality

The emphasis of this independent review is on the hydrogeological studies completed for the Red Chris tailings storage facility (TSF) to assess the magnitude of seepage and resulting potential impact on the downstream environment (i.e. surface water quality).

3.1.1 TSF Source Concentrations

The first issue to consider in this context is whether the water quality of the tailings seepage ("source concentration") represents a risk to the environment.

The proponent has included several pre-emptive measures in its mine plan to minimize the contaminant concentrations in the TSF process water, including:

- De-pyritize rougher tailings to be used for tailings dam construction

- Place PAG tailings under water during operations and maintain PAG tailings permanently saturated post-closure
- Use seepage collected from open pit and rock storage area (RSA) in milling process (prior to discharge into TSF)

These initiatives are state-of-the-art for ARD prevention and control and are predicted to minimize oxidation of sulphides in the tailings and hence contaminant concentrations in TSF seepage.

Table 1 shows the predicted TSF seepage water quality for selected water quality parameters during operation and post-closure (as described in AMEC, 2012). Those predicted values exceeding the "BC WQ guidelines" for freshwater are shown in red bold font. None of the parameters exceed the Mining Metal Effluent Regulations (MMER).

Table 1. Predicted water quality (selected parameters) in TSF process water (taken from AMEC, 2012)

Parameter	Mining Metal Effluent Regulations (MMER)+	"BCWQ Guidelines"*	Max predicted conc. in TSF during operations	Max predicted conc. in TSF (128 yrs after closure)
Sulphate (SO_4 in mg/L)	n/a	65	**115**	40
Aluminum (Al in ug/L)	n/a	50	45	52
Cadmium (Cd in ug/L)	n/a	0.05	**0.16**	**0.11**
Copper (Cu in ug/L)	300	5.8	3.4	**51**
Iron (Fe in ug/L)	n/a	1,000	430	200
Lead (Pb in ug/L)	200	17	1.7	0.5
Selenium (Se in ug/L)	n/a	2	**7.3**	1.4
Zinc (Zn in ug/L)	500	58	7	28

+ n/a = not applicable; *as used in AMEC, 2012

In general, the predicted TSF water quality meets all BC water quality guidelines except for the following parameters:

- Sulphate (during operations and post-closure)
- Cadmium (during operations and post-closure)
- Copper (post-closure only)
- Selenium (during operation and post-closure)

Note that the highest exceedance of BCWQ guidelines is predicted for post-closure conditions for copper (about 10 times above guidelines)[1].

It is concluded from this comparison that seepage from the TSF will likely require some degree of dilution in the receiving environment (by runoff and/or local groundwater) and/or seepage recovery during operations and post-closure to meet all BC water quality guidelines in the receiving surface water.

Note that a review of the geochemical modeling used to predict the TSF water quality was beyond the scope of this hydrogeological review. For the purpose of this review it is simply assumed that the predicted TSF source water quality is reasonable. However, it is noted that these water quality predictions are based on full implementation of the above ARD mitigation measures.

3.1.2 Surface Water Quality Predictions

AMEC has completed water quality predictions for different locations in the three streams potentially affected by TSF seepage, i.e. Quarry Creek, Trail Creek and Nea Creek (AMEC, 2012).

Table 2 summarizes predicted maximum concentrations for the four water quality parameters of concern (SO4, Cd, Cu, and Se) at selected (upstream) locations. Again, those predicted values above the BC Water Quality Guidelines are highlighted in red bold font.

Exceedances of BC water quality guidelines are predicted for SO4 and Cd during operations and Cd, Cu and Se after closure. The author recognizes that the predicted exceedances are marginal and likely within the accuracy of such water quality predictions. However, it should be noted that these predictions assume that all ARD

[1] Note that the copper concentrations predicted for long-term post-closure conditions in the TSF (50 ug/L) is still significantly (6 times) lower than the MMER for copper (300 ug/L).

mitigation measures are properly implemented and predicted source concentrations are correct. The fact that the "base case" predictions are at or above guidelines leaves little buffer room for potential errors in prediction of source terms and/or operational upsets which may lead to "off-spec" concentrations in TSF process water and higher contaminant loading (and hence contaminant concentrations in surface water) than predicted.

Table 2. Predicted surface water quality in receiving streams downstream of Red Chris TSF.

Location	SO4 (mg/L)	Cd (ug/L)	Cu (ug/L)	Se (ug/L)
BC WQGL (Freshwater)	65	0.05	5.8	2.0
Operations				
Quarry Creek (Fish Point)	**85**	**0.15**	3.1	**7.0**
Trail Creek Mouth	**100**	**0.13**	3.3	**6.0**
Nea Creek	n/a	n/a	n/a	n/a
Closure (t ~130 yrs)				
Quarry Creek (Fish Point)	52	0.036	**7.8**	**2.7**
Trail Creek Mouth	23	**0.063**	2.8	0.75
Nea Creek	60	**0.13**	1	**5**

Note also that the base case predictions (shown in Table 2) assume that 50% of all seepage by-passing the North and South Reclaim Dams will be captured and returned to the TSF during operations. In other words, predicted contaminant concentrations in Trail Creek (and Quarry Creek during winter months) could be significantly higher during operations if no seepage interception was implemented.

From my review of the water quality modeling, I conclude the following:

- There is at least a potential for water quality impacts to the three receiving surface waters (Trail Creek, Quarry Creek and Nea Creek) during operations and post-closure as defined here by an exceedance of BCWQ guidelines

- The surface water quality predictions (and probability of exceeding BCWQ guidelines) are sensitive to the various hydrogeological assumptions made in the water quality model, including:
  - The magnitude of seepage discharging from the Red Chris TSF (through TSF foundation, TSF dams and reclaim dams) during operation and post-closure
  - The relative proportion of seepage recovery (using "groundwater extraction wells" located downstream of the reclaim dams) during operations
  - The relative proportion of seepage discharge into creeks with distance from the reclaim dam during operations and closure.

As discussed in more detail below, only the first assumption is based on site-specific field data and/or modeling while the latter two assumptions are simply "judgment calls" which are not backed up by any data or analysis. In my opinion, all three assumptions bear significant remaining uncertainty.

If the upstream reaches of Trail Creek and Quarry Creek require water quality protection (to BCWQ guidelines)[2] then additional hydrogeological studies will be required to reduce this uncertainty. For the remainder of this review, I have (conservatively) assumed that at least some portion of the upstream reaches of Quarry Creek (post-closure) and Trail Creek (active operations and closure) will require water quality protection. If water quality protection for those headwater creeks is not required then the effort of future hydrogeological studies and monitoring could be significantly reduced.

3.2 Magnitude of TSF Seepage

The magnitude of seepage from the foot print area of the tailings storage facility has been estimated using 2D seepage modeling (using SEEP/W) and 3D groundwater flow modeling (MODFLOW) (AMEC, 2011). AMEC concluded the following from these modeling studies:

- Seepage from the North Dam starter water pond are predicted to range from 60 L/s (no liner) to 6 L/s (100% liner), with 20 L/s predicted for the 50% lined base case

[2] It is my understanding that Nea Creek is not fish-bearing and hence BCWQ guideline will likely not apply

- Seepage rates from the TSF (during operations and closure) are primarily controlled by the (relatively low) hydraulic conductivity of the tailings
- Seepage rates from the North Dam and South Dam (at closure) are predicted to range from 3-15 L/s and 5-20 L/s, respectively
- Total seepage losses from the TSF (at closure) are predicted to range from 10-35 L/s

A detailed review of these modeling studies is provided in section 6 of this review report. The main conclusions of my review with respect to the predicted rates of seepage from the TSF can be summarized as follows:

- In my opinion, the seepage rates predicted from the TSF for post-closure conditions are reasonable (and likely conservative), because:
    - The hydraulic conductivity (K) values used for these seepage predictions (K_h= 5*10^{-7} m/s; K_v=5*10^{-8} m/s) are consistent with (and possibly higher than) K values determined for other (fully consolidated) copper tailings of similar particle size distribution (i.e. 65% fines content, see AMEC, 2011b)
    - The simplified 2D (and even 3D) models ignore the complex valley geometry which tends to concentrate groundwater flow in the valley center; ignoring this complexity tends to overestimate TSF seepage
- In contrast, no seepage analyses were completed to predict seepage rates during operational conditions, i.e. active sand dam construction and tailings discharge. In my opinion, seepage rates during active operation of the tailings impoundment, in particular during the early phases of impoundment development, could potentially be higher than post-closure seepage rates, because:
    - The hydraulic conductivity of freshly deposited tailings (slurry) or under-consolidated tailings tends to be significantly higher (up to 1-2 orders of magnitude) than fully consolidated tailings
    - Free water (from the pond) may be in direct contact with moderately to highly permeable foundation soils resulting in high unit seepage rates;
    - The tailings deposit may remain completely underdrained during early stages of impoundment filling (i.e. water table in valley sediments remains below the bottom of the tailings deposit) resulting in higher unit seepage rates than predicted for closure

- Active discharge of tailings slurry (total tailings and/or slimes) from the dam provides an additional source of recharge to the beach areas (not included in closure scenarios)
- Active discharge of cycloned sands provides an additional source of recharge to the outer slope of the dams during active dam construction (not included in closure scenarios)

- Groundwater flow and seepage modeling did not address the relative proportion of tailings seepage collected (as toe seepage) versus seepage by-passing the North/South Dams and associated reclaim dams during active operations; in my opinion, a significant proportion of TSF seepage can be expected to by-pass the shallow collection systems (underdrains, reclaim dam) because of the presence of thick valley deposits of highly permeable sediments

Based on the above, I conclude the following:

- TSF seepage rates assumed for post-closure water quality predictions (20 L/s from North Dam and 20 L/s from South Dam) are reasonable (and may be conservative);
- TSF seepage rates assumed for water quality predictions during active operations (up to 14 L/s for North Dam and up to 12 L/s for South Dam) are not based on explicit modeling results and may not be conservative; I therefore recommend that additional seepage modeling be completed to refine the initial seepage estimates for active operations and to estimate the relative contribution of such seepage captured (in toe seepage and reclaim dam) vis-à-vis seepage by-pass (underflow) reaching the downstream environment (see section 8.2).

3.3 Seepage Recovery using Extraction Wells

The proponent has proposed to install groundwater extraction wells immediately downgradient of the North and South Reclaim Dams. The primary purpose of these extraction wells is to augment mill water supply. A secondary objective of these wells is to reduce discharge of TSF seepage into the downstream environment.

The water quality model assumed that 50% of all tailings seepage is collected in these groundwater extraction wells. However, no rationale and/or analysis were provided to back up this assumption. In fact, no details were provided in the TSF Detailed Design report (AMEC, 2011) on the design and performance of these groundwater extraction wells. Note, however, that Table 7-1 in this report indicates 6 groundwater extraction wells each for the North Dam and South Dam, respectively.

In a follow-up response, AMEC (2012b) pointed out that "*seepage is partially captured by operation of freshwater supply wells located downstream of the North and South Dams. These wells are not intended or designed to be seepage recovery wells*". However, the fact, that seepage interception is assumed for "base case" water quality predictions (AMEC, 2012), presumably implies that the proponent is planning to use those wells to intercept TSF seepage.

In my opinion, it would be prudent to design these groundwater extraction wells in such a way as to maximize future recovery of TSF seepage (beyond the assumed 50%) and hence further minimize potential future water quality impacts to the downstream aquatic environment. This approach would safeguard against potential upsets in mining, milling and/or tailings operation which could potentially result in higher contaminant loading from TSF seepage than is currently predicted.

To date, four pumping tests have been performed (two in the South Dam area and two in the North Dam area). These pumping tests indicated that the well yields and the zone of influence (ZOI) of individual pumping wells vary significantly by location and screening interval due to the highly heterogeneous nature and distribution of the valley sediments. For example, of the two pumping wells drilled in 2011 downstream of the North Reclaim Dam, one (NPW1) had to be abandoned (well silted in during development) while the other well (NPW2) produced a very high yield (69 L/s). Similarly, two pumping wells drilled in the South Dam area (PT04-1 and BH10-208) produced high yields (> 6.2 L/s) while one well (SMW) drilled near the South Reclaim Pond was unproductive and had to be abandoned. These initial results demonstrate that seepage interception using groundwater extraction wells is generally feasible but will require careful design and planning.

In the reviewer's opinion, the assumed seepage interception target of 50% is modest and likely achievable. However, additional hydrogeological field work will be required to finalize the technical specifications for these groundwater extraction wells (specific locations and number of wells, screening interval etc).

It should be noted that all productive test wells completed to date are screened in highly permeable, confined layers at greater depth. Such deep wells may not be very efficient in intercepting seepage from the TSF which can be expected to flow preferentially in shallow sediments (potentially still only partially saturated today) due to the vertical anisotropy of the alluvial sediments and upward gradients in the valley. However, pumping from these deep groundwater wells may gradually "pull" the TSF seepage plume into these deeper confined aquifer layers. Consideration should therefore be given to screening permeable layers at shallower depth (near the water table) to maximize seepage interception and minimize cross-contamination of deeper layers.

I recommend that additional pumping wells be drilled and pumping tests be conducted in the proposed areas of groundwater recovery (i.e. immediately downstream of the North and South Reclaim Dams). The results of these tests should then be used to assist in calibration of a 3D groundwater flow model and final design of groundwater recovery wells (see section 8 for more details).

3.4 Relative Proportion of Seepage Discharge To Quarry and Trail Creeks

Table 3 summarizes the relative (incremental) proportion of seepage water discharging into Trail Creek and Quarry Creek at selected locations downstream of the respective reclaim dams assumed by AMEC (2012) for water quality predictions. No rationale and/or supporting analysis was provided by AMEC for these assumed discharges with distance from the TSF facility.

The relative proportion of TSF seepage discharging into Quarry Creek and Trail Creek will depend on several factors including,

- depth of TSF seepage plume (influenced by hydraulic gradients and vertical anisotropy of valley sediments beneath the TSF)
- geometry and transmissivity of valley sediments downstream of the Reclaim Dam
- recharge from valley side hills and resulting vertical (upward) hydraulic gradients

At the present time insufficient information is available to evaluate the above controlling factors and to estimate the likely discharge pattern of TSF seepage with distance from the reclaim dams with any degree of accuracy.

In my opinion, the proportion of discharge of TSF seepage in the first few hundred meters downstream of the reclaim dam may be significantly higher than assumed by AMEC (2012) because (i) TSF seepage can be expected to move preferentially in shallow, permeable layers due to the vertical anisotropy of the valley sediments and (ii) upward gradients are likely to prevail downstream of the reclaim dams due to the valley topography, in particular near the South reclaim dam where the valley floor narrows significantly.

Table 3. Assumed relative proportion of TSF seepage discharging to surface water with distance from the reclaim dam (AMEC, 2012).

Water Quality Point	Distance from Reclaim Dam (m)	Assumed Relative (Incremental) Discharge of TSF Seepage Water (%)
Quarry Creek Drainage		
Quarry Creek at Immediate Dilution Zone (IDZ)	~100 m	8%
Quarry Creek (Fish Barrier)	~500 m	15%
Quarry Creek at W11N	~3,700 m	77%
Trail Creek Drainage		
Trail Creek at W4 (below South Reclaim Dam)	123 m	7%
Trail Creek at diversion ditch discharge point	260 m	14%
Trail Creek Mouth (at Kluea Lake)	~1,600 m	79%

Additional sensitivity analyses should be completed using the water quality model to predict water quality in these streams for a reasonable range of assumed relative discharges with distance from the North and South Reclaim Dams.

If these sensitivity analyses indicate that exceedance(s) of water quality objectives in the upstream reaches of Trail Creek (above Kluea Lake) and/or Quarry Creek (above W11N) are dependent on the assumed % relative discharge then additional field work and numerical modeling should be completed to provide a basis for estimating the discharge pattern of groundwater impacted by TSF seepage with distance from the reclaim dam, including

- Complete surveys of stream flow and water quality parameters (field EC and temperature) along the stream reaches of interest (during base flow conditions) to delineate zones of groundwater discharge

- Measure vertical hydraulic gradients between the creek and the underlying valley aquifer (using drive points) to assess direction of flow
- Calibrate a 3D groundwater flow model for the stream reach of interest (using available groundwater levels and results of stream surveys) and use model to estimate relative discharge of TSF seepage to Trail Creek and/or Quarry Creek.

3.5 Seepage from RSA

A review of the hydrogeological conditions in the Rock Storage Area (RSA) was beyond the scope of this review. However, seepage from the RSA represents a significant potential source of contaminant loading to the TSF area and affected drainages (Trail Creek and Quarry Creek), in particular after closure, and is therefore briefly discussed in this context.

The RSA is located within the TSF and Trail Creek watersheds. Using surface topography as a proxy, about 40% of the RSA drains towards the TSF, 40% drains to Trail Creek upstream of Kluea Lake and 20% drains to the open pit (AMEC 2012b).

The water quality predictions presented in AMEC (2012) assumed that all waste rock seepage (100%) is collected and treated during active operation. In other words, no additional contaminant loading was assumed to occur during active operations due to seepage from the RSA. In my opinion, this assumption is optimistic. Some degree of seepage by-pass is likely inevitable and should be allowed for in the water quality predictions.

In a follow-up response, AMEC (2012b) estimated that about 5% of RSA seepage (or 0.6 L/s) may bypass the RSA seepage collection system and enter the local/regional groundwater system during active operations. Assuming groundwater flow follows surface topography, AMEC estimated that 40% of this seepage (or 0.25 L/s) would drain towards the TIA and 40% (or 0.25 L/s) would drain directly into Trail Creek. AMEC (2012b) noted that this seepage may take on the order of 50 years to reach Trail Creek. However, in my opinion, travel times could be significantly shorter due to low bedrock storage (<< 10%), preferential flow along high-permeability pathways and/or re-emergence as springs along the hill sides. I therefore recommend that the influence of potential seepage by-pass from the RSA on water quality in Trail Creek during active operations be evaluated in a sensitivity analysis using a range of potential seepage by-pass rates (say 5 to 20%).

For post-closure conditions, the water and load balance model assumes that 30% of waste rock seepage reports to the TSF and 70% reports to the open pit. However, no rationale or explanation was provided to justify this assumption. Furthermore, it is unclear how seepage from the RSA was allocated between the Trail Creek and Quarry Creek drainages.

Water quality predictions indicate that these assumed RSA seepage rates would significantly increase the loading of selected metals (Al, Cu, Zn) to the TSF post-closure (see Figure 3.4-60 in AMEC 2012) and potentially result in post-closure exceedances of BCWQ guidelines in Quarry Creek (see table 2)[3]. These water quality predictions highlight the importance of intercepting seepage from the RSA post-closure.

Considering the potential for post-closure exceedances in Quarry Creek (and Trail Creek?) further details should be provided on the proposed design of the seepage interception system of the RSA, its long-term operation (post-closure) and predicted performance (including seepage by-pass). Furthermore, the potential fate of seepage from the RSA towards the TSF area and Trail Creek should be evaluated and incorporated into the load balance model. For example, surface topography suggests that all seepage from the RSA ultimately drains to Trail Creek (with negligible flow towards Quarry Creek). Consideration of such detailed routing of RSA seepage into the load balance model may significantly change the post-closure water quality predictions for Trail Creek and Quarry Creek.

It is my understanding that the design of the seepage collection system for the RSA has not been completed yet and that additional hydrogeological studies are planned in the RSA to better understand the local hydrogeological conditions in this area. Seepage estimates from the RSA and their effects on water quality predictions during active operations (and closure) should be updated once these studies have been completed.

3.6 Scheduling and Priorities of Hydrogeological Work

The priorities and scheduling of any additional hydrogeological work in the TSF area depends on the following:

- Potential for environmental impact
- Construction Schedule

[3] It is unclear to me why the predicted post-closure water quality in Trail Creek does not increase in a similar fashion as predicted for Quarry Creek. Based on surface topography, I would expect that most, if not all uncontrolled seepage from the RSA will report to Trail Creek and not to Quarry Creek.

The potential for environmental impact depends on the seepage volumes and associated contaminant loads and the resulting receiving water quality (see table 2). However, these impacts need to be measured against applicable guidelines. It is my understanding that MMER guidelines will apply to the upper reaches of Quarry Creek during the period of active operation of the TSF. Water quality modeling suggests that seepage by-pass from the TSF in the North dam area will not exceed any MMER in Quarry Creek over the life of the mine, even in close proximity of the facility (Table 2). In other words, there is no immediate concern for seepage impacts to Quarry Creek.

Note, however, that BC water quality guidelines will eventually apply to Quarry Creek (once the TSF is closed and mine effluent discharge ceases). Current water quality predictions suggest that these guidelines may be exceeded in the upstream reaches of Quarry Creek (for Cu and Se) due to long-term seepage from the TSF post-closure (Table 2). However, the predicted exceedances are marginal and are well within the uncertainty of these types of predictions.

In my opinion, additional hydrogeological studies in the North Dam area (for environmental purposes) therefore have a lower priority (than in the South Dam area, see below) despite the fact that construction of the North Dam and tailings discharge will commence first (as early as late summer of 2014). I therefore recommend that additional hydrogeological work in the North Dam area be initially limited to installation of additional monitoring wells and groundwater extraction wells (if required for mill water supply). Monitoring of TSF seepage water quality and groundwater response to active tailings discharge and groundwater extraction (for mill water supply) will provide very valuable information to further assess potential future TSF seepage by-pass and associated contaminant loading to Quarry Creek. I recommend that the requirements for additional seepage interception downstream of the North Reclaim Dam (beyond mill water supply) be re-evaluated after the first 3 years of active operation of the Red Chris TSF.

It is my understanding that BCWQ guidelines may apply to Trail Creek during active operations and post-closure. Based on the information provided, I conclude that seepage from the TSF may potentially result in exceedances of SO4, Cd, and Se (Table 2) and possibly Cu (due to the potential impact of seepage from the RSA) in Trail Creek during active operations and/or post-closure.

Considering the potential for environmental impact to Trail Creek, additional hydrogeological studies in the South Dam area should be a priority, despite the fact that tailings discharge into the South Dam area is not scheduled to start until year 3 of operations (~ late 2016). The primary objective of these additional hydrogeological studies should be to evaluate the requirements for seepage interception, and, if required, design and installation of suitable seepage mitigation measures. I recommend that these additional hydrogeological studies be completed at least 2 years prior to start-up of tailings discharge into the South Dam area.

In my opinion, additional hydrogeological studies in the Northeast Dam area have the lowest priority because (i) discharge and/or TSF seepage into the Nea Creek drainage will not occur until closure of the facility and (ii) the upper reach of Nea Creek is not fish-bearing. At the present time, I do not recommend additional hydrogeological studies in the Northeast Dam area (other than installation of proposed monitoring wells).

4 Information Gaps

4.1 Subsurface Characterization

A large number of drill holes have been completed over the years in the Red Chris TSF area commensurate with the size of the foot print area and the complexity of the subsurface conditions

The emphasis of these drilling programs has been on dam design (in particular stability) and as a result the majority of drill holes (and monitoring wells) are therefore completed along the alignment of the two proposed major dams (North and South Dams). However, sufficient additional drilling was completed within the foot print area of the TSF to provide a general understanding of the nature and spatial extent of the subsurface materials.

A review of the drill logs suggests the presence of glacio-fluvial valley sediments with a very wide range of particle size distributions ranging from silt&clay to gravels and cobbles. The majority of these glaciofluvial sediments are highly consolidated (moderately to very dense) except shallow sediments near the stream bed and isolated, deeper layers (paleo-channels?).

Initially, AMEC had subdivided the valley sediments into an "upper" and "lower" aquifer separated by a confining till layer. However, additional drilling in 2010 and water level readings suggest a very complex interlayering of fine-grained (low permeability) and coarse-grained (high permeability) sediments. Drilling and hydraulic testing suggest the presence of high-permeability zones (channels?) comprised of "clean" sands and/or gravels of limited lateral and vertical extent which run parallel to the valley. These highly permeable zones appear to be interbedded with lower permeability sediments of silty sand/gravels and till-like silts and/or clay.

The high heterogeneity of these sediments complicates the characterization of "average" hydraulic properties based on a few boreholes. Furthermore, this heterogeneity reduces our ability to model the hydrogeological system, in particular with respect to solute transport. Finally, installation and operation of seepage recovery wells can also be expected to be difficult, potentially requiring several pilot holes until a high-permeability zone suitable for pumping is intercepted.

In my opinion, the valley sediments within the foot print area of the Red Chris TSF (including dam foot prints) are characterized adequately for the purpose of TSF design and seepage assessment. However, additional characterization work is recommended in the reaches downstream of the North Dam and in particular the South Dam, where interception of TSF seepage may be required to protect the receiving environment (see section 8.1 for more details).

The valley sediments are underlain by relatively low permeability bedrock comprised primarily of sandstones and siltstones with occasional intrusives (diorite, andesite). Hydraulic testing in bedrock suggests that the permeability of these bedrock units is generally low (except for localized fracture zones) and is typically several orders of magnitude lower than the "bulk" permeability of the valley sediments. Therefore, I agree with AMEC's conclusion that the bedrock represents only a minor pathway for seepage from the TSF. In my opinion, additional bedrock characterization in the TSF area is therefore not warranted at this time.

4.2 Depth to Bedrock

Seismic refraction surveys have been completed along several cross-sections in the TSF area (including the center line of all three proposed dams and two reclaim dams) in two campaigns (2004 and 2010) to determine the depth to bedrock.

A comparison of the 2004 seismic surveys with more detailed drilling results (obtained during the 2010 drilling program) indicated that the earlier geophysical interpretation underestimated the depth to bedrock by about 20-30m (because the highly consolidated deeper sediments showed a similar signal to that of bedrock). It is my understanding that a correction was applied to the 2004 seismic survey results (to correct for this discrepancy) in developing the bedrock profiles shown in AMEC (2011). The additional surveys completed in 2010 showed good agreement with the depth to bedrock determined directly from drilling (notably at the alignment of the North Dam).

In my opinion, the updated seismic surveys provide a reasonable approximation of the depth to bedrock for all dam locations except the South Reclaim Dam. Drilling along the alignment of the South Reclaim Dam has been very limited (only one well) providing no opportunity to check the seismic refraction results. Furthermore, the contrast between the velocity of the deeper sediments (~2,000) and the inferred bedrock (~3,000 m/s) was smaller than in other areas of the TSF. Finally, the seismic survey at the South Reclaim Dam only covered the proposed alignment of the South Reclaim Dam and the full width of the bedrock "trough" is not known at this time.

Additional drilling and geophysical surveys are recommended to improve our understanding of the depth to bedrock across the Trail Creek valley (including side slopes) at the proposed location of the South Reclaim Dam (see also section 8.1.2).

4.3 Hydraulic Properties of Valley Sediments

In my opinion, the hydraulic properties of the valley sediments are not adequately understood and will require further study.

Hydraulic testing completed in the TSF area valley sediments is limited to two pumping tests in the South Dam area and two pumping tests in the North dam area. In all four tests, the pumping well was screened in very permeable clean gravel layers (typically confined at depth) and the inferred hydraulic properties (transmissivity, storage) may therefore not be representative of "average" aquifer properties.

To the best of my knowledge, no other hydraulic testing (lab testing, slug testing) and/or theoretical analysis (estimation of K from grain size analyses, estimation of average aquifer properties) has been completed to date to estimate representative hydraulic properties for the different sediments observed in the TSF area (ranging from clean sand and/or gravel to silty sand/gravel to silt/clay) and representative "average" aquifer properties in different portions of the TSF area.

I recommend that additional hydraulic testing (slug testing, pumping tests) be completed to determine the hydraulic properties for a wider range of glaciofluvial sediments observed in the TSF area. To this end, slug testing should be performed in less permeable valley sediments (in existing wells and possibly during drilling) and future pumping tests should include monitoring and interpretation of responses in less permeable units of the aquifer system not directly stressed. Future hydraulic testing should focus on the reaches downstream of the North and South Dams where TSF seepage may by-pass the passive collection systems and active seepage interception may be required.

In addition, an attempt should be made to estimate average aquifer properties (Kh, Kv, Sy, Ss) in critical reaches of the TSF (e.g. North and South Dam) based on the observed relative proportions of different sediments (e.g. clean S/G, silty S/G, silts/clay) in the valley aquifer system.

Finally, the 2010 pumping tests completed in the North and South Dam reaches (at BH10-006 and BH10-208, respectively) should be re-interpreted using an updated 3D groundwater flow model (see section 8.2).

4.4 Groundwater Flow Field

A significant number of groundwater monitoring wells and piezometers have been installed over the years in the Red Chris TSF area and groundwater levels have been monitored in some of those wells by RCDC staff since September 2010. However, to the best of my knowledge, no systematic monitoring plan has been developed and no detailed interpretation of the groundwater flow field has been completed to date.

The only interpretation of groundwater levels for the Red Chris TSF provided to date was a compilation of historic groundwater levels for historic wells (from a wide range of dates) and an inferred (generalized) contour plan of piezometric levels across the TSF area (AMEC, 2012a). No further discussion was provided in this response on the general groundwater flow field (such as a comparison to the groundwater flow field predicted by the 3D groundwater flow model), the observed horizontal and vertical gradients and/or potential reasons for significant outliers.

Furthermore, I could not find any discussion on the influence of the existing 3D groundwater flow field, notably the significant depth to groundwater (unsaturated zone), on the side terraces and converging groundwater flow towards the center of the valley, on seepage estimates from the TSF. In my opinion, the groundwater flow field and its potential influence on TSF seepage should be evaluated in more detail.

I recommend that the following information be compiled:

- A reconnaissance of all existing monitoring wells (and piezometers) in the Red Chris TSF area (including measurement of well ID, total depth, stick-up) and geodetic survey of top-of-casing of all existing wells
- Summary of all currently available monitoring wells with well construction details (well ID, total depth, screening interval, stick-up, TOC elevation) (preferably in a searchable database)
- A compilation of historic groundwater level data (preferably in a searchable database)

- A hydrogeological interpretation of the groundwater flow field, including horizontal and vertical gradients, recharge and discharge areas
- A review and interpretation of seasonal time trends in groundwater levels
- An assessment of the influence of the 3D groundwater flow field (depth to groundwater, converging flow towards valley center, vertical gradients) on TSF seepage over the life of the project

As discussed earlier, additional drilling and monitoring well installation is proposed for the areas downstream of the North and South Dams. Any new monitoring wells installed during these proposed field programs should be included in this analysis of the groundwater flow field.

4.5 Baseline Groundwater Quality

Limited information is available to date on the natural baseline groundwater quality in the TSF area and associated drainages (Trail Creek and Quarry Creek). It is my understanding that RCDC has initiated a groundwater quality monitoring program across the site (Jack Love, pers. Comm.). However, such groundwater quality data have not been systematically compiled and interpreted. I recommend that the following work be completed:

- A compilation of historic groundwater quality data (preferably in a searchable database)
- Development of a formal groundwater quality monitoring plan that outlines the monitoring wells to be sampled, sampling procedures, the parameters to be analysed, QA/QC procedures and reporting requirements;
- A hydrogeochemical interpretation of spatial variations in baseline groundwater quality by area, depth, lithology, etc. (e.g. potential influence of mineralized bedrock on groundwater quality; source of elevated natural sulphate levels in Trail Creek/Kluea Lake)
- A review and interpretation of seasonal time trends in groundwater quality

Again, any new monitoring wells installed during these proposed field programs downstream of the North and South Dams should be included in future groundwater quality monitoring and hydrogeochemical interpretation.

5 Review of Contingencies and Mitigation Measures

The scope of this independent third party includes a review of contingencies and mitigation measures proposed by RCDC for seepage management of the TSF footprint and receiving environment potentially impacted by seepage.

The following contingencies and mitigation measures have been proposed to manage seepage:

- Geomembrane Liner upstream of North dam (during start-up)
- Dam Drainage Collection system (Underdrain and Reclaim Dams)
- Groundwater extraction wells

Note that the primary focus of seepage mitigation has been to control seepage losses to reduce make-up water requirements and secure mine water supply (in particular during early stages of mining).

5.1.1 Geomembrane Liner

The detailed design of the Red Chris TSF (AMEC, 2011) includes placement of a 60-mil HDPE liner over 50% of the foot print of the start-up pond. This liner will be keyed into the low-permeability till core of the North Dam. The primary purpose of this liner will be to reduce seepage losses from the start-up pond during the initial years of operations. Numerical modeling suggests that this liner will reduce seepage losses from the startup pond by about 50% (from ~70 L/s to ~35 L/s) provided a high quality installation can be achieved (i.e. $K_{liner} = 10^{-9}$ m/s or lower).

The use of a 60-mil HDPE liner for seepage control is standard industry practice and can be expected to significantly reduce the seepage from the start-up pond. It should be noticed, however, that good quality control will be required to achieve the targeted reduction in seepage. This will require careful preparation of the ground surface and quality control during welding of the joints of the liner.

AMEC concluded that lining of the full extent of the startup pond is not required because the predicted seepage losses can be compensated for by extraction of groundwater from recovery wells. This assessment is supported by pumping test results which indicated adequate yield for groundwater pumping (~70 L/s in NPW2 alone).

In my opinion, the proposed lining of 50% of the start-up pond is a reasonable mitigation measure to reduce seepage from the start-up pond for operational needs. The existing production well (in the deep aquifer) appears to be capable of making up the water losses incurred from the remaining unlined 50% of the pond area.

AMEC did not explicitly assess the environmental impact of lining only 50% of the start-up pond. Seepage rates from the unlined portion of the start-up pond have been estimated to be ~32 L/s (using MODFLOW model). Such initial seepage rates (prior to sealing with tailings) are higher than the seepage rates assumed in the water quality model for active operation of the Red Chris TSF (~20 L/s). However, water quality in the start-up pond initially represents (uncontaminated) runoff water (i.e. no environmental impact) and is only gradually displaced by mill process water. Considering the short period of losses of process water from the start-up pond and the permitted discharge of TSF water into Trail Creek (i.e. MMER apply), lining of only 50% of the start-up pond appears, in my opinion, acceptable from an environmental perspective.

It should be emphasized that this liner placement is primarily intended to reduce seepage during the start-up period (when the pond water represents clean runoff water). Once milling operations start, tailings will be discharged into the startup pond, gradually sealing the base of the TSF foot print area due to the low permeability of the tailings. Numerical modeling indicated that placement of the liner has only a very small effect on seepage rates once the tailings cover the foot print of the TSF (and have sufficiently consolidated) (AMEC 2001, Appendix E).

It is my understanding, that TREAT and the community have suggested a full geosynthetic lining of the entire foot print area of the TSF as an option to minimize tailings seepage. In my opinion, lining of the full TSF with a geosynthetic liner is not required because (i) current water quality predictions suggest that seepage from the TSF (without full liner) has only a marginal impact on Trail and Quarry Creeks and (ii) active seepage recovery (using recovery wells) downgradient of the North and South Reclaim Dams is a feasible contingency measure.

5.1.2 Dam Collection System

A number of features have been included in the TSF design to collect seepage from the North and South Dams, including (i) an underdrain system consisting of clean S&G (with max fines content of 5%) and (ii) seepage collection dams (so-called reclaim dams).

The use of an underdrain system is standard practice for such tailings dams and is designed to maintain the phreatic surface at the ground surface (for stability). It should be noted that the underdrain systems will only collect seepage if the hydraulic head in the foundation soils is equal to or higher than ground surface. At present, this condition is only met in the center of the valley. Groundwater levels towards the valley sides are currently many meters below ground surface. Hence the underdrain systems may not intercept much seepage until the piezometric head in the underlying foundation soils have risen due to tailings seepage.

The detailed design of the Red Chris TSF (AMEC, 2011) also calls for the construction/operation of small seepage collection dams (i.e. reclaim dams) to be located about 650m downstream of the center-line of the North and South dam, respectively. The purpose of these collection dams is twofold (i) to facilitate seepage capture, and (ii) collection of construction water draining from the hydraulically-placed cyclone sand (AMEC, 2011). To reduce seepage from the reclaim ponds a geomembrane liner tied into the till core will be extended upstream approximately 70m from the centerlines of both dams.

To the best of my knowledge no rationale was provided for (i) the distance of these reclaim dams from the center line of the tailings dams and (ii) the extent of lining of the upstream pond area. Furthermore, no analyses were presented to estimate the amount of TSF seepage collected in these collection dams and/or lost from the collection pond to the subsurface[4].

In my opinion, there is significant uncertainty about the efficacy of these collection ponds in intercepting seepage from the TSF facility which is not already collected in the dam underdrain system. Considering the significant depth of permeable sediments beneath the North and South Reclaim Dams it is likely that a significant portion of TSF seepage will not be collected in the reclaim dam but instead by-pass within the valley sediments beneath the reclaim dams. I recommend that additional modeling be completed to estimate the amount of seepage by-passing in the permeable valley sediments underlying the reclaim dams (see section 8.2).

5.1.3 Groundwater Extraction Wells

Groundwater extraction wells are proposed downstream of the North and South Dams to provide freshwater make-up as required for the processing plant. When in operation, these wells will also capture a portion of the seepage exiting the TSF (p. 44, AMEC, 2011).

[4] Although these reclaim dams were included in the 3D MODFLOW model, no estimates of seepage recovery in the collection ponds were reported (these ponds were not included in the SEEP/W cross-sectional model). In any event, the 3D MODFLOW model is, in my opinion, not sufficiently detailed and calibrated to observed groundwater levels to predict such localized seepage rates.

In my opinion, the seepage control strategies reviewed above will likely not be sufficient to control TSF seepage which enters the underlying (permeable) valley sediments. Therefore, seepage recovery using active pumping downstream of the reclaim dams may be required to reduce seepage by-pass and associated contaminant loading to the receiving surface water (in particular in the Trail Creek drainage).

The water quality model assumed that 50% of all TSF seepage by-passing the dam collection system (drains, reclaim dams) will be captured by the groundwater recovery wells. As discussed in section 3.3, this is a modest and achievable target but will nevertheless require careful planning and design. One concern would be that extraction wells which are screened in deep, confined aquifer layers (like NPW2) may not intercept seepage in shallow (permeable) sediments. I recommend that additional field work and numerical modeling be completed to assist in the design of such seepage recovery wells (see section 8 for more details).

6 Model Assessment

This section provides review comments on the groundwater flow modeling (SEEP/W and MODFLOW) completed to date for the Red Chris TSF area in support of permit applications (AMEC, 2011).

In addition, some general comments are provided on hydrogeological aspects of the water and load balance model which was developed to predict water quality impacts (AMEC, 2012). Note again that a review of geochemical modeling (to determine source terms) was beyond the scope of this review.

6.1 3D MODFLOW Analysis

In 2004, a 3D groundwater flow model was developed for the Red Chris TSF using MODFLOW (AMEC, 2004). This early model was used to provide initial estimates of groundwater flow in the valley aquifer and future seepage from the proposed TSF (at closure). In 2010, this flow model was updated to incorporate recent findings of the 2010 field program (drilling, hydraulic testing) (AMEC, 2011, Appendix D).

6.1.1 Model Setup

The MODFLOW model consists of 3 uniformly thick model layers, which represent the following hydrostratigraphic units:

- Model Layer 1 (10m): Upper aquifer ("upper sands" or "discontinuous till")
- Model Layer 2 (18m): Lower aquifer ("lower sands")

- Model layer 3 (10m): Lower aquifer ("lower sands" or "buried high K channel")

The underlying bedrock was assumed to be impermeable and was therefore represented as a no-flow boundary.

The assumption of uniform thickness of overburden sediments significantly simplifies the true 3D geometry of the valley aquifer and limits the ability of the model to evaluate the true direction and quantity of groundwater flow. Drilling and geophysics clearly demonstrate that the valley sediments are significantly deeper in the thalweg of the valley (in excess of 100m) and "pinch" out towards the valley sides (as described in AMEC, 2011). This valley geometry likely explains the observed convergence of groundwater flow in the center of the valley (see e.g. groundwater level contours near the North and South Dams).

Furthermore, no rationale is provided for the lateral and vertical extent of the high-K channels (assumed in model layer 3). These high K channels are a critical component of the aquifer system (acting as a major drain in the valley) and their spatial distribution in the model should be consistent with drilling results and pumping test results completed in these layers.

The seepage from the tailings (and associated pond) was simulated indirectly by using a general head boundary (GHB) condition. This approach tends to overestimate seepage for free-draining conditions (as gradients greater than 1 can be produced with a GHB). Conversely, this approach may underestimate seepage if the piezometric head in the aquifer reaches into the tailings deposit[5]. In my opinion, an explicit representation of the tailings deposit will provide more reliable estimates of tailings seepage.

6.1.2 Model Calibration

The 2010 model was "calibrated" for current conditions using only a small subset of groundwater levels (in fact using only the 6 wells and groundwater levels available for calibration of the 2004 model). More recent groundwater levels observed in the BH10 series of wells and/or drawdown observed during the 2010 pumping tests were not used for calibration of the 2010 MODFLOW model.

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[5] Note also that I could not reproduce the reported conductance terms provided in Appendix D using the assumed K for tailings of 1*10-7 m/s. The tailings conductances used for the GHB should be checked to confirm that they represent the reported tailings K of 1*10-7 m/s.

For current conditions, recharge from precipitation was assumed to be the only input to the valley aquifer. Lateral recharge from the side valleys (via shallow overburden and/or deeper bedrock flow) was not modeled.

In my opinion, there are serious flaws with calibration of this flow model. First, the calibration targets used for model calibration are too few and clustered in one area (four of the five in two areas and do not cover a sufficiently large portion of the model domain to allow a calibration of such a large scale model. Second, as pointed out by THREAT (2012), several groundwater levels used for model calibration differed by many meters from the groundwater levels reported in the original drill logs (and used for plotting of piezometric contours (see AMEC, 2012a). Finally, the "calibrated" recharge value of 600mm implies essentially 100% recharge which is unrealistic and suggests problems with the conceptual model and/or model calibration.

6.1.3 Model Predictions

The 2010 model predicts that current "baseline" groundwater flow beneath the North Dam and South Dam are about 20 L/s and 100 L/s, respectively. According to AMEC, the significantly higher flows predicted for the South Dam area are caused by additional groundwater flow from the Northeast valley and the resulting steeper gradients near the South Dam area. If correct, this would imply that seepage interception downstream of the South Dam may require significantly higher pumping rates than beneath the North Dam.

In my opinion, these flow predictions are very preliminary and carry significant uncertainty due to the simplified setup of the model and lack of model calibration. Additional model calibration and sensitivity analyses should be completed to evaluate current groundwater flow beneath these two dam reaches (see section 8.2).

The model was also used to predict seepage rates from the TSF for the following scenarios:

- Start-up Pond (unlined and lined; pond level at el. 1101m amsl[6])
- Intermediate stage of TSF filling (tailings at el. 1130m amsl)
- Closure conditions (Pond at el. 1170m amsl)

The highest seepage rates were predicted for the start-up pond without liner (72 l/s). The lowest seepage rates were predicted for the intermediate stage of TSF filling (13-25 L/s)

[6] Note that the SEEP/W analysis assumed a pond elevation of 1096m amsl (i.e. 5m lower)

with seepage rates for post-closure conditions predicted to be only slightly higher (18-32 L/s). Again, TSF seepage rates towards the South Dam are predicted to be significantly higher than towards the North Dam (about 4 times higher for closure).

Unfortunately, no sensitivity analyses were performed to assess the influence of the hydraulic conductivity and spatial distribution of the valley sediments (for the two aquifer units as well as the till aquitard unit) on predicted seepage rates. In addition, no contour plans of predicted piezometric heads were presented to assess whether the tailings remain underdrained or whether seepage flows are restricted due to the transmissivity of the valley aquifer system.

In my opinion, these predictions for TSF seepage are preliminary and carry significant uncertainty due to the idealized geometry of the model and lack of adequate model calibration. Additional model calibration and sensitivity analyses should be completed to evaluate future seepage from the TSF facility (see section 8.2).

The MODFLOW model was also used to assess the efficacy of various seepage mitigation measures, including lining of the start-up pond, installation of a seepage cut-off wall and operation of groundwater extraction wells.

The MODFLOW model predicted that full lining of the start-up pond with an imperfect liner ($K=1*10^{-8}$ m/s) would not significantly reduce seepage from this pond (i.e. seepage reduction from 73 to 69 L/s). The model predicted that a liner with a permeability of $1*10^{-9}$ m/s would be required to reduce pond seepage to 32 L/s. However, no differences in seepage rates were predicted for the case of 50% and 100% lining of the pond. This finding is not intuitive and contradicts findings from the SEEP/W modeling, which suggested a 10-20 fold decrease in seepage for the case of 100% lining vs 50% lining (see below). These discrepancies in predicted pond seepages using MODFLOW and SEEP/W should be explained.

The MODFLOW model also predicted that installation of a cutoff wall to a depth of 30m (reasonable practical depth limit of installation) would not be effective. I generally agree with the conclusion that cutoff walls are an inefficient means of reducing seepage from the start-up pond and TSF for this deep aquifer. However, it should be noted that the simplified MODFLOW model may significantly overestimate seepage by-pass beneath a cutoff wall. In practice, the presence of low-permeability layers (either low-K till or even silty sand layers with moderate K) may reduce vertical by-pass beneath a cutoff wall. The current model does not consider this aquifer complexity (other than assuming an anisotropy ratio of 10) and is therefore not well suited to assessing the efficacy of cutoff walls.

Finally, it should be noted that documentation of the modeling results (in particular model predictions) was very limited. For example, the modeling report did not include any discussion/presentation of predicted piezometric heads (in plan view and/or cross-section) or any presentation/discussion on predicted water balances. Such information should be included in future reports on groundwater modeling studies to allow an independent assessment of the modeling results.

6.1.4 Steady-state vs Transient

All MODFLOW modeling runs were completed assuming steady-state conditions. No discussion or analysis was provided to justify this approach. Clearly, seepage from a water storage pond or a TSF facility is a transient process and seepage rates will change over time. Although the TSF area grows over time (suggesting an increase in seepage volume over time), unit seepage rates (per unit area) are typically significantly higher during the early stages of TSF filling because:

- Free water or tailings slurry (with higher K) is in direct contact with the ground surface
- Free-draining conditions may persist for extended periods of time at the base of the pond and/or tailings deposit implying maximum vertical hydraulic gradients (“unit gradient”) until foundation soils saturate completely

AMEC should demonstrate whether the steady-state assumption is a conservative approach for estimating seepage rates from the TSF (in particular during start-up and active filling). To this end, the magnitude of transient seepage rates and the time required to reach steady-state conditions should be evaluated.

6.1.5 Conclusions

In my opinion, the 3D MODFLOW model for the Red Chris TSF is highly simplified and has not been properly calibrated against the available field data (i.e. observed groundwater levels, pumping test results). As such the model should be considered an initial “conceptual model” rather than a “calibrated model” and the predictive capability of this model is, in my opinion, limited. Considering the preliminary nature of this model, the scope of sensitivity analyses for key predictive parameters (such as the rate of TSF seepage) is insufficient.

I recommend that the existing 3D groundwater flow model be updated and refined using the 2010 field investigation results (and any additional characterization work completed prior to model update). Once refined, this groundwater flow model should be calibrated using all available groundwater level information. Seasonal trends in groundwater levels should be used to estimate/calibrate the recharge to the valley aquifer system. In addition, the transient response of the pumping tests completed in 2010 and 2011 in the Red Chris TSF area should be used for transient calibration of the model.

Once calibrated the updated model should be used to update current predictions of TSF seepage for active and post-closure conditions (see section 8.2 for more details).

6.2 2D Seep/W Analysis

Two-dimensional SEEP/W modeling analyses were performed in 2010 to support the detailed design of the TSF (see Appendix E of AMEC, 2011). The primary objective of this modeling was to assess the phreatic surface in the dam (for dam stability calculations). Furthermore, the 2D model was used to check post-closure TSF seepage estimates obtained using the 3D MODFLOW model.

Additional sensitivity analyses were also completed in late 2011 using the 2D SEEP/W model to address additional requests for information from the regulatory agencies (AMEC, 2011b).

6.2.1 Model Setup

The SEEP/W model comprises idealized cross-sections for the South Dam and the North Dam, respectively. Each model includes the following hydrostratigraphic units:

- Tailings (where applicable)
- Dam construction materials (four main zones)
- Foundation soils
- Bedrock

The selected cross-sections approximate the conditions encountered near the center of the valley ("thalweg"), i.e. the alignment with the greatest thickness of tailings and greatest depth of "foundation soils" or valley sediments. To obtain estimates of total seepage, the cross-sectional fluxes were multiplied by the length of the dam, then adjusted for the average depth of the aquifer (AMEC, 2011; Appendix E).

In my opinion, the setup of the 2D model is reasonable but the extrapolation to 3D seepage estimates is not conservative (with respect to estimating TSF seepage). By scaling cross-sectional seepage rates to the depth of the aquifer, AMEC implicitly assumes that seepage rates are controlled by the transmissivity of the valley sediments (i.e. shallower sediments = less seepage flow). This assumption contradicts the findings of sensitivity analyses which indicated that seepage rates are primarily controlled by the (vertical) hydraulic conductivity of the tailings. Supporting calculations and/or simulation (using a 3D model) should be provided to support this approach of scaling 2D fluxes to 3D fluxes.

It might be argued that the general agreement of seepage rates obtained using the 3D MODFLOW model and the 2D SEEP/W model justifies the use of the assumed scaling factor. However, as mentioned earlier, the 3D MODFLOW model is not calibrated and its seepage predictions carry significant uncertainty at this point. Furthermore, the assumed hydraulic parameters for aquifer materials differ significantly between those two models. For example, the MODFLOW model assumed the presence of highly permeable flow channels at depth which is absent in the 2D SEEP/W models (even in sensitivity analyses). A direct comparison of modeling results would only be possible if the same hydraulic conditions are assumed.

6.2.2 Boundary Conditions

The SEEP/W model assumed constant head boundaries at the upstream and downstream boundaries. No justification was given for the assumed head values used at these boundaries.

The upstream boundary (for post-closure) was assumed to be equal to the elevation of the post-closure tailings pond (el=1175m amsl). At present, the groundwater level in the valley aquifer in this upstream area is about 1097m amsl. In other words, it is assumed that the piezometric level in the upstream area will increase by about 80m. Note that this assumption significantly reduces vertical gradients through the tailings deposit and hence seepage rates from the pond (relative to free-draining conditions that would prevail during early filling). Supporting analyses (preferably transient modeling) should be carried out to demonstrate that seepage from the TSF will indeed result in the assumed mounding at closure.

6.2.3 Steady-state vs Transient Model

All SEEP/W modeling runs were completed assuming steady-state conditions. As for the case of MODFLOW modeling, no discussion or analysis was provided to justify this approach. Again, I recommend that transient effects be evaluated to determine whether steady-state models provide conservative seepage estimates.

6.2.4 Model Predictions

The SEEP/W analyses were undertaken for the following cases:

- The starter dam for the North Dam with the start-up water pond and prior to deposition of tailings into the impoundment.
- The North Dam in its closure configuration
- The South Dam in its closure configuration

In all three cases, numerous sensitivity analyses were completed to assess the sensitivity of the predicted seepage rates to the assumed K_h/K_v of the tailings, K of the foundation soils and extent of liner (North Dam only).

Notwithstanding the limitations of the 2D modeling approach discussed above, the results of these sensitivity analyses are plausible and provide good insight into the dependency of the predicted seepage rates on the liner extent (for start-up pond) and the hydraulic conductivity of tailings and foundation soils (for post-closure TSF).

The pond start-up simulations illustrate the strong control of (i) the hydraulic conductivity of the foundation soils and (ii) the extent of the geomembrane liner on seepage losses from the pond.

The post-closure simulations suggest that post-closure seepage rates are primarily controlled by the vertical hydraulic conductivity of the tailings deposit. According to these sensitivity analyses the hydraulic conductivity of the foundation soils only becomes a significant factor for "average" K values of the entire tailings deposit greater than $K_h=5*10^{-7}$ m/s ($K_v=5*10^{-8}$ m/s). As discussed earlier, I agree with AMEC's conclusion that it is unlikely that the average permeability of the Red Chris tailings deposit (at closure) will be higher than this assumed base case (see section 3.2).

Note again, that these sensitivity analyses assume that groundwater levels under the tailings pond mound to levels approaching the pond level. I recommend that additional sensitivity analyses be completed to assess the influence of this assumption on post-closure seepage rates. If post-closure seepage rates are sensitive to the assumed upstream boundary, transient analyses should be completed to determine a more appropriate boundary condition for the upstream boundary.

Finally, it should be noted that the 2D SEEP/W model predicted very similar post-closure seepage rates for both the North and South Dams. In contrast, the 3D MODFLOW model predicted significantly higher seepage rates for the South Dam relative to the North Dam (see section 6.1.3). This discrepancy in predicted seepage rates for the North and South Dams (using SEEP/W and MODFLOW) should be reconciled.

6.2.5 Conclusions

In my opinion, the seepage conditions for the Red Chris TSF (and in particular near the North and South Dams) have a significant three-dimensional component (due to the shape of the valley). I therefore recommend that future modeling of TSF seepage be completed using a 3D model to better capture the three-dimensional aspects of seepage. This approach will result in more realistic predictions of TSF seepage during operations and closure.

For more detailed recommendations of future groundwater modeling the reader is referred to section 8.2.

6.3 Water Quality Model

AMEC has developed a water quality model to predict water quality impacts due to operation of the Red Chris TSF (AMEC, 2012). As discussed in section 3.1.2, this water quality model makes several simplifying hydrogeological assumptions, including (i) the amount of seepage discharging from the TSF deposit and reclaim ponds, (ii) seepage collection & bypass, and (iii) discharge of seepage with distance from the reclaim dams.

As discussed earlier, there is significant remaining uncertainty about the magnitude of TSF seepage, seepage by-pass and discharge of seepage to the receiving surface water. Similarly, some uncertainty can also be expected on the assumed source terms for TSF seepage.

To the best of my knowledge no detailed sensitivity analysis has been provided to evaluate the influence of uncertainty in estimates of source terms, seepage rates from TSF and seepage interception on the water quality predictions for the receiving surface water, specifically Trail Creek[7].

I recommend that such sensitivity analyses be completed to demonstrate the potential influence of those uncertainties (TSF source term, amount of TSF seepage, % seepage by-pass) on water quality predictions in the Trail Creek watershed during active operations and post-closure. The results of such a sensitivity analysis will provide guidance on the scope of additional hydrogeological studies required for the Red Chris TSF area.

[7] The sensitivity analysis presented in AMEC (Dec 2011) only addresses creeks affected by mine effluent discharge (i.e. Quarry Creek and NEA Creek during active operations)

7 Monitoring Plan

The proposed groundwater monitoring plan for the Red Chris TSF is outlined in AMEC, 2011 (pp. 75-76). The proposed monitoring plan includes 2 sets of nested monitoring wells (screened at a depth of 15m in the upper aquifer and at a depth of 70m in the deep aquifer) at five locations:

- 2 pairs of nested wells downstream of the North Reclaim Dam
- 2 pairs of nested wells downstream of the South Reclaim Dam
- 1 pair of nested wells downstream of the Northeast Dam

In my opinion, the complexity of the local hydrogeology (heterogeneous sediments, 3D groundwater flow field) and the potential for surface water quality impacts will require a more comprehensive monitoring network than proposed by AMEC (2011).

I recommend that 3 sets of nested monitoring wells be installed downstream of the North and South Reclaim Dams, respectively (immediately downstream of any seepage recovery wells) for future monitoring of groundwater levels and groundwater quality:

- 1 set of 3 nested monitoring wells (screened in clean sediments at shallow depth (~5-15m), intermediate depth (~40-50m) and greater depth (~70-80m) in the central portion of valley floor
- 1 set of 2 nested monitoring wells each (screened in clean sediments at shallow and intermediate depth) on the eastern and western side of the valley floor

In addition, 1 set of 2 nested monitoring wells (screened in clean sediments at shallow and intermediate depth) should be completed in the central portion of the valley at a distance of about 500m downstream of each reclaim dam.

A single set of nested monitoring wells located at a central valley location immediately downgradient of the NE Dam (as proposed by AMEC) is considered sufficient in the NEA creek watershed.

Groundwater monitoring should include monthly water level monitoring and quarterly water quality sampling. Groundwater monitoring in those monitoring wells should commence at least one year prior to start of tailings deposition to establish baseline trends.

The groundwater monitoring plan for the Red Chris TSF should be reviewed and potentially updated once additional subsurface characterization and seepage analyses in the North and South Dam reaches (see section 8) have been completed.

8 Recommendations

8.1 Site Characterization Work

8.1.1 North Dam Area

The focus of future subsurface characterization work in this part of the TSF should be the reach downstream of the North Dam. I recommend that the following additional subsurface characterization work be completed prior to start-up of tailings operations:

- Drilling of 2 boreholes to bedrock downstream of the final toe of the North Dam (about 200m to the east and west of BH10-007, respectively) for further subsurface characterization; these boreholes should be completed as nested monitoring wells (screened at shallow and intermediate depth) for operational monitoring;
- Installation of a pair of nested monitoring wells screened in shallow aquifer (5-15m) and deep aquifer (60-70m) at the final toe of the North Dam (in the center of the valley near BH10-007) for operational monitoring;
- Installation of 1-2 additional groundwater extraction wells located immediately downstream of the North Reclaim Dam (as required for mine water supply);
- Installation of 3 sets of nested monitoring wells downstream of the North Reclaim Dam and associated groundwater extraction wells for routine monitoring (see section 7 for recommended screening intervals)
- Installation of 1 pair of nested monitoring wells about 500m downstream of the North Reclaim Dam for routine monitoring (see section 7 for recommended screening intervals)

Drilling and installation of all monitoring and pumping wells should be supervised by a qualified hydrogeologist or geotechnical engineer. Drill cuttings should be logged for colour, texture and moisture.

After completion of all monitoring wells, pumping test(s) should be conducted (3 days minimum) in the existing and/or any additional extraction wells to evaluate well capacity and radius of influence. Monitoring should include piezometers screened in the shallow, unconfined aquifer to evaluate potential capture of shallow seepage using these extraction wells.

8.1.2 South Dam Area

The following additional site characterization work is recommended in the reach downstream of the South Dam:

- Drilling of 2 boreholes to bedrock downstream of the final toe of the South Dam (about 200m to the east and west of BH10-206, respectively) for further subsurface characterization; these boreholes should be completed as nested monitoring wells (screened in shallow and intermediate aquifer) for operational monitoring;
- Installation of a monitoring well downstream of the final toe of the South Dam near BH10-206 (screened in shallow aquifer) for operational monitoring
- Installation of 3 sets of nested monitoring wells downstream of the South Reclaim Dam and associated groundwater extraction wells for routine monitoring; one set of wells should be completed in the center of the valley ("thalweg") and two sets on the eastern and western side terraces (see section 7 for recommended screening intervals)
- Installation of 1 pair of nested monitoring wells about 500m downstream of the South Reclaim Dam for routine monitoring (see section 7 for recommended screening intervals)

The drilling/well installation program should include detailed logging of soil samples, well development, hydraulic testing of a range of lithologies (including lower permeability units), and initial water quality sampling. Subsequently, the top of casing of all wells should be surveyed in and groundwater levels monitored monthly for an initial period of one year to determine horizontal and vertical hydraulic gradients. The monitoring wells should be sampled quarterly for an initial period of one year to determine baseline groundwater quality.

Consideration should be given to using transverse and longitudinal geophysical surveys (e.g. seismic refraction) in the Trail Creek valley (in particular near the alignment of the South Reclaim dam) to delineate the depth to bedrock and to assist in selecting locations for monitoring wells and recovery wells.

After completion of monitoring wells, a minimum of two groundwater recovery wells should initially be drilled downstream of the South Reclaim Dam. These pumping wells should be designed to intercept groundwater (and potential future seepage) from shallow and intermediate depth of the valley sediments. Drilling and well installation should be supervised by a qualified hydrogeologist and drilling logs prepared for each pumping well. Step tests and multi-day constant discharge tests should be performed to assess the capacity of these wells and to determine the capture zone of these recovery wells. Monitoring during these pumping tests should include piezometers screened in the shallow, unconfined aquifer to evaluate potential capture of shallow seepage using these extraction wells.

In addition, I recommend that a stream survey be conducted along Trail Creek (between the toe of South Dam and Kluea Lake) during baseflow conditions to evaluate zones of potential groundwater discharge. The stream survey should include measurements of stream flow and selected field water quality parameters (such as EC, Redox, and temperature). Consideration should also be given to installing shallow drive points to determine vertical hydraulic gradients along Trail Creek.

I recommend that the hydrogeological field work in the South dam area be completed at least 2 years prior to start of tailings discharge in the South Dam reach to allow adequate time for baseline monitoring and design of contingency measures for seepage interception (if required).

8.2 Groundwater Modeling

The following recommendations are provided for additional groundwater modeling for the Red Chris TSF:

- Update the 3D groundwater flow model for the entire TSF area using the results of the existing and additional proposed hydrogeological field work, including:
  - Refine geometry of the valley aquifer
  - Refine distribution of valley sediments; hydrostratigraphic units to be considered for this updated model may include[8]:
    - Coarse gravel/boulders
    - Clean sands and gravel
    - Silty sands and/or gravel
    - Silt/clay layers (till aquitards)

[8] In general, the concept of parsimony should be used, i.e. the complexity of the model (i.e. number of hydrostratigraphic units and their spatial distribution) should be commensurate with available site characterization and model calibration data. Hence, all five units may be included in areas of interest (e.g. near alignment of Dams or where pumping test data are available) while less detail may be sufficient in other areas of the valley where site characterization is incomplete or missing

        - Weathered bedrock
    - For future model include:
        - all proposed seepage collection components such as liner, dam underdrains, reclaim dams, extraction wells
        - any changes to the subsurface conditions due to planned borrow activities
- Calibrate this updated flow model using groundwater monitoring data from all existing and newly installed monitoring wells (including pumping test responses) plus observed baseflows in upper reaches of Quarry Creek and Trail Creek;
- Predict total amount of TSF seepage (total magnitude, seepage collection and seepage by-pass) for the following conditions:
    - Early start-up conditions (North dam reach only)
    - Start-up of South Dam area
    - Active operation (intermediate stage)
    - Post-closure conditions

    Scoping calculations/simulations should be completed to determine whether a steady-state approach is justified or whether a transient seepage analysis is required to predict TSF seepage rates for these conditions.
- Complete sensitivity analyses for active operations and post-closure conditions to assess the potential range of TSF seepage for a plausible range of key model parameters (including Kh/Kv of tailings & valley sediments)
- Evaluate the relative discharge of groundwater (and TSF seepage) between the toe of the South Dam and the mouth of Trail Creek (a smaller sub-domain may be used for this analysis)
- Use the calibrated groundwater flow model to assist in the final design of seepage interception system(s) downstream of the reclaim dams (if required for environmental protection)

The model documentation should include predicted TSF seepage, relative proportion of TSF seepage collected in drains, reclaim dam, extraction wells and seepage by-pass (underflow) reaching the downstream environment for the different conditions evaluated. The model documentation should also include visualization of predicted groundwater flow fields (in plan and section view).

The results of this updated groundwater modeling should be used to update the water quality model, specifically the hydrogeological assumptions made in the model. These updated water quality predictions should then be used to develop operational targets for seepage interception downstream of the North and South Reclaim Dams (if required for water quality protection).

I recommend that the proposed groundwater modeling be initiated after completion of the proposed hydrogeological field work and be completed prior to start of tailings discharge into the Red Chris TSF. These initial model predictions should then be compared to the observed initial response of the groundwater system to the early tailings discharge (from the North Dam). If required, the model should then be updated to reflect these large-scale field responses prior to start-up of tailings discharge from the South Dam.

9 Closure

We trust that the information provided in this review report meets your requirements at this time.

Should you have any questions or if I can be of further assistance, please do not hesitate to contact the undersigned.

ROBERTSON GEOCONSULTANTS INC.

Prepared by:

Christoph Wels, Ph.D., M.Sc., P.Geo. (B.C.)
Principal and Senior Hydrogeologist

END

APPENDIX A

Scope of Work

for Independent Hydrogeological review

DRAFT

Red Chris Mine

Third Party Review

Scope of Work - Hydrogeology

Submitted to: Red Chris Monitoring Committee (RCMC)

Version	Prepared or Edited by
V1	Scott Jackson MoE
V2	Patrick Hudson THREAT
V3	Jack Love RCDC compilation and edits
V3.1	THREAT
V3.1a	THREAT
V4.1	RCDC
V4.2	THREAT

1.0 Scope

The scope of the 3rd party review is to:

- assess the hydrogeological characterization work done to date for the Red Chris project; and
- Identify gaps in the data as required to assess the hydrogeological conditions for the site.

The review should be based on the Tailings Storage Facility (TSF) footprint and predicted downstream seepage plumes and potential seepage return zones within the receiving environment.

As a component of an independent third party review, it is likely that it will involve further focus on components of the TSF, and specific receiving environments at the discretion of the reviewer.

Further related details are in the document "Red Chris – Work Plan to resolve outstanding water issues" – April 12, 2012.

2.0 Objectives

1. Review available data (well(s), geotechnical, soil surveys, etc.) for the TSF footprint and potential seepage flowpath receiving environment areas to identify information gaps and potential deficiencies in the monitoring network.
2. Provide an assessment of models run to date, with respect to parameterization, calibration, assumptions and overall representativeness of the related groundwater system. This includes information from the mill/processing plant predictive water quality work.
3. Review proposed contingencies and mitigation measures for seepage management for the TSF footprint and potential seepage receiving environment.

3.0 Additional Information for Consideration

The following section outlines information that may be useful for the third party review. It will be at the discretion of the reviewer to consider the relevance and suitability of consideration of the following information in the review to achieve the objectives defined in Section 2 and within the scope described in Section 1:

1. Assess the accuracy and precision of the predicted maximum seepage rate from the TSF reporting to Trail Creek for each potential pathway (seepage beneath and through dam, others?), and for various mine life stages, including the interval between construction of the South Dam and the period when the hydraulic conductivity of the TSF base is governed by the tailings, and not the overburden.

2. Assess where seepage is expected to daylight, and identify areas where a surface water quality monitoring program and environmental effects monitoring program would be most likely to characterize effects of seepage on the receiving environment.
3. Assess the statistical confidence around the available data data and provide a recommendation for the rigor required in the studies to achieve acceptable statistical significance.
4. Assess the effectiveness of any seepage mitigation measures that could be employed to ensure seepage does not result in Water Quality Objectives exceedances, at any flow, including:, pump-back wells, collection ditches/ponds, overburden stripping, lining or grouting of base and grading towards TSF, etc.
5. Recommend strategies for any necessary additional monitoring and/or characterization of groundwater for the TSF footprint and receiving environment:
6. Identify areas where hydrogeological data can support the surface water monitoring and modeling to integrate the surface and groundwater sampling and predictions.

4.0 Communication

A communications protocol for the third party review needs to be established to preserve third party reviewer independence and ensure the process is transparent and inclusive. The protocol is as follows;

1. E-mail is the preferred method of communication between Robertson Geo and the working group. Robertson Geo is to maintain a record of e-mail communications
2. A similar phone record is to be kept for technical phone calls.
3. All parties will be notified and invited to participate in advance of any teleconferences, meetings or site visits.
4. Technical documents and assessments will be distributed to the entire working group at the same time.
5. Communications between Robertson and the Tahltan shall be directed to the THREAT Team project manager, Norm MacLean.
6. Communications between Robertson and Imperial shall be directed to the Byng Giraud, Raj Anand, Jack Love, and Steve Robertson.
7. Communications between Robertson and the provincial ministries shall be directed to Diane Howe, Jeanien Carmody-Fallows, and Scott Jackson.

The reviewer will include in the final report, a list of all technical information considered in the review of the hydrogeological characterization work for the Red Chris project. This will include any technical information provided through email, telephone or any other means of communication during the review process.

5.0 Deliverables

Following completion of a draft report of the third party review, a meeting with representatives from government, THREAT and RCDC will be arranged as soon as possible. The draft report will be provided to all parties at least a week in advance of the meeting. Robertson Geo will provide a detailed presentation of the Third Party Review and any results and recommendations that result. The Parties can include their technical expertise to participate at this meeting.

After comments are provided at the meeting a final report will be issued to all parties, namely government, THREAT and RCDC, as soon as practical. Preparation of the final report is the sole responsibility of Robertson Geo.

APPENDIX B

Materials Provided for Review

Materials provided for Review

AMEC (2004) Appendix to EA Application (Oct. 2004) – 4H – Groundwater Modeling

AMEC (2011) Red Chris Permitting Response Submission. Part 3 of Three. TAB 1 DETAILED DESIGN REPORT FOR TSF. Report prepared by AMEC, 06 June 2011, including following appendices:

APPENDIX A – 2010 SI Report_FINAL_24Nov.2010

APPENDIX B - Clearwater Consultants Memoranda

APPENDIX C - Slope Stability Analyses Report_December 2010

APPENDIX D - MODFLOW analyses_DRAFT report_16Dec10

APPENDIX E - SEEPW analysis report_Dec 2010

AMEC (2011b) Permitting Checklist V1 Response to Water Quantity and Quality Dec 30, 2011

AMEC (2012) RED CHRIS MINE WATER QUALITY EFFECTS PREDICTIONS - UPDATE. Report prepared by AMEC, August 2012.

AMEC (2012a) Red Chris Projects: Elanco Enterprises Comments on Groundwater. Technical Memo prepared by D. Emerson, July 9, 2012.

AMEC (2012b) D. Emerson letter with responses to C Wels enquiries

AMEC (2012c) Red Chris Tailings Pond Feasibility Study. Technical Memo prepared by Scott Green, October 2012.

DRT (2012) Red Chris EMA preliminary GW comments_DRT ENV

Dakin (2012). Red Chris TSF Hydrogeology - Technical Memo prepared by Alan Dakin, May 14, 2012

Red Chris - Work plan to resolve outstanding water issues (unknown author)

THREAT (2012) Red Chris Mine Water Management Modeling Review. Memorandum prepared by THREAT, January 2012