CH2M’s Responses to Comments on Faro Mine Modelling Deliverables, Faro Mine Remediation Project

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| PREPARED FOR: | Government of Yukon |
| PREPARED BY: | CH2M HILL Canada Limited (CH2M) |
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This memorandum presents a response to comments provided on March 24, 2015, by Dr. Christoph Wels, M.Sc., P. Geo., Principal, Robertson Geoconsultants Inc. and on April 30, 2015, by Leslie Gomm, P.Eng., Ph.D., Principal Consultant, Faro Mine Remediation Project regarding the following:

* CH2M’s Fiscal Year 14 Water Modelling Presentation consisting of the following modelling subjects: Surface Water, Groundwater, Geochemistry, and GoldSim
* Draft Cross Valley Dam Seepage Interception System Phase 2 – Groundwater Modelling Draft Technical Memorandum
* Update of Rose Creek Tailings Area Geochemical Reactive Transport Model Technical Memorandum
* Fiscal Year 2013 Water Quality Modelling Analysis Report

| Number | Page/ Section/ Slides | Comments | Response |
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| **Surface Water Modelling PowerPoint Presentation**  |
| **Reviewer: Dr. Christoph Wels, M.Sc., P. Geo., Principal, Robertson Geoconsultants Inc.** |
| 1 | Slides 21-22 | Slides 21-22 provided a very general overview of additional hydrology work completed in FY14. This work included:* Collection of continuous flow data at existing stations as well as new ones supplement rating curves for stations
* Expansion of spot flow measurement program (i.e. more sites and simultaneous measurements)
* Ongoing processing and QA/QC of flow and climate data
* Operation and maintenance of site met stations
* Further discretization of sub-catchments – quantify unique hydrologic response (i.e. disturbed areas)
* Updated Regional Analysis for extreme flood event prediction
* Development of intensity-duration-frequency (IDF) curves for FMC (event based modelling)

However, insufficient information was provided to comment on this work.  | Acknowledged. |
| 2 | Slides 23-24 | The final two slides (23-24) of this presentation discussed “next steps” for hydrological modeling. Proposed improvements to the HEC/HMS model comprise:* Improved integration with groundwater, geochemical and site-wide water quality tools
* Continuous improvement of data collection, processing and QA/QC protocols
* Incorporate processed flow and met data into model – updated calibration
* Updated catchment delineation and parameterization – focus on disturbed areas
* Improved representation of low-flow conditions
* Apply historic climate record (temp/ppt) to model
* Use IDF data for event-based simulations
* Wider range of continuous simulations (wet/dry year)
* Potential impacts of climate change on runoff response

The author generally supports the proposed steps in further surface water modeling but notes that no sensitivity analyses appear to be planned for future work (as recommended earlier). Furthermore, no details or supporting documents were provided to allow an in depth review of these proposed activities.The author would like to re-emphasize earlier review comments that the HEC-HMS runoff model, in its current form:* is not a good predictor of stream baseflow and caution should be exercised when using stream flows predicted by the runoff model for water quality predictions during baseflow
* may not be representative of areas disturbed by mining (specifically waste rock dumps) and should be recalibrated for such disturbed areas.

In the author’s opinion, consideration should be given to employing a more complex watershed-based runoff model suitable for northern climates which overcomes some of the limitations of the HEC-HMS model (in particular related to seasonal variations in runoff).CH2M Hill also acknowledged that HEC-HMS is not an optimal tool for WRD hydrology and water balance. Instead, they propose a “compartmentalized approach based on RMUs” which focuses on specific areas of interest (i.e. WRD, cover area, etc.). They further proposed to utilize existing work, including Janowicz’s water balance work on WRDs and trial covers.The author agrees that the earlier work and existing flow data (e.g. at X23) should be reviewed prior to defining a suitable modeling approach and framework for runoff from disturbed areas.  | The initial goal of the HEC-HMS model work in Fiscal Year (FY) 2012 was to develop a baseline hydrology tool in which available meteorological data, flow records, catchment discretization, and related parameterization could be incorporated. The modelling platform was selected based on the then-current understanding of data availability and the initial objective of completing a calibration of rainfall-runoff from the Rose Creek and Vangorda catchments. The HEC-HMS model was considered an appropriately complex model at the time given the understanding of the hydrological system including available input and calibration data. The objective of the FY2012 modelling efforts was to simulate rainfall-runoff responses from large, undisturbed catchments tributary to the main Faro Mine Complex (FMC) conveyance features. This would allow for initial characterization of seasonal variations in flow for more frequent return period events. This would also form a baseline tool that could be further developed based on subsequent collaboration with the hydrogeological and geochemical modelling teams and by incorporating updated meteorological, flow, and physical data. It was recognized at the time that the tool was not as appropriate for modelling attenuation impacts from impacted landforms including a waste rock dump (WRD) or for simulating baseflow conditions in which groundwater-surface water interaction is the dominant process.Flow and meteorological data compilation was completed in parallel with model development during FY2012. From this work, various issues related to processing this data and associated operations and maintenance of the equipment resulted in concerns with the quality of the data and suitability for model calibration. In addition, two key data gaps were identified, including (1) a lack of understanding of meteorological and physical conditions in the upper reaches of catchments tributary to the FMC, and (2) unknown impacts of WRD and related disturbed landforms on infiltration and subsequent sub-surface flow of water. The focus of hydrological analyses subsequent to FY2012 was on developing estimates of peak instantaneous flow and runoff volumes in FMC diversion features that convey runoff from the larger, undisturbed tributary catchments. It was determined that regional analyses incorporating data from a variety of catchments and over a number of years was more appropriate for estimation of peak flow rate and runoff volume in diversion channels around the FMC for larger, less-frequent events (i.e., 1-in-10 year to 1-in-1000-year). This data was used for conveyance design as well as conceptual design of proposed attenuation facilities. Numerous recommendations were made regarding meteorological and hydrological data collection at the site with the intention of incorporating improved data sets into subsequent modelling efforts.It is recommended that subsequent modelling efforts include consideration of improvements listed CH2M’s Fiscal Year 14 Water Modelling Presentation. This includes calibration and validation based on flow and meteorological data collected since FY2012. A sensitivity analysis is also recommended on key modelling parameters to account for uncertainties in catchment physical characteristics including runoff processes and conveyance. |
| **Reviewer: Dr. Leslie Gomm, P. Eng., Ph.D. Principal Consultant, SLR Consulting (Canada) Ltd.** |
| 1 | Overall | Overall a significant amount of work that has been done on surface water modelling to characterise the flow year round at several key locations in the project area. One concern that I have is the lack of year round flow data at several key locations, specifically winter low flow, including R7, X2, X14, V1 and V8. The workplan moving forward, as highlighted in the presentation, is to improve the representation of low flow conditions. To facilitate this robust site low flow data is required. Characterization of the low flow conditions is key as this is when the impacts of seepage and groundwater inflows on surface waters is most pronounced. Therefore I recommend that permanent Water Survey of Canada (WSC) type stations be established at these key monitoring locations. This would consist of the installation of a stilling well to adequately house the level logger during year round conditions and ensure year round operations. It is also recommended, to ensure the work completed to date meets the needs and expectations for potential reviewers, that the surface water model work be reviewed by the Government of Yukon’s Department of Environment hydrologist, Richard Janowicz. This will ensure that the work is consistent with and meets the needs and expectations from a government perspective for the assessment and permitting process.The information provided in the presentation, and therefore supporting modelling work, only includes data up to 2011. This work should be updated to include all data collected from that time, up to and included 2014, which will provide for an additional 3 years of data to base the model work on.Finally, for the monitoring data in Vangorda Creek at V8, the flow data collected by YG at their station should also be included to increase the amount of available data used for the modelling. | We agree that subsequent hydrological analyses should include improved representation of low-flow conditions, maintenance of the existing flow monitoring network and installation of new permanent flow monitoring stations, and consultation with YG Department of Environment hydrologists. This is in addition to other recommendations listed in the response to comment 2 above.Please refer to the response to comment 2 for a description of hydrologic analyses completed to date as well as recommendations related to subsequent analyses.Regarding flow monitoring, please refer to the following documents for a list of recommendations made by CH2M:- CH2M. 2015. *2014 Hydrology Field Program Report, Faro Mine Remediation Project.* Draft 1. Prepared for the Government of Yukon and Government of Canada as represented by Aboriginal Affairs and Northern Development Canada. February.- CH2M. 2015. *Surface Water Data Processing Report, Faro Mine Remediation Project*. Prepared for Government of Yukon and Government of Canada as represented by Aboriginal Affairs and Northern Development Canada. March. |
| Groundwater Modelling PowerPoint Presentation |
| **Reviewer: Dr. Christoph Wels, M.Sc., P. Geo., Principal, Robertson Geoconsultants Inc.** |
| 1 | 2.2.1 2013/2014 Hydrogeological Field Activities; Rose Creek Diversion Leakage Study | Key findings of the RCD leakage study were presented (see slide 16). The methodology of this work is briefly summarized in CH2M Hill (2014a) and indicates that leakage rates along different reaches of the RCD were based on Darcy calculations using local field observations (local stratigraphy, hydraulic parameters and hydraulic gradients).The author would like to point out that Darcy calculations (with point estimates of K and hydraulic gradients) carry a significant uncertainty. Direct measurements of flow rates along the RCD (and hence leakage rates from specific reaches by difference) are, in the author’s opinion, more reliable and have been collected during previous investigations.For example, Laberge Environmental Services of Whitehorse, Yukon, carried out two field surveys as part of a water and load balance study for the Rose Creek Tailings Facility (RGC Report 118001/1) to determine stream flow and constituent loading in various streams and seeps in the Rose Creek Valley2. The first survey was carried out on October 19-20, 2004 under moderate low flow conditions (~500 L/s at X14). The second survey was conducted on April 15-17, 2005 under winter base flow conditions (~235 L/s at X14). These surveys suggested significant variations in leakage from the RCD depending on flow conditions.In the author’s experience, leakage from the RCD has a significant effect on groundwater flow and water quality in the RCAA, and as such, on the performance of any seepage interception system in the RCAA (in particular downgradient of the CVD). The author therefore recommends that these earlier flow measurements be reviewed and considered for any further calibration of the groundwater flow model. If required, additional flow surveys may have to be carried out to determine leakage rates along different reaches of the RCD.Slide 16 also summarizes the simulated water balance in the RCAA for average flow conditions, including water balances for the Intermediate Pond and the CVD Pond and simulated groundwater flows along different reaches of the RCAA. In this section wecomment only on the reconstructed (average) water balances for the two ponds. The groundwater modeling results are commented on in section 2.2.2 below.According to CH2M Hill (2014a), historic pumping records (from 2007 to 2013) for the Intermediate Pond and CVD Pond were compiled and reviewed to reconstruct the long-term average water balances for these ponds. This review suggested an average net inflow of 51.7 L/s to the CVD Pond which CH2M Hill attributed to groundwater inflow. This is an important finding as it suggests that a significant amount of groundwater (almost 50% of all groundwater in the RCAA upstream of the ID) is currently discharging to the CVD Pond. | Estimates of leakage from the Rose Creek Diversion (RCD) were primarily obtained from site-specific models constructed for individual segments of the RCD along the RCTA, not just using Darcy’s Law as is inferred in the comment. These site-specific models used the RCD stage measurements, the location-specific stratigraphy observed during drilling at that location (alluvial thickness, thickness of weathered bedrock, and competent bedrock topography), hydraulic conductivity estimates from aquifer testing, and groundwater levels measured at the site. Darcy’s Law calculations were also performed as a check on model estimates or in areas where site-specific boring/aquifer testing data was not available to support model development. It should also be noted that estimates of RCD leakage rates through comparison of measured surface water flow rates also contain significant uncertainty. The accuracy of surface water flow measurements were estimated by the U.S. Geological Survey (USGS) to be +/- 10 percent in ideal situations and more typically +/- 20 percent. When comparing two flow estimates that both contain uncertainties of this magnitude, the estimate yielded by this procedure can also contain significant uncertainty. However, the independent RCD seepage estimates referred to in the comment will be assessed and incorporated into the groundwater model as appropriate. |
|  |  | Considering the importance of this conclusion, the author recommends that these water balance calculations be checked and verified with on-site staff to ensure that the records are correct and no other water additions/extractions took place.For the Intermediate Pond, pumping records indicated an average extraction rate (water pumped out of the pond) of 41.7 L/s during the period 2007 to 2013. CH2M Hill closed the water balance for this pond by assuming 57.9 L/s of surface inflow, 67.5 L/s groundwater inflow and 24.7 L/s leakage to groundwater (see Slide 16). The author could not find any data or calculations that support these assumed water balance fluxes.However, the author cautions that the Intermediate Pond is underlain by many meters of low permeability slimes that can be expected to limit interaction of the pond water with the groundwater in the underlying aquifer. The author recommends that simplified 2D cross-sectional modeling be completed to estimate the potential range of seepage into and out of the Intermediate Pond using reasonable K estimates for the underlying tailings (slimes) and the Intermediate Dam.In addition, the author recommends that a transient (say monthly) water balance be developed for the Intermediate Dam pond and the Cross Valley Dam pond with explicit tracking of the pond stage, including the winter periods when no water management (water treatment and discharge) is taking place to confirm that net groundwater discharge into these ponds is indeed as significant as suggested by the current conceptual (and numerical) model. | Water balance estimates for the Cross Valley Dam (CVD) Pond and Intermediate Dam (ID) Pond were further evaluated during development of the transient groundwater flow model of the site. Estimates obtained during that modeling effort were compared to observations and measurements made by field operations staff where available and indicate the model provides reasonable agreement with the observed values. |
|  |  | The author recommends that any updated water balance calculations for the ID pond and CVD pond to be used for updates to the RCAA groundwater model be summarized in a technical memorandum for review. | As part of the transient groundwater flow model development effort, a detailed monthly water balance was developed for the ponds based on pumping and changes in storage. The modeling team elected to use the existing three-dimensional model to develop these pond budgets as opposed to creating separate two-dimensional models as suggested by the commenter. Seepage estimates are consistent with the numbers provided in the comment. These calculations will be provided in the Draft 2014/2015 Modelling Report.The reviewers comment that no water management takes place during winter period is incorrect. The Care and Maintenance (C&M) contractor releases water from the pond via the siphon, as necessary year round including during winter periods when water treatment is not taking place. The siphons are not equipped with inline flow meters and the discharge from the CVP is calculated by the C&M contractor based on valve position, elevation, and intermittently pipe flow measurements. |
| 2 | NFRC Leakage Study | Slides 17-20 show vertical hydraulic gradients and zinc concentrations in shallow piezometers measured along the NFRC (in August 2013 and July 2014). The results of these surveys are generally consistent with hydrogeological studies completed by RGC in 2013. Specifically, the surveys suggest that (i) shallow groundwater in the reach between the Zone 2 outwash area and the rock drain is only moderately impacted (~3-5 mg/L Zinc) and not a major source of zinc loading to NFRC and (ii) shallow groundwater discharging to the NFRC immediately downgradient of the toe of the rock drain is only slightly impacted (Zn < 0.1 mg/L) and not a significant source of zinc loading to NFRC. These observations support the hypothesis that the significant zinc load observed at the toe of the rock drain is caused by a discrete (potentially perched) seep entering the NFRC under the rock drain.The author would like to caution, however, that vertical hydraulic gradients driving the surface/groundwater interaction and contaminant loading may vary significantly throughout the flow seasons. The author recommends that additional measurements of VHG and water quality be obtained (using manual surveys or in-situ probes/loggers) during late fall and/or early spring (when the NFRC is most impacted) to evaluate seasonal variations in the surface water/groundwater interactions. | Vertical hydraulic head and water quality were measured during fall 2015 and the results will be incorporated into the transient groundwater flow model. |
| 3 | 2.2.3 Modeling Activities in Response to IPRP | Slides 21-27 provide a brief overview of modeling work completed in FY14 and/or planned by CH2M Hill in response to comments from the IPRP. |  |
|  |  | The key comments/concerns raised by the IPRP were as follows:* “Idealized” valley alluvium profile using a very coarse grid Heterogeneity poorly represented at the scale of the individual wells and local zones of permeability differences
* Model may not be suitable for assessing groundwater capture in alluvial aquifers given significant spatial heterogeneity in hydraulic properties at scales smaller than the model grid blocks
* The incorporation of a dewatered trench with pressure relief wells reduces well drawdown fluctuations and improves the security of maintaining water extraction capacity.
* The incorporation of a cut-off wall secures the efficiency of contaminated water interception…and could provide storage upon system failure.

Subsequently, CH2M Hill evaluated an alternative SIS using a 2-cell dewatering trench with a drawdown of 4-5m in the trench and passive dewatering wells down to bedrock. According to the power point presentation the predicted pumping rate for this scenario was 177 L/s. This predicted interception rate is only marginally higher than the 164 L/s predicted for 9 SIS wells (Scenario A) using the updated FY13 model report to fully capture the RCAA groundwater flow.The author acknowledges the significant operational advantage of using a dewatering trench with passive wells which (i) provides a uniform drawdown across the width of the aquifer (at least in the upper portion of the aquifer) and (ii) reduces the requirements for a larger number of pumping wells (with associated submersible pumps and pump controls).However, the dewatering trench also provides operational disadvantages. Specifically, the dewatering trench is less flexible in controlling drawdown in specific portions of the RCAA than the use of a series of traditional pumping wells. In the trench option, (i) the drawdown cannot be easily adjusted locally to account for spatial variations in the local aquifer transmissivity, groundwater quality and/or well losses and (ii) the SIS is more difficult to bring on line in stages or upgrade as contaminant breakthrough proceeds (e.g. first in the northern portion and later in the center and southern portion of the valley). | The grid spacing of the initial CVD model was too coarse to capture all the complexities in the valley alluvium, however, refinements to the groundwater model were made to significantly increase the resolution of the tool, and to include the flexibility to add heterogeneity where needed. This refined version of the model tested all the failure scenarios mentioned in the comment and results were presented to the Independent Peer Review Panel (IPRP) in early 2015. The IPRP responses were favorable and they felt that the heterogeneity issue had been adequately addressed. These have been documented in CH2M, 2015 – CVD SIS Alternative Analyses Report. March.  |
|  |  | The author notes that potential alternative SIS options were not evaluated in FY14 (or at least not presented in the presentations); these options include:* Pumping from the CVD Pond to intercept seepage from the RCAA
* Use of alternative alignment(s) for the SIS (wells and/or cutoff walls) including
* Distance of SIS wells and cutoff walls from the CVD down the valley
* Spacing and screening intervals of the SIS wells
* Use of secondary or tertiary fences of wells to improve capture efficiency and/or provide redundancy (in lieu of cutoff walls)
* Lining of the RCD to reduce leakage (and hence water to be collected and treated)

The potential influence of pumping of the CVD Pond on groundwater flow towards the CVD SIS has already been discussed above. To the best of the author’s knowledge, different alignments of the SIS have not been evaluated at this point. The currently proposed alignment is very close to the toe of the CVD and the CVD Pond. This alignment can be expected to intercept significant seepage from the CVD Pond (if retained). An SIS alignment further downgradient would have the benefit of reducing induced seepage from the CVD Pond and potentially easier capture of seepage through the northern embankment, but may result in significant additional capture of (clean) leakage from the RCD (if not cut off).In FY13, different alignments of cutoff walls along the RCD were simulated for the active pumping well scenario to assess the effects on seepage interception rates. An alternative, and potentially more cost-effective, method for reducing leakage from the RCD may be lining of the diversion channel (using geosynthetics, shotcrete or concrete) along reaches where leakage provides significant flow to the CVD. This option should be evaluated using the FY13 model by reducing the streambed conductance accordingly in selected reaches of the RCD.The author recommends that several alternative SIS designs (and alignments) be evaluated with respect to performance (% by-pass), operational efficiency (pumping rates and power requirements), risk of failure and overall cost (CAPEX & OPEX) prior to selection of a preferred alternative.CH2M Hill also outlined a list of planned work tasks to evaluate potential for hydraulic failure. These include:* Assess scale of heterogeneity from boring logs
* Analyze conditions most likely to compromise capture:
* Full pool behind the CVD
* High permeability conduit oriented US/DS between extraction wells
* Passive wells screened in lower permeability materials surrounded by higher permeability sediments
* High permeability conduit connected to high head pool behind CVD and extending between extraction/passive wells
* High horizontal to vertical anisotropy (layering of low permeability material)
* Simulations will be run to steady-state and flowline analysis performed to evaluate capture

The author supports the above proposed analyses and recommends that these sensitivity analyses be run for (i) a fence of pumping wells (original design) and (ii) trench with passive wells (alternative scenario)8. -----8 Note: using both scenarios for these sensitivity analyses may already be planned by CH2M HILLCare should be taken in those simulations to account for well losses in pumping wells which reduce the available drawdown at a given well point. | Pumping the CVD Pond to intercept seepage from the Rose Creek Alluvial Aquifer (RCAA) was not considered as a viable alternative by the client or the IPRP and, therefore, was not further evaluated during this effort. Alternative locations for the Seepage Interception System (SIS) further downstream of the CVD, as well as various configurations of screened intervals and well locations were evaluated. The results are presented in the 2014 CVD SIS Design Basis Report. The use of secondary or tertiary fences of wells were not evaluated as the modelling analysis indicated that a single line of wells is sufficient to obtain complete hydraulic capture and meet remedial objectives. Lining the RCD was evaluated as part of the overall alternatives analysis, but was not explicitly simulated in the modelling effort as the effects of cutting off RCD seepage to the RCTA is similar whether it is achieved using a cut-off wall or liner. |
|  |  | The author further recommends that additional sensitivity analyses be conducted to evaluate the uncertainty in:* Hydraulic conductivity of the sediments in the CVD Pond controlling seepage from the CVD Pond
* Seepage conditions along the northern abutment (where impacted seepage is already observed)
* Leakage from the RCD (in particular downgradient of the Cross Valley Dam) and its effect of clean water capture in the SIS
 | Project focus in 2015 shifted to development of the North Fork Rose Creek (NFRC) Diversion Design and resulted in redirection of the project team away from issues associated with the CVD SIS. Therefore, these sensitivity analyses were not performed. |
|  |  | Finally, the author notes that the power point presentation makes no mention of any water and load balance studies for the RCAA. It is unclear whether such work was undertaken to understand current conditions in the CVD area and support the hydrogeological modeling for the CVD SIS. In the author’s experience, a water and load balance model is a very valuable tool to understanding seepage and groundwater flow in the CVD area (see RGC Report 118001/1 for details). If not already completed, the author recommends that the earlier water and load balance model for the RCAA (RGC Report 118001/1) be updated using recent flow and water quality monitoring data in the RCAA. | Water and load balances were evaluated during transient groundwater flow model development. Full documentation of the groundwater flow model development and calibration will be provided in the FY2015 Groundwater Development Report. Results from the groundwater flow model are summarized in the FY 2015 Comprehensive Design Road Map report, including summary level water budgets.  |
| 4 | 2.2.5 Future Modeling Work | Slides 28-34 of the power point presentation touched on future groundwater modeling work for the FMRP. CH2M Hill proposes to use the recently developed Un-Structured Gridding (USG) code for MODFLOW to allow for subarea refinement of grid cells and layering. CH2M Hill proposed the following grid refinements in subareas of interest: |  |
|  |  | * CVD: 1.5m×1.5m cells
* Zone 2 Outwash, S-Wells, ETA, CVD SIS areas: 3m×3m cells
* RCD: 12m×12m cells
* Along NFRC, SFRC, Lower Rose Creek and other principal streams: 25m×25m cells

In the author’s opinion, the proposed cell sizes appear to be adequately refined for the simulation of hydraulic conditions (groundwater flow).However, as mentioned in earlier reviews, the author prefers the telescopic modeling approach in which a coarser regional model is initially used to develop a regional groundwater flow field and more detailed sub-models are subsequently developed for specific areas of concern, e.g. the NFRC area or the RCAA. This approach provides more flexibility in model setup (cell grid spacing and layering) and typically results in a more transparent and efficient numerical model.During the presentation CH2M Hill pointed out that numerical difficulties were encountered with the new USG MODFLOW package and that the assistance of the original programmer of the USG package was sought. In the author’s opinion, there is significant risk that the modeling work could get delayed due to numerical issues when applying this new USG code to this large regional model. Again, it is recommended that stand-alone subarea models be developed which do not require the use of the USG package. | The groundwater modelling team opted to use the MODFLOW-USG modelling platform over the subarea modelling approach because it provides flexibility for future model refinement which is much more difficult and time consuming to achieve with local or “subarea” models. MODFLOW-USG allows both subgridding and sublayering in any portion of interest in the model grid and eliminates the need to define and transfer boundary conditions between the parent and local subarea models. For instance, if the model is used to support the design of an SIS or seepage collection pond at the site, the existing transient groundwater flow model grid can be refined spatially by adding additional elements, and refined vertically by adding additional layers, to whatever scale the designer deems necessary. The refined model will then automatically integrate surrounding boundary heads and fluxes into the refined areas to support design efforts. Initial numerical challenges applying MODFLOW-USG were solved through consultation with the model developer and the resulting current transient groundwater flow model provides effective analysis to support the project. |
|  |  | Slide 33 provided an overview of the planned groundwater flow modeling activities for FY15, including: FY15, including:* Develop transient GW flow model
* Monthly stress periods
* Simulation period coincident with GoldSim
* Advance SIS designs
* CVD to 90% level
* Zone 2 Outwash to 30% level
* S-Wells Optimization to 30% level
* Evaluate subsurface flowpaths from WRD source areas to NFRC discharge areas (with and w/o stream realignment)
* Evaluate cover effectiveness
* Evaluate lining of new stream diversions (NFRC & SFRC)
* Evaluate constructability and performance of low-permeability cutoff walls

The author generally supports these planned modeling activities for FY15. The development of a transient flow model using monthly time steps is considered an important and necessary improvement to the groundwater flow model. The groundwater flow system at Faro is significantly influenced by seasonal runoff, specifically high groundwater flow during spring runoff and late fall and recession flow during the cold winter period. These seasonal runoff patterns cause significant variations in seepage rates from mine waste units and flow in receiving groundwater and surface water and need to be considered in the design of seepage interception systems in the various sub-areas (CVD, Zone 2 Outwash, S-Wells).The author noted that CH2M Hill is planning to complete SIS designs for the Zone 2 Outwash area and the S-Wells area of the NFRC reach. These areas had previously been identified as high and moderate priority areas by the author for seepage interception, respectively.However, recent monitoring and hydrogeological studies in the NFRC reach have shown that recent increases in zinc concentrations in the NFRC are not caused by seepage from the Zone 2 outwash area or the reach along the S-Cluster SIS, but instead by (potentially perched) seepage from the Intermediate Dump which reaches the NFRC under the rock drain.In the author’s opinion, design of a seepage interception system along the reach of the rock drain should have priority over an improved design of the S-cluster SIS or a new design in the Zone 2 outwash area. | As discussed above, the transient groundwater flow model of the FMC was developed and calibrated. However, the scope of the current project changed to focus solely on the design of the NFRC re-alignment and associated water management strategies. Under the current scope, the advancement of detailed SIS designs was deemed lower priority and was not completed in FY2015. This is also true for cover effectiveness evaluations and this analysis was also not completed.  |
|  |  | The author also supports an evaluation of subsurface flowpaths from WRD source areas to NFRC discharge areas (with and w/o stream realignment). However, no details were provided for this work task. The author recommends that this modeling work be preceded by a detailed data review and formal development of a conceptual model of groundwater flow and contaminant transport for the NFRC. Once such a conceptual model has been developed (and reviewed) a numerical model for the NFRC subarea should be developed. This model should then be used to evaluate integrated closure strategies for the NFRC reach (i.e. local SISs, stream realignment, stream bed lining, etc.).It is recommended that a detailed work plan be developed for analysis and modeling of the NFRC reach which integrates data review, conceptual model development and numerical modeling of closure strategies for this aquifer reach. This work plan should be reviewed by the Technical Advisors of YG-AAM (who are familiar with the NFRC issues) prior to execution of this work. | While a more comprehensive analysis of the flow and transport characteristics of the NFRC system would be beneficial to the overall project, this effort was not scoped or funded in FY2016, and, therefore, was not completed. However, the flowpath analysis was performed and used in conjunction with groundwater budgets defined by the flow model to evaluate subsurface pathways and flow rates between WRD source areas and NFRC discharge areas. These efforts are documented in Appendix C and D of the 2016 NFRC Design Basis Report (CH2M, March 2016b). |
| Geochemical Modeling PowerPoint Presentation  |
| Reviewer: Dr. Christoph Wels, M.Sc., P. Geo., Principal, Robertson Geoconsultants Inc. |
| 1 | GW beneath Rose Creek Tailings Area (RCTA) (FY2012, updated FY2013)  | The presentation on geochemical modeling included four sections:* Faro Pit Lake (FY2012)
* GW beneath Faro waste rock dumps (WRDs) (FY2012, 2013)
* GW beneath Rose Creek Tailings Area (RCTA) (FY2012, updated FY2013)
* External review (FY2014)

This review focusses on the geochemical modeling in the RCTA (third bullet), and specifically any updates completed in FY13. Note that a detailed review of the FY12 PHAST modeling of the RCTA was reviewed by the author (and Dr. Paul Ferguson) in provided in an earlier review report dated May 26, 2013. The present review comments should be read in conjunction with these earlier review comments. |  |
| GoldSim Water Model Presentation from the January 20, 2015 meeting  |
| Reviewer: Dr. Leslie Gomm, P. Eng., Ph.D. Principal Consultant, SLR Consulting (Canada) Ltd. |
| 1 | Overall | This document describes model updates to support the Interim Works Project Proposal, incorporation of PHREEQC to support geochemical components of the model, development of model for use as water management tool and next steps. I was actively involved in the updates of the model to support the Interim Works, many of which are then incorporated into the closure model so I do not have many specific comments on model. I feel that the team has made significant progress refining the model, specifically with respect to how it deals with source inputs from waste rock dumps and getting better calibration with historical data. As the work continues it will be important to continuously re-evaluate the calibration with more recent site data as conditions on the site are progressing and this will help provide confidence in the ability of the model to adequately predict these changes. For the overall closure model, during the presentation the issue of stratification and turnover of the Faro Pit was discussed and whether this was incorporated into the model. It was highlighted that it was not. The concern stems from the potential for increased lime demand due to mixing of deeper metal laden waters during spring and fall turn over. Following the meeting Jim Stefanoff provided some clarification on the physical stability of Faro Pit with respect to turn over and impact on operation of the water treatment plant. Based on his assessment, based on current pit water quality data, there will be minimal impact on the treatment system due to turn over.Although this clarification was provided, the potential for turnover should be incorporated into the closure model to ensure as water quality conditions in the pit changes during closure and post-closure that any turnover is taken into consideration.With respect to the water management tool component of the model, again this should be routinely updated based on calibration as more recent site data becomes available. I think this is a powerful tool to assist in site water management decisions and planning so ensure ongoing update and calibration is key to is use. | a. Agree. The model is a working, evolving tool that will be regularly be compared with newly collected data and updated as significant discrepancies with observed data are discovered.b. Pit lake turnover potential should continue to be considered as a potential hazard as design progresses, and could be incorporated into the closure model should the need arise. |
| Update of RCTA Geochemical Reactive Transport Model Technical Memorandum  |
| Reviewer: Dr. Christoph Wels, M.Sc., P. Geo., Principal, Robertson Geoconsultants Inc. |
| 1 | Overall | The following changes were made to the FY12 model:* Adjustments to the hydraulic aquifer properties and boundary conditions (from updated RCAA flow model)
* Spatially distributed source concentrations by tailings area (adjusted by model calibration)
* Adjusted location for surficial recharge of ETA seepage (along surface channel on Intermediate Impoundment; see figure 6)

These adjustments resulted in an overall improvement in the model calibration, i.e. overall match of observed time trends of sulphate and zinc at selected monitoring wells in the RCAA (in particular at the ID and CVD).In the author’s opinion, the primary improvement to the PHAST model of the RCTA is the use of spatially distributed source terms (sulphate and zinc concentrations via the use of infiltration concentration factors for each of the 11 tailings areas). This allowed more flexibility in matching observed water quality trends in the RCAA.However, the calibrated infiltration concentration factors are not consistent with field observations and our conceptual model of pore water quality evolution in the tailings. For example, the oldest and coarsest tailings area IN-c has a calibrated concentration factor of only 0.1 (representing a low source concentration) whereas the much younger and finer tailings area of IIIS-f had a calibrated concentration factor of 0.6 (higher source concentrations). Field observations and experience would suggest the opposite, i.e. much earlier breakthrough and higher sulphate and zinc concentrations in zone IN-c compared to at IIIS-f.As mentioned in our initial review of the FY12 work, we recommend that as a first approximation, the breakthrough curves for sulphate and zinc estimated for each tailings area in SRK (2005c) should be used to develop these time-dependent source terms9. If required, adjustments should then be made to individual source terms during model calibration (using observed water quality and/or thermodynamic considerations) to better match the observed groundwater quality in the RCAA.---9 The author has the original sulphate and zinc predictions for different tailings areas (in EXCEL format) and could provide these for use by CH2M Hill, if requiredThe following comments/recommendations from our earlier review still apply to the revised FY13 version of the PHAST model and are repeated here for ease of reference (with slight modifications):* CH2M Hill used seepage water quality observed at station X-23 to represent Faro Creek seepage (FCS). As discussed earlier the water quality at X-23 differs significantly from that observed at the mouth of Faro Creek canyon (FCS-4). The water quality observed at station FCS-4 is more representative of Faro Creek seepage contributing to contaminant loading to RCAA (in particular with respect to metals such as Fe and Zn) and should be used as input to the RCAA reactive transport model.
* In the reactive transport model FCS seepage was assumed to enter the RCAA in two ways:
* Lateral groundwater inflow (w/ X-23 water quality) in an appr. 800m long reach along the northern boundary of the model domain (near the Faro Creek canyon)
* Seepage from the Intermediate Pond referred to as “ETA surface water infiltration zone” in Figure 6 (w/ IIIN-c water quality)

Both of these assumed contaminant loads strongly influence the predicted groundwater quality in the northern portion of the RCAA and deserve further comment.CH2M Hill assumed that 10% of the FCS load entered the RCAA as surficial recharge through the tailings. This is a reasonable assumption.It is unclear, however, whether the other 90% of the flow and load of FCS seepage was assumed to enter the RCAA as lateral groundwater inflow. To the best of our knowledge this lateral inflow is the product of the groundwater flux (determined from the regional groundwater model) and the assumed water quality (X-23). In our experience, the main source of contaminant load in this area is leakage from the FCS running in the diversion channel (not groundwater flow from the upstream areas). Hence, leakage estimates from flow surveys along the diversion channel rather than groundwater flow estimates from the regional model should be used for this source term. As mentioned above, this flow term should be multiplied by FCS-4 water quality (rather than X-23 water quality) to estimate the load entering the RCAA via this lateral inflow.* The RCAA was represented as a single model layer in the reactive transport model. In our opinion, this is a reasonable approach for this modeling exercise. However, this raises the question on how to average variations in groundwater quality observed with depth in the aquifer for calibration targets. CH2M Hill decided to use observed water quality in selected wells rather than vertical averaging, both for initial conditions as well as transient model calibration. In our opinion, both initial conditions and calibration targets should be obtained by vertical averaging wherever water quality from multiple screening depths in the RCAA are available.
* A comparison of predicted and observed time trends indicated reasonably good agreement in many wells (especially for the wells at the ID and the CVD). However, some wells showed poor agreement. Of particular note here are the wells P03-06-04 and X21-96B, both located in the northern portion of the RCTA, which showed significantly higher zinc concentrations in recent years than predicted by the model. The fact that zinc concentrations in recent years have increased more than predicted suggests either (i) higher zinc-to-sulphate ratios for ETA seepage and/or for tailings seepage and/or (ii) lower sorption of zinc along the flow path than assumed. The mismatch of zinc breakthrough at those wells (lower zinc predicted than observed) can be expected to underestimate future zinc concentrations at the CVD.
* The PHAST model predicts that zinc concentrations will remain below 0.2 mg/L for the next 20 years. CH2M Hill points out that this delay in zinc breakthrough is a direct function of the sorption capacity of the alluvial sediments (i.e. FeOOH concentration). However, no discussion or sensitivity analysis is presented to illustrate the influence of this parameter (or any other uncertainty in the model) on predicted breakthrough of zinc along the CVD.
* Considering the large number of modeling assumptions required for this type of reactive transport modeling (time-dependent source terms, seepage and groundwater flow rates, reaction parameters) model calibration will never be unique, i.e. different sets of modeling assumptions may be able to describe the observed system response. This non-uniqueness of model calibration is not discussed in the report and no sensitivity analyses are presented to explore the uncertainty in modeling predictions. In our opinion, this is a serious limitation of the reactive transport modeling presented in this draft report.
* In our opinion, the deliverables of such a reactive transport study should include a sensitivity analysis that illustrates the controls on groundwater quality and brackets the uncertainty in water quality predictions. To this end we recommend that the following parameters be evaluated in a sensitivity analysis:
* Different source terms for tailings (e.g. use of sulphate-to-metal rations vs use of observed tailings pore water)
* FCS seepage rate (groundwater inflow from flux boundary)
* Tailings seepage rate(s)
* Range of FeOOH concentrations (controlling metal sorption)
* The modeling results presented in this draft report only include predictions for sulphate and zinc. However, concentrations of other constituents of concern, including major cations (Ca, Mg) and other metals (Fe and Mn) have also increased significantly in the RCAA over time. Consideration should be given to including these other CoCs into the transport model. Simulation of these additional constituents may provide additional clues and constraints on the sources and geochemical controls on contaminant transport in the RCAA.

At a more conceptual level, the author feels that significant compromises have been made in the physical aspects of groundwater flow and contaminant transport in the PHAST model to allow the use of the very complex and computing intensive reactive transport code (e.g. simplified model grid and lack of vertical discretization, simplification of water budgets for ponds). In the author’s opinion, more emphasis should be placed on understanding the physical aspects of solute transport before tackling the reactive transport.To this end, the author recommends that the sulphate transport in the RCTA be modeled using a conventional solute transport model (e.g. MT3D) that is integrated with the RCAA sub-area model (in MODFLOW). The physical transport parameters should first be calibrated using the historic sulphate time trends (again using the spatially distributed source terms for sulphate developed by SRK, 2005c). Once this aspect of the model is calibrated, zinc transport should be modeled using the simplified geochemical options available in MT3D (e.g. using a retardation factor approach). Insight gained from the PHAST modeling to date should be used to constrain assumptions about the reactive transport of zinc. Provided this reactive transport model for zinc can be calibrated against historic time trends, this model could then be used to predict future zinc transport in the RCAA.If successful, such a calibrated solute transport model could also be used to evaluate the efficiency of different SIS option to extract contaminant loads (sulphate and/or zinc) from the aquifer.The author recommends that geochemical transport modeling using PHAST be put on hold until the results of solute transport modeling using MT3D has been completed. | a. The sulphate loading estimates for the Original, Secondary (east), Secondary (west), and Intermediate tailings impoundments from the SRK 2005 study could be used in replacement of the overall average sulphate loading previously used in the model. It would be useful and more efficient to use the Excel source calculations offered by RGC in the footnote to this comment. As noted in in Section 2.5 of SRK (2005), the zinc loading estimates are likely overestimated because of the lack of consideration of zinc precipitate formation. This was shown to be the case in the use of the average loading values during initial calibration of the model, and use of these estimates was abandoned, with a sulphate ratio method used instead. In the interest of time efficiency, this could be repeated for the sulphate loading of individual impoundments.Observed tailings porewater and underlying groundwater quality should be used as guiding ranges during calibration. The water quality is highly variable because of the heterogeneous nature of the tailings, and therefore does not lend itself to specific calibration unless the model was made to be much more detailed than required by the stated objectives. Proposed refinements in the next iteration could include adjustments to loading estimates, as well as thermodynamic considerations, to improve the match with observed data.b. We agree that the water quality at FCS-4 is the most representative of the current water quality that is entering the RCTA from the Faro Creek canyon drainage. FCS-4 data was used for model calibration for the period between 2009 and 2014; since data is only available for this station beginning in 2009.In prior years of the calibration period (between 2002 and 2009), drainage from X23 was used as an estimate of water quality input to the RCTA from the ETA. The FCS-4 data was weighed more heavily during calibration for this key node point in GoldSim, which is named X23 for convenience purposes only.c. The GW model has been extensively refined to accommodate more specific flow processes at the ETA/RCTA interface and this model will be used as the basis for any future PHAST model improvements. The FCS-4 water chemistry will be assigned to this flow for present/recent years, and into the future by the WRD mixing model.d. We agree that consideration of groundwater chemistry at all depths should be used at each calibration point, where available. Although the multi-depth data were reviewed during calibration, we only displayed what we felt was the most representative water chemistry (erring on the side of more conservative concentrations). In the next iteration, all data at each location (coded by depth) could be displayed to give a more complete picture of the calibration process. We feel this would provide a clearer depiction of the water quality at each location than would a vertical average.e. Agreed that there is room for improvement in the calibration at these locations. Zinc is much more reactive than sulphate and therefore predictions of concentration will be expected to have greater uncertainty and variation compared to observed data. The work reported was envisioned to be an intermediate product during development of the final model. In addition to improving the ETA source terms, the adsorptive properties in the model were planned to be adjusted to improve fits to the degree that is reasonable, given literature ranges and expected variability in this setting.f. Reporting of parameter sensitivity was to be performed with the next series of model improvements. Some parameters are dependent on one another in order to achieve a reasonable calibration. An example of this is the pairing of adsorptive capacity and zinc loading: if adsorptive capacity is decreased, the zinc source would need to be decreased to maintain calibration. Dispersivity may also play a role in this process. Ultimately, the final model will require professional judgement to select the most reasonable transport and geochemical parameters.g. As stated above, parameter sensitivity was to be discussed in the next version. No groundwater model presents a truly unique solution, and this is especially true for groundwater transport models. Professional judgement must and does play a role in calibrating a reasonable model with defensible choices for parameters. The work reported was envisioned to be an intermediate product during development of the final model; this could be made more clear further versions.h. Agreed, to the extent of geochemical and transport parameters. For hydraulic parameters such as seepage rates from Faro Creek and through the tailings, the groundwater flow model has been calibrated to head data and other calibration targets. These parameters will be updated in the transport model as they are altered in the groundwater flow model. Unless a reasonable calibration is not possible in the transport model without altering one or more of the hydraulic parameters, they will be fixed to maintain consistency between the models.i. We agree that additional constituents provide useful information to assist in calibration. These have been used internally for calibration in the past. Key general chemistry constituents could be reported for comparison to observed data in addition to zinc and sulphate. However, these constituents have been used as geochemical system checks rather than calibration points. Attempting to fit all parameters would result in excessive calibration time and was considered out of scope. The objective remains to produce a reasonable geochemical transport model for use in comparing design alternatives and the relative effects of each alternative on mobility of constituents. Sulphate has been chosen as the general chemistry transport indicator, and zinc as the trace metal indicator, and will remain the principal calibration constituents.j. We appreciate your input, but respectfully disagree with this approach. The use of a retardation coefficient in transport is a generalized empirical approach that ignores the variety of chemical interactions that affect trace metals like zinc. For example, precipitation of ferric hydroxide, which will occur along the flowpath, will produce additional adsorbate surface for attenuation of zinc. This is a dynamic process that will lead to underestimation of adsorption using a fixed isotherm equation. The use of this approach will not assist in improving the predictive capability, nor the improvement of the PHAST model.The PHAST model was deliberately made in a more simple grid density than the MODFLOW model for the purpose of providing a reasonably fast-running tool for use in comparing alternatives for design and predicting breakthrough times. We feel that adding layers and increasing cell density will produce what we feel would be a time-intensive, complex calibration process which will not add proportionate value to the model.With the previously recommended changes and ideas provided by the reviewers, we feel the current PHAST model will provide a useful tool for design that can be ready for use with some additional refinements and updates. |
| Draft Technical Memorandum on Phase 2 CVD SIS Modeling (FY13) AKA: Cross Valley Dam Seepage Interception System Phase 2 – Groundwater Modelling Draft Technical Memorandum  |
| Reviewer: Dr. Christoph Wels, M.Sc., P. Geo., Principal, Robertson Geoconsultants Inc. |
| 1 | Overall | The author has the following comments on the updated model and its calibration results: |  |
|  |  | * Earlier drilling and interpretation of the geological section along the Cross Valley Dam by the author had indicated large variations in grading ranging from very coarse gravel to silty sand and silt layers (see Figure 2-2 in RGC, 20065). The inferred stratigraphic model shown in figure 2 of CH2M Hill (2014a) is a highly simplified representation of actual site conditions;
 | To the extent possible, the site complexities are integrated into the numerical model. Site heterogeneities deemed important to assessing contaminant migration are also incorporated into the current transient numerical groundwater flow model. |
|  |  | * The modeling memo does not provide a direct comparison of the observed drill logs to the spatial distribution of K zones in the model; however, a visual comparison of figures 2 and 3 suggests that the model is significantly simplified, even compared to the conceptual cross-section shown in figure 2;
* In the author’s opinion, the model discretization and assumed spatial distribution of K zones may not be adequate to assess the performance of a seepage interception system with a high degree of confidence; potential issues currently not addressed include:
* Seepage by-pass in high K channels (not considered in current model)
* Difficulties in installing and operating pumping wells screened across the entire thickness of the valley sediments (as assumed in the model)
 | The development of any numerical model is necessarily a simplification of the true complexity of the hydrogeologic system being evaluated. The degree of complexity required to support the SIS design centers on the ability of the model to accurately replicate the hydraulic conditions that result from groundwater extraction in the CVD area. As is discussed above, the influence of small scale aquifer heterogeneity on achievement of full hydraulic capture was evaluated with a refined model. This analysis was performed and presented to the IPRP in early 2015. |
|  |  | * The updated RCD leakage rates (150 L/s) are significantly higher than in the FY12 model (111 L/s) resulting in higher groundwater flows in the RCAA (e.g. 117 L/s vs 100 L/s underflow beneath CVD). These updated flow rates are more consistent with earlier modeling results (RGC, 2006) which were calibrated using measured leakage rates in the RCD and seepage rates downstream of the CVD.

---5 RGC Report 118004/1 entitled “DESIGN OF GROUNDWATER INTERCEPTION SYSTEM FOR ROSE CREEK TAILINGS STORAGE FACILITY, FARO MINE, YUKON TERRITORY”, submitted October 2006.* The calibrated FY13 model overestimated hydraulic heads in wells near the toe of the CVD (by about 0.5 to 1.5m) and significantly overestimated seepage rates at the toe of the CVD (56 L/s vs ~20 L/s observed at X13). In addition, the simulated pond elevation in the CVD Pond was about 2m less than the target. CH2M Hill points out that these discrepancies are conservative in that they result in higher seepage rates for SIS design. However, in the author’s opinion, these discrepancies are significant and may indicate a problem with the conceptual model. For example, why was the model calibration not improved by increasing the Kv of the CVD pond material thus raising the pond level to the observed calibration target? How would this have affected the heads along the toe of the CVD and toe drainage at X13? The author recommends that the cause and effect of the significant remaining discrepancies be evaluated using a series of sensitivity analyses to confirm that the current conceptual model is correct. Such sensitivity analyses should be discussed and documented in a modeling report.
* The FY13 model differs significantly from the RGC (2006) model with respect to the predicted groundwater flow rates downstream of the CVD. The FY13 model predicted a groundwater discharge of 158 L/s to surface (between the CVD and the end of the RCD) with only 21 L/s remaining in the aquifer. In contrast, the RGC (2006) model predicted 82 L/s GW discharge to surface and 175 L/s underflow. These discrepancies are very significant and require further discussion. It should be pointed out that the RGC (2006) model was calibrated against observed seepage rates in this reach of the RCAA. It is unclear what additional field data were collected by CH2M Hill that justify such a significant change in predicted groundwater flow both to surface and in groundwater.
 | Improved flux estimates, including in the areas near the toe and downstream of the CVD, were included as flux calibration targets during calibration of the current groundwater flow model. Improved agreement between simulated and observed flows was achieved during calibration of the 2015 version of the model (CH2M, March 2015gg). |
|  |  | * In the author’s opinion, the revised representation of the CVD Pond and the Intermediate Pond in the FY13 model as “pseudo-lakes” with high Kh and low Kv is problematic. This representation is highly conceptualized and the Kv of the ponds has no physical meaning. In the author’s opinion, a better representation of the ponds would be as a general head boundary (GHB) or as “lake nodes” using the lake package of MODFLOW in which the pond stage can be input as a fixed (known) variable and the underlying tailings (or sludge in the case of the CVD pond) can be represented more explicitly as a vertical conductance term. This way the flow conditions are more accurately represented and the model is calibrated using known pond stages rather than net inflows.
 | The representation of the RCAA ponds was revised during development and calibration of the 2015 transient groundwater flow model. The ponds are no longer represented as “pseudo-lakes.” This change is documented in the FY2015 Groundwater Flow Model Development Report.  |
|  |  | Once calibrated, the FY13 model was used to evaluate alternative designs of a seepage interception system using a combination of interception wells and cutoff walls. For these model predictions the ponds were assumed to be “decommissioned”, i.e. without the current manipulation of the hydraulic system, which pumps and siphons water in and out of the ID Pond and the CVD Pond.The author has the following comments on those predictive runs:* The model predicts a significant increase in groundwater flow under the CVD (from 117 L/s to 156 L/s) due to not managing the ponds. No further information was provided in the TM to explain this significant increase in underflow. The physical reason(s) for this significant increase in groundwater flow (to be collected by the SIS) should be explained. This should include a presentation of the simulated flow field (head solution) in cross-section for this scenario.
 | In the FY2013 groundwater model, the rate of siphon out of the CVD Pond was greater than the rate of input from the water treatment plant, so the pond is a net sink of groundwater (the current operations results in the net removal of groundwater from the aquifer). If water management is halted, groundwater will flow into the CVD Pond until a dynamic equilibrium is reached with the groundwater system. At this point, there will no longer be a net removal of groundwater from the aquifer and the groundwater discharge below the CVD will increase. The current transient groundwater flow model was re-configured using transient constant head boundary conditions to represent the CVD Pond and ID Pond in the RCTA. |
|  |  | * It is not clear to the author why the ponds were assumed to be “decommissioned” for SIS design predictions. Assuming the model predictions are correct and the CVD Pond does indeed intercept a significant portion of the groundwater flow from the RCAA it would be prudent to continue pumping from the CVD Pond to intercept seepage from the RCAA. In fact, the CVD Pond could potentially be pumped even more aggressively to capture more groundwater upstream of the SIS and further reduce the groundwater flow to be intercepted in the interception wells. The author recommends that several sensitivity runs be completed with different pond stages in the CVD Pond to evaluate the potential for seepage interception by pumping the CVD Pond6

---6 These sensitivity runs should preferably be run using a modified/refined model in which the ponds are represented as GHBs or lake nodes with an explicit representation of surrounding embankment material and underlying tailings (see earlier recommendation) | The ponds were assumed to be decommissioned because it was initially assumed that they could be used to capture stormwater runoff and provide onsite storage to help manage the movement of mine impacted water at the site. Additional simulations were later conducted to assess the influence of a full pool on CVD effectiveness as is discussed in earlier comment responses. Also discussed in earlier comment responses, the pumping of the CVD Pond was never endorsed by the overall project team (Government of Yukon, Indigenous and Northern Affairs Canada, IPRP) as a viable alternative and was, therefore, not evaluated in detail. |
|  |  | * The FY13 predicts a significantly higher seepage interception rate for the “base case” SIS of 9 interception wells (164 L/s) compared to the FY12 model (106 L/s). This increase in predicted seepage interception rates is primarily due to the higher RCD leakage rates used in the FY13 model.
* The FY13 model predicted only a marginal reduction in the seepage interception rate for the “base case” SIS of 9 interception wells (164 L/s) compared to the FY12 model (106 L/s). This increase in predicted seepage interception rates is primarily due to the higher RCD leakage rates used in the FY13 model.
 | In both cases, the higher seepage interception rate is primarily from the alternate method of simulating the ponds versus the FY2012 model, as described above. |
|  |  | * The FY13 model predicted only a marginal reduction in the seepage interception rates for the scenario with a cutoff wall across the RCAA sediments (Scenario B). The cross-valley cutoff wall (scenario B) may not provide a significant decrease in pumping rates but would provide additional flexibility during operation of the SIS wells, i.e. providing full capture in the case of local heterogeneity and/or preventing immediate off-site migration during temporary system failure (such as shut-down of some or all of the pumping wells).
 | Agreed. A cut-off wall may help eliminate risk posed by difficult-to-otherwise-capture groundwater flowing in hypothesized continuous high-hydraulic conductivity sediments, as well as temporarily holding back groundwater flow in the case of temporary well shut down  |
|  |  | * The FY13 model also predicted only a marginal reduction in the seepage interception rates for the scenario with a cutoff wall across the RCAA and extending south to the RCD berm and along the berm to the ID (Scenario C). This modeling result is surprising as a cutoff wall along the d/s side of the RCD along this 1km reach should significantly reduce leakage from the RCD and hence the total amount of water flowing in the RCAA to be collected and treated. The author recommends that detailed flow nets be plotted (in section) and flow budgets be extracted along the southern side of the RCAA from this modeling run to determine why the predicted seepage interception rate is not declining with a commensurate decrease in the lateral inflow from the RCD into the RCAA.
* The predicted decreases in seepage rates to be extracted from the SIS for the other scenarios (providing larger extents of the cutoff wall along the RCD) appear consistent with the assumed leakage rates from the RCD (along the respective reaches of the RCD) and appear therefore reasonable7.

---7 Note that the text descriptions and predicted seepage rates quoted for Scenarios G and H in the TM do not match the figures and tables provided with the text; these apparent errors should be corrected in the final version of the TM.  | Scenario C has a cut-off wall that only extends along the CVD Pond. The 50 USGPM reduction is consistent with estimates of leakage across this reach.  |
|  |  | In summary, considering the potential importance of the ID and CVD ponds in influencing groundwater flow in the RCAA and the extraction rates for a future SIS the author recommends that the interaction of the groundwater system with the ID Pond and CVD Pond be studied in more detail. As outlined above this should include the development of a transient (monthly) water balance for these ponds, and more detailed cross-sectional modeling of the flow field in the reach between the Intermediate Pond and the CVD. The results of this 2D cross-sectional modeling should be compared to the results of the current (simplified) modeling approach used in the 3D model. If required, a more realistic representation of these ponds and/or additional model layers should be introduced in the 3D RCAA sub-model that allow a more accurate representation of the hydraulic interaction of the aquifer with the ponds and the surrounding embankment materials and underlying tailings/sludge.It is further recommended that the RCAA sub-model be developed as a stand-alone model (de-coupled from the regional model) which would facilitate local changes to the model grid (layers and cell spacing) without constraints and extra effort required for the very large regional model. | A transient water budget was developed for the ID Pond and CVD Pond as documented in the FY2015 Groundwater Flow Model Development Report. Additional studies of the CVD SIS were deferred due to re-prioritization of project focus to the NFRC Diversion Design.  |
| Fiscal Year 2013 Water Quality Modelling Analysis Report, Faro Mine Remediation Project/Goldsim Model Revisions, March 2014 |
| Reviewer: Dr. Leslie Gomm, P. Eng., Ph.D. Principal Consultant, SLR Consulting (Canada) Ltd. |
| 1 | Overall | These documents provide details on updates to the model that were made in 2013 and 2014 in including updates on how geochemical source terms from waste rock are incorporated into the model as well as changes to the RCTA model (reviewed by others). I have not specific comments on these update other than a significant amount of progression has been made on refining and improving on how the geochemical source terms are dealt with in the model. |  |