Memo

To:	Josée Perron, P.Eng.		
From:	Serge Chevrier, P.Eng. Charles Masala, P.Eng.	**Reviewed By:**	Brian Geddes
Tel:	604-294-3811	**AMEC File No:**	VM00605.TAR3.3240
Email:	serge.chevrier@amec.com	**cc**	Paul Morton
Date:	8 October, 2013		
Subject	Mount Nansen Remediation Project – Water Quality Modelling Progress Report		

This memo outlines the efforts undertaken during TAR #3 to review and define the scope of predictive water quality modelling requirements for the Mount Nansen project. A predictive modelling capability is required to evaluate the relationship between key design parameters for remedial Option 4 and the resulting water quality parameters downstream. This memo constitutes the Modelling Progress Report that is included in the list of TAR #3 deliverables. The outcomes of this modelling scope development work have been incorporated into the scope and budget definitions included in TAR #6.

1.0 PURPOSE AND OBJECTIVES OF THE WATER BALANCE/QUALITY MODEL

The purpose of the integrated water balance/water quality model is to evaluate the proposed remediation design for Mount Nansen and predict the resulting water quality parameters downstream. The model will help assess the existing conditions at the site and evaluate the long-term performance of the selected remediation design. Specifically, the model will meet the following objectives for selected points at the site:

- predict water quality (parameters of concern include Total Suspended Solids (TSS), cyanide, sulphate and metals (e.g. As, Zn Cd);
- predict surface water flow rates;
- estimate groundwater flow rates;
- demonstrate that downstream water quality will meet design specifications; and
- provide the basis for assessing requirements for water treatment and estimate water quantities and quality.

The two key parameters to the prediction of downstream water quality are the assessment of water quality source terms (Geochemistry) and the estimation of groundwater discharge from the Open Pit and Waste Rock (Hydrogeology).

AMEC Environment & Infrastructure
A division of AMEC Americas Limited
140 Quarry Park Boulevard S.E.
Calgary, Alberta, CANADA T2C 3G3
Tel: +1 (403) 248-4331
Fax: +1 (403) 248-2188
www.amec.com

2.0 EXISTING GOMM WATER BALANCE AND WATER QUALITY MODEL

The existing Gomm model was developed with the objective of assessing the six closure alternatives for the Mount Nansen site and provided the basis for selecting the remediation design option. While the Gomm model had less rigorous objectives compared to the current model, it provides a starting point for the current modelling effort. The following is a summary review of the existing GoldSim model:

Conceptual Model:

- The model was evaluated using a monthly time step over a 12 months period, covering dry, average and wet year scenarios.
- The model assumptions, inputs and outputs were reasonable for the modelling objectives at the time, which was focused on a comparative analysis of the six options, using some simplified assumptions, which were sufficient for that stage of the project, but not with sufficient depth to support the current detailed design.
- Results for predicted water quality in Victoria Creek in Appendix A of the report (Gomm 2011) do not always match those produced by the model; for example:
  - *Option 1b* – average year results are recorded as wet year results;
  - *Options 3 and 4* – results of some parameters such as As cannot be reproduced by the model as presented in the appendix; and
  - *Option 4* – average precipitation year results interchanged with dry year results.

Hydrology:

- For Dome Creek during spring/summer/fall (April through October), flow data was estimated using precipitation data and runoff coefficients. Runoff coefficients were not derived from local or measurements, but were based on professional judgment.
- For Dome Creek during fall/winter/spring (November through March), zero flow was assumed.
- For Victoria Creek (with flow during winter), a monthly distribution of annual flow as measured at the Water Survey Gauging Station on the Nordenskiold River was used.
- Site precipitation data was generated for the site for the period of 1964 to 2006, based on climate data collected at the Environment Canada Station at Carmacks.
- Lake evaporation rates estimated for the Pelly Ranch Environment Canada Meteorological station were used.

Hydrogeology:

- For the Open Pit pond, groundwater rates leaving the Open Pit and discharging towards Dome Creek were estimated to range from 157 to 4,249 m^3/year (0.13 L/sec). A discharge rate of 0.13 L/sec was used in the model.
- The large range in Open Pit groundwater discharging to the Dome Creek valley reflected high uncertainty in the rock mass hydraulic conductivity (i.e., over four-order of magnitude range).

- Option 4 was modelled assuming that 50% attenuation of arsenic will occur from the disposed tailings source in the Open Pit, to the Victoria Creek receptor. The 50% value was considered conservative, with precedence of 90% attenuation cited from NW Ontario and British Columbia mine studies.
- An Open Pit cover infiltration of 5% of average precipitation was used.

Geochemistry:

- Source terms were developed thoroughly using the comprehensive leachate and water quality data obtained from the seepage and surface water quality monitoring program, and laboratory and field geochemical testing.
- Source terms represented two different cases, ‘the conservative best estimate” and “the worst case estimate”. The source terms for the conservative best estimate were selected from the worst of median or mean of the data, while the maximum data were selected for the source term of the worst case estimation.

Water Quality:

- As discussed below in Section 3 Water Quality, the existing groundwater analytical data may be suspect for some key parameters including sulphide, arsenic and cyanide. The standard field sampling protocols for these parameters do not account for the transformations and reactions of these compounds during sampling and/or preservation. Therefore, the existing water quality data set may under-estimate the concentrations of sulphide, total cyanide and arsenic.
- As cyanide and arsenic are key contaminants of concern, the existing monitoring wells need to be re-sampled using revised field protocols in an attempt to better characterize the site conditions.
- The source terms applied by Gomm to estimate the water quality appear to be reasonable with the possible exception of cyanide and arsenic. The total cyanide source term of 0.07 mg/L (0.0027 mmol/L) presented in Table 4-27 of Gomm Environmental Engineering Consulting (2011) for the tailings area may actually be more like 0.5 mmol/L (i.e., 200 times higher) based on the 30 mg/L of thiocyanate that was detected. Thiocyanate forms when sulphide and cyanide are present in a water sample and the sample is preserved with NaOH without removing the sulphide first. Arsenic may be under-estimated by the precipitation of thioarsenical compounds in dissolved metals samples when acidified in the field. The arsenic concentrations may be under-estimated, but this effect is likely not as pronounced as it is for cyanide.
- The under-estimation of sulphide may also be significant in that the formation of metal sulphides would tend to remove metals from solution. There is significant loading of total organic carbon to the tailings pond area and it is to be expected (and there are indications) that sulphate reducing bacteria are actively oxidizing this Total Organic Carbon (TOC) to carbon dioxide (which provides acid buffering capacity as bicarbonate alkalinity). The resulting sulphide is highly reactive and difficult to sample, but the presence of sulphide will remove many metals from water including arsenic, cadmium and zinc which have been identified as the primary metals of concern.

- Re-sampling of the groundwater and surface water using revised sampling protocols will probably provide a better characterization of the site conditions. An improved understanding of the groundwater quality would likely provide a more defensible basis to evaluate the attenuation of arsenic than the existing application of 50% attenuation based on experience at other sites.

3.0 UPDATING THE EXISTING MODEL

The existing model should be updated to support upcoming Option 4 design development activity as described below.

Update of the Conceptual Model:

- Model to be evaluated such that it focuses on only the selected design option and not the six options.
- Evaluate model to cover existing, remediation and post-remediation periods. The post-remediation period could extend water quality predictions out to as much as 30 years, rather than the current 12 months, to provide a better characterization of the remedial design's long term performance.
- Evaluate the existing water balance/quality model to the level of detail consistent with existing site data. The model should include the following nodes:
    - *Dome Creek*:
        - DX (upperstream Mill Area),
        - DC-02 (downstream Mill Area),
        - DC-U1/U2 (upperstream Tailings Area),
        - DC-M (downstream Tailings Area),
        - DC-R (at the river);
    - *Pony Creek:*
        - PC-U (upperstream pit area),
        - PC-1 (pit area),
        - PC-02 (downstream pit area),
        - PC-BC (Pony and Back creeks confluence);
    - *Victoria Creek:*
        - VC-01/VC-Ref (upstream of confluence of Back and Victoria creeks),
        - VC-BC (Victoria and Back creeks confluence),
        - VC-02 (Victoria and Dome creeks confluence),
        - VC-03 (Victoria downstream point).
    - Open Pit.
    - Waste Rock.
    - Tailings Area/Seepage Pond.

- Evaluate the post-remediation period, to assess the proposed design specification and resulting water quantity/quality. Some of the existing model above will be eliminated (e.g., tailings area/seepage pond).
- Assess the ability of the proposed design to satisfy water quality objectives.

The update of key input parameters will be evaluated for each of the following disciplines.

Hydrology:

- Update input precipitation data to include data collected from 2007 to current. The Gomm model is based on pre-2006 data.
- Update the complete precipitation data for the site using the Carmacks data from 1964 to current (use site data where available).
- Use the generated historical data to evaluate the remedial design's post construction performance for periods of up to 30 years (different 30 year periods within the 50 year dataset may be used).
- Update the percentage snowmelt assumptions for April and May, based on recent site data, and validate against regional data (this process will consider the impacts of any anomalous data results that have been identified under the current monitoring program).
- Update/validate runoff coefficient estimates based on precipitation and flow data of the site from 2009 to 2012.

Hydrogeology:

- Update rock mass hydraulic conductivity inputs (from the 2013 site investigation) for the Open Pit floor and the rock mass south and southeast, between the Open Pit to the tailings pond.
- Update Open Pit deeper (regional) groundwater inputs and outputs.
- Assess groundwater-surface water interactions along Dome and Pony Creeks (2013 site investigation), including groundwater seepage rates and quality contributing to these key drainage courses.
- Assess drainage rates and quality from the Huestis mine adit making use of information/data from new groundwater monitoring wells installed during the 2013 site investigation).

Geochemistry:

- Update sources terms based on site samples collected monthly during 2013 SI.
- Source terms updates will include those for the PAG waste rock volumes that will be transferred to the Open Pit containment structure.

Water Quality:

- Use the more relevant monthly water quality values for assessing loading for the model (the existing Gomm's model used annual median water quality values for assessing loading).
- Update input water quality data to include data collected from 2007 to the present.
- Use total concentration for evaluation of metals for the model.
- Conduct a mass balance of measured water quality and flow data for Dome and Victoria Creeks to estimate loading in Victoria Creek originating from the tailings facility and the pit.
- Assess the basis for estimating the attenuation of arsenic for the model.
- Incorporate current site investigation results into the model to refine the understanding of source terms from geochemistry and hydrogeology.

A review of the groundwater and surface water analytical data indicates that there were sampling procedures used that may have resulted in the mis-identification of cyanide species, and possibly the under-estimation of arsenic concentrations. This under-estimation of cyanide and arsenic is due to the probable presence of sulphide in ground and surface waters. Sulphide levels may also be underestimated given the challenges associated with sulphide sampling. When sulphide is present, it will react with cyanide to form thiocyanate (SCN-) which is reportedly present at high concentrations. This is likely a mis-identification of either free cyanide (CN-) or iron-cyanide complexes as thiocyanate. When sulphide is present, it will react with arsenic when the dissolved metals sample is preserved with nitric acid (as is standard procedure). This will result in the formation of thioarsenical compounds that will tend to precipitate from the water sample. This can result in an under-estimation of the total arsenic concentration. The standard sampling protocols, as presumably were applied by the previous consultants, may not be sufficient to properly characterize the sulphide, arsenic and cyanide concentrations at this site, particularly near the tailings dam. The significance of these issues will be assessed during the site investigation program and any revisions to analytical procedures for ground waters and/or surface waters that may be appropriate will be described.

4.0 PROPOSED DESIGN MODELLING OUTPUTS

One of the key project deliverables for the modelling effort will be the definition of design criteria for critical project elements. These critical design criteria and/or issues will include:

- the maximum allowable pit cover infiltration rate;
- the maximum allowable seepage rate from the tailings placed in the pit (i.e., allowable tailings consolidation rates);
- maximum allowable moisture content in the placed tailings;
- the maximum allowable seepage from the pit (i.e., the general pit containment specification);

- the degree of direct control over pit groundwater levels that the remedial system must provide (i.e. the extent to which the ability to close or restrict adits would be useful or necessary); and
- the general sensitivity of water quality at compliance points to variations in key design parameters (i.e., how reliable must data inputs be to provide sufficient confidence in model predictions).

The influence of pit groundwater levels relative to the base of placed tailings will be assessed as these outputs are developed during the modelling effort.

5.0 PRELIMINARY GOLDSIM MODEL UPDATE

A preliminary working version of the GoldSim Model (Preliminary Model) update was developed (this version reflects perhaps 20% of the effort that will ultimately be required for the project's modelling component). The model represents two scenario: Existing Conditions and Proposed Design Conditions. The purpose of the Existing Conditions scenario is to represent current site conditions prior to any remediation activities on the site. The Existing Condition scenario will be used as a baseline for evaluating the effectiveness of the Proposed Design Conditions.

The preliminary working version of the GoldSim Model was developed using the "Mount Nansen Closure Alternatives Water Balance/Water Quality Model" developed by Gomm Environmental Engineering Consulting (Gomm Model) as the basis. Alternative 2a in the Gomm model which is the closest to the existing conditions, was modified to reflect the current conditions on site. The Existing Condition model takes into account contaminate loading from the following, the tailings; waste rock, open pit, ore and residual loading in the creeks from upstream of the site. The main results of the model is the resulting water quality on Victoria Creek downstream of the site. The inputs to the model are based on the Gomm Model and have not been updated to reflect the current understanding of the site. Preliminary results presented in Table 1 have not yet been validated.

The Proposed Design Conditions scenario will provide input to the design process as discussed in Section 4.0 and will also be used to evaluate the effectiveness of the proposed design. The Proposed Design Conditions is based on Option 4 of the Gomm Model. Since the design process has not yet started, the Proposed Design Conditions is only included in the current model as a placeholder.

References

Gomm Environmental Engineering Consulting, 2011. "Mount Nansen Closure Alternatives Water Balance/Water Quality Model"

RBG/sms
Attach.

Table 1 - Preliminary (Unvalidated) Existing Conditions Results at Victoria Creek Downstream of the Site

Time (months)	R1:Vic_WQ_2a[As] [mg/l]	R1:Vic_WQ_2a[Cd] [mg/l]	R1:Vic_WQ_2a[Cu] [mg/l]	R1:Vic_WQ_2a[Fe] [mg/l]	R1:Vic_WQ_2a[Mn] [mg/l]	R1:Vic_WQ_2a[Zn] [mg/l]	R1:Vic_WQ_2a[SO4] [mg/l]	R1:Vic_WQ_2a[NH4] [mg/l]	R1:Vic_WQ_2a[Nitrate] [mg/l]	R1:Vic_WQ_2a[Nitrite] [mg/l]	R1:Vic_WQ_2a[Cyanide_T] [mg/l]	R1:Vic_WQ_2a[CN_WAD] [mg/l]	R1:Vic_WQ_2a[Cyanate] [mg/l]	R1:Vic_WQ_2a[Ca] [mg/l]	R1:Vic_WQ_2a[Mg] [mg/l]	R1:Vic_Hardness_2a [mg/l]	R1:Vic_Cd_CCME2a [mg/l]
0	0.00268	0.00019	0.00249	0.66433	0.42382	0.02527	49.01311	0.22425	0.17346	0.01342	0.02369	0.00277	0.15036	36.04666	9.69399	129.91170	0.00030
1	0.00393	0.00033	0.00282	1.05812	0.68388	0.04161	74.55107	0.42506	0.27542	0.02123	0.04565	0.00348	0.19705	44.05738	10.83098	154.59087	0.00035
2	0.00358	0.00029	0.00273	0.94858	0.61154	0.03706	67.44683	0.36920	0.24706	0.01906	0.03954	0.00329	0.18406	41.82893	10.51469	147.72552	0.00033
3	0.00164	0.00011	0.00223	0.31617	0.19957	0.01765	30.42943	0.04722	0.08536	0.00656	0.00433	0.00214	0.10908	29.98923	8.92146	111.60957	0.00027
4	0.00139	0.00005	0.00215	0.25462	0.15374	0.00894	23.01926	0.01540	0.06752	0.00531	0.00085	0.00203	0.10180	27.86580	8.54509	104.75881	0.00026
5	0.00143	0.00005	0.00215	0.26753	0.16190	0.00910	23.76245	0.02198	0.07071	0.00556	0.00157	0.00205	0.10334	28.10827	8.57722	105.49641	0.00026
6	0.00149	0.00006	0.00217	0.27994	0.17135	0.01122	25.72850	0.02846	0.07433	0.00582	0.00228	0.00207	0.10481	28.66536	8.68127	107.31559	0.00026
7	0.00153	0.00008	0.00219	0.28482	0.17692	0.01414	27.39042	0.03111	0.07649	0.00593	0.00257	0.00208	0.10538	29.10230	8.77310	108.78452	0.00027
8	0.00152	0.00009	0.00220	0.28551	0.17793	0.01460	27.13186	0.03140	0.07696	0.00594	0.00260	0.00208	0.10543	29.02155	8.75599	108.51247	0.00027
9	0.00157	0.00008	0.00221	0.31227	0.19373	0.01332	27.18666	0.04483	0.08327	0.00646	0.00407	0.00213	0.10860	29.12601	8.73462	108.68513	0.00027
10	0.00182	0.00010	0.00226	0.39317	0.24529	0.01460	31.59831	0.08599	0.10347	0.00805	0.00857	0.00228	0.11821	30.56922	8.92055	113.05345	0.00027
11	0.00215	0.00013	0.00235	0.49833	0.31420	0.01839	38.24757	0.13960	0.13048	0.01013	0.01443	0.00247	0.13068	32.66974	9.21469	119.50819	0.00029
12	0.00294	0.00022	0.00256	0.74546	0.47740	0.02864	54.27439	0.26562	0.19446	0.01503	0.02822	0.00292	0.15998	37.69702	9.92823	134.99606	0.00031