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MEMORANDUM

To:	Alexey Klyashtorin and Chris Reid – Saskatchewan Research Council, Project CLEANS Gunnar Uranium Mine
From:	Kristie Bonstrom, P.Geo.
cc:	Denise Chapman – O'Kane Consultants Inc.
Date:	August 12, 2015
Re:	**SRC Gunnar Main Tailings Post-Closure Groundwater Flow Analysis**

The Saskatchewan Research Council (SRC) was contracted by the Government of Saskatchewan to act as Project Manager, licence applicant and designated agent to undertake remedial activities at the Gunnar uranium deposit (the Site). SRC has retained O'Kane Consultants Inc. (OKC) and Ecometrix (Project Team) to develop a detailed cover system design for Gunnar Main, Gunnar Central, and Langley Bay tailings areas. A conceptual tailings remediation plan (OKC, 2015)[1] was submitted to the Canadian Nuclear Safety Commission (CNSC) for review July 16. 2015.

Following review of the conceptual remediation plan, CNSC identified several areas of the Tailings Remediation Plan that will require further clarification. This included providing further detail regarding mass loading to environmental receptors. Specifically, CNSC requires model input parameters, model assumptions and data analysis for loading calculations of constituents of potential concern (COPC) to be clarified. The objective of this memorandum is to provide a summary of the estimated post-closure groundwater flow rates from the Gunnar Main tailings (Gunnar Main) to Ecometrix. Estimated flow rates will allow Ecometrix to refine current COPC load estimates, thereby addressing the CNSC comments discussed above. In addition, CNSC requested a detailed assessment of the phreatic surface within the tailings deposits. The phreatic surface assessment will provide a range in water table depth for the Gunnar Main landform to ensure that capillary rise of COPCs can be assessed. The phreatic surface in Gunnar Central and Langley Bay deposits is likely to be at or near the current ground surface, therefore the phreatic surface contours for these deposits have not been included.

<u>Current Conditions:</u>

In order to estimate the post-closure condition of groundwater within Gunnar Main, it is necessary to develop an understanding of the current groundwater regime. Cone penetration testing (CPT) at Gunnar Main was completed by SNC-Lavalin in April and May 2012 to estimate the depth of the phreatic surface (SNC-Lavalin, 2014)[2]. Piezometers were also installed in 2012 and readings were taken through the late

[1] O'Kane Consultants Inc. 2015. Gunnar Site Remediation Plan – Tailings Remediation Plan. Prepared for Saskatchewan Research Council July 16, 2015.
[2] SNC-Lavalin. 2014. Geotechnical Investigation Gunnar Mine Site Tailings Areas. Prepared for Saskatchewan Research Council April 16, 2014.

summer and fall (MDH, 2012)[3]. Table 1 summarizes the compiled groundwater level data available for Gunnar Main.

Table 1
Summary of phreatic surface data at Gunnar Main (SNC-Lavalin, 2012, MDH, 2012).

CPT ID	Measurement Type	Measurement Date (dd/mm/yy)	Ground Surface Elevation (masl)	Estimated Phreatic Surface Depth (m)
AA1	CPT	30/04/12	241.6	1.8
AB1	CPT	30/04/12	242.1	2.3
AC1	CPT	30/04/12	241.0	1.3
AD1	CPT	30/04/12	244.5	5.1
AE1	CPT	01/05/12	243.7	3.2
AF1	CPT	30/04/12	242.1	2.5
AH1	CPT	30/04/12	240.0	0.5
AI1	CPT	01/05/12	241.9	0.8
AJ1	CPT	01/05/12	245.9	6.4
AK1	CPT	30/04/12	240.8	0.5
AL1	CPT	30/04/12	248.9	8.8
AM1	CPT	01/05/12	241.2	0.8
AN1	CPT	01/05/12	241.5	1.0
AO1	CPT	01/05/12	245.0	3.5
AQ1	CPT	01/05/12	244.8	5.2
AR1	CPT	01/05/12	243.6	8.9
16A	Piezometer Reading	10/07/12 22/09/12 02/11/12*	238.9	0.11
18A	Piezometer Reading	10/07/12 17/09/12 02/11/12*	250.41	Dry (max depth 6.12m)
19A	Piezometer Reading	10/07/12 21/09/12 02/11/12*	242.43	2.52
20A	Piezometer Reading	15/07/12 21/09/12 02/11/12*	241.5	1.49

*Average water level reading taken

Water levels within Mudford Lake and Beaver Pond were estimated to be 239.0 masl based on the most recently available topography provided by SRC. Based on the 2012 groundwater data and current topography, the phreatic surface within Gunnar Main was estimated in Figure 1. The north-south and east-west phreatic surface water divides were also estimated and are shown in pink. In the north-west area,

[3]MDH Engineered Solutions. 2012. Subsurface Hydrogeological Characterization for the Gunnar Site. Prepared for Saskatchewan Research Council December, 2012

groundwater within the tailings drains freely to Mudford Lake along the northern and western boundaries of the tailings facility, eventually reporting to Langley Bay (not shown). In the north-east east, groundwater reports to the pit through Catchment-3 in zones of high permeability within the bedrock along the eastern boundary of Gunnar Main. Along the southern boundary, it is thought that groundwater moves St. Mary's Channel, in smaller amounts compared to northwards flow, through zones of high permeability within the bedrock.

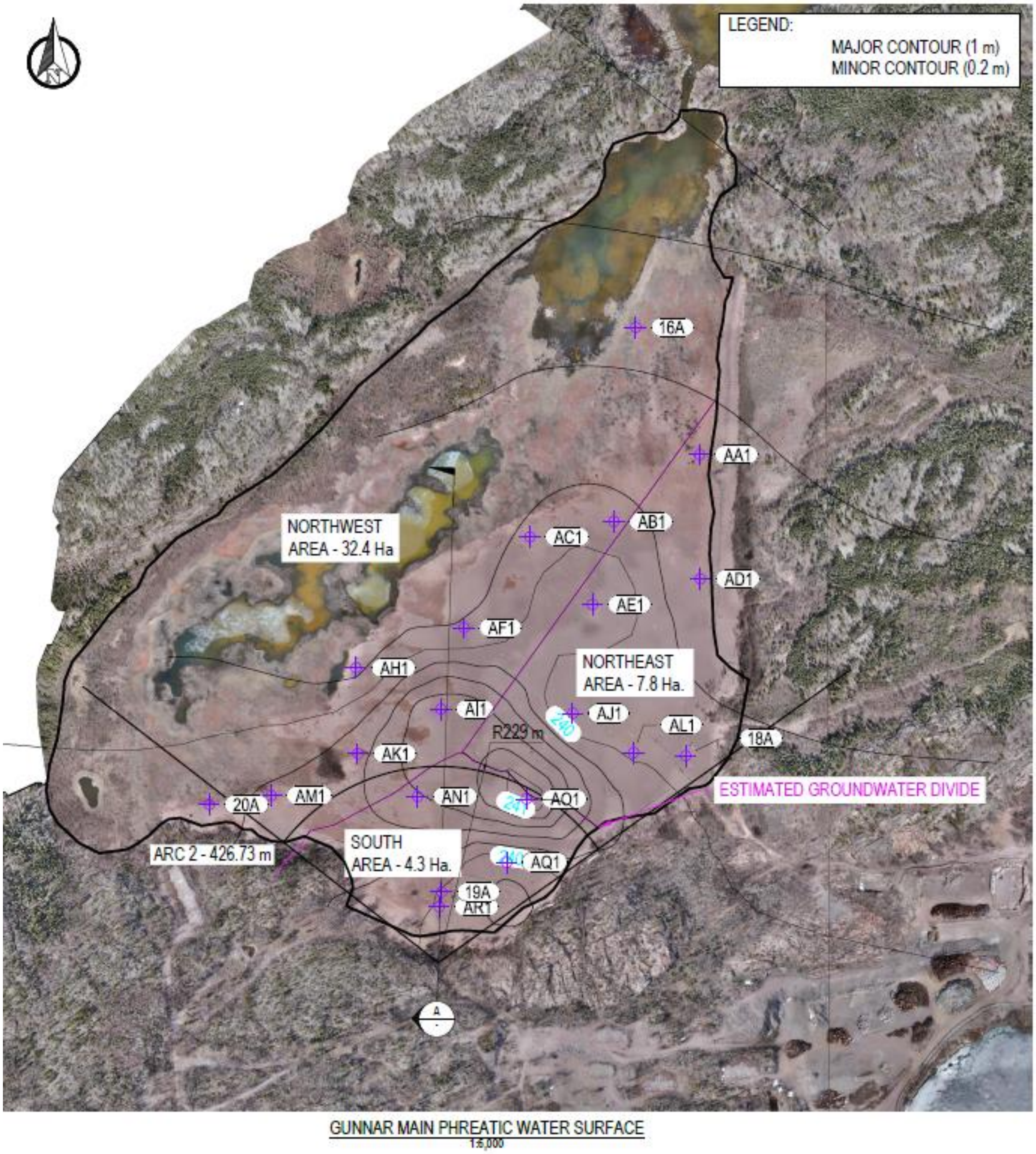

Figure 1 Estimated current phreatic surface at Gunnar Main.

Groundwater flowing both north and south in Gunnar Main was approximated using a 2-dimensional analytical spreadsheet model and the Dupuit equation [Eqn 1] for steady flow in an unconfined groundwater with mounding due to recharge. Cross section A (Figure 1) was chosen to represent the observed radial flow in two dimensions.

$$q'_x = \frac{K(h_s^2 - h_n^2)}{2L} - W(\frac{L}{2} - x) \qquad \text{[Eqn 1]}$$

where:

q_x' = unit flow at point 'x' (m^2/day);

K = hydraulic conductivity of the tailings (m/day);

h_s = hydraulic head at the southern boundary of the cross section (masl);

h_n = hydraulic head at the northern boundary of the cross section (masl);

W = estimated surface infiltration rate to the tailings (m/day);

L = the length of the cross section (m); and

x = the distance from the southern edge at which flow is being measured (m).

In addition, the maximum height of the water table, and the distance from the southern boundary at which maximum groundwater height occurs were also calculated using the Dupuit equation [Eqn 2] and [Eqn 3].

$$h_{max} = \sqrt{h_s^2 - \frac{(h_s^2 - h_n^2)x}{L} + \frac{W}{K}(L-d)d} \qquad \text{[Eqn 2]}$$

$$d = \frac{L}{2} - \frac{K}{W}\frac{(h_s^2 - h_n^2)}{2L} \qquad \text{[Eqn 3]}$$

where:

h_{max} = maximum water table elevation (masl) and

d = distance from southern edge at which maximum water table elevation occurs (m).

Unit flow (q_x') along Cross Section A was calculated using the following input parameters seen in Table 2. Hydraulic heads were estimated from groundwater contours shown in Figure 1. Surface infiltration rates were estimated based on concurrent surface water balance VADOSE/W modelling being completed by OKC.

Table 2
Input parameters for Dupuit equation.

Parameter	Value
h_s	239.75 masl
h_n	239 masl
W	88 mm/year
L	518 m

h_{max} and d values were then calibrated to observed site conditions by varying the K of the tailings material. Concurrent numerical modelling by OKC determined that the K of the tailings is approximately 1×10^{-5} cm/s or 0.00864 m/day. This value agrees well with the Dupuit calibrated K of 2.4×10^{-5} cm/s. Table 3 summarizes the observed and calculated parameters listed above.

Table 3
Summary of observed and calculated Dupuit parameters at Gunnar Main under current conditions.

Scenario	Saturated Hydraulic Conductivity, K (cm/s)	Maximum Water Table Elevation, h_{max} (masl)	Distance to Maximum Water Table Elevation, d (m)
Observed Data	1×10^{-5} *	241	229
Calculated	2.4×10^{-5}	241	229

*Based on material properties developed for concurrent VADOSE/W numerical modelling.

The north-south groundwater divide (d) was then approximated using a circular arc as shown in Figure 1 to delineate 3 separate contributing areas over which the infiltration rate (W) could be applied assuming steady state flow. North-west flow towards Langley Bay is estimated to be 78 m^3/day, east flow towards Catchment-3 is estimated to be 19 m^3/day, while 12 m^3/day discharges south towards St. Mary's Channel.

Closure Conditions:

The remediation plan for Gunnar Main, Gunnar Central and Langley Bay includes water shedding landforms with positive surface drainage towards Langley Bay. Waste rock fill or working platforms will be placed above the tailings at Gunnar Main and Gunnar Central, which will be overlain by a cover system. Fill material will be placed at Langley Bay and also overlain by a cover system. Cover systems are anticipated to affect the surface infiltration rate (W) to the new landform. In addition, Beaver Pond will be drained and a water shedding landform will be constructed, as positive drainage will be required from Gunnar Main to Langley Bay.

The change in water levels at Beaver Pond will impact the current hydraulic head boundary (h_n) assumed to exist under current conditions. It is anticipated that water levels within Beaver pond will drop approximately 2 m. A drop in water levels in Beaver Pond of 1 m and 3 m were modelled under different surface infiltration conditions as final topography of the landforms has not yet been confirmed. The effect of lower water levels within Beaver Pond was examined using the Dupuit equation to estimate the change in location of the north-south phreatic surface water divide. It was assumed that the north-south phreatic surface water divide would maintain its circular arc shape and that the radius of the circular arc would increase or decrease based on the changing northern boundary condition. The east-west phreatic surface water divide was assumed to remain in its current location. Based on the results of the Dupuit equation for Cross Section A, new contribution areas were delineated for the 1 m drained and 3 m drained conditions. Seepage from each of these areas was then estimated under a number of infiltration conditions. Table 4 highlights the range of parameters evaluated and their effect on groundwater flow.

Table 4
Summary of Dupuit parameters and resulting groundwater flow volumes for Gunnar Main under several closure conditions.

Cover System	Expected Surface Infiltration, W (mm/year)	Expected Water Level in Beaver Pond, h_n (masl)	Maximum Water Table Elevation, h_{max} (masl)	Distance to Maximum Water Table Elevation, d (m)	Total Groundwater Flow to Langley Bay, Q_{NW} (m^3/day)	Total Groundwater Flow to C-3, Q_{NE} (m^3/day)	Total Groundwater Flow to St. Mary's Channel, Q_S (m^3/day)
Current Bare Condition	88	239	241.0	229.0	78	19	12
1 m Till	90	238	240.7	191.9	82	20	8
0.3 m Coarser-Textured Material Overlying 0.3 m Fine Sand	95	238	240.7	193.3	87	22	9
1.0 Coarser-Textured Material Overlying 0.5 m Silty Clay	80	238	240.5	183.7	74	18	7
0.3 m Coarser-Textured Material Overlying 0.3 m Fine Sand Overlying 0.5 m Waste Rock	110	238	241.0	203.4	100	25	11
1 m Till	90	236	240.1	115.6	86	22	3
0.3 m Coarser-Textured Material Overlying 0.3 m Fine Sand	95	236	240.1	118.7	90	23	3
1.0 Coarser-Textured Material Overlying 0.5 m Silty Clay	80	236	240.0	98.1	77	20	2
0.3 m Coarser-Textured Material Overlying 0.3 m Fine Sand Overlying 0.5 m Waste Rock	110	236	240.3	140.2	104	27	5

Based on the results from the Dupuit analysis, it is apparent that a drop in hydraulic head at the northern boundary of Gunnar Main results in a movement southward of the north-south groundwater divide currently observed at Gunnar Main. This in turn results in a greater area contributing to groundwater flow towards

Langley Bay. The effect of changes in surface infiltration also affects the location of the north-south groundwater divide but to a much smaller extent. An increase in surface infiltration rates causes a proportional increase in seepage rates from each contributing area.

It is expected that this summary of the estimated post-closure groundwater flow rates from Gunnar will provide a basis for refining COPC load estimates to Langley Bay. However, it is evident that changing the surface water flow regime has the potential to affect seepage volumes to Langley Bay. As the total landform design for Gunnar Main, Gunnar Central, and Langley Bay continue to evolve, these groundwater flow estimates will continue to be refined, in turn allowing for refinement of the COPC load estimates.

Closure:

We trust information provided in this memorandum addresses seepage and groundwater flow from Gunnar Main adequately. Please do not hesitate to contact me at (306) 955-3249 or kbonstrom@okc-sk.com should you have any questions or comments.