# TECHNICAL MEMORANDUM

**DATE** February 18, 2015 **PROJECT No.** 1407256/4200/20

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**JAY PROJECT: GOLDER ACTION ITEMS FROM FEBRUARY 3, 2015 MEETING WITH ENR**

## Background

On February 3, 2015, a meeting was held in Yellowknife to discuss the Jay Project (the Project), with attendees including Dominion Diamond Ekati Corp. (Dominion Diamond), the Government of Northwest Territories, Environment and Natural Resources, Water Resources and their consultants for the Project, and Golder Associates Ltd. (Golder). The meeting minutes are provided under separate cover. There were two action items for follow-up assigned to the Golder team:

- **Hydrogeology**: Willy to provide information on hydraulic head conditions at pit wall.
- **Water Quality Modelling**: Mike to provide the depth of the cell at the first assessment node (LDS-P1) in Lac du Sauvage (LdS). Additionally ENR requested water quality results for the cell(s) where waste rock storage area (WRSA) runoff is included in the model.

The following provides the information requested at the meeting.

## Hydrogeology

The following provides additional information on the Jay Project numerical hydrogeologic model.

The hydrogeological model used to predict groundwater conditions near the Jay Pipe during mining and flooding of the Jay Open Pit was described in Appendix 8A of the Developer's Assessment Report (DAR) and is referred to below as the Operation Model. The hydrogeological model used to simulate post-closure conditions at the Jay pipe, as described in Appendix 8B, is referred in the following as the Post-Closure Model.

The Operation Model simulates groundwater flow and advective-dispersive transport of solutes (e.g., total dissolved solids [TDS]) without consideration for the effects of solute density. This approach was adopted as it resulted in a conservative (i.e., high) prediction of TDS concentration in mine inflow; it also reduced model complexity and associated computational effort. With higher-TDS (salinity) water present at greater depth beneath the open pit, density-related gravity effects are expected to somewhat offset the effect of upward hydraulic gradient created by pit dewatering. The Operation Model does not include density-related gravity effects, and as such, the predicted upwelling of more saline groundwater from deep bedrock beneath the open pit is more pronounced than the scenario that includes these effects.

The importance of the density-related gravity effects on solutes transport was assessed in the early stages of model development using the driving force ratio (DFR) approach developed by US Geological Survey (Open File Report 88-490). This ratio provides an indication of the significance of gravity effects on flow compared to pressure effects, with a DFR of less than approximately 0.5 being indicative of conditions when the density-related gravity effects are relatively small and could be neglected. The most conservative DFR for the Operation Model (i.e., 0.3) was calculated for the vertical profile (i.e., gravity gradient of 1) beneath the ultimate open pit; a smaller DFR was calculated for profiles that were not vertical. These calculated DFRs provided additional rationale for not including gravity-related density effects in the Operation Model, and suggested that a model with or without these effects would provide predictions that are essentially the same (but, as explained above, the model without the density effect will tend to predict somewhat faster upwelling of high-TDS water).

The DFR calculated for conditions that are expected immediately after the Jay Open Pit is flooded is much higher than the one estimated for the mining period. This is because following pit flooding, the large hydraulic gradients associated with pit dewatering will diminish, but the upwelling of the high-TDS groundwater during mining results in large contrast in groundwater density near the pit bottom. Therefore, the Post-Closure Model used to represent groundwater conditions during post-closure coupled the groundwater flow and solute transport via density. This allowed for adequate representation of density effects of the relatively slow “sinking” of the high-TDS groundwater from beneath the pit bottom and associated convective circulation of shallow groundwater near the pit walls.

The specific question regarding model boundary conditions was whether pit lake water density was considered during back-flooding of the open pit. In the Operation Model, time-dependent specified head conditions were assigned to the pit walls, with the head values gradually increased in time according to the pit flooding schedule. These head values were not expressed in terms of freshwater head (i.e., based on lake TDS vs. depth profile) for consistency with the overall approach that excluded density effects from this model. It should be noted that the maximum difference between the freshwater head calculated at the base of the fully flooded pit based on the lake TDS vs. depth profile relative to the lake level was approximately 0.3 m, a difference that is negligible considering the large hydraulic head differentials that develop behind the pit walls during flooding.

In the Post-Closure Model, the pit walls were assigned time-constant specified head boundaries that represented the pit lake elevation at post-closure. These boundaries were expressed as freshwater head that was calculated using the lake TDS vs. depth profile. This is consistent with the modelling approach that included density-related gravity effects in the Post-Closure Model.

## Water Quality Modelling

During the February 3, 2015 meeting, ENR asked for the water quality depth assumed in the model at assessment location LDS-P1 (Figure 1), which includes the discharge from the Misery Pit via the diffuser. The water column depth at this location was assumed to be 14 metres in the water quality model.

In addition to this information, ENR also requested the water quality model results from cells where WRSA drainage is assumed to report to Lac du Sauvage in post-closure. The total drainage from the WRSA is distributed evenly to five model cells in Lac du Sauvage, as presented in Figure 1. The maximum projected depth averaged concentration during post-closure for each of these locations is provided in Table 1.

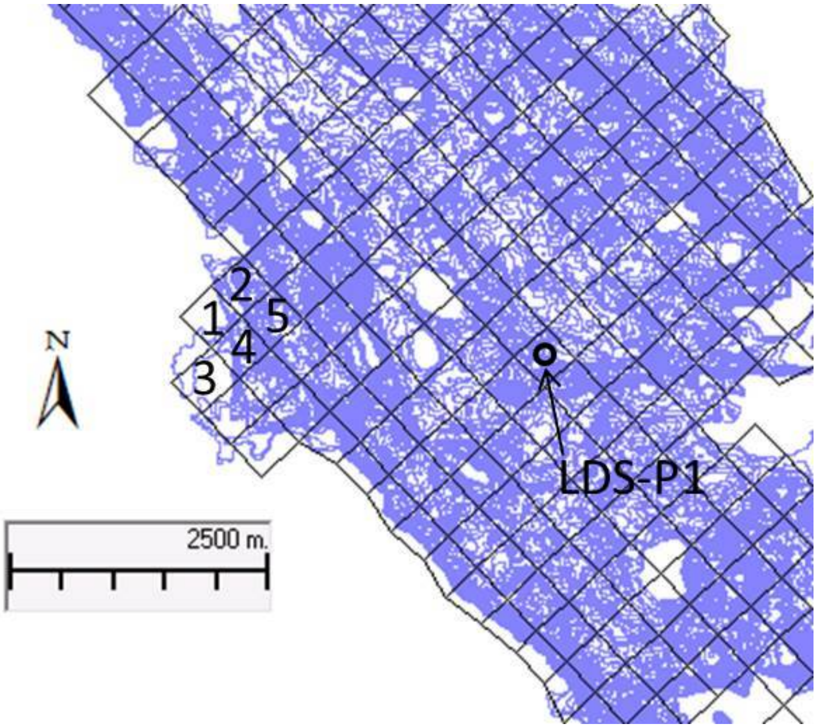


*Figure 1: Location in Lac du Sauvage where WRSA Drainage is Assumed to Report in Post-closure*

**Table 1: Predicted Maximum of Depth-Averaged Water Quality in Lac du Sauvage near the Jay Waste Rock Storage Area**

| Parameter | Units | WRSA-1 Post-Closure (2034–2060) | | WRSA-2 Post-Closure (2034–2060) | | WRSA-3 Post-Closure (2034–2060) | | WRSA-4 Post-Closure (2034–2060) | | WRSA-5 Post-Closure (2034–2060) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Under Ice | Open Water | Under Ice | Open Water | Under Ice | Open Water | Under Ice | Open Water | Under Ice | Open Water |
| **Model Characteristics** | | | | | | | | | | | |
| Column Depth[a] | m | 2.5 | 4.0 | 4.5 | 6.0 | 2.5 | 4.0 | 4.0 | 6.5 | 8.5 | 10 |
| **Field Measured** | | | | | | | | | | | |
| Water temperature | °C | 1.6 | 17 | 1.6 | 17 | 1.6 | 17 | 1.7 | 17 | 1.6 | 17 |
| Dissolved oxygen[b] | mg/L | 6.4 | 6.6 | 6.6 | 6.8 | 6.3 | 6.5 | 6.5 | 6.7 | 7.5 | 7.8 |
| **Conventional Parameters** | | | | | | | | | | | |
| Hardness (calculated) | mg/L | 12 | 9.5 | 11 | 9.6 | 12 | 9.5 | 11 | 9.8 | 11 | 9.8 |
| Total dissolved solids | mg/L | 24 | 19 | 24 | 19 | 24 | 19 | 24 | 19 | 22 | 20 |
| Total suspended solids[c] | mg/L | 1.8 | 1.3 | 1.7 | 1.3 | 1.8 | 1.3 | 1.7 | 1.3 | 1.5 | 1.3 |
| **Major Ions** | | | | | | | | | | | |
| Calcium | mg/L | 3.2 | 2.6 | 3.2 | 2.5 | 3.3 | 2.6 | 3.2 | 2.6 | 2.9 | 2.6 |
| Chloride | mg/L | 6.9 | 5.5 | 6.8 | 5.4 | 6.9 | 5.4 | 6.8 | 5.5 | 6.2 | 5.6 |
| Fluoride | mg/L | 0.013 | 0.0095 | 0.012 | 0.0093 | 0.013 | 0.0094 | 0.012 | 0.0093 | 0.011 | 0.0096 |
| Magnesium | mg/L | 0.89 | 0.75 | 0.82 | 0.78 | 0.83 | 0.73 | 0.82 | 0.79 | 0.85 | 0.79 |
| Potassium | mg/L | 0.71 | 0.61 | 0.64 | 0.6 | 0.73 | 0.6 | 0.65 | 0.61 | 0.66 | 0.62 |
| Sodium | mg/L | 2.1 | 1.7 | 2.1 | 1.7 | 2.1 | 1.7 | 2.1 | 1.7 | 1.9 | 1.7 |
| Sulphate | mg/L | 2.3 | 1.8 | 2.0 | 1.8 | 1.9 | 1.7 | 2.0 | 1.9 | 2.0 | 1.8 |

**Table 1: Predicted Maximum of Depth-Averaged Water Quality in Lac du Sauvage near the Jay Waste Rock Storage Area**

| Parameter | Units | WRSA-1 Post-Closure (2034–2060) Under Ice | WRSA-1 Post-Closure (2034–2060) Open Water | WRSA-2 Post-Closure (2034–2060) Under Ice | WRSA-2 Post-Closure (2034–2060) Open Water | WRSA-3 Post-Closure (2034–2060) Under Ice | WRSA-3 Post-Closure (2034–2060) Open Water | WRSA-4 Post-Closure (2034–2060) Under Ice | WRSA-4 Post-Closure (2034–2060) Open Water | WRSA-5 Post-Closure (2034–2060) Under Ice | WRSA-5 Post-Closure (2034–2060) Open Water |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nutrients** | | | | | | | | | | | |
| Total nitrogen (calculated) | mg-N/L | 1.4 | 0.9 | 1.2 | 0.98 | 1.1 | 0.85 | 1.2 | 1.0 | 1.1 | 0.92 |
| Total ammonia | mg-N/L | 0.46 | 0.27 | 0.38 | 0.29 | 0.34 | 0.24 | 0.38 | 0.31 | 0.35 | 0.27 |
| Nitrate | mg-N/L | 0.81 | 0.47 | 0.68 | 0.52 | 0.6 | 0.45 | 0.67 | 0.55 | 0.63 | 0.48 |
| Total phosphorus (calculated) | mg-P/L | 0.0094 | 0.0085 | 0.0091 | 0.0083 | 0.0088 | 0.0085 | 0.009 | 0.0084 | 0.009 | 0.0084 |
| Dissolved orthophosphate | mg-P/L | 0.0035 | 0.0026 | 0.0031 | 0.0024 | 0.0028 | 0.0025 | 0.0031 | 0.0025 | 0.003 | 0.0025 |
| Phytoplankton (as Chlorophyll a) | µg/L | 2.7 | 3.6 | 2.7 | 3.6 | 2.7 | 3.6 | 2.7 | 3.6 | 2.7 | 3.5 |
| Silica, reactive | mg/L | 0.18 | 0.14 | 0.17 | 0.14 | 0.18 | 0.14 | 0.17 | 0.14 | 0.15 | 0.15 |
| **Total Metals** | | | | | | | | | | | |
| Aluminum | µg/L | 40 | 32 | 34 | 35 | 31 | 30 | 34 | 36 | 33 | 32 |
| Arsenic | µg/L | 0.4 | 0.33 | 0.39 | 0.33 | 0.39 | 0.33 | 0.39 | 0.34 | 0.39 | 0.33 |
| Barium | µg/L | 4.0 | 2.9 | 3.6 | 3.0 | 3.3 | 2.7 | 3.5 | 3.1 | 3.4 | 2.8 |
| Beryllium | µg/L | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Bismuth | µg/L | 0.0069 | 0.0064 | 0.0068 | 0.0065 | 0.0066 | 0.0062 | 0.0068 | 0.0065 | 0.0068 | 0.0064 |
| Cadmium | µg/L | 0.03 | 0.028 | 0.029 | 0.028 | 0.029 | 0.028 | 0.029 | 0.028 | 0.029 | 0.028 |
| Chromium | µg/L | 0.21 | 0.13 | 0.21 | 0.13 | 0.2 | 0.13 | 0.21 | 0.14 | 0.21 | 0.13 |
| Cobalt | µg/L | 0.39 | 0.25 | 0.33 | 0.27 | 0.3 | 0.23 | 0.33 | 0.28 | 0.31 | 0.25 |
| Copper | µg/L | 0.81 | 0.68 | 0.79 | 0.69 | 0.78 | 0.67 | 0.79 | 0.7 | 0.78 | 0.68 |
| Iron | µg/L | 39 | 37 | 33 | 39 | 30 | 34 | 33 | 40 | 31 | 36 |
| Lead | µg/L | 0.056 | 0.076 | 0.051 | 0.078 | 0.048 | 0.074 | 0.051 | 0.079 | 0.049 | 0.076 |

**Table 1: Predicted Maximum of Depth-Averaged Water Quality in Lac du Sauvage near the Jay Waste Rock Storage Area**

| Parameter | Units | WRSA-1 Post-Closure (2034–2060) Under Ice | WRSA-1 Post-Closure (2034–2060) Open Water | WRSA-2 Post-Closure (2034–2060) Under Ice | WRSA-2 Post-Closure (2034–2060) Open Water | WRSA-3 Post-Closure (2034–2060) Under Ice | WRSA-3 Post-Closure (2034–2060) Open Water | WRSA-4 Post-Closure (2034–2060) Under Ice | WRSA-4 Post-Closure (2034–2060) Open Water | WRSA-5 Post-Closure (2034–2060) Under Ice | WRSA-5 Post-Closure (2034–2060) Open Water |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Manganese | µg/L | 15 | 13 | 13 | 13 | 12 | 12 | 13 | 14 | 12 | 13 |
| Mercury | µg/L | 0.0034 | 0.0026 | 0.003 | 0.0028 | 0.0028 | 0.0024 | 0.003 | 0.0028 | 0.0029 | 0.0026 |
| Molybdenum | µg/L | 0.17 | 0.13 | 0.17 | 0.14 | 0.15 | 0.12 | 0.17 | 0.14 | 0.17 | 0.13 |
| Nickel | µg/L | 0.77 | 0.6 | 0.69 | 0.63 | 0.65 | 0.57 | 0.69 | 0.64 | 0.66 | 0.6 |
| Selenium | µg/L | 0.074 | 0.064 | 0.07 | 0.066 | 0.068 | 0.063 | 0.07 | 0.067 | 0.069 | 0.065 |
| Silver | µg/L | 0.051 | 0.051 | 0.051 | 0.051 | 0.051 | 0.051 | 0.051 | 0.051 | 0.051 | 0.051 |
| Strontium | µg/L | 88 | 50 | 87 | 49 | 88 | 50 | 87 | 50 | 80 | 50 |
| Uranium | µg/L | 1.2 | 0.68 | 0.97 | 0.75 | 0.86 | 0.64 | 0.96 | 0.79 | 0.89 | 0.7 |
| Vanadium | µg/L | 0.044 | 0.039 | 0.043 | 0.04 | 0.04 | 0.038 | 0.043 | 0.041 | 0.042 | 0.039 |
| Zinc | µg/L | 1.2 | 0.9 | 1.1 | 0.94 | 1.0 | 0.87 | 1.1 | 0.96 | 1.0 | 0.91 |
| **Dissolved Metals** | | | | | | | | | | | |
| Aluminum | µg/L | 13 | 8.2 | 11 | 8.6 | 11 | 7.8 | 11 | 8.9 | 11 | 8.3 |
| Arsenic | µg/L | 0.4 | 0.33 | 0.39 | 0.33 | 0.39 | 0.33 | 0.39 | 0.34 | 0.39 | 0.33 |
| Barium[(d)] | µg/L | 3.8 | 2.6 | 3.4 | 2.8 | 3.2 | 2.5 | 3.4 | 2.9 | 3.2 | 2.6 |
| Beryllium | µg/L | 0.0056 | 0.0054 | 0.0056 | 0.0054 | 0.0055 | 0.0054 | 0.0056 | 0.0054 | 0.0056 | 0.0054 |
| Bismuth | µg/L | 0.0066 | 0.0061 | 0.0065 | 0.0062 | 0.0063 | 0.006 | 0.0065 | 0.0063 | 0.0065 | 0.0061 |
| Cadmium | µg/L | 0.0077 | 0.0058 | 0.0068 | 0.0061 | 0.0063 | 0.0054 | 0.0068 | 0.0062 | 0.0065 | 0.0056 |
| Chromium | µg/L | 0.087 | 0.017 | 0.084 | 0.019 | 0.082 | 0.016 | 0.084 | 0.019 | 0.082 | 0.017 |
| Cobalt | µg/L | 0.35 | 0.2 | 0.29 | 0.22 | 0.26 | 0.19 | 0.29 | 0.23 | 0.27 | 0.21 |
| Copper | µg/L | 0.81 | 0.65 | 0.79 | 0.66 | 0.78 | 0.64 | 0.79 | 0.66 | 0.78 | 0.65 |

**Table 1: Predicted Maximum of Depth-Averaged Water Quality in Lac du Sauvage near the Jay Waste Rock Storage Area**

| Parameter | Units | WRSA-1 | | WRSA-2 | | WRSA-3 | | WRSA-4 | | WRSA-5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Post-Closure (2034–2060) | | Post-Closure (2034–2060) | | Post-Closure (2034–2060) | | Post-Closure (2034–2060) | | Post-Closure (2034–2060) | |
| | | Under Ice | Open Water | Under Ice | Open Water | Under Ice | Open Water | Under Ice | Open Water | Under Ice | Open Water |
| Iron | µg/L | 33 | 22 | 28 | 23 | 25 | 20 | 27 | 24 | 26 | 22 |
| Lead | µg/L | 0.031 | 0.02 | 0.027 | 0.022 | 0.024 | 0.019 | 0.026 | 0.023 | 0.025 | 0.02 |
| Manganese | µg/L | 15 | 8.8 | 13 | 9.5 | 12 | 8.2 | 13 | 10.0 | 12 | 8.9 |
| Mercury | µg/L | 0.00084 | 0.00064 | 0.00074 | 0.00067 | 0.00069 | 0.0006 | 0.00074 | 0.00069 | 0.00072 | 0.00063 |
| Molybdenum | µg/L | 0.17 | 0.13 | 0.17 | 0.14 | 0.15 | 0.12 | 0.17 | 0.14 | 0.17 | 0.13 |
| Nickel | µg/L | 0.76 | 0.56 | 0.69 | 0.58 | 0.64 | 0.53 | 0.69 | 0.6 | 0.66 | 0.56 |
| Selenium | µg/L | 0.045 | 0.035 | 0.041 | 0.036 | 0.039 | 0.034 | 0.041 | 0.037 | 0.039 | 0.035 |
| Silver | µg/L | 0.0048 | 0.0039 | 0.0044 | 0.004 | 0.0042 | 0.0037 | 0.0044 | 0.0041 | 0.0043 | 0.0039 |
| Strontium | µg/L | 88 | 50 | 87 | 49 | 88 | 49 | 87 | 50 | 80 | 50 |
| Uranium | µg/L | 1.2 | 0.68 | 0.96 | 0.75 | 0.86 | 0.64 | 0.96 | 0.78 | 0.89 | 0.69 |
| Vanadium[(d)] | µg/L | 0.04 | 0.034 | 0.038 | 0.035 | 0.036 | 0.033 | 0.038 | 0.036 | 0.037 | 0.034 |
| Zinc[(d)] | µg/L | 1.2 | 0.79 | 1.1 | 0.83 | 0.99 | 0.76 | 1.1 | 0.85 | 1.0 | 0.8 |

a) Column depth in model, based on modelled water elevation.
b) Dissolved Oxygen presented as minimum.
c) Total Suspended Solids modelled as baseline.
d) Total baseline concentrations used in calculations.