Influence of Probability Distribution Function Sampling Frequency on Stochastic Water Quality Model Predictions

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ABSTRACT

Stochastic water quality models provide a mechanism to estimate uncertainty in water quality model inputs. This approach requires fitting an input dataset to a statistical distribution, which is entered into the model as a Probability Distribution Function (PDF). The input PDFs are randomly sampled at user-defined intervals using the Monte Carlo method to generate a model input time series for the duration of the model run.

A stochastic water quality model was developed to support the Environmental Assessment and Water Licence Permit applications for the Jay Project, a new open pit development at the Ekati diamond mine, located in the Northwest Territories, Canada. Model input PDFs were developed using existing seepage monitoring data from a surrogate waste rock storage area at the mine selected to represent the drainage water quality for the Jay Waste Rock Storage Area (WRSA). The total drainage from the Jay WRSA is estimated to be small in comparison to other mine site flows (e.g., Jay Pit groundwater inflow); however, as part of the model sensitivity analysis, it was identified that the combined site discharge water quality results (including Jay WRSA drainage) were sensitive to the sampling frequency selected for the Jay WRSA input PDFs for some constituents. This paper presents a case study to highlight how stochastic model results can be sensitive to PDF sampling frequency and the implications to mine permit applications. An approach for selecting PDF sampling frequencies is also presented.

Additional Key Words: mine water quality prediction

Introduction

Dominion Diamond ULC (Dominion Diamond) is currently constructing the Jay Project at the Ekati Mine in the NWT, Canada (Figure 1). A stochastic site-wide water quality model was developed to predict the concentration of chemical constituents in discharge to Lac du Sauvage. Predicted concentrations were used as the basis for evaluating impacts to surface water quality as part of the Developer's Assessment Report (DAR) (Dominion Diamond 2014) and to evaluate if proposed effluent quality criteria (EQC) developed for discharge to the receiving environment in the Water Licence application (Golder 2016a) would be achievable.

Probability distribution functions (PDF), developed based on seepage monitoring data from the Misery WRSA, were used as an analogue for the proposed Jay WRSA seepage and runoff water quality. During the DAR (Dominion Diamond 2014), model input PDFs were sampled once per realization; however, when the DAR model was updated and used to evaluate if proposed EQC would be achievable as part of the Water Licence submission (Golder 2016b), it was identified that predicted upper percentile concentrations in Misery Pit discharge were sensitive to the PDF sampling frequency of the Jay WRSA for select parameters, even though the total drainage from the Jay WRSA represented a small component of the total inflow to Misery Pit. To account for uncertainty in model inputs, a conservative assumption that is often applied is to select a percentile above 50 to bias the results away from underprediction. The risk with this approach is that it can indicate a need for costly mitigation, sometimes due to the conservatively selected percentile of input. Therefore, an additional examination of the PDF sampling frequency was warranted to determine if the predicted discharge concentrations were reasonable or were an artefact of the PDF sampling frequency.

This paper presents predicted Misery Pit discharge water quality for nitrate under three PDF sampling frequencies (once per realization, annually and monthly) over 200 realizations to illustrate how stochastic modelling results can be sensitive to PDF sampling frequencies for a fixed number of model realizations. Guidance on selecting sampling frequencies is also presented.

Project description

The Ekati mine is located approximately 300 kilometres (km) northeast of Yellowknife, NWT, Canada (Figure 1). The Jay kimberlite pipe will be mined using open pit methods. Access to the Jay Pit requires partial dewatering of a small area of Lac du Sauvage, which will be separated from the main body of the lake through construction of a dyke (Figure 2).

Mining in Jay Pit will produce saline groundwater and contact catchment runoff that will need to be managed during operations. During mining of Jay Pit, saline groundwater and catchment runoff draining to Jay Pit will be pumped to the bottom of Misery Pit and subsequently discharged to Lac du Sauvage once the storage capacity of Misery Pit is exceeded. Water pumped from Jay Pit will mix with Jay Waste Rock Storage Area (WRSA) runoff, Misery Pit wall rock and catchment runoff.

Waste rock produced from mining of Jay Pit will be stored in the Jay WRSA (Figure 2). Approximately, 67% of the Jay WRSA seepage and runoff will drain to Misery Pit (Golder 2016b), where it will mix with water pumped from Jay Pit, Misery Pit wall rock and catchment runoff.

Methods

A stochastic site-wide water quality model was developed in GoldSim v.11 (GoldSim 2010). In GoldSim, each flow that could influ-

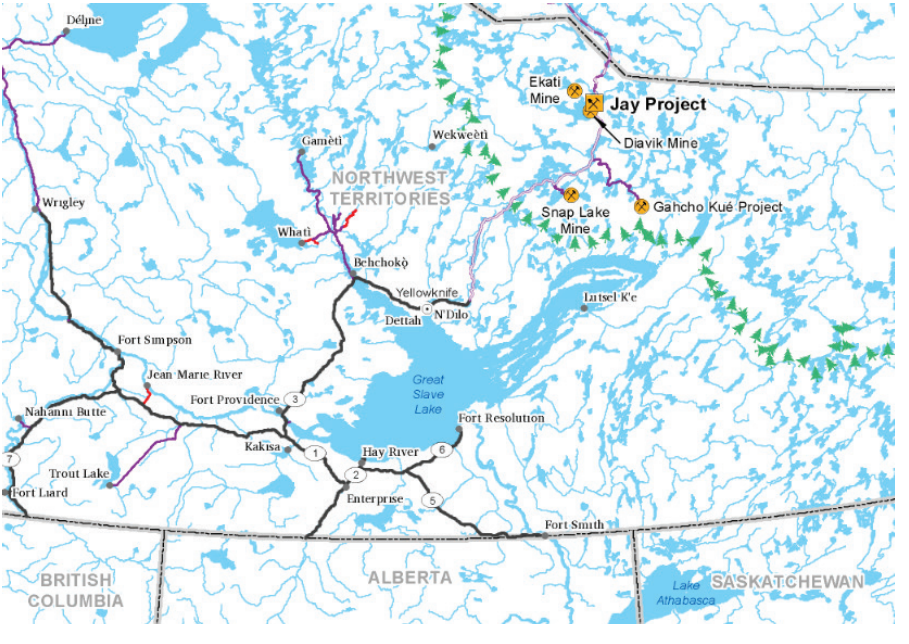

Figure 1 *Location of the Jay Project*

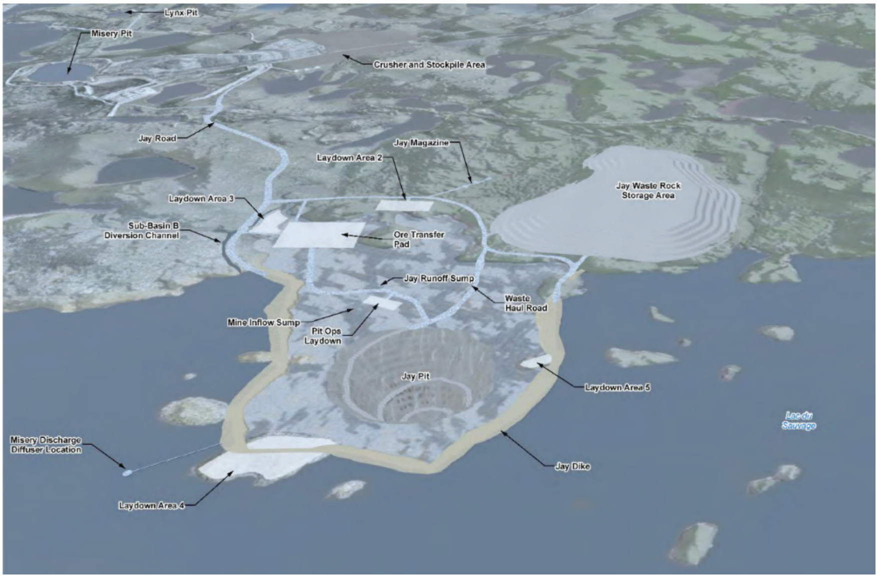

Figure 2 *Proposed Jay Project Infrastructure*

ence water quality was itemized and assigned a source term chemical profile based on geochemical test work of mine waste materials, mine site facility monitoring data, baseline surface and groundwater monitoring results or outputs from supporting models (e.g., hydrogeological model outputs).

PDFs were developed using seepage water quality monitoring results from the Misery WRSA and, based on the compositional similarity (Dominion Diamond 2014), were used to represent the quality of seepage and runoff from the Jay WRSA. PDFs were developed using the approach described in Vandenberg et. al. (2015). The model input PDFs were randomly sampled using the Monte Carlo approach for 200 model realizations at three different frequencies: once per realization, annually and monthly. The randomly generated input concentrations were used to represent the drainage quality from the Jay WRSA in the model.

Only model results for nitrate are presented in this paper. This constituent was selected since during the Jay Project Water Licence application process, it was identified that predicted nitrate concentrations were sensitive to PDF sampling frequency. The reader is referred to the following documents for a detailed description of the model setup, inputs and subsequent updates: Appendix 8E of Dominion Diamond (2014) and Golder (2015; 2016b).

Results

Predicted nitrate concentrations, accounting for all sources that can influence Misery Pit discharge water quality, are presented in Figure 3. Only predicted concentrations in the surface layer (from which discharge occurs) are presented in Figure 3. Therefore, concentrations are zero prior to water being stored in this layer in October 2026.

Predicted average nitrate concentrations show virtually no variability for the scenarios modelled, indicating the average model results are not sensitive to the Jay WRSA PDF sampling frequency. This occurs because the magnitude change in peak and trough nitrate concentrations in the stochastic time-series generated for Jay WRSA for annual and monthly sampling frequencies is small, and all sampled concentrations are similar to the average concentrations produced when the Jay WRSA PDF is sampled once per realization. In addition, Jay WRSA represents a small component of the overall flow to the Misery Pit on an annual basis. Therefore, the variation in average WRSA concentrations is not large enough to increase loadings to an extent that influences Misery Pit discharge water quality.

The predicted 95th percentile nitrate concentrations decrease with increased sampling frequency. This trend occurs for the following reasons:

- When a single value is selected for an entire simulation, that value will be a driver of the long-term chemistry of the waterbody. With higher frequency sampling, all scenarios, even those at higher percentiles, will include a mixture of high and low values. Over time, these values will regress toward the mean, as illustrated by lower 95th percentiles for higher frequency sampling scenarios in Figure 3.
- Lower 95th percentile concentrations will be selected and used when Jay WRSA and wall rock runoff accounts for higher proportion of the inflow to the Jay Pit earlier in operations (e.g., prior to Misery Pit being flooded).
- Peak concentrations are not always coupled to peak flows (i.e., freshet) in the model loadings calculations for higher frequency sampling scenarios, resulting in lower cumulative loadings over the model duration (Figure 4).

Discussion

As part of the Water Licence application, the 95th percentile Misery Pit discharge nitrate concentrations were predicted to be greater than proposed EQC at different times during operations but the mean concentrations were predicted to be consistently lower than the proposed EQC. A detailed review of the model inputs revealed that elevated 95th percentile concentrations were occurring because there was a large degree of variability in the nitrate input data that was used to develop the Jay WRSA PDF.

Upon further examination of the dataset used to define the nitrate PDF, it was identified that the maximum concentration (326 mg-N/L) was much greater than the mean concentration (34 mg-N/L) and the lognormal nature of the distribution fitted to the data resulted in high concentrations, that have lower probabilities of occurrence, being carried forward into the model predictions. Concentrations rapidly decrease from the maximum value with the 95th percentile concentration (185 mg-N/L) being approximately half of the maximum. Therefore, it is considered highly unlikely that drainage from the Jay WRSA would contain nitrate concentrations at the 95th percentile value for the duration of operations.

The maximum concentration was not screened out as an outlier using the statistical methods described above and therefore, it cannot be excluded from the dataset. However, only sampling the distribution once per realization assumes all drainage from the Jay WRSA will be equal to or higher than the 95th percentile concentrations in some model realizations, which is unlikely to occur in reality. To account for the upper percentile concentrations (e.g., maximum, 95th percentile, etc.), that are based on empirical data, the sampling frequency of the PDF was increased. This approach carries forward the upper percentile concentrations but for a shorter duration. This is considered to be a reasonable replication of what would occur in reality for a parameter such as nitrate, which is observed to be highly variable at mining operations.

Conclusion

The Jay Project water quality model indicates that the predicted Misery Pit discharge water quality is sensitive to the PDF sampling frequency for some constituents. If too long a frequency is selected, the model can produce overly conservative, and potentially unrealistic, predictions. This requires the modeller to develop an intimate understanding of the input data for each PDF and use professional judgement to determine if the loadings that are being produced are realistic, or an artefact of an anomalously high concentration being sustained as a result of an unreasonable PDF sampling frequency.

The appropriate PDF sampling frequency is partially dependent on the purpose of the water quality model. For example, sampling once per realization was determined to be appropriate for the DAR, where overly conservative model predictions did not change the outcomes of the study. From this perspective, the PDF sampling frequency was considered fit for purpose. As part of the Water Licence

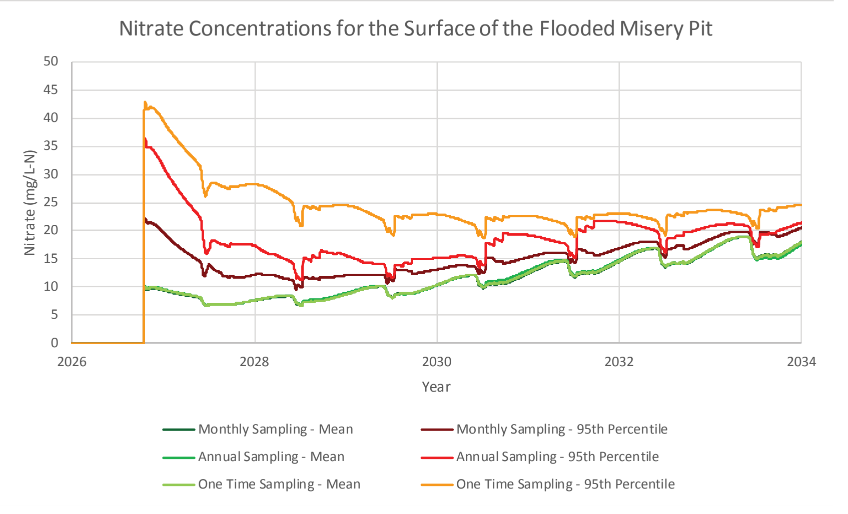

Figure 3 *Modelled Nitrate Concentrations in Jay WRSA Drainage*

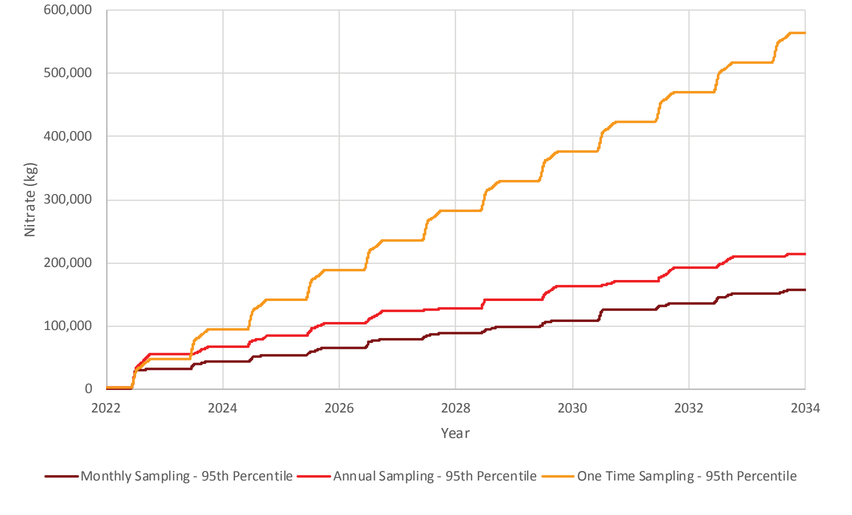

Figure 4 *Cumulative Jay WRSA Runoff Nitrate Loadings*

application, it was identified that model predictions based on sampling the PDF once per realization were overly conservative and adjustment of the sampling frequency was warranted.

Ideally it would be preferable to have sufficient data to develop PDF that are seasonal or linked directly to flow to better align predictions to different precipitation events. However, such datasets rarely exist at the planning stages of projects and it becomes incumbent on the modeller to select the most appropriate approach, balancing conservatism with realism. In such cases, the degree of autocorellation observed in datasets from similar facilities at other sites may be a guide to setting the appropriate sampling frequency. Similarly, the residence time of the waterbody being modelled is an important consideration, with the waterbodies with shorter residence time being more sensitive to selection of sampling frequency.

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