Globe Progress Lake – Closure Performance Monitoring and Adaptive Management

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Abstract

The Globe Pit Lake (GPL), part of the Globe Progress Mine, located near Reefton New Zealand is an orogenic Au mine that is in the final stages of closure and rehabilitation. As part of early closure activities, the GPL was dosed with $FeCl_3$ to remove arsenic (As) from solution via adsorption onto hydrous ferric oxides (HFO).

A high-level empirical As load model was developed to understand future management options for the GPL including possible scenarios such as As remobilisation/desorption from the HFO and increasing As inputs. This study considered As inputs from Union Creek Waste Rock Stack (WRS), which appear to be minor, and As inputs from the pit wall rock, which appear to be the greater contributor of As into the GPL (and potentially underground workings).

Data indicates that the Union Creek WRS underdrain seepage has a negative correlation between As and Sb, not consistent with the positive correlation observed in the GPL. Furthermore, the average As load from the Union Creek WRS is ≈14.6 kg/year, significantly lower than the load estimated for the first few years of GPL filling of ≈ 950 kg/year.

Three events contributed significantly to the decrease of As load in the GPL. The first one being the planned removal of As with $FeCl_3$ dosing, the second one due to rock and sediment input from the construction of the pit lake spillway (which might also have stirred up Fe precipitates on the floor of the pit), and the third one due to a second $FeCl_3$ dosing event. Monitoring results indicated that Sb does not seem to be affected by co-precipitation or absorption as demonstrated by no decrease in Sb concentrations following the $FeCl_3$ dosing events. Therefore, the original positive Sb:As correlation (prior to $FeCl_3$ dosing)was used to derived As loads over the monitoring timeframe and hence the quantity of As immobilised in pit sludge / sediment.

Modelling results suggest that if As in the HFO sludge/sediment was to be remobilised, that As concentrations could increase up to 0.45 mg of As/L with poor water quality (> 0.1 mg/L) lasting for 10 -16 years after remobilisation commences. Management options have been identified if this was to occur, which are supported by trigger action response plans.

Introduction

As part of the Reefton Restoration Project at the Globe Progress Mine, OceanaGold is decommissioning the water treatment plant (WTP), which previously treated mine-impacted water at the site. OceanaGold need to confirm that the decommissioning of the WTP is acceptable from a risk management perspective as well as confirming that the potential for exceeding the resource consent limits of 0.1/0.25/3.3 mg As/L (median-12 month/ 90th percentile-12 month / maximum) at the compliance water monitoring location DC01, downstream in Devils Creek is low, and that adaptive management options are in place if As concentrations increase in the future.

One of the key components of the Reefton Restoration Project that require assessment to understand water quality risks after the removal of the WTP is the GPL. GPL currently receives water inputs from the Union Creek

WRS, nearby clean water catchments, and the Globe Progress Pit walls (and potentially underground workings).

As concentrations were elevated in the GPL prior to treatment using ferric chloride ($FeCl_3$), which was added to the pit lake to remove As through As sorption to Fe hydroxides (e.g. Pierce & Moore, 1982). Following this treatment, As concentrations are now sufficiently low that GPL waters can be discharged directly from the pit lake via the spillway without treatment. Arsenic source hazards contributing to the As load in the GPL include:

- As input from Union Creek WRS;
- As input from the Globe Progress Pit walls; and
- Potential As remobilisation from sludge associated with FeCl3 dosing and sediment adsorption.

The purpose of this study is to review the potential effects of these source hazards to understand what adaptive management options may be required.

Methods

Load estimation and theoretical concentration

GPL load for arsenic and antimony was estimated by using Eq. 1. To address the thermal stratification occurring in the lake which causes variable concentration as a function of depth, the lake is discretised in the epilimnion and hypolimnion to estimate loads separately.

(Eq.1)

$$Load\,(kg) = Volume\,(m^3) \times Concentration\,(kg/m^3)$$

From the estimated total GPL load, a theoretical concentration can be estimated based on the pit lake volume. That theoretical concentration represents a weighted average for As and Sb.

Arsenic and antimony reservoir load model

An empirical As GPL reservoir load model was developed to estimate the potential impact on water quality if As is remobilised into the lake from HFO sludge / sediment. Data utilised included the GPL As load model results and volumes between October 2015 to March 2022 to understand the amount of As that could be stored in the GPL (i.e., the As reservoir). This data is then used to determine the risks for elevated As in the GPL should this be remobilised.

Based on the As load model, an As input rate is proposed with a decay constant. In order to replicate the observed concentrations of As and Sb as shown in Eq. 2.

(Eq.2)

$$Input_{AsLoad}(kg/week) = C_1 \left(\frac{M}{M_0}\right)^{C_2}$$

Where C_1 corresponds to the initial input rate of As, C_2 is a decay exponent; and M and M0 correspond to the current and initial mass of As and Sb. Values were calibrated using measured data in GPL from September 2015 to July 2019, prior to pumping / discharge of pit water (required to maintain a low pit lake level for construction activities, which then influence the contaminant load model). Arsenic input rates to GPL were assumed to be 133% of the Sb input rates to GPL. Theoretical concentrations were then calculated as the load divided by GPL volume.

Modelled scenarios

Two scenarios are defined for the previous model to predict future loads and concentrations post-closure:

1. **Scenario 1: Arsenic remobilisation** from pit lake sediments/sludge could occur if the pit lake became anoxic and the HFO was reduced to Fe(II) or As (V) to As(III), which could release As back into solution (e.g. Xie *et al.*, 2018).
2. **Scenario 2: Higher As inputs** from the GPL pit walls and/or Union Creek WRS where the As input rate increases by a factor of 5 or 10 once GPL is filled.

Both scenarios are unlike to occur, however, quantifying the possible loads and concentrations was useful to understand what adaptive management options may be required.

Results

Load and concentration

Arsenic load into the pit lake was estimated to be ≈ 950 kg/year during the first 2 – 3 years (As and Sb loads into the GPL are shown in

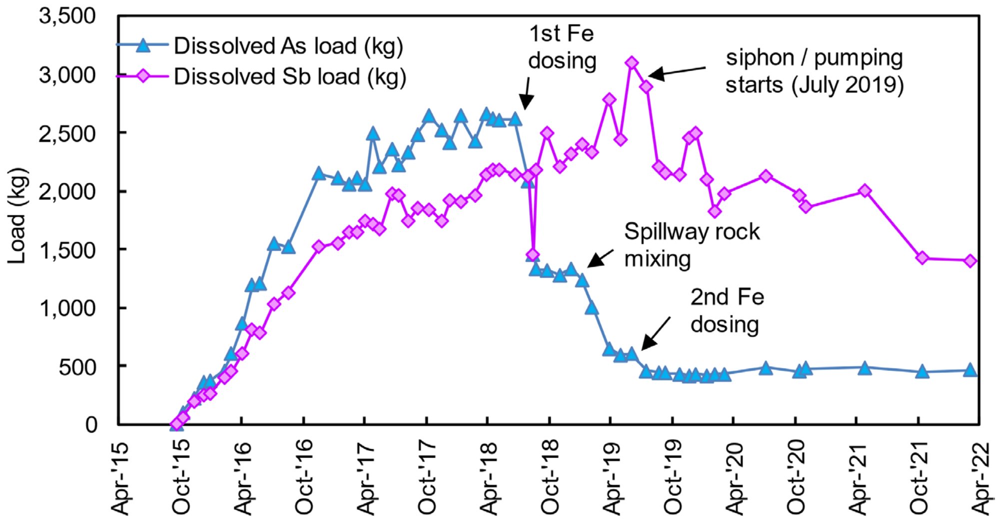

***Figure 1** Arsenic and antimony loads estimation.*

Figure 1). Arsenic load from the Union Creek WRS was estimated to be 14.6 kg/year, which is considered negligible and not material compared to the current state (≈ 1.5% of the total input in the first 2-3 years) indicating pit walls / underground workings are the major contributor to load.

Prior to the $FeCl_3$ dosing event (see Figure 1), the load of As and Sb increased rapidly and proportionally. Results indicate that the As load stabilised at ≈460 kg after the Fe dosing events and rock and sediment addition (2018-2019). The antimony (Sb) load decreases from July 2019, which aligns with the start of the GPL pumped / siphon discharge starting in July 2019 (i.e., Sb load is being removed via discharge). The events that contributed to a decrease of 2,156 kg of arsenic within the GPL between June 2018 and June 2019 are:

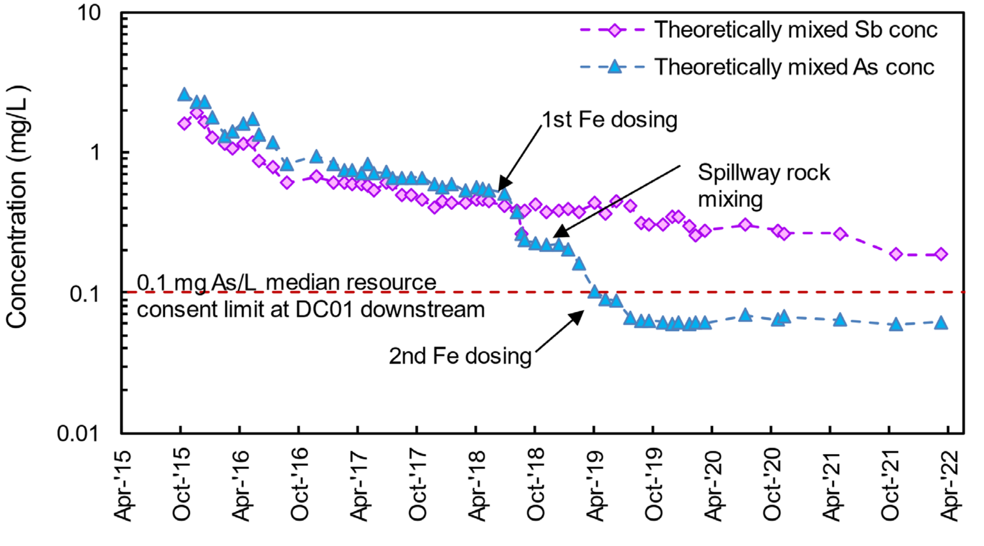

***Figure 2** Arsenic and antimony theoretical concentrations and the As median resource consent limit (0.1 g/m³) for reference.*

- $FeCl_3$ dosing event #1.
- GPL "Spillway rock mixing" event associated with pushing a significant amount of rock and sediments into the pit lake (and possibly resuspending Fe precipitates).
- $FeCl_3$ dosing event #2.

Figure 2 indicates that As and Sb concentrations had similar declining trends in concentration and were well correlated until the Fe dosing events occurred. This is also seen by similar increases in pit lake loads up to the start of the dosing events (Figure 1). Following the dosing events, which had no effect on the Sb load (i.e., Sb behaves conservatively), the Sb concentration continued to decrease at the same rate. In contrast, As concentrations post-dosing have remained steady. The results support the hypothesis that Sb can be used to forecast ongoing As contributions to the GPL.

Arsenic and antimony reservoir load model

The GPL reservoir load model includes As loads in the GPL based on empirical data from 2015 to 2019. From 2022 onwards, the input rate is extrapolated from the empirical trend observed in Figure 1.

Results calibrated to the As load model (Figure 3 - green line) shows that the As in the HFO sludge/sediment increases in steps due to three events (Fe dosing #1, spillway rock mixing, Fe dosing #2), and later increases due to the modelled 'As adsorption rate'. This model for the 'As adsorption rate' is assumed to start at the 1st Fe dosing event. It is reasonable to assume that As adsorption to pit wall sediment would have been occurring before this event, which has not been assessed as part of this study. If the As load is to remain constant, which is currently occurring, three factors must be balanced:

- As load entering the pit lake.
- As discharged from GPL via pumping/ siphon.
- As removed by co-precipitation/ adsorption with HFO sludge/sediment – derived from the Sb trend line pre dosing.

The mass of As adsorbed/co-precipitated in the HFO sludge/sediment is estimated to be ≈3,450 kg in March 2022, with an increasing trend (Figure 3). This is higher than the 2,156 kg estimated from the load model estimates based on the three events. The As load in the GPL may be even greater if As sequestered within the pit sediments, adsorbed prior to the first dosing event are considered.

Modelled scenarios

Results are presented in Figure 4 and Figure 5 for As concentrations in Scenario 1 (remobilisation of As) and Scenario 2 (higher As input) respectively. Within the model when As remobilisation starts, As load in sludge is estimated to be ≈ 3,570 kg. It is observed from the results that:

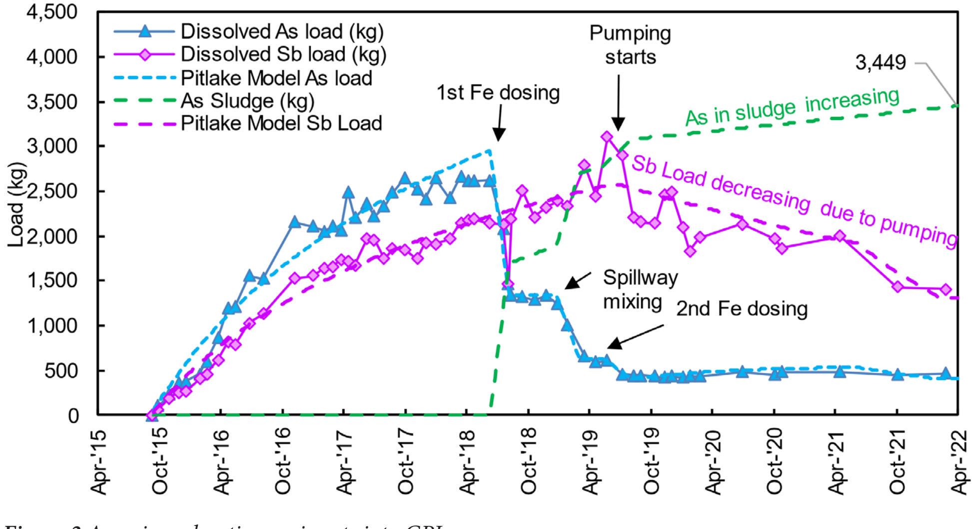

Figure 3 *Arsenic and antimony inputs into GPL.*

Modelled scenarios

Results are presented in Figure 4 and Figure 5 for As concentrations in Scenario 1 (remobilisation of As) and Scenario 2 (higher As input) respectively. Within the model when As remobilisation starts, As load in sludge is estimated to be ≈ 3,570 kg. It is observed from the results that:

- Forecast concentrations for Scenario 1 reach a maximum of 0.45 mg/L in the '1 week' case, and 0.4, 0.32 and 0.23 mg/L for the 2-, 5-, and 10- year periods respectively. For Scenario 2 concentration peaks at 0.21 and 0.16 mg/L for the 5 and 10 factor respectively.
- After the remobilisation period, the As concentration decreases, due to the loss of As by pit lake discharge with concentrations decreasing to <0.1 mg/L within 10 to 16 years after remobilisation begins.

Adaptive Management

Adaptive management is a recognised management option in New Zealand under the Resource Management Act (RMA) (e.g., Leckie 2017). Effective adaptive management is supported by understanding the nature and duration of possible events that could occur, monitoring these events, and then having options in place should there be variance from the expected condition. This requires:

- Understanding the risks.
- Monitoring (as early warning, i.e., performance monitoring).
- Variance planning.
- Trigger Action Response Plans (TARPS).

High level geochemical mechanisms that could contribute to elevated As concentrations in GPL have been presented in this study include:

- As input from Union Creek WRS.

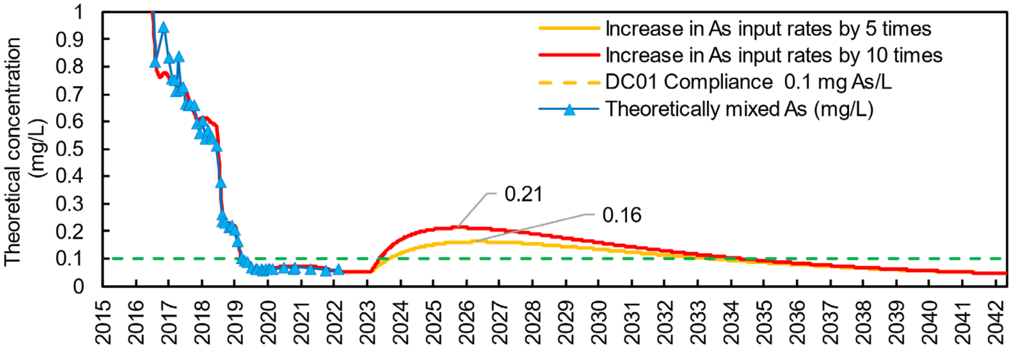

***Figure 4** Resulting arsenic concentrations for scenario 1: As remobilisation.*

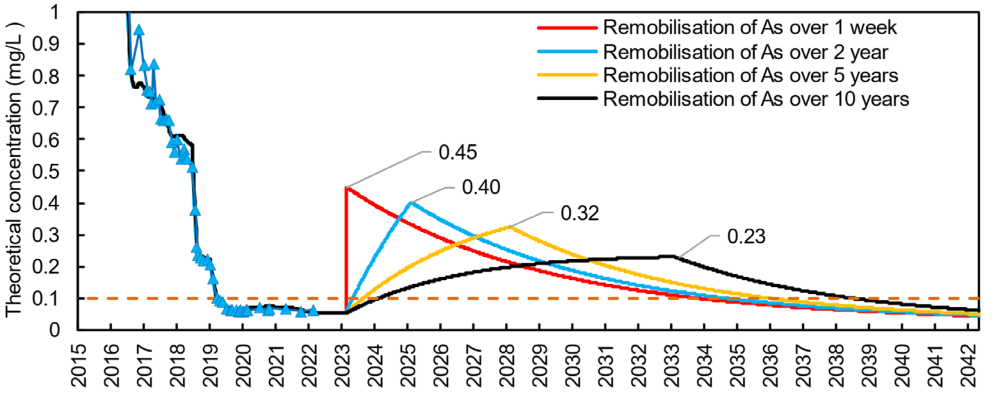

***Figure 5** Resulting arsenic concentrations for scenario 2: increasing inputs of As.*

- As input from the GPL Pit Walls.
- As remobilisation from sludge associated with $FeCl_3$ dosing and sediment adsorption.

The following performance monitoring is recommended to determine if these mechanisms that could contribute to high As in GPL are occurring:

- Continue to measure discharge rates and water quality within the Globe Pit Lake to ensure load models and forecasts can be continued to understand trends.
- Ensure that regular flow and quality measurements are taken for the Union Creek WRS to confirm longer term geochemical trends.
- Continue to monitor water quality at depth within the GPL to determine if reducing conditions are occurring near the pit bottom together with Oxidation-Reduction Potential (ORP) measurements.
- As adsorption is pH-dependant, hence, pH monitoring should be continued.
- Undertake wall wash testing of the GPL wall rock to understand water quality over time to understand if the load is decreasing/increasing.

If performance monitoring demonstrates that additional management options are required, then these options should be investigated so that they can be implemented in a timely manner. The implementation of such options should be managed by TARPs. For the risks associated with elevated As concentrations within the GPL the following management options are potentially available / suitable and should be investigated further:

- Additional $FeCl_3$ dosing (perhaps better for higher As concentrations compared to lower arsenic concentrations).
- Increase the sediment load reporting to the GPL and confirm this process removes As.
- Direct pit lake overflow to the Devils Creek vertical flow reactor (VFR) if concentrations are > 0.1 mg/L (Trumm *et al.*, 2022)
- Introduce other Fe-rich streams to the GPL (e.g., Devils WRS underdrain).
- Placement of the VFR Fe-rich sludge within the GPL.
- Other options developed through the risk assessment exercise.

Conclusions

From this study the following conclusions can be drawn:

1. The GPL is potentially storing ≈3,450 kg of adsorbed As, and 450 kg of dissolved As.
2. One environmental risk identified is that the adsorbed As within the GPL could be remobilised. If that happens within a week period, the concentration peak could reach 0.45 mg/L.
3. If As input into the GPL increases by 5 and 10 times, concentration could reach peaks of 0.21 and 0.16 mg/L respectively.
4. Both scenarios are unlike to occur, however, they are modelled to assess the adaptive management options that may be required after closure of the site.
5. Performance monitoring should be continued in order to anticipate any changes in the GPL.
6. If any changes in the GPL occur causing an increase in As concentrations in the GPL, then an adaptive management approach should be used to asses the best options to face the potential risks.

Acknowledgements

The authors would like to thank OceanaGold for the opportunity to publish this paper and Will Olds, formerly of Mine Waste Management for his contributions to this work.

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