Appendix 13.5-K Calcite Precipitation Evaluation Technical Memorandum

TELKWA COAL
LIMITED

SRK Consulting (Canada) Inc.
1066 West Hastings Street, Suite 2200
Vancouver, BC V6E 3X2
Canada

+1 604 681 4196 office
+1 604 687 5532 fax

vancouver@srk.com
www.srk.com

DRAFT

Technical Memo

September 27, 2021

To	Dan Farmer
From	Jonathon Doherty and Michael Herrell
Cc	
Subject	Tenas Project – Calcite Precipitation Evaluation
Client	Telkwa Coal Limited
Project	1CT027.007

1 Introduction

Telkwa Coal Limited (TCL) submitted a draft application information requirement report (DAIR) for the Tenas Coal Project located near Telkwa, BC to the BC Environmental Assessment Office (EAO) in 2020. During the public response period, the Northwest Institute commented that calcite precipitation has been observed in tributaries downstream of waste rock spoils in the Elk Valley, and the DAIR should also include an evaluation of the likelihood for calcite to precipitate in drainages downstream of mine site facilities at the Tenas Project. TCL agreed to evaluate the likelihood of calcite precipitation to occur within the management ponds, Goathorn Creek and Tenas Creek during. TCL retained SRK Consulting (Canada) Inc. (SRK) to complete the calcite evaluation. This memo presents the methods, assumptions and results of the calcite precipitation evaluation.

2 Background

The Tenas Coal Project is a proposed coal mine located 25 kilometers south of Smithers and six kilometers southwest of Telkwa in northwestern British Columbia. The project is expected to produce approximately 800,000 tonnes of steelmaking coal annually over a 21-year mine life. Coal will be extracted using open pit mining methods.

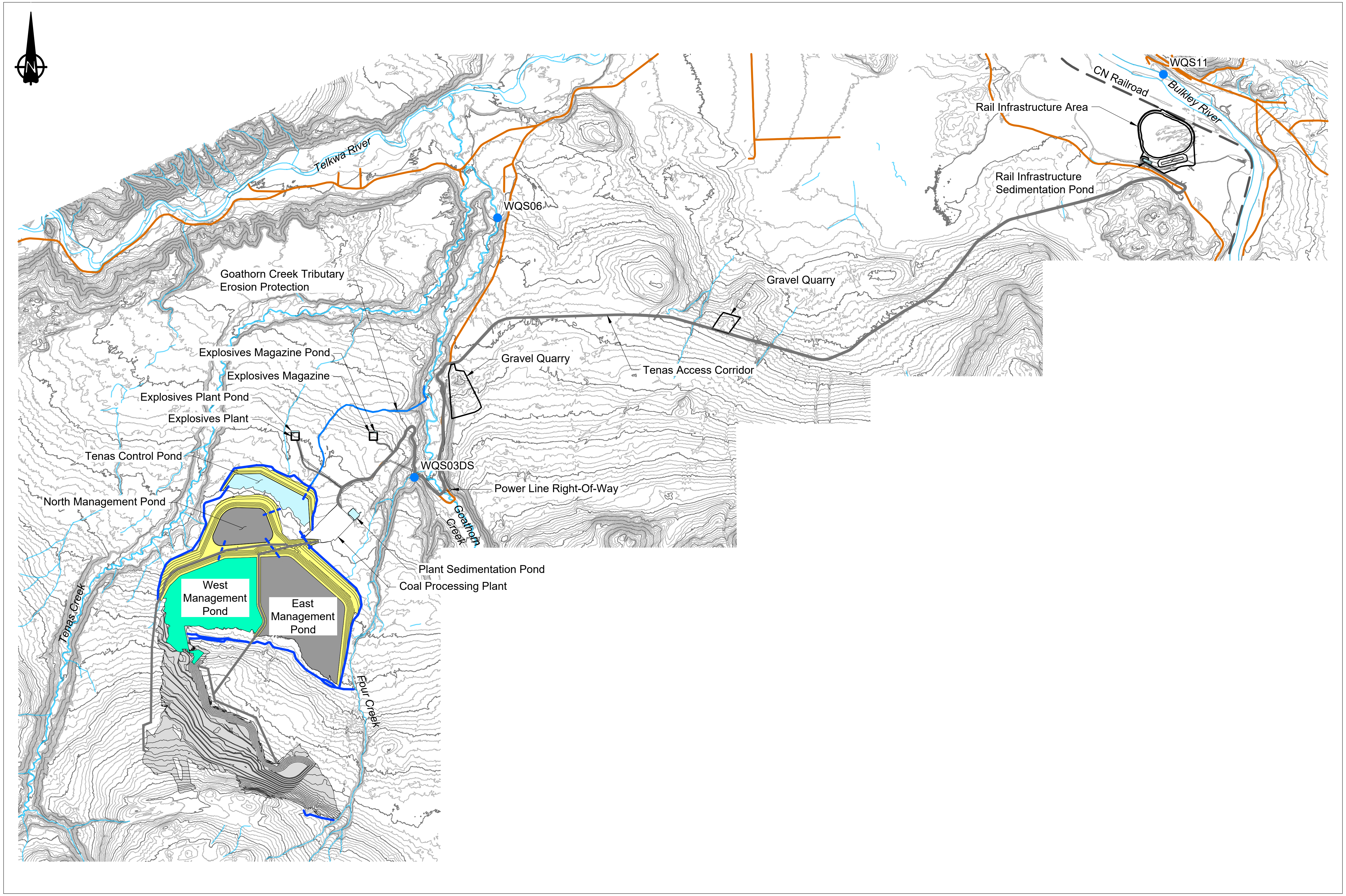
Geochemical testing (SRK 2021) indicates that a large component of the waste rock to be mined from the Tenas open pit will be potentially acid generating (PAG). Prior to and during mining, TCL will construct management ponds at the northern limits of the open pit where PAG rock will be permanently stored underwater to minimize oxidation of sulfides and acid generation (Figure 2-1). Non-acid generating waste rock will be used as pit backfill or in the final cover on the management ponds.

Drainage from the open pit and NAG waste rock backfill will be directed to the management ponds during operations and closure. Water from the management ponds will report to the downstream watercourses through one of the following pathways:

- Surface discharge from the Tenas control pond to Goathorn Creek during operations.
- Surface discharge from the North Management Pond to Goathorn Creek during closure.

Seepage from the management ponds will also report to Tenas, Four and Goathorn Creeks. A collection sump will also be constructed at the rail load out area (Figure 2-1). Water stored in this pond will discharge to the Bulkley River.

Calcite precipitation has been observed downstream of waste rock storage facilities at other mine sites in British Columbia. Calcite precipitation occurs as waste rock seepage, enriched in carbon dioxide, equilibrates with atmospheric gases. Additional detail of the geochemical mechanisms governing calcite precipitation at coal mines is discussed in Section 2.1. Water in the management ponds, which includes seepage from NAG waste rock backfill, and downstream tributaries will be in equilibrium with atmospheric carbon dioxide which could result in calcite precipitation.



LEGEND

- Water Quality Monitoring Stations and Prediction Nodes
- Water Management Feature
- Spillway
- Existing Watercourse
- Existing Road
- Proposed Road
- Dams and Buttresses
- Sedimentation Pond
- Active Management Pond
- Backfill / NAG Pile
- Covered Inactive Management Pond

NOTES

1. Contours shown at 5.0m intervals.
2. All dimensions shown in meters unless otherwise stated.
3. Pile designs by SRK Consulting Ltd.

REFERENCE

NAD83 UTM Zone 9.

0m 500 1000 1500 2000

srk consulting

TELKWA COAL LIMITED

Calcite Precipitation Evaluation

Water Management Overview

SRK JOB NO.: 1CT027.003	Telkwa Coal	DATE: 2021/05/21	APPROVED: --
FILE NAME: 1CT027.003 Overview (Geochem).dwg		FIGURE: 2-1	

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2.1 Conceptual Model

Water seeping through the Tenas Project waste rock storage piles and coal storage piles can become enriched in carbon dioxide due to the coupled processes of acid generation through sulfide oxidation and reaction of the resulting acid with carbonate minerals. The flow through the material storage piles occurs under conditions under which gases do not fully exchange with the atmosphere. This results in an increase in carbon dioxide concentrations in solution (compared to atmospheric conditions) and pH depression due to formation of carbonic acid as per Equation 1.

$$CO_2(g) \leftrightarrow CO_2\,(aq) + H_2O\,(l) \leftrightarrow H_2CO_{3(aq)} \leftrightarrow H^+_{(aq)} + HCO_3^- \qquad \text{(EQ1)}$$

The subsequent further dissolution of carbonates and weathering of silicate minerals by carbonic acid will also enrich the solution with other ions (e.g., Ca, Mg, Fe, etc.).

Seepage entering collection channels and reporting to the sedimentation and management ponds will equilibrate with the atmosphere, resulting in off-gassing of aqueous carbon dioxide and an associated increase in solution pH. Based on the expected presence of dissolved calcium and carbonate/bicarbonate in the solutions, the increased pH could result in calcite becoming supersaturated which would result in calcite precipitation according to Equation 2, which shows that calcite supersaturation is favored by increasing alkalinity or the concentration of calcium. Since alkalinity is linked to pH, calcite precipitation is also favored by higher pH.

$$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3 \qquad \text{(EQ2)}$$

This process is illustrated in Figure 2-2 which shows the calculated calcite saturation index (SI), for adjusted pH values for one of the Tenas Project NAG rock source terms using the average baseline surface water temperature of 5.5 °C and a pCO_2 of -3.7.

Figure 2-2 shows that as solution pH increases above 8 during equilibration of dissolved carbon dioxide with atmosphere, calcium carbonate is predicted to become supersaturated (i.e., saturation index > 0) causing calcite to precipitate from solution.

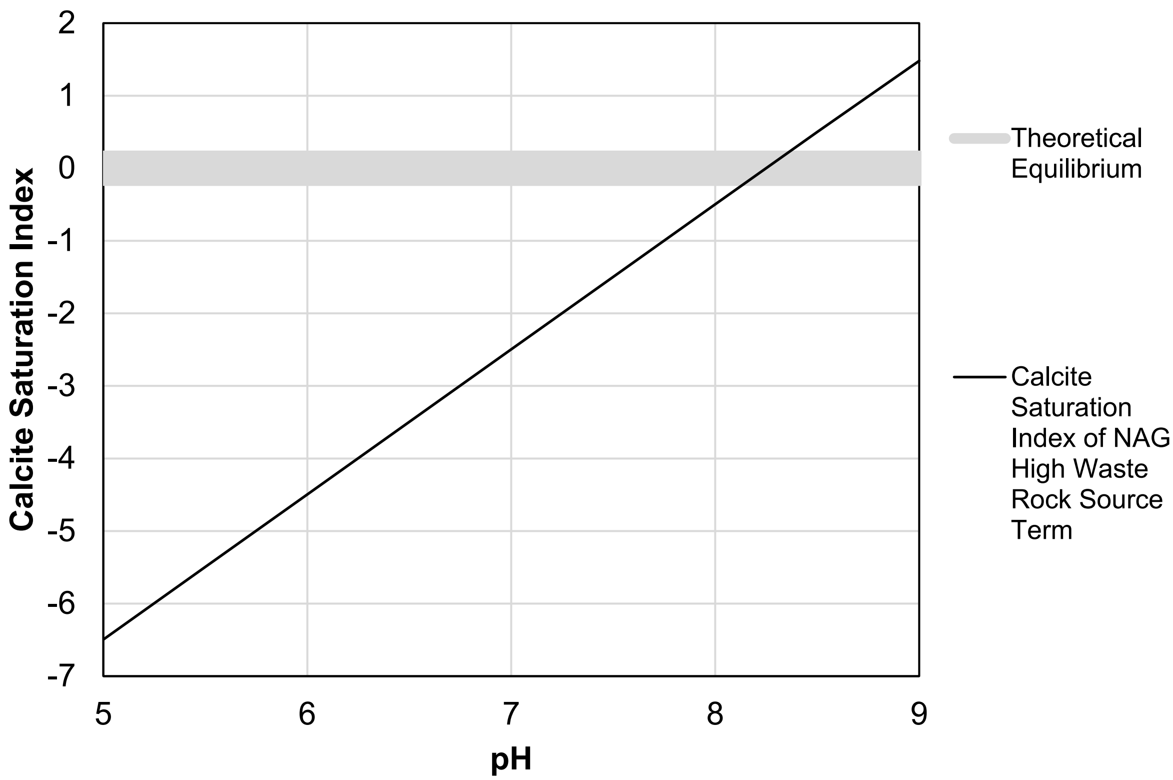

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Figure 2-2: Calcite Saturation Indices (SI) vs. Solution pH at pCO_2=-3.7 and T=5.5ºC

3 Methods

Two methods were used to evaluate the likelihood of calcite to precipitate at the Tenas Project. Calcite saturation indices were calculated on solutions that can be used to evaluate if calcite would precipitate in mine site facility drainage and site facility water storage facilities. A semi-quantitative approach was used to evaluate the likelihood for calcite to precipitate in downstream water courses. In this approach, key constituents related to calcite saturation were compared to concentrations under existing conditions. Additional details of the two approaches are provided in the following subsections.

3.1 Site Facility Calcite Precipitation Evaluation

The likelihood of calcite to precipitate in drainage from site facilities at the Tenas project was evaluated by calculating the calcite saturation index (SI) using the aqueous geochemical modelling code PHREEQC (Parkhurst and Appelo 2003) and the Minteq V4 thermodynamic database (U.S. EPA 1998). The SI is calculated as the quotient of the ion activity product (IAP) and the solubility product (K_{sp}) as described by the following formula:

$$SI = log \frac{IAP}{K_{sp}}$$

The IAP is the product of the activities of the reaction products in solution. The K_{sp} is a constant representative of ion activities in equilibrium with a solid mineral phase under standard conditions. Therefore, a SI > 0 indicates concentrations are supersaturated and the mineral has the potential to precipitate from solution whereas a SI < 0 indicates concentrations are undersaturated and the mineral will dissolve.

Calcite SIs were calculated on the following solutions:

1. Humidity cell testing (HCT) leachate concentrations.
2. Predicted drainage source term water qualities for waste rock, pit walls and coal stockpiles (SRK 2021).
3. Predicted water management pond and coal load out area sedimentation pond water quality (SRK 2021).

A description of the calculation inputs for the above solutions is provided in the following subsections.

3.1.1 Calculation Inputs

3.1.1.1 Humidity Cell Test Results

HCT results are not representative of site facility drainage water quality under ambient conditions due to several factors (Kempton 2012) unless concentrations are solubility controlled. In general, constituent concentrations will be higher under ambient conditions in comparison to humidity cell test results. Therefore, if calcite is identified to be supersaturated in the humidity cell tests, it can be reasonably assumed that calcite will be supersaturated under ambient conditions if solution pHs are comparable. TCL proposes to manage mine rock in a manner that will result in alkaline drainage with pH values similar to those observed in the HCTs.

Humidity cells were initiated for overburden and each stratigraphic zone that will be mined during operations (zones 1 to 6) and two footwall zones (zones 7 and 8). Only HCT results from zones to be mined were included in this evaluation (i.e., zones 1 to 6). SIs were calculated on average stable waste rock and overburden humidity cell test results. Oxidation redox potential (ORP) was not measured in the HCTs and a value of 400 mV was assumed in the calcite SI calculations. This ORP was used since it is a typical surface water value.

3.1.1.2 Site Facility Water Quality

3.1.1.2.1 Site Facility Source Terms

SRK (2021) developed a site wide water quality model for the Tenas Project. The model is a water and load balance model that mixes site facility source term water qualities with other inflows (e.g., groundwater and natural catchment runoff) to estimate site pond, site effluent and receiving environment water quality. As part of the water quality model, SRK (2021) developed geochemical source terms for drainage from the following mine site components:

- Non-acid generating (NAG) waste rock runoff/seepage;
- Pit wall runoff; and
- Coal stockpile runoff/seepage.

Typical and high source terms were developed for each of the above mine site drainages. The source terms were estimated by scaling HCT results to field conditions and evaluating if any dissolved constituents could be limited by secondary mineral precipitation. This process included calculation of calcite SIs in the source term solutions. The calcite SIs for the site facility source terms were used to evaluate if calcite precipitation is likely to occur from mine site facility drainage. The coal stockpile runoff/seepage source term was not included in the evaluation since coal will only be temporarily stored on site and does not represent a long-term loading source from the Project. The reader is referred to SRK (2021) for additional detail on the source term derivation. Calcite SIs in the source terms included the following assumptions:

- An ORP value of 400 mV which is a typical value for surface waters; and
- The average annual temperature in Goathorn and Tenas Creeks of 5.5ºC.

3.1.1.2.2 Predicted Management Pond Water Quality

The site facility source terms were mixed with other sources (e.g., soluble load flushed from PAG waste rock placed in the management ponds, natural runoff, etc.) to estimate future pond water quality in the following facilities (Figure 2-1):

- East Management Pond;
- West Management Pond;
- North Management Pond; and
- Tenas Control Pond.

The site model also includes a prediction of the Plant Sedimentation Pond; however, this pond is not considered in the current evaluation for the following reasons:

- It collects runoff and seepage from the plant pad and not from waste rock storage areas.
- The plant pond is pumped to the Tenas Control Pond during operations and any influence drainage to this pond has on calcite precipitation will be included in the Tenas Control Pond evaluation.
- It is decommissioned at closure.

Calcite saturation indices were calculated for the monthly base case water quality predictions (SRK 2021). The following assumptions were made in the calculations:

- An ORP of 400 mV.

- An average water temperature of 10ºC from May until September. The average water temperature in Goathorn and Tenas Creeks during these months is 8ºC; however, the temperature was increased by two degrees since water in the management ponds is not flowing. For the months of October till April a temperature of 3°C was used, which is two degrees higher than the average water temperature observed in Goathorn and Tenas creeks during these months. As calcite is more likely to precipitate at higher temperatures these assumptions are considered to be conservative.
- The pH of the ponds is not modelled in the site water and load balance model. Calcite precipitation is pH dependent, and two pH scenarios were assumed. A pH of 8.0 was used to evaluate a typical calcite precipitation scenario and a pH of 8.5 was assumed to reflect a high calcite precipitation scenario. These values represent the likely and upper pH value, respectively, observed in the HCTs.

3.2 Evaluation of Calcite Precipitation Within Receiving Waters

Calcite is not currently observed in water courses downstream of the proposed project footprint (TCL, 2021, pers. comm.). To evaluate the likelihood of calcite precipitation downstream of project discharges in Four and Goathorn creeks, predicted alkalinity, calcium and magnesium concentrations at each prediction node downstream of the pond discharge locations (see Section 3.1.1) were compared to the maximum concentrations observed in the baseline water quality. This approach was selected because saturation indices calculated on baseline water quality monitoring results indicated that calcite is supersaturated; however, there is no visible evidence of calcite precipitation occurring in these creeks under existing conditions. An increase in alkalinity could increase the pH of the solution resulting in more favorable conditions for calcite precipitation.

Comparisons were completed during operations since this mine phase is predicted to have the highest loadings of these constituents. If an increase of more than 25% was predicted, then the calcite saturation index was calculated for the timeseries water quality data for the prediction node to determine calcite saturation.

4 Results and Discussion

4.1 Calcite Precipitation in Humidity Cells

The calculated calcite SI for the average stable leachate concentration for each humidity cell is provided in Table 4-1. With the exception of HC7 (Zone 4), all average HCT leachate concentrations were undersaturated with respect to calcite. The average stable leachate concentrations from HC5 (Zone 1a) and HC10 (Zone 6) are near equilibrium with SIs of -0.3. The SI for Zone 4 was effectively zero (i.e., 0.082) indicating this average solution for this sample is in equilibrium with respect to calcite.

These results indicate drainage from the waste rock piles is likely to be supersaturated with respect to calcite due to lower water to rock ratios which can lead to higher concentrations of calcium and alkalinity. As expected, the calcite SI showed higher values in HCTs with higher pH, alkalinity, and calcium concentrations.

Table 4-1: Summary of HCT Calcite Saturation Indices

		Stable Humidity Cell Results			Calcite Evaluation	
HCT ID	**Zone**	**Average Stable pH**	**Average Stable Alkalinity**	**Average Stable Calcium Concentration**	**Calcite Saturation Index**	**Comment**
		s.u.	mg $CaCO_3$/L	mg/L		
HC4	Zone 1	8.2	61	5.6	-0.68	
HC5	Zone 1a	7.7	65	42	-0.30	
HC6	Zone 2-3	2.4	0.25	118	-	HCT developed acidic conditions, calcite SI is undefined
HC7	Zone 4	8.1	129	19	0.082	
HC8	Zone 5	6.7	5.5	90	-2.2	
HC9	Zone 55	7.9	55	15	-0.52	
HC10	Zone 6	7.7	67	47	-0.29	

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Notes:

SI < 0 indicate solution is undersaturated with respect to calcite

SI > 0 indicate solution is supersaturated with respect to calcite

4.2 Source Term Calcite Saturation Indices

The calculated calcite SI for each source term is presented in Table 4-2, which shows that the source terms for the NAG waste rock storage piles and the pit wall runoff source terms are supersaturated with respect to calcite. These results indicate that calcite is expected to precipitate in seepage from the NAG waste rock storage piles and the pit walls during operations and in closure.

It is important to note that the NAG Pile Runoff-High source term is modelled to have a lower calcite SI than the NAG Pile Runoff-Typical source term (Table 4-2). This is an artifact of the scaling method used to develop the high source term. The high source term is estimated by increasing sulfate concentrations to gypsum saturation through anhydrite addition and calculating element concentrations by preserving the element/sulfate ratio in the typical source term (SRK 2021). During the anhydrite addition, the solution was allowed to precipitate equilibrium phases so that sulfate concentrations would be limited. The equilibrium phases used in the model included calcite, which was predicted to precipitate when from calcium dissolution from anhydrite added to the solution. Therefore, the SI for the NAG Pile Runoff-High source term in Table 4-2 is underestimated and would be expected to be greater than the SI for the NAG Pile Runoff-Typical source term.

Table 4-2: Calcite SIs for Tenas Project Source Terms

Facility	Source Term	Calcite SI
NAG Piles	NAG Pile Runoff - Typical	1.82
	NAG Pile Runoff - High	-0.32
Pit Walls	Pit Wall Runoff - End of NMP - Typical	-0.76
	Pit Wall Runoff - End of EMP - Typical	-0.67
	Pit Wall Runoff - End of EOM - Typical	-0.03
	Pit Wall Runoff - End of NMP - High	1.24
	Pit Wall Runoff - End of EMP - High	1.15
	Pit Wall Runoff - End of EOM - High	0.99

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Notes:

SI < 0: Calcite is undersaturated

SI > 0: Calcite is supersaturated

4.3 Calcite Precipitation in Management Ponds

Calcite saturation indices were calculated on the monthly water quality predictions for the North Management, East Management, West Management and Tenas ponds. Timeseries of the calcite SIs timeseries for each of these ponds for the two pH scenarios are shown in Figure 4-1 to Figure 4-.

The calcite saturation indices are sensitive to pH and the saturation indices are higher in solutions with a pH of 8.5 compared to 8.0 in all of the management ponds. Individual pond results can be summarized as follows:

- **East Management Pond**: calcite is predicted to supersaturated in the first half of operations for both pH scenarios. The saturation index decreases below zero later in operations and calcite remains undersaturated for the remainder of operations and during the closure, and post-closure phases.
- **West Management Pond**: calcite is predicted to be supersaturated for both pH scenarios during operations and closure. The calcite saturation index is predicted to decrease in post-closure; however, it remains supersaturated in the pH 8.5 scenario. Calcite is predicted to be undersaturated during the post-closure phase for the pH 8 scenario.
- **North Management Pond**: calcite is predicted to be supersaturated for both pH scenarios during the first half of operations and then subsequently decreases and becomes undersaturated. The saturation index increase in both scenarios during closure after the cover is placed on the facility

(SRK 2021). Initially, following placement of the cover during closure, calcite is predicted to be supersaturated but subsequently decreases. Predicted saturation indices indicate that calcite will remain undersaturated in the pH 8 scenario and is in equilibrium in the pH 8.5 scenario.

- **Tenas Sedimentation Pond**: calcite saturation indices are predicted to increase during operations and calcite is predicted to be supersaturated in both the pH 8 and 8.5 scenarios until the pond is decommissioned in closure.

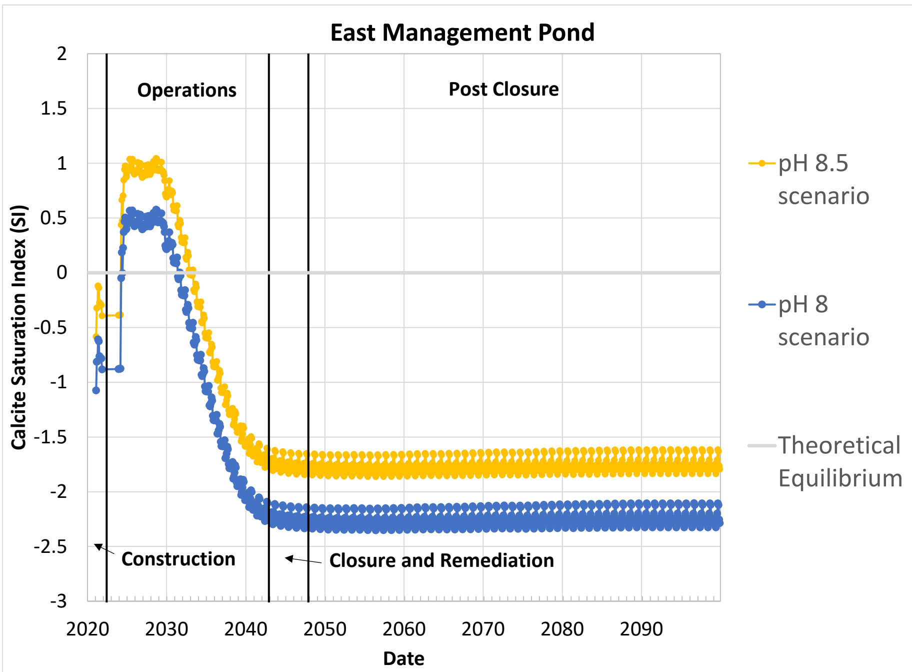

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Figure 4-1: East Management Pond Calcite Modelled Calcite Saturation Index

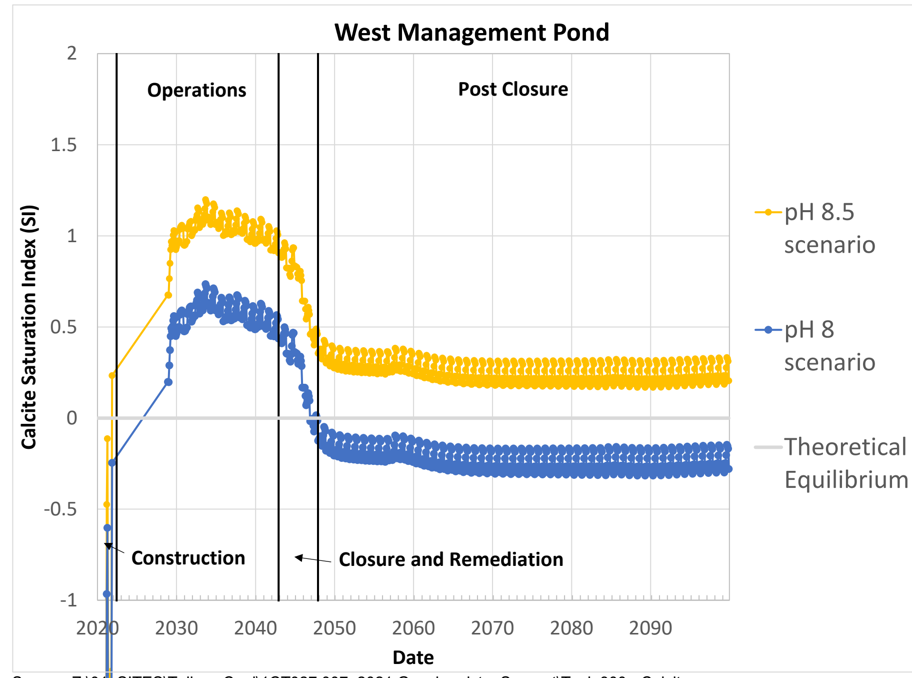

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Figure 4-2: West Management Pond Modelled Calcite Saturation Index

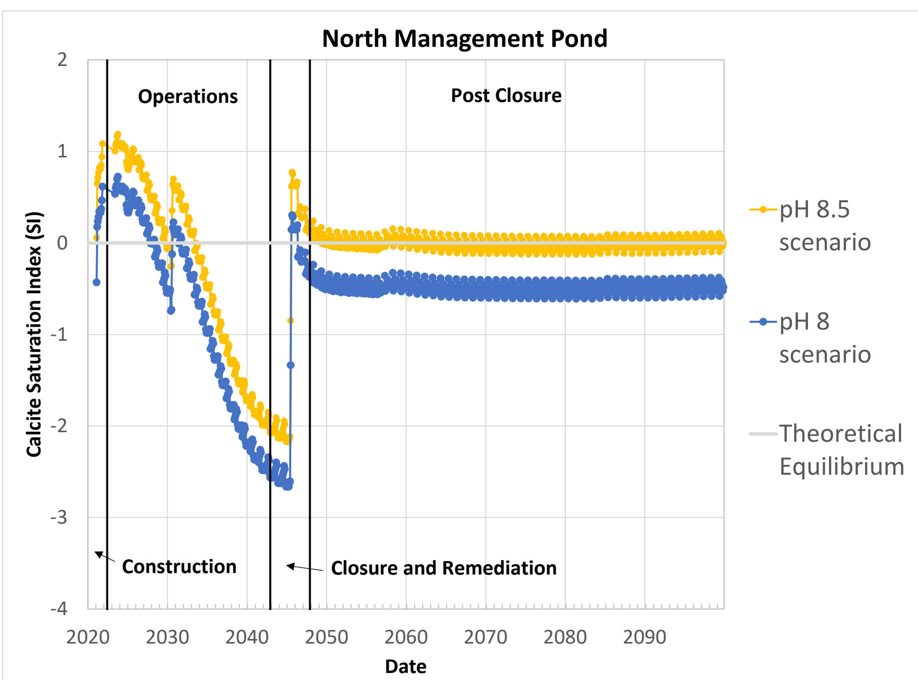

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Figure 4-3: North Management Pond Modelled Calcite Saturation Index

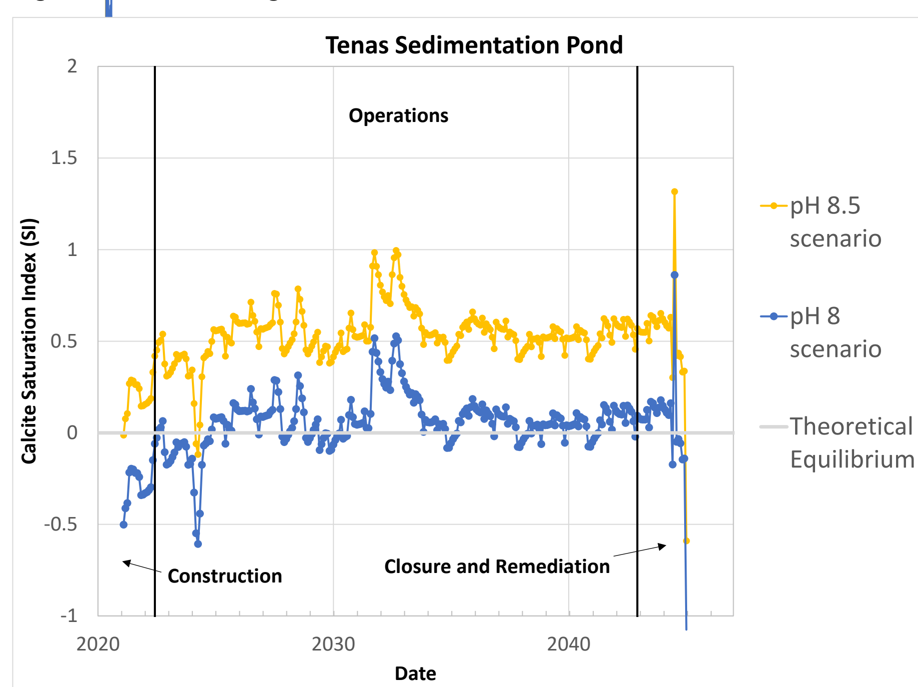

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Figure 4-4: Tenas Pond Modelled Calcite Saturation Index

4.4 Calcite Precipitation Within Receiving Waters

Table 4-3 presents a statistical comparison of the predicted water quality in Goathorn Creek (WQS06) and Four Creek (WQS03_DS) downstream of the site discharge during operations to the maximum concentrations observed in the baseline water quality dataset. Model results are for the upper case SA2 scenario (see SRK 2021 for details). The comparison indicated the following:

- Predicted alkalinity, calcium and magnesium concentrations were generally less than the maximum concentrations observed under existing conditions in Goathorn Creek. The maximum predicted magnesium concentration (50 mg/L) was greater than the baseline concentration plus 25%.
- Predicted alkalinity, calcium and magnesium concentrations were all less than the maximum baseline concentrations in Four Creek.

This comparison indicates that project discharges to Four and Goathorn creeks is not expected to result in calcite precipitation since predicted concentrations of alkalinity, calcium and magnesium and not expected to be greater than the maximum baseline concentrations, which currently do not result in calcite precipitation under existing conditions.

Table 4-3: Comparison of Predicted Water Quality to Baseline Water Quality for Stations WQS03DS and WQS06

Creek	Predicted or Baseline	Statistic	Alkalinity	Ca	Mg
			mg/L as $CaCO_3$	mg/L	mg/L
Goathorn Creek (WQS06)	Baseline	Max	87	36	8.5
	Operations	Min	42	17	3
		P25	42	18	3.1
		P50	56	23	5.2
		P75	59	24	7.5
		Max	95	41	50
		Count	250	250	250
Four Creek (WQS03_DS)	Baseline	Max	170	37	18
	Operations	Min	28	5	2.8
		P25	37	6.6	3.7
		P50	110	20	11
		P75	130	23	13
		Max	130	23	13
		Count	250	250	250

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Notes:

Values highlighted in bold are more than 25% higher than baseline values

Predicted Values for Operations Reflect Upper Case SA2 Scenario

5 Summary and Recommendations

SRK evaluated the calcite saturation index of several solutions to determine the likelihood of calcite precipitation at the Tenas Coal project. The results of this analysis indicate that calcite precipitation is likely to occur in seepage from mine site facilities and in site water management ponds in varying degrees during operations, closure and post-closure. The following is a summary of the results:

- The waste rock humidity cells had average stable leachate concentrations which were near equilibrium with respect to calcite in Zones 1a, 4 and 6. Since water to rock ratios will be lower under field conditions, constituent concentrations will be higher and calcite precipitation is considered to be likely in drainage from waste rock at the Project.
- The calculated saturation index for the Project's geochemical source terms, which reflect the predicted drainage chemistry for each mine component indicated that the predicted runoff chemistry for pit walls and NAG waste rock is supersaturated with respect to calcite. This indicates that calcite precipitation could occur downstream of these mine site components.
- The calculated saturation index for each of the management and sedimentation ponds indicated that calcite is predicted to precipitate in each of the four ponds during operations under both the best-estimate (pH 8) and upper-case (pH 8.5) scenarios and in post-closure in the West Management Pond for the pH 8.5 scenario.

Predicted alkalinity, calcium and magnesium concentrations were compared to the maximum concentrations observed in Four and Goathorn creeks indicates. With the exception of the maximum predicted magnesium concentration in Goathorn Creek, all predicted concentrations were less than maximum plus 25% baseline concentration in Four and Goathorn creeks. This comparison indicates that calcite precipitation is not expected to occur downstream of the proposed project footprint since there is no visible evidence of calcite precipitation occurring at these locations (TCL 2021, pers. comm.) even though baseline solutions are supersaturated with respect to calcite.

The results included in this study indicate that, similar to other coal mines in BC, calcite management will be required during the construction, operation, and closure of the Project. Although calcite precipitation is not expected to occur downstream of project discharges in Four and Goathorn creeks, operational plans should include calcite monitoring and management until the predictions included in this memo can be validated during operations.

Regards,
SRK Consulting (Canada) Inc.

DRAFT

Jonathon Doherty, MSc, GIT
Consultant (Geochemistry)

and reviewed by:

DRAFT

Michael Herrell, MSc, PGeo
Principal Consultant (Geochemistry)

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