Appendix 13.5-C Aluminum SPO Recommendation Memo

TELKWA COAL LIMITED

200 West Mercer St. • Suite 401 • Seattle, WA 98119 USA

148 East 25th St. • North Vancouver, BC V7N 1A1 CANADA

TECHNICAL MEMORANDUM

To: Dan Farmer (Chief Operating Officer, Allegiance Coal)

From: David DeForest (Windward), Aaron Edgington (Windward),[1] Graham Matheson (Borealis), and Guy Gilron (Borealis)

Subject: Development of a Site Performance Objective (SPO) for Aluminum in Tenas Mine Receiving Waters

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INTRODUCTION

A water quality model developed by SRK Consulting is being used to support the aquatic effects assessment for the Tenas Mine's environmental assessment (EA) application. This water quality model predicts the concentrations of metals and other inorganic constituents in receiving waters of the proposed Tenas Mine during operations and under long-term post-closure conditions.

This technical memorandum first reviews the basis for the Federal and BC aluminum WQGs, and then provides recommendations for site performance objectives (SPOs) for aluminum for the Tenas Mine.

EXISTING FEDERAL AND BC WATER QUALITY GUIDELINES FOR ALUMINUM

The Federal aluminum WQG for total aluminum was adopted in 1987 (CCREM 1987). The total aluminum WQG of 100 µg/L for waters with a pH ≥6.5 was adopted from NAS and NAE (1972), which, on behalf of the U.S. Environmental Protection Agency, included a review of the limited information on aluminum toxicity available at that time. Based on a single study by Freeman and Everhart (1971), it was observed that 50 µg/L of dissolved aluminum at neutral pH did not result in any sublethal effects on fish and concluded that "[i]n most natural waters, the ionized or potentially ionizable aluminum would be in the form of anionic or neutral precipitates, and anything greater than 0.1 mg/L [100 µg/L] of this would be deleterious to growth and survival of fish."

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[1] Aaron Edgington is now affiliated with Exponent (Bellevue, WA, USA).

The current BC WQG (for aquatic life) of 50 µg/L for dissolved aluminum was published in 1988 (Butcher 1988). This guideline was based on a review of aluminum toxicity to aquatic life and a review of aluminum guidelines and criteria from other jurisdictions, including CCREM, Ontario, and the USEPA. As stated in Butcher (1988), the recommended guideline of 50 µg/L "was set arbitrarily at 50 percent of the maximum criterion level" at pH >6.5. This guideline is, therefore, not scientifically based.

As such, both the Federal and BC WQGs for aluminum represented the state of the knowledge on aluminum toxicity at the time they were developed. Since the 1980s, and especially over the last 20 years, the understanding of aluminum chemistry, fate, and effects in freshwater has progressed greatly. The next section summarizes this more recent research, which has led to the development of aluminum bioavailability models adopted by the USEPA in updating its ambient water quality criteria for aluminum.

RECENT ALUMINUM RESEARCH AND UPDATED AMBIENT WATER QUALITY CRITERIA

It has been known for decades that increasing dissolved organic carbon (DOC) and hardness concentrations can reduce aluminum bioavailability under acidic conditions (e.g., pH 6) (Gensemer and Playle 1999). It has also been well-known that pH significantly influences aluminum speciation, which in turn influences aluminum bioavailability and toxicity (Gensemer and Playle 1999). Substantial research has recently been conducted on aluminum bioavailability and chronic toxicity to freshwater organisms; this research was published in a series of papers in 2018 (Adams et al. 2018):

- New chronic toxicity data were derived for ten species, which resulted in a chronic species sensitivity distribution (SSD) that meets the minimum data requirements for water quality guideline and criteria development in Canada, the European Union, the United States, and other jurisdictions (Cardwell et al. 2018; Gensemer et al. 2018; Wang et al. 2018).
- To evaluate aluminum bioavailability as a function of toxicity-modifying factors (TMFs), chronic toxicity tests were conducted over a range of dissolved organic carbon (DOC), hardness, and pH conditions (Gensemer et al. 2018; Cardwell et al. 2018). These tests were conducted with an invertebrate (*Ceriodaphnia dubia*), a fish (*Pimephales promelas*), and a green alga (*Pseudokirchneriella subcapitata*).
- The updated toxicity data were then used to inform the development of two types of aluminum bioavailability models: (1) the biotic ligand model (BLM), which is based on mechanistic principles (Santore et al. 2018); and, (2) an empirical statistical model, based on multiple linear regression (MLR) (DeForest et al. 2018). For the MLR models, aluminum toxicity (expressed as either an EC10 or EC20)[2] is predicted as a function of DOC, hardness, and pH.

[2] The EC10 and EC20 are the 10% and 20% effect concentrations, respectively.

The USEPA used the aluminum MLR models described in DeForest et al. (2018) to develop updated draft ambient water quality criteria for aluminum (USEPA 2017). Based on recommendations from technical reviewers of the draft criteria, additional toxicity testing was conducted to expand the range of DOC, hardness, and pH conditions used to develop the MLR models. The results of that testing and the updated MLR models were provided to the USEPA, and then incorporated into its final updated aluminum criteria (USEPA 2018).

The updated chronic aluminum toxicity data and MLR models provided to the USEPA, were also published in DeForest et al. (2020). In the latter publication, MLR models and a chronic SSD following an approach similar to CCME (2007) guidelines for WQG development were provided, including: (1) the use of EC10s as chronic toxicity thresholds; and, (2) inclusion of algae and plants in the SSD (in contrast, the USEPA criteria are based on EC20s, and algae and plants are not included in the SSD).

DeForest et al. (2020) also recommended different chronic aluminum MLR models than those used in USEPA (2018). The USEPA used the individual-species MLR models for *C. dubia* to represent invertebrates and for *P. promelas* to represent fish, while DeForest et al. (2020) recommended use of a pooled *C. dubia* and *P. promelas* MLR model that would be applied to all invertebrates and fish in the SSD. The reason for the latter is that the pooled model performed comparably to the individual-species MLR models and eliminated some of the unexpected relationships between criteria and TMFs under certain conditions. This was because use of different invertebrate and fish models in developing the criteria resulted in changes to the species sensitivity rankings in the SSD depending on the DOC, hardness, and pH conditions being evaluated. This change in rankings sometimes influenced the SSD structure in a way that resulted in criteria that sometimes did not reflect expected patterns. Use of a pooled invertebrate and fish model eliminates that issue.

An example of the chronic aluminum SSD based on an assumed DOC of 2 mg/L, pH of 7, and hardness of 75 mg/L is provided in Figure 1. For this scenario, based on a log-normal distribution, the resulting 5^{th} percentile of the SSD is 243 µg/L as total aluminum. The most sensitive species in the SSD, and hence the “driver” of the 5^{th} percentile (or HC5), is brook trout (*Salvelinus fontinalis*).

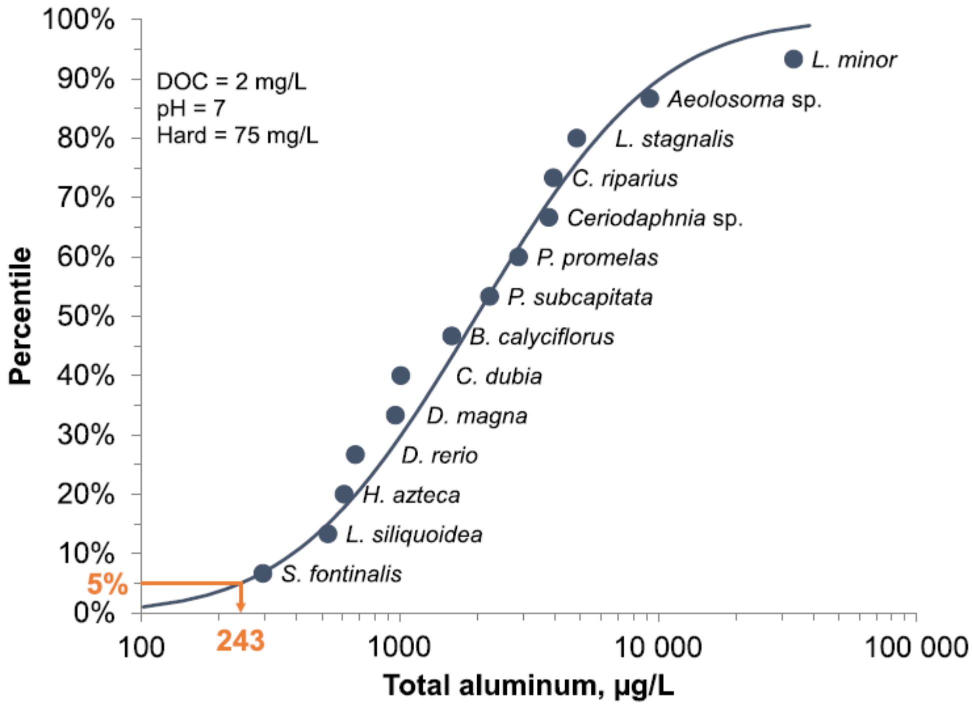

Figure 1. Example of total aluminum water quality guideline for a water with a DOC of 2 mg/L, pH of 7, and hardness of 75 mg/L. Source: Adapted from DeForest et al. (2020).

RECOMMENDATIONS FOR AN ALUMINUM SPO

The 5th percentile of the MLR-adjusted SSD based on EC10s, as described in DeForest et al. (2020), is recommended for defining the aluminum SPO. This MLR-based SSD reflects the latest research on aluminum bioavailability and toxicity. It is similar in concept to the USEPA’s recently-finalized MLR-adjusted aluminum criteria but includes an approach that is more consistent with the CCME protocol for WQG development (e.g., use of EC10s, inclusion of algae and plants in the SSD).

Deriving an SPO following this approach requires DOC, hardness, and pH data as inputs. For future conditions in Tenas Mine receiving streams, hardness was modelled, but DOC and pH were not. Using WQS03_DS and WQS06 as examples, maximum hardness concentrations are predicted to range up to 376 and 298 mg/L, respectively, with average concentrations predicted to range up to 155 and 89 mg/L, respectively (Table 1). Since DOC concentrations were not modelled in receiving streams, DOC is preliminarily assumed to be equivalent to measured total organic carbon (TOC) concentrations measured in baseline samples. At WQS03_DS and WQS06, the minima of mean monthly TOC concentrations were approximately 2.5 and 1 mg/L, respectively, but with high variability among months. For the purposes of the example provided herein, DOC concentrations of 1, 2, and 4 mg/L were used. Since pH was likewise not modelled, baseline pH data were also used for this example, which generally ranged between 7.5 and 8.0.

Total aluminum SPOs vary from 262 to 739 µg/L at WQS03-DW among the various hardness predictions and DOC and pH assumptions, and from 236 to 753 µg/L at WQS06 (Table 1). Final SPOs, however, would be developed based on agreement of hardness, DOC, and pH inputs for each receiving water location of interest. An Excel-based calculator is appended to this technical memorandum, which allows for calculation of proposed SPOs for the DOC, hardness, and pH conditions of interest.

Table 1. Examples of potential total aluminum SPOs (µg/L) as a function of different DOC, hardness, and pH assumptions for WQS03_DS and WQS06.

Station		pH = 7.5				pH = 8.0			
WQS03_DS		Hardness (mg/L)							
	DOC (mg/L)	Summer Max 281	Winter Max 376	Summer Avg. 155	Winter Avg. 153	Summer Max 281	Winter Max 376	Summer Avg. 155	Winter Avg. 153
	1	287	300	263	262	318	309	336	336
	2	458	475	423	422	453	434	488	489
	4	715	739	667	666	623	592	685	687
WQS06	DOC	Hardness (mg/L)							
	DOC (mg/L)	Summer Max 138	Winter Max 298	Summer Avg. 78	Winter Avg. 89	Summer Max 138	Winter Max 298	Summer Avg. 78	Winter Avg. 89
	1	258	290	236	241	338	317	350	348
	2	416	461	383	391	494	449	523	517
	4	658	720	611	623	697	617	753	740

CLOSURE

We trust that this technical memorandum meets your needs. Please do not hesitate to let either of the undersigned know if you have any questions or require additional information.

Guy Gilron, MSc, RPBio, ICD.D
Principal, Borealis Environmental

David DeForest
Partner, Windward Environmental LLC

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