Appendix 13.5-D Cadmium SPO Recommendation Memo

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TECHNICAL MEMORANDUM

To:	Dan Farmer (Chief Operating Officer, Allegiance Coal)
From:	Bob Santore (Windward), David DeForest (Windward), Graham Matheson (Borealis), and Guy Gilron (Borealis)
Subject:	Development of a Site Performance Objective (SPO) for Cadmium in Tenas Mine Receiving Waters
Date:	October 4, 2021

APPROACH FOR DEVELOPING A CADMIUM SITE PERFORMANCE OBJECTIVE

The cadmium (Cd) guideline for British Columbia was based on the lowest observed effect approach (BCMOE 2015). This approach has been the traditional guideline derivation method used by the British Columbia Ministry of Environment (BCMOE), now the British Columbia Ministry of Environment and Climate Change Strategy (BCMOECCS). However, most other jurisdictions, including: the Canadian Council of Ministers of the Environment (CCME), Environment and Climate Change Canada (ECCC), and other Canadian provinces use a different approach based on the distribution of the sensitivity of all species to cadmium (a species sensitivity distribution, or SSD). SSD-based approaches derive the guideline from the 5th percentile of effect concentrations for the most sensitive toxicity endpoints for all aquatic species used to derive the guideline. Recently, BCMOECCS has proposed a new approach that is also based on the 5th percentile of the SSD (BCMOECCS 2019). The BCMOECCS SSD-approach differs from the SSD-based approaches of CCME and ECCC, as it is based on a modeling-averaging technique (Schwarz and Tillmanns 2019). In the development of a Site Performance Objective (SPO) for Cd, we propose using the toxicity data from BCMOE (2015), with the modeling-averaging approach of Schwarz and Tillmans (2019).

DATA COMPILATION

Chronic Cd toxicity data for aquatic life relevant to British Columbia were compiled from BCMOE (2015). Species mean chronic values were based on the lowest toxicological effect observed for that species (e.g., survival, reproduction, growth), and averaged if multiple observations were available. These data were normalized to a hardness of 50 mg/L as $CaCO_3$, and are summarized in Table 1.

Table 1. Toxicity data from BCMOE (2015) used in the derivation of the Cd SPO. The normalized effect values are adjusted to a hardness of 50 mg/L.

Receptor Group/Species (all resident in BC)	Selected Toxicity Test Endpoint	Duration	Normalized Effect Value (µg/L)	Confidence Interval Lower Limit	Confidence Interval Upper Limit	Species Mean Value (µg/L)	Reference
Fish - Non-salmonid Species							
Catostomus commersoni	LOEC; biomass	40-d	13			13	Eaton et al. (1978)
Cottus bairdi	LOEC; biomass	21-d	0.764			0.764	Besser et al. (2007)
Esox lucius	LOEC; biomass	35-d	13.9			13.9	Eaton et al. (1978)
Pimephales promelas	LOEC; growth	7-d	2.18			2.18	Castillo and Longley (2001)
Pimephales promelas	LC_{50}	10-d	3.54	2.88	4.42		Suedel et al. (1997)
Acipenser transmontanus	LC_{20}	27-d	6.79	6.17	7.42	6.79	Vardy et al. (2011)
Fish - Salmonid Species							
Oncorhynchus kisutch	LOEC; biomass	27-d	3.67			3.67	Eaton et al. (1978)
Oncorhynchus mykiss	LOEC; biomass	28-d	1.59				Besser et al. (2007)
Oncorhynchus mykiss	LC_{10}	200-h	1.24	1.06	1.42		Chapman (1978)
Oncorhynchus mykiss	LC_{50}	7-d	2.43	2.09	2.78		Cusimano et al. (1986)
Oncorhynchus mykiss	LOEC; mortality	30-d	4.69				Hollis et al. (1999)
Oncorhynchus mykiss	LOEC; mortality	30-d	3.19				Hollis et al. (2000)
Oncorhynchus mykiss	LOEC; growth	62-d	0.237			0.237	Mebane et al. (2008)
Oncorhynchus tshawtscha	LC_{10}	200-h	2.13	1.59	2.48	2.13	Chapman (1978)
Oncorhynchus tshawtscha	LOEC; mortality	120-d	3.13				Chapman (1982)
Prosopium williamsoni	IC_{20}; biomass	90-d	1.33			1.33	Brinkman and Viera (2008)
Salmo trutta	IC_{20}; biomass	30-d	1.29			1.29	Brinkman and Hansen (2007)
Salmo trutta	LOEC; biomass	63-d	4				Eaton et al. (1978)
Salvelinus confluentus	LOEC; growth	55-d	1.13				Hansen et al. (2002)
Salvelinus fontinalis	LOEC; biomass	150-d	4.11			4.315	Eaton et al. (1978)
Salvelinus fontinalis	LOEC; growth	60-d	4.53				Sauter et al. (1976)
Salvelinus namaycush	LOEC; biomass	74-d	13.3			13.3	Eaton et al. (1978)

Table 1. Toxicity data from BCMOE (2015) used in the derivation of the Cd SPO. The normalized effect values are adjusted to a hardness of 50 mg/L. (cont'd.)

Receptor Group/Species (all resident in BC)	Selected Toxicity Test Endpoint	Duration	Normalized Effect Value (µg/L)	Confidence Interval Lower Limit	Confidence Interval Upper Limit	Species Mean Value (µg/L)	Reference
Invertebrates							
Baetis rhodani	LC_{50}	120-h	1000			1000	Gerhardt (1992)
Chironomus riparius	LC_{50}	10-d	382	273	545	382	Watts and Pascoe (2000)
Chironomus dilutus	LOEC; growth	14-d	221			221	Suedel et al. (1997)
Chironomus dilutus	LC_{50}	10-d	403	273	600		Watts and Pascoe (2000)
Leptophlebia marginata	LC_{50}	120-h	3600			3600	Gerhardt (1992)
Rhithrogena hageni	LOEC; mortality	10-d	3630			3630	Brinkman & Johnston (2008)
Gammarus pulex	LOEC; mortality	120-h	2.29			2.29	Felten et al. (2008)
Hyalella azteca	IC_{20}; biomass	28-d	0.253	0	1.11	0.253	Chadwick Ecological Consultants (2004)
Hyalella azteca	LOEC; mortality	14-d	0.553				Suedel et al. (1997)
Ceriodaphnia dubia	LOEC; reproduction	14-d	8.85			8.85	Suedel et al. (1997)
Daphnia magna	IC_{20}; reproduction	21-d	1.35	1.16	1.73	1.35	Chadwick Ecological Consultants (2004)
Daphnia magna	LC_{50}	14-d	6.2	5.48	6.92		Suedel et al. (1997)
Daphnia pulex	IC_{20}; mortality	18-d	1.41	0.358	n/c	1.41	Chadwick Ecological Consultants (2004)
Daphnia pulex	LOEC; mortality	60-d	5.75				Ingersoll & Winner (1982)
Orconectes virilis	LC_{50}	14-d	1130	809	1590	1130	Mirenda (1986)
Plants/Algae							
Lemna minor	EC_{50}; growth rate	7-d	88.5			88.5	Drost et al. (2007)
Pseudokirchneriella subcapitata	EC_{20}; growth rate	72-h	23.3	15.9	35	23.3	Källqvist (2009)
Amphibians							
Ambystoma gracile	LOEC; growth	24-d	209			209	Nebeker et al. (1995)

EC20 – 20% effect concentration; EC50 – 50% effect concentration; IC20 – 20% inhibition concentration; LC50 – 50% lethal concentration; LOEC – lowest observed effect concentration; n/c – not calculable

SSD FITTING

The model averaging approach was conducted using the Shiny app made available by BCMOE (https://bcgov-env.shinyapps.io/ssdtools/) and applied to the toxicity data presented in Table 1. The shiny app includes log-logistic, log-normal, and gamma distributions by default; however, none of these were good approximations of the shape of the Cd SSD. The log-Gumbel was a better description of the Cd SSD and that distribution was also considered in the modeling-averaging approach. The BCMOE approach uses a weighted average to combine the results from these different distribution methods, where the weighting factor is based on goodness-of-fit, as defined by Akaike's Information Criterion corrected for sample size. The 5th percentile of each of these distributions is shown in Table 2, along with the model-average result of 0.292 µg/L.

Table 2. Calculation of the 5th percentile Cd values (µg/L) using toxicity data in Table 1.

Distribution	5th percentile	Std error	Lower confidence limit	Upper confidence limit
Weighted-Average	0.292	0.248	0.127	1.02
Log-logistic	0.086	0.173	0.0124	0.586
Gamma	0.00141	0.131	6.42E-06	0.246
Log-normal	0.143	0.24	0.0308	0.876
Log-Gumbel	0.34	0.248	0.142	1.04

The fitted distribution is illustrated in Figure 1.

SPO DEVELOPMENT

The proposed Cd SPO is based on this 5th percentile of the Cd SSD adjusted using an assessment factor of 2 and a hardness slope that are consistent with what was BCMOE (2015).

Allowing for hardness adjustment of this value results in the following SPO equation:

$$\text{Cd SPO } (\mu g/L) = e^{(0.736 * \ln(\text{hardness}) - 4.8034)}$$

The intent of specifying the SPO in the form of a hardness equation is to provide means for adjusting the value of the SPO to match hardness conditions at the site. Examples of values for other hardness concentrations are provided in Table 3.

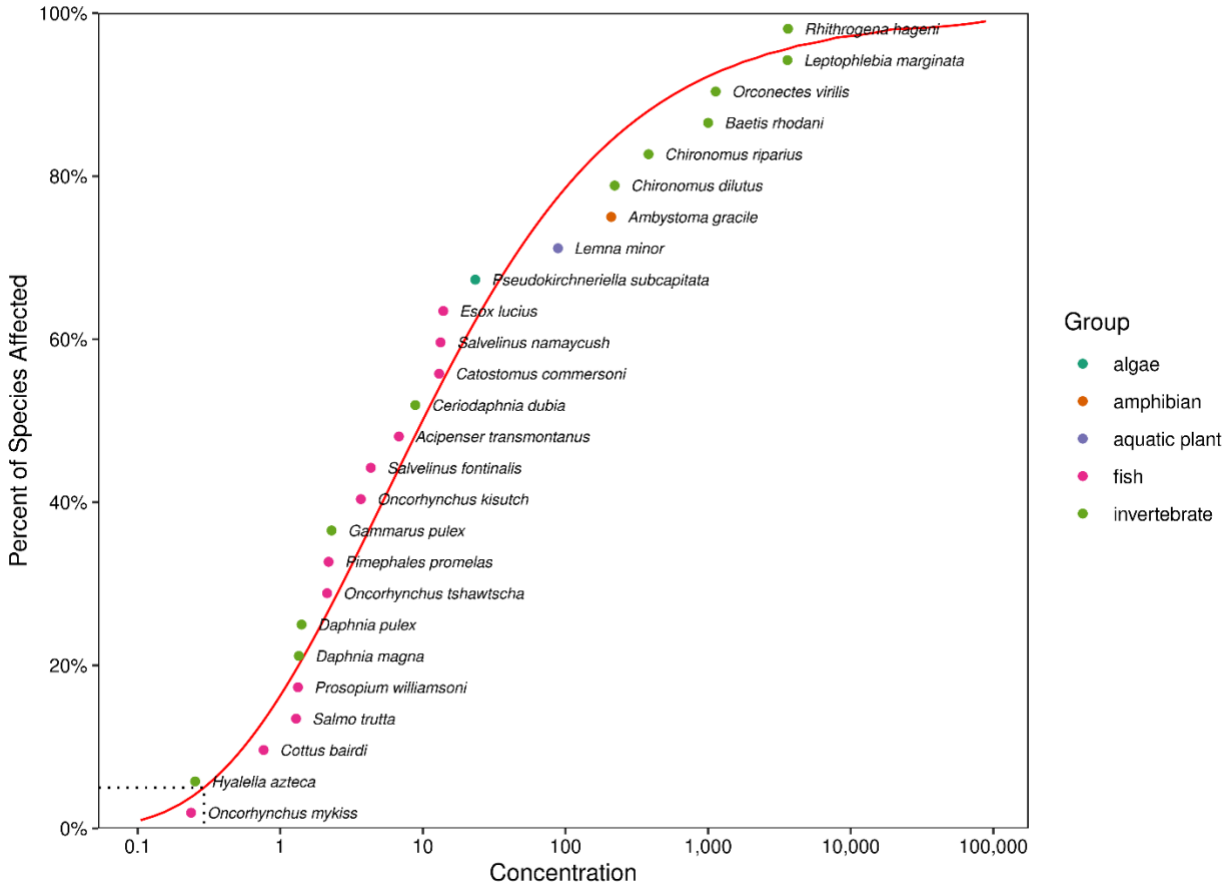

Figure 1. Cadmium SSD illustrating toxicity data from Table 1 and the model average-fitted curve provided by the fitting routine (as described in Schwarz and Tillmans (2019)).

Table 3. Comparison of BCMOE 2015 and the Cd SPO for different hardness conditions.

Hardness (mg/L as $CaCO_3$)	BCMOE 2015 Cd Aquatic Life Guideline (µg Cd/L)	Cd SPO (µg Cd/L)
25	0.0762	0.0877
50	0.127	0.146
100	0.212	0.243
200	0.352	0.405
285	0.457	0.526

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.

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