Appendix 13.5-H Thallium SPO Recommendation Memo

TELKWA COAL
LIMITED

200 First Avenue West ♦ Suite 500 ♦ 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: Kate McPeek, David DeForest (Windward Environmental LLC)
Aphrodite Koseos, Guy Gilron (Borealis Environmental)

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

Date: February 16, 2022

INTRODUCTION

A water quality model developed by SRK Consulting (SRK) (S. Barnes, SRK, *personal communication*) is being used to support the aquatic effects assessment for the Tenas Mine's British Columbia (BC) provincial environmental assessment (EA) application, in addition to subsequent permitting activities. The water quality modelling results indicate that thallium concentrations may exceed the Canadian Council of Ministers of the Environment (CCME) water quality guideline (WQG) of 0.8 µg/L (CCME 1999)[1] in receiving waters of the proposed Tenas Mine, specifically during operations and under long-term post-closure conditions. This technical memorandum first reviews the derivation basis for the CCME WQG for thallium; it then provides a science-based recommendation for a Site Performance Objective (SPO) for use in evaluating toxicity risk associated with downstream thallium concentrations.

[1] Currently, no BC aquatic life guideline for thallium exists. A CCME WQG for freshwater aquatic life is a reasonable surrogate for application at this site.

Existing CCME Guideline for Thallium

The CCME WQG for thallium was developed in 1998, and the basis for its derivation was summarized in CCME (1999). Chronic thallium toxicity data were compiled for three vertebrates (two fish, *Salmo salar* [Atlantic salmon] and *Pimephales promelas* [fathead minnow] and an amphibian, *Gastrophryne carolinensis* [toad]), one invertebrate (*Daphnia magna* [cladoceran]), and one aquatic plant (*Lemna minor* [duckweed]). *L. minor* data indicated that plants are more sensitive to thallium than are fish and invertebrates; the lowest toxicity value identified was an effective concentration to 50% of the population (EC50) of 8 µg/L. Per the CCME guidance at the time of the guideline's derivation, this lowest toxicity value was multiplied by a safety factor of 0.1 to derive the final CCME WQG of 0.8 µg/L.

Methods

The British Columbia Ministry of Environment and Climate Change Strategy (BC MOECCS) guidance document *Derivation of Water Quality Guidelines for the Protection of Aquatic Life in British Columbia* states that BC aquatic life guidelines are generic provincial recommendations (BC MOECCS 2019). The technical guidance in BC MOECCS (2019) was consulted to identify acceptable long-term toxicity tests with thallium and methods for developing the species sensitive distribution (SSD) for aquatic species, but the policy-based guidance for developing WQGs and assessment factors were not considered in developing the recommended thallium SPO (the basis for this is discussed below).

Following BC MOECCS (2019) guidance, toxicity data were compiled from the US Environmental Protection Agency's (EPA's) Ecotoxicology Knowledgebase (ECOTOX) (EPA 2021) and the peer-reviewed scientific literature for laboratory tests conducted with freshwater organisms with effects measurements for growth, reproduction, population effects, and/or survival. The ECOTOX search was limited to studies reporting data for relevant concentration-based endpoints, including: non-lethal effect concentrations (ECx values), inhibitory concentrations (ICx values), lethal concentrations (LCx values), no-observed-effect concentrations (NOECs), lowest-observed-effect concentrations (LOECs), and maximum acceptable toxicant concentrations (MATCs).[2] The general preference for endpoint selection, following BC MOECCS (2019) recommendations for a Type A2 guideline, is as follows:

ECx/ICx representing a no-effects threshold > EC10/IC10 > EC11-25/IC11-25 > MATC > NOEC > LOEC >nonlethal EC26-49/IC26-49 > nonlethal EC50/IC50

Once the toxicity data were compiled, the most sensitive endpoint was selected for each species. With some exceptions, the hierarchy of endpoints presented herein was

[2] The NOEC is the highest concentration in a test that does not result in a statistically significant effect relative to the control, the LOEC is the lowest concentration in a test that results in a statistically significant effect relative to the control, and the MATC is the geometric mean of the NOEC and LOEC.

followed. One exception was for *L. minor* (duckweed), for which an LOEC from one study was less than the EC10 from another study. In that case, the LOEC was selected over the higher EC10 for conservatism. All of the long-term thallium toxicity data compiled are provided in Attachment A; the selected species mean toxicity thresholds are summarized in Table 1.

The species mean thallium toxicity thresholds in Table 1 were then used to develop an SSD, from which the 5th percentile (or HC5) could be calculated. The HC5 is assumed to protect 95% of the species in an aquatic community and is the approach followed by BC MOECCS (2019), as well as several other jurisdictions (ECB 2003; Stephan et al. 1985). Model distributions were fit to the species mean thallium toxicity thresholds using the *ssdtools* software.[3]

[3] https://bcgov-env.shinyapps.io/ssdtools/

Table 1. Species mean thallium toxicity thresholds used to develop the SSD

Test Species	Common Name	Test Duration (Mean or Range) (days)	Biological Effect	Test Endpoint	Chemical Analysis	Species Mean Thallium Toxicity Threshold (µg/L)	Reference
Stichococcus bacillaris	green alga	12–14	population	LC50	unmeasured	40,880	Aliotta et al. (1983)
Chlorella saccharophila	green alga	12–14	population	LC50	unmeasured	8,170	Aliotta et al. (1983)
Coenochloris sp.	green alga	12–14	population	LC50	unmeasured	8,170	Aliotta et al. (1983)
Carassius auratus	goldfish	7	mortality	LC50	measured	7,000	Birge (1978)
Chlorella protothecoides	green alga	12–14	population	LC50	unmeasured	1,590	Aliotta et al. (1983)
Oncorhynchus mykiss	rainbow trout	28	mortality	LC50	measured	170	Birge (1978)
Gastrophryne carolinensis	eastern narrow-mouthed toad	7	mortality	LC50	measured	110	Birge (1978)
Ceriodaphnia dubia	cladoceran	7	reproduction	IC25	measured[b]	100	Pickard et al. (2001)
Raphidocelis subcapitata[a]	green alga	3	growth	IC25	measured[b]	90	Pickard et al. (2001)
Pimephales promelas	fathead minnow	30	mortality	LOEC	measured	40	LeBlanc and Dean (1984)
Chlorella vulgaris	green alga	91–122	population	MATC	unmeasured	28	Doore de Jong and Roman (1965)
Lemna minor	common duckweed	10	population	LOEC	unmeasured	16.4	Smith and Kwan (1989)
Hyalella azteca	amphipod	70	reproduction	EC25	measured[b]	4.4	Borgmann et al. (1998)
Daphnia magna	cladoceran	21	reproduction	MATC	measured	2.8	Nagel et al. (2021)

[a] Formerly *Selenastrum capricornutum.*

[b] EC25s were reported based on nominal thallium concentrations. Pickard et al. (2001) reported that measured thallium concentrations were 89% of nominal. Borgmann et al. (1998) reported that measured thallium concentrations were, on average, 94% of nominal (95% confidence interval: 92-99%, n=149).

EC25 – concentration that causes a non-lethal effect in 25% of an exposed population
IC25 – concentration that causes an inhibitory effect in 25% of an exposed population
LC50 – concentration that is lethal to 50% of an exposed population
LOEC – lowest-observed-effect concentration
MATC – maximum acceptable toxicant concentration
SSD – species sensitivity distribution

Note: Unable to fit the Gompertz distribution.

RESULTS

The fits of all six distributions (i.e., log-normal, log-logistic; log-Gumbel, gamma, Gompertz, and Weibull) in ssdtools to the species mean thallium toxicity thresholds were first evaluated. The model fits were variable, with the gamma distribution providing the poorest fit to the lower end of the tail (i.e., the most sensitive species) and the log-Gumbel distribution providing the best fit to the most sensitive species (Figure 1). The Gumbel distribution had the best goodness-of-fit based on almost all of the statistics, including Anderson-Darling, Kolmogorov-Smirnov, Cramer-von Mises statistic, and AIC (Table 2; lower goodness-of-fit statistics indicate a better fit). The gamma distribution consistently had the poorest fit (Table 2). Visually, the shapes of both the gamma and Weibull distributions are strongly influenced by the five species in the SSD that have the highest thallium toxicity thresholds (Figure 1). The shapes of the log-normal and log-logistic distributions are less strongly influenced by the less sensitive species in the SSD, while the log-Gumbel distribution, in addition to providing the best overall fit to the data, provides the best fit to the most sensitive species in the SSD (Figure 1).

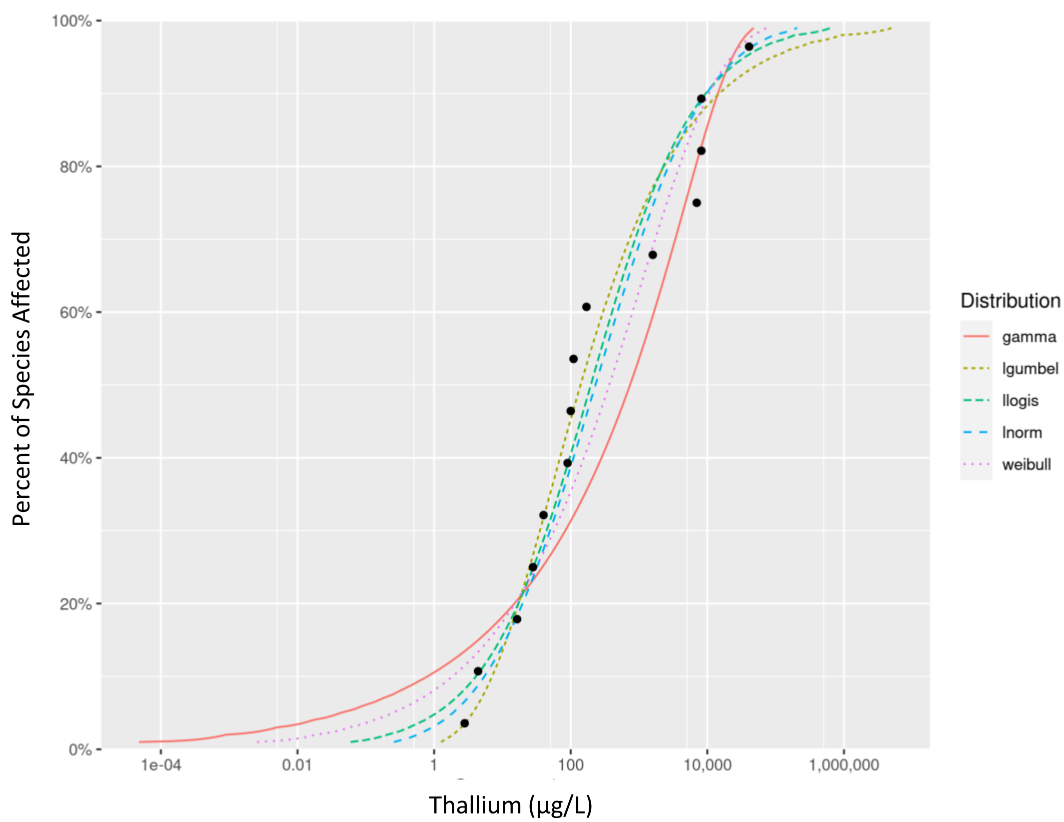


Figure 1. Fit of five distributions to species mean thallium toxicity thresholds using *ssdtools*

Table 2. Statistics for distributions plotted in Figure 1

Distribution	A-D	K-S	CvM	AIC	AICc	BIC	Delta	Weight
log-Gumbel	0.333	0.152	0.0482	226	227	227	0	0.37
log-Normal	0.469	0.184	0.082	226	227	227	0.365	0.308
log-Logistic	0.461	0.169	0.0738	227	228	228	1.54	0.171
Weibull	0.631	0.233	0.116	228	229	229	2.39	0.112
Gamma	0.913	0.288	0.178	230	231	231	4.53	0.038

A-D – Anderson-Darling statistic
K-S: Kolmogorov-Smirnov statistic
CvM: Cramer-von Mises statistic
AIC: Akaike's Information Criterion
AICc: AIC corrected for sample size
BIC: Bayesian Information Criterion
Delta: AICc difference
Weight: AICc based Akaike weight (weight)

RECOMMENDATIONS FOR A THALLIUM SPO

The weighted average distribution provides an HC5 of 2.2 µg/L (Figure 2), while the best-fitting log-Gumbel distribution provides an HC5 of 3.7 µg/L (Figure 3). Because the HC5of the log-Gumbel distribution (i.e., 3.7 µg/L) exceeds the thallium toxicity threshold for the most sensitive species (i.e., *D. magna*; 2.8 µg/L), the HC5 of 2.2 µg/L is recommended as the thallium SPO. This SPO is expected to be protective of aquatic life in Tenas Mine receiving waters, which are predominantly characterized by periphyton, aquatic insects, and trout (ERM 2019). As illustrated in Figure 2, algae and trout (represented by *O. mykiss*) are relatively insensitive to thallium compared to invertebrates. Although thallium toxicity data from long-term studies with aquatic insects were not identified, long-term toxicity data were identified for the amphipod *H. azteca* and the cladocerans *C. dubia* and *D. magna*. These species, particularly *H. azteca* and *C. dubia*, are generally sensitive to metals relative to aquatic insects.

H. azteca is often the most sensitive organism, or among the most sensitive organisms, to several metals. Inclusion of reliable, long-term toxicity data for *H. azteca* and *C. dubia* in the thallium SSD indicates that the HC5 will be protective of the aquatic community at the site. For example, *H. azteca* is the most sensitive organism in the EPA database used to derive its ambient water quality criterion for cadmium (EPA 2016). EPA's cadmium database includes chronic data for one aquatic insect species, the midge *Chironomus dilutus*, which is approximately threefold less sensitive than *H. azteca*. *H. azteca* was also identified as the third and fourth most sensitive species to lead and zinc, respectively, based on SSDs wherein the bioavailabilities of these metals were adjusted to a common water chemistry condition; *C. dubia* was identified as the most sensitive species to zinc and the fifth most sensitive species to lead (DeForest and Van Genderen 2012; DeForest et al. 2017). Chronic lead toxicity data were available for the midges *C. dilutus* and *C. riparius*, which were approximately 13- and 29-fold less sensitive, respectively, than *H. azteca*, and for the mayfly *Baetis tricaudatus*, which was approximately 109-fold less sensitive than *H. azteca* (DeForest et al. 2017). Additionally, chronic zinc toxicity data were available for a midge (*C. tentans*) and a caddisfly (*Clistoronia magnifica*), which were approximately threefold and more than 150-fold less sensitive than *H. azteca* (DeForest and Van Genderen 2012).

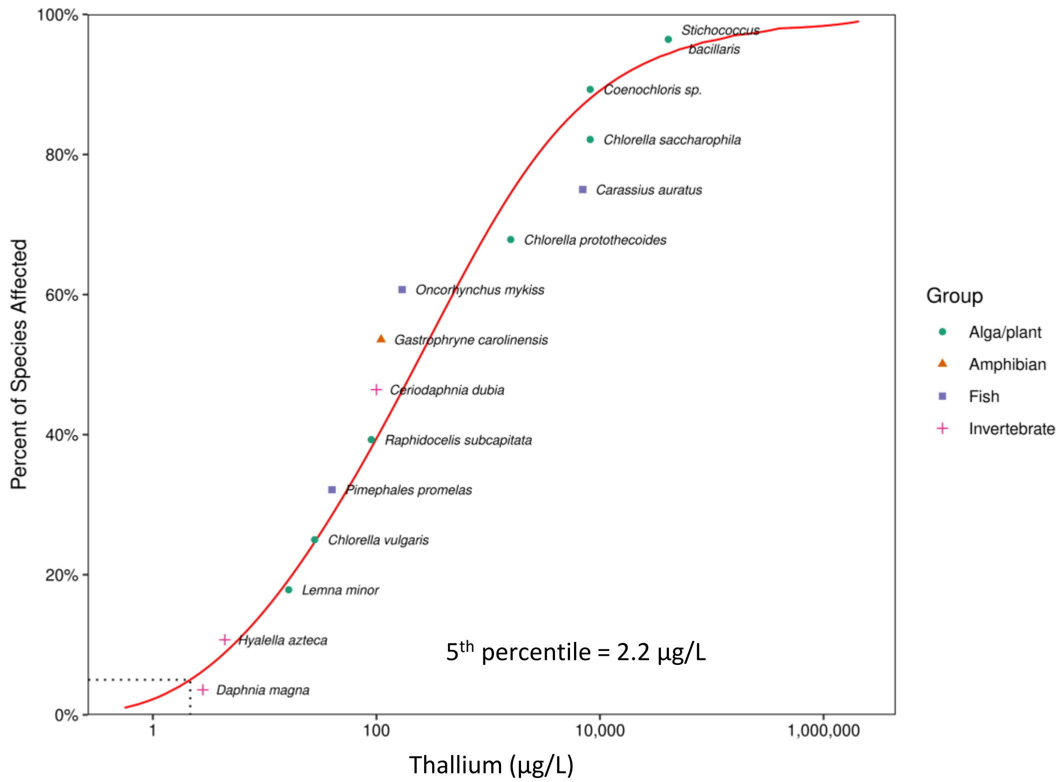


Figure 2. Fit of the weighted average distribution using BC *ssdtools*

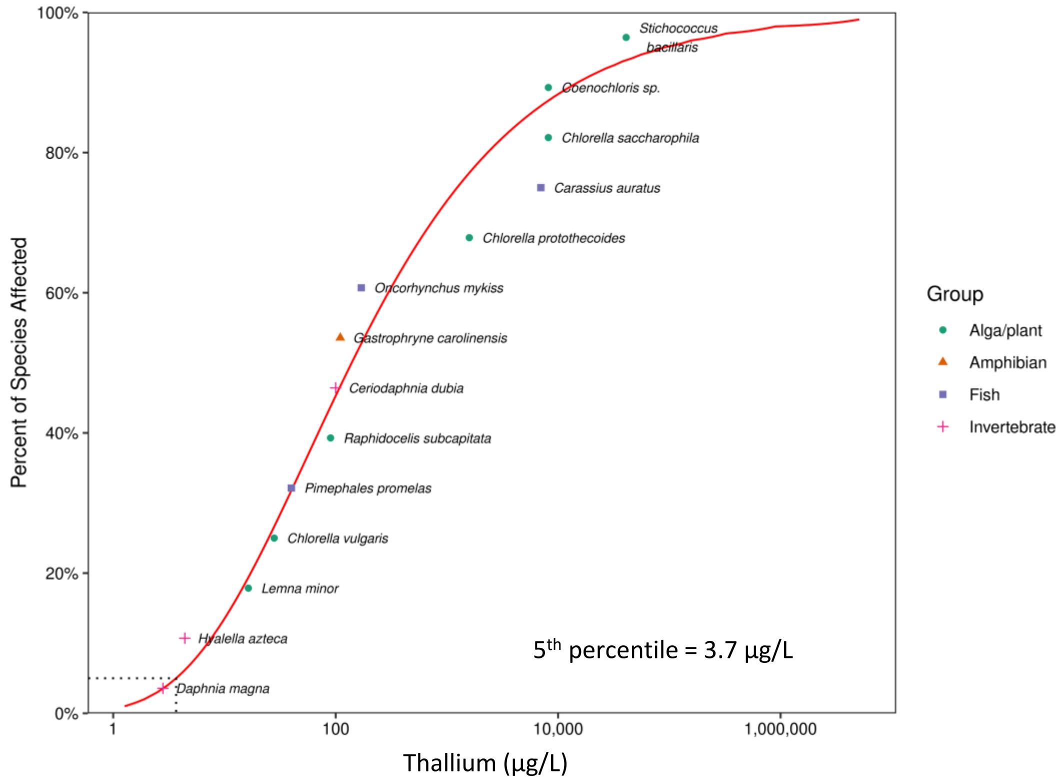


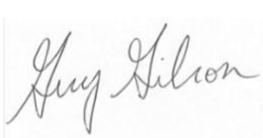
Figure 3. Fit of the log-Gumbel distribution using BC *ssdtools*

CONCLUSION

A thallium SPO of 2.2 µg/L is recommended for Tenas Mine receiving waters. Using BC's *ssdtools,* this SPO is based on the 5th percentile of an SSD for long-term thallium toxicity tests with a variety of algae, plant, invertebrate, fish, and amphibian species.

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

REFERENCES

Aliotta G, Pinto G, Pollio A. 1983. Observations on tolerance to heavy metals of four green algae in relation to pH. G Bot Ital 117(5-6):247-251.

BC MOECCS. 2019. Derivation of water quality guidelines for the protection of aquatic life in British Columba. Water Quality Guideline Series, WQG-06. British Columbia Ministry of Environment and Climate Change Strategy, Victoria, BC.

Birge WJ. 1978. Aquatic toxicology of trace elements of coal and fly ash. In: Thorp JH, Gibbons JW, eds, Energy and environmental stress in aquatic systems: papers from symposium, Augusta, Georgia, November 1977. Technical Information Center, US Department of Energy, Washington, DC, pp 219-240.

Borgmann U, Cheam V, Norwood WP, Lechner J. 1998. Toxicity and bioaccumulation of thallium in *Hyalella azteca*, with comparison to other metals and prediction of environmental impact. Environ Pollut 99(1):105-114.

CCME. 1999. Canadian water quality guidelines for the protection of aquatic life. Thallium. Canadian Council of Ministers of the Environment, Winnipeg, MB.

DeForest DK, Van Genderen EJ. 2012. Application of US EPA guidelines in a bioavailability-based assessment of ambient water quality criteria for zinc in freshwater. Environ Toxicol Chem 31(6):1264-1272.

DeForest DK, Santore RC, Ryan AC, Church BG, Chowdhury MJ, Brix KV. 2017. Development of biotic ligand model-based freshwater aquatic life criteria for lead following US Environmental Protection Agency guidelines. Environ Toxicol Chem 36(11):2965-2973.

Doore de Jong LE, Roman WB. 1965. Tolerance of *Chlorella vulgaris* for metallic and non-metallic ions. Antonie van Leeuwenhoek 31(1):301-313.

ECB. 2003. Technical guidance document on risk assessment. European Chemicals Bureau.

EPA. 2016. Aquatic life ambient water quality criteria cadmium - 2016. EPA-820-R-16-002. US Environmental Protection Agency, Washington, DC.

EPA. 2021. ECOTOXicology database [online database]. US Environmental Protection Agency, Available from: https://cfpub.epa.gov/ecotox/.

ERM. 2019. Tenas project 2017 to 2019 baseline report. Prepared for Telkwa Coal Limited.

LeBlanc GA, Dean JW. 1984. Antimony and thallium toxicity to embryos and larvae of fathead minnows (*Pimephales promelas*). Bull Environ Contam Toxicol 32(5):565-569.

Nagel AH, Cuss CW, Goss GG, Shotyk W, Glover CN. 2021. Chronic toxicity of waterborne thallium to *Daphnia magna*. Environ Pollut 268, Part B.

Pickard J, Yang R, Duncan B, McDevitt CA, Eickhoff C. 2001. Acute and sublethal toxicity of thallium to aquatic organisms. Bull Environ Contam Toxicol 66:94-101.

Smith S, Kwan MKH. 1989. Use of aquatic macrophytes as a bioassay method to assess relative toxicity, uptake kinetics and accumulated forms of trace metals. Hydrobiogia 188:345-351.

Stephan CE, Mount DI, Hansen DJ, Gentile JH, Chapman GA, Brungs WA. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB85-227049. Office of Research and Development, US Environmental Protection Agency, Washington, DC.