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Soil Quality Guidelines for Selected Trace Metals
Executive Summary Report
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1.0 INTRODUCTION

The Alberta Tier 1 Soil and Groundwater Remediation Guidelines (Alberta Environment and Parks, AEP, 2016) are used for the assessment and remediation of contaminated sites in Alberta; the Canadian Environmental Quality Guidelines (Canadian Council of Ministers of the Environment, CCME, 1999 and updates) are used for Federal Government lands and in several other provinces. Typically, if concentrations of chemical contaminants exceed these guidelines, the contamination requires remediation, risk management, or site-specific risk assessment.

Both the Alberta and CCME soil quality guidelines were derived based on A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines (CCME, 2006). This protocol describes the approach, assumptions and models for deriving widely applicable soil quality guidelines that are protective of both human and environmental health. However, some substances, particularly certain metals, have not been evaluated using the CCME (2006) protocol or its 1996 precursor, and are still assessed using prior interim guidelines from 1991. Specifically, antimony, beryllium, boron, cobalt, fluoride, molybdenum, silver, sulphur, tin and several organic substances (primarily chlorinated organics and phenolics) do not have modern risk-based guidelines.

In the absence of risk-based guidelines, concentrations of these substances measured during contaminated site investigations cannot be readily related to potential risks to human and environmental health. Without this information, it is unknown whether remediation is necessary to protect human and environmental health, or whether remediating to guidelines will achieve human and environmental health protection. The available options for cost-effective site-specific risk assessment for the metals in particular are also very limited without a risk-based guideline as a starting point. Risk management plans are also difficult to develop, since the 1991 interim guidelines do not provide any information on what receptors or exposure pathways may be affected by different chemical concentrations in soil.

The purpose of the present work is to develop risk-based guidelines consistent with the CCME (2006) protocol for selected trace metals which occur at oil and gas sites, specifically antimony, beryllium, cobalt and molybdenum. The guideline development process for each metal is detailed in a scientific supporting document; a brief summary of the results is provided herein.

2.0 ANTIMONY

2.1 Background

Antimony is a metalloid that has been associated with some oil and gas sites due to its use as a weighting material in some drilling fluids, as well as presence in oil. It is also released to the environment through combustion of fossil fuels and some refinery processes.

Background concentrations are generally less than 1 mg/kg, with a median concentration in Ap horizon soil across Canada reported as 0.6 mg/kg, and a median concentration in glacial clay reported as 0.4 mg/kg. Much higher concentrations have been reported in mining areas and near smelters.

Bioconcentration of antimony in plants and other organisms is generally relatively low and determined primarily by the soluble component.

2.2 Environmental Guidelines

The available plant and soil invertebrate toxicity data were not quite sufficient to develop a direct ecological soil contact value using the preferred weight of evidence with EC_{25} values approach, but were sufficient to derive a guideline using an effects/no effects data distribution. Using this approach, the 25th percentile of the effects/no-effects distribution was 120 mg/kg and the 50th percentile of the distribution was 240 mg/kg; these are recommended as guidelines for sensitive and non-sensitive land uses, respectively.

The data were not sufficient to calculate a nutrient and energy cycling check; however, the limited available data suggested that guidelines for this pathway would likely be higher than the guideline based on plant and soil invertebrate data.

No livestock or wildlife toxicity data were identified and therefore the minimum requirements for the livestock and wildlife soil/food ingestion guidelines were not met. A provisional guideline was calculated using the available rodent toxicity data, based on the same endpoint used for the human health assessment below. The resulting livestock guideline was 2,100 mg/kg, and the wildlife guideline was 590 mg/kg.

Guidelines for the protection of groundwater were not calculated due to limitations of the model when applied to metals.

2.3 Human Health Guidelines

The human health guidelines were based on a tolerable daily intake (TDI) of 0.006 mg/kg-bw/d adopted from the World Health Organization (WHO). There is an older Health Canada TDI, but the WHO value is based on updated information. An estimated daily intake (EDI) of 0.00013 mg/kg-bw/d for toddlers and 0.00004 mg/kg-bw/d for adults was established; this EDI was dominated by food ingestion.

The resulting human direct soil contact guidelines were 120 mg/kg for agricultural and residential/parkland, 240 mg/kg for commercial land use, and 240 mg/kg for industrial land. No guidelines for groundwater pathways were calculated as noted above, and data were insufficient to reliably assess the produce, meat and milk ingestion check.

2.4 Proposed Soil Quality Guidelines

The proposed soil quality guidelines for antimony are summarized below.

Table 1 Proposed Soil Quality Guidelines for Antimony

Pathway	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial
Guideline (SQG_F)	**120**	**120**	**120**	**240**	**240**
Human health guidelines					
SQG_{HH}	***NA***	***240***	***240***	***870***	***3,400***
Direct Contact (SQG_{DH})	NA	240	240	870	14,000
Protection of Indoor Air Quality (SQG_{IAQ})	NA	NA	NA	NA	NA
Protection of Potable Water (SQG_{PW})	NA	NA	NA	NA	NA
Off-site migration check (SQG_{OM-HH})	NA	NA	NA	3,400	3,400
Produce, meat & milk check (SQG_{FI})	NC	NC	NC	NC	NC
Environmental health guidelines					
SQG_E	***120***	***120***	***120***	***240***	***240***
Soil contact (SQG_{SC})	120	120	120	240	240
Soil and food ingestion (SQG_I)	590[a]	2100[a]	NA	NA	NA
Protection of freshwater life (SQG_{FL})	NA	NA	NA	NA	NA
Livestock watering (SQG_{LW})	NA	NA	NA	NA	NA
Irrigation water (SQG_{IR})	NA	NA	NA	NA	NA
Nutrient and energy cycling (SQG_{NEC})	NC	NC	NC	NC	NC
Off-site migration check (SQG_{OM-E})	NA	NA	NA	1,700	1,700
SQG_M (non-toxicity considerations)	NA	NA	NA	NA	NA
Interim soil quality criterion (CCME 1991)	20	20	20	40	40

a – provisional value, data requirements for guideline not met

3.0 BERYLLIUM

3.1 Background

A human health-based soil quality guideline for beryllium was recently developed by CCME (2015). However, no environmental guideline was developed and therefore the 1991 interim criteria, which are much lower than the human health guideline, remained applicable. The present work is intended to establish an environmental guideline so that the 1991 criteria no longer need to be applied. As part of the work, additional plant toxicity testing for beryllium was conducted.

3.2 Environmental Guidelines

Sufficient plant and soil invertebrate toxicity data were available to calculate a direct ecological soil contact guideline using the preferred weight of evidence approach with EC_{25} values, using the newly generated plant toxicity data. The 25th percentile of the combined plant and invertebrate species sensitivity distribution was 85 mg/kg and the 50th percentile was 170 mg/kg; these values were applied for sensitive and less sensitive land uses, respectively.

The minimum data requirements for the livestock and wildlife ingestion pathways were not met, due to the lack of avian and non-rodent mammal toxicity data. Rodent toxicity data was used to derive provisional guidelines of 16 mg/kg for wildlife and 73 mg/kg for livestock.

3.3 Proposed Soil Quality Guidelines

The proposed soil quality guidelines for beryllium are summarized below, including consideration of the published human health guidelines.

Table 2 Proposed Soil Quality Guidelines for Beryllium

Pathway	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial
Guideline (SQG_F)	**16**	**73**	**75**	**110**	**170**
Human health guidelines					
SQG_{HH}	***NA***	***75***	***75***	***110***	***1100/550***
Direct Contact (SQG_{DH})	NA	75	75	110	1400
Direct Contact (Inhalation)					
10-6 ILCR		550	550	550	550
10-5 ILCR		5500	5500	550	5500
Threshold		5300	5300	19,000	19,000
Protection of Indoor Air Quality (SQG_{IAQ})	NA	NA	NA	NA	NA
Protection of Potable Water (SQG_{PW})	NA	NA	NA	NA	NA
Off-site migration check (SQG_{OM-HH})	NA	NA	NA	1100	1100
Produce, meat & milk check (SQG_{FI})	NC	NC	NC	NC	NC
Environmental health guidelines					
SQG_E	***16***	***73***	***85***	***170***	***170***
Soil contact (SQG_{SC})	85	85	85	170	170
Soil and food ingestion (SQG_I)	16[a]	73[a]	NA	NA	NA
Protection of freshwater life (SQG_{FL})	NA	NA	NA	NA	NA
Livestock watering (SQG_{LW})	NA	NA	NA	NA	NA
Irrigation water (SQG_{IR})	NA	NA	NA	NA	NA
Nutrient and energy cycling (SQG_{NEC})	NC	NC	NC	NC	NC
Off-site migration check (SQG_{OM-E})	NA	NA	NA	1,700	1,700
SQG_M (non-toxicity considerations)	NA	NA	NA	NA	NA
Interim soil quality criterion (CCME 1991)	5	4	4	8	8

a – provisional value, data requirements for guideline not met

4.0 COBALT

4.1 Background

Cobalt is a metal present in several minerals. It has a wide range of industrial uses as well as being present in various alloys, and is found above guidelines at some oil and gas sites. Background concentrations in Canada are typically in the range of 18 to 34 mg/kg. It has been shown to bioaccumulate in plants, and is an essential nutrient in humans. The existing interim criterion is 20 mg/kg, which would frequently be exceeded by background concentrations.

4.2 Environmental Guidelines

The plant and soil invertebrate data were not sufficient to calculate an ecological direct soil contact value based on the preferred weight of evidence approach using EC_{25} data, but were sufficient to calculate a guideline based on an effects/no-effects distribution. The 25th percentile of the of the species sensitivity distribution was 37 mg/kg and the 50th percentile was 83 mg/kg; these were applied for sensitive and non-sensitive land uses respectively.

Livestock and wildlife toxicity data, including avian toxicity data, were available and the minimum data requirements for the wildlife and livestock food and soil ingestion guidelines were met. Guidelines of 880 mg/kg for wildlife and 2,950 mg/kg for livestock were calculated.

4.3 Human Health Guidelines

Background exposures for cobalt were estimated to be 0.00042 mg/kg-bw/d for toddlers and 0.00021 mg/kg-bw/d for adults. Cobalt has threshold (non-cancer) effects from oral exposure but is treated as a carcinogen for inhalation exposure. A TDI of 0.0014 mg/kg-bw/d and an inhalation unit risk of 9 $(mg/m^3)^{-1}$ were recommended.

Human direct contact guidelines, based on oral threshold effects and inhalation non-threshold effects, were 42 mg/kg for agricultural and residential/parkland, 58 mg/kg for commercial, and 390 mg/kg for industrial (based on a 1 in 100,000 cancer risk).

No guidelines for the protection of groundwater were calculated, and data were inadequate to reliably assess the produce, meat and milk ingestion check.

4.4 Proposed Soil Guidelines

Proposed soil quality guidelines for cobalt are summarized below.

Table 3 Soil Quality Guidelines for Cobalt

Pathway	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial
Guideline (SQG_F)	**37**	**37**	**37**	**58**	**83**
Human health guidelines					
SQG_{HH}	***NA***	***42***	***42***	***58***	***390***
Direct Contact (SQG_{DH})	NA	42	42	58	390
Protection of Indoor Air Quality (SQG_{IAQ})	NA	NA	NA	NA	NA
Protection of Potable Water (SQG_{PW})	NA	NA	NA	NA	NA
Off-site migration check (SQG_{OM-HH})	NA	NA	NA	470	470
Produce, meat & milk check (SQG_{FI})	NC	NC	NC	NC	NC
Environmental health guidelines					
SQG_E	**37**	**37**	**37**	**83**	**83**
Soil contact (SQG_{SC})	37	37	37	83	83
Soil and food ingestion (SQG_I)	880	2950	NA	NA	NA
Protection of freshwater life (SQG_{FL})	NA	NA	NA	NA	NA
Livestock watering (SQG_{LW})	NA	NA	NA	NA	NA
Irrigation water (SQG_{IR})	NA	NA	NA	NA	NA
Nutrient and energy cycling (SQG_{NEC})	NC	NC	NC	NC	NC
Off-site migration check (SQG_{OM-E})	NA	NA	NA	400	400
SQG_M (non-toxicity considerations)	NA	NA	NA	NA	NA

5.0 MOLYBDENUM

5.1 Background

Molybdenum is used in drilling muds and drilling fluids, pipeline corrosion inhibitors, and process catalysts, and as a result occurs as a contaminant at some oil and gas sites. It is also present naturally in soil, with background concentrations averaging around 1.4 mg/kg but in some areas much higher.

5.2 Environmental Guidelines

Plant and soil invertebrate toxicity data were sufficient to calculate an ecological direct soil contact value using the preferred weight of evidence approach using EC_{25} values. The 25th percentile of the species sensitivity distribution was 32 mg/kg and the 50th percentile was 55 mg/kg; these values were applied as guidelines for sensitive and non-sensitive land uses, respectively.

Some data were available for nutrient and energy cycling; the available studies suggested effects levels higher than the plant and soil invertebrate data and therefore the guideline was not adjuted for nutrient and energy cycling.

Toxicity data were available for terrestrial wildlife and livestock, but not avians. Ungulates have been found to be more sensitive to molybdenum than other mammals, and therefore separate toxicity benchmarks were used to evaluate ungulates and other mammals. The resulting wildlife ingestion guideline (based on a vole) was 50 mg/kg, and the livestock ingestion guideline (based on a cow) was 15 mg/kg.

5.3 Human Health Guidelines

Molybdenum is an essential nutrient, although deficiency is rare. Background exposures to molybdenum were estimated to be 0.0083 mg/kg-bw/d for toddlers and 0.0025 mg/kg-bw/bd for adults. Age-specific tolerable upper limits of exposure have been established by Health Canada, including 0.023 mg/kg-bw/d for toddlers and 0.028 mg/kg-bw/d for adults.

The resulting human direct soil contact guidelines were 600 mg/kg for the agricultural and residential/parkland land uses, 910 mg/kg for commercial land use, and 26,000 mg/kg for industrial land use.

No guidelines were calculated for groundwater protection or indoor air quality; data were insufficient to reliably assess the produce, meat and milk ingestion check.

5.4 Proposed Soil Quality Guidelines

Proposed soil quality guidelines for molybdenum are summarized below.

Table 4 Soil Quality Guidelines for Molybdenum

Pathway	Natural Area	Agricultural	Residential/ Parkland	Commercial	Industrial
Guideline (SQG_F)	**32**	**15**	**32**	**55**	**55**
Human health guidelines					
SQG_{HH}	***NA***	***600***	***600***	***910***	***8,600***
Direct Contact (SQG_{DH})	NA	600	600	910	26,000
Protection of Indoor Air Quality (SQG_{IAQ})	NA	NA	NA	NA	NA
Protection of Potable Water (SQG_{PW})	NA	NA	NA	NA	NA
Off-site migration check (SQG_{OM-HH})	NA	NA	NA	8,600	8,600
Produce, meat & milk check (SQG_{FI})	NC	NC	NC	NC	NC
Environmental health guidelines					
SQG_E	***32***	***15***	***32***	***55***	***55***
Soil contact (SQG_{SC})	32	32	32	55	55
Soil and food ingestion (SQG_I)	50	15	NA	NA	NA
Protection of freshwater life (SQG_{FL})	NA	NA	NA	NA	NA
Livestock watering (SQG_{LW})	NA	NA	NA	NA	NA
Irrigation water (SQG_{IR})	NA	NA	NA	NA	NA
Nutrient and energy cycling (SQG_{NEC})	NC	NC	NC	NC	NC
Off-site migration check (SQG_{OM-E})	NA	NA	NA	200	200
SQG_M (non-toxicity considerations)	NA	NA	NA	NA	NA
Interim soil quality criterion (CCME 1991)	4 (Alberta Tier 1)	5	10	40	40

6.0 REFERENCES

AEP (Alberta Environment and Parks). 2016. Alberta Tier 1 Soil and Groundwater Remediation Guidelines.

Canadian Council of Ministers of the Environment (CCME). 2006. *A protocol for the derivation of environmental and human health soil quality guidelines.* CCME, Winnipeg, MB. Can.

Canadian Council of Ministers of the Environment (CCME). 2015. Scientific Criteria Document for *Canadian Soil Quality Guidelines for the Protection of Human Health: Beryllium.* CCME, Winnipeg, MB. Can.