APPENDIX A: CONCENTRATIONS OF MOLYBDENUM IN THE CANADIAN ENVIRONMENT

Table A-1 Background Concentrations of Molybdenum in the Atmosphere

Location		Number of Samples	Sampling Duration	Concentration	Analytical Technique	Reference
7 Sites in Eastern and Western Canada		>1000	24 hr	Approximately 0.06 to 0.35 ng/m3[a]	ICP-MS	Celo and Dabek-Zlotorzynska, 2010, Canadian National Air Pollution Surveillance Program
Rural locations in Alberta	Ester Summer	136	24 hr	0.95 ng/m3[b]	PIXE	Cheng et al., 2000
	Ester Winter		24 hr	1.00 ng/m3[b]	PIXE	
	Swan Hills Summer	1	1 month	0.04 ng/m3	ICP-MS	
	Swan Hills Winter	1	1 month	0.03 ng/m3	ICP-MS	
Urban environments in the City of Calgary	Residential	2	1000-2000 hr	0.2-2.0 ng/m3	ICP-MS	Lane et al., 2013
	Weather Station	3	800-2000 hr	0.7-0.9 ng/m3	ICP-MS	
	Laboratory	2	340-1400 hr	0.07-0.3 ng/m3	ICP-MS	
	Bus Garage	8	100-330 hr	0.88-19.0 ng/m3	ICP-MS	

[a]Median concentration

[b]Not specified

PIXE - particle induced X-ray emission

ICP-MS - inductively coupled plasma mass spectrometry

Table A-2 Background Concentrations of Molybdenum in Soil and Dust

Location		Number of Samples	Concentrations	Analytical Technique	Reference
City of Ottawa	Garden Soil	50	0.30 to 1.70 mg/kg, 0.64 mg/kg[a], 0.59 mg/kg[b], 0.60 mg/kg[c], 1.26 mg/kg[d]	ICP-MS	Rasmussen et al., 2000
	House Dust	48	0.66 to 28.64 mg/kg, 3.16 mg/kg[a], 1.96 mg/kg[b], 1.70 mg/kg[c], 14.22 mg/kg[d]	ICP-MS	
	Street Dust	45	0.38 to 2.68 mg/kg, 1.39 mg/kg[a], 1.29 mg/kg[b], 1.38 mg/kg[c], 2.16 mg/kg[d]	ICP-MS	
Manitoba		619	1 to 31 mg/kg, 3.2 mg/kg[a],3 mg/kg[c], 5 mg/kg[d] for all soils, 2 mg/kg[a] in coarse-textured soils, 4 mg/kg[a] in fine-textured soils	NR	Haluschak et al., 1998
43 benchmark sites within agricultural regions of Alberta across seven ecoregions	Peace Lowlands	129 for each sampling depth	0.020 mg/kg[a] for 0-15 cm, 0.029 mg/kg[a] for 15-30 cm	ICP-MS	Penney, 2004, Alberta Environmentally Sustainable Agriculture
	Mixed Boreal Upland		0.067 mg/kg[a] for 0-15 cm, 0.056 mg/kg[a] for 15-30 cm	ICP-MS	
	Boreal Transition		0.013 mg/kg[a] for 0-15 cm, 0.011 mg/kg[a] for 15-30 cm	ICP-MS	
	Aspen Parkland		0.022 mg/kg[a] for 0-15 cm, 0.025 mg/kg[a] for 15-30 cm	ICP-MS	
	Moist Mixed Grassland		0.025 mg/kg[a] for 0-15 cm, 0.022 mg/kg[a] for 15-30 cm	ICP-MS	
	Fescue Grassland		0.018 mg/kg[a] for 0-15 cm, 0.023 mg/kg[a] for 15-30 cm	ICP-MS	
	Mixed Grassland		0.015 mg/kga for 0-15 cm, 0.053 mg/kg for 15-30 cm	ICP-MS	
Soil and till surveys covering parts of nine Canadian provinces and territories		12496	0.5 to 206 mg/kg, 1.4 mg/kg[a], 0.50 mg/kg[c], 4 mg/kg[d]	AAS, ICP-OES, ICP-MS	Grunsky et al., 2012

[a]Arithmetic mean

[b]Geometric mean

[c]Median

[d]95th percentile

NR-not reported

ICP-MS - inductively coupled plasma mass spectrometry

AAS - atomic absorption spectroscopy

ICP-OES - inductively coupled plasma optical emission spectrometry

Table A-3 Background Concentrations of Molybdenum in Water

Location		Number of Samples	Concentrations	Analytical Technique	Reference
Canadian rivers and lakes, compilation of benchmarks			<0.1 µg/L to 500 µg/L		OMOEE, 1995 as referenced in CCME, 1999
British Columbia Surface Waters		NR	<0.1 µg/L - 57 µg/L	NR	CCME, 1999
British Columbia Lakes		NR	<0.010 - 0.04 mg/L, <0.010 mg/L[a]	NR	Swain, 1986
Great Lakes	Lake Huron	1	0.62 µg/L[b]	AAS	Rossman and Barres, 1988
	Lake Erie	10-11	1.5 µg/L[b]		
	Lake Michigan	11	1.3 µg/L[b]		
	Lake Superior	20-22	0.14 µg/L[b]		
	Lake Ontario	23	1.9µg/L[b] (1981), 1.5µg/L[b] (1985)		

[a]Arithmetic mean

[b]Median

NR-not reported

AAS - atomic absorption spectroscopy

Table A-4 Background Concentrations of Molybdenum in Sediments

Location		Number of Samples	Concentrations	Analytical Technique	Reference
Stream sediments			2 mg/kg[a] of molybdenum		Webb et al., 1968 as referenced in Swain, 1986
Fraser River sediment, Lower Mainland			5 and 10 mg/kg		Swain, 1985 as referenced in Swain, 1986
British Columbia, lake sediments		202	1 to 183 mg/kg, 14.2 mg/kg[a]	NR	Swain, 1986
Grand Lake, New Brunswick and East River, Nova Scotia	Grand Lake	3	5.6 mg/kg (dw)[b]	ICP-MS	Benoit, et al., 2011
	East River	2	1.75 mg/kg (dw)[b]	ICP-MS	

[a]Arithmetic mean concentration

[b]Median concentration

NR - not reported

ICP-MS - inductively coupled plasma mass spectrometry

Table A-5 Background Concentrations of Molybdenum in Aquatic Organisms

Location	Number of Samples	Concentrations	Analytical Technique	Reference
Cayuga Lake, Ontario	36 total (3 per age group)	8.5 and 8.2 µg per kg fresh weight for fish one and two years old, respectively. 2.2 and 2.8 µg per kg fresh weight for fish eleven and twelve years old, respectively	MS	Tong et al., 1974
Fraser River	273 muscle and 43 liver tissues	<1 to 1.39 µg/g of wet weight in muscle tissue; less than DL to 1.23 µg/g in liver tissue	ICP-MS	Singleton, 1983
Nass River, British Columbia	10	<0.3 to 3.1 µg/g (dry weight) in the muscle of eulachons	ICP-ES	Futer and Nassichuk, 1983
Alice Arm, British Columbia	30	<0.4 µg/g of dry weight in cockles	ICP-ES	Farrell and Nassichuk, 1984

ICP-MS - inductively coupled plasma mass spectrometry

MS - spark source mass spectrometry

ICP-ES - inductively coupled optical emission spectrometry

Table A-6 Background Concentrations of Molybdenum in Plants

Location	Number of Samples		Concentrations	Analytical Technique	Reference
Not specified			Concentrations of 0.03 to 0.15 mg/kg are generally adequate for plant physiological requirements, plant leaves have concentrations in the order of 1 mg/kg		Jones, 1994 (review)
Former Soviet Union	NR	Molybdenum-rich areas	82 µg/kg in beans, 57 µg/kg in mint, 13 µg/kg in eggplant, 11 µg/kg in potatoes (dry weight)	NR	Kovalskiy et al., 1961
		Control areas	5.1 µg/kg in beans, 1.4 µg/kg in mint , 0.97 µg/kg in eggplant, 3.3 µg/kg in potatoes (dry weight)		

NR-not reported

Table A-7 Background Concentrations of Molybdenum in Animals

Location	Number of Samples	Concentrations	Analytical Technique	Reference
Ontario	197 bovine	253 to 429 µg per kg (wet weight) in bovine muscle, 799 to 886 µg/kg in bovine kidney	AAS	Frank et al., 1986
	33 porcine	214 µg/kg[a] porcine muscle, 854 µg/kg[a] porcine kidney		
	115 avian	474 µg/kg[a] (under 14 weeks) to 562 µg/kg[a] (over 14 weeks)in avian muscle and 1490 µg/kg[a] (under 14 weeks) to 1750 µg/kg[a] (over 14 weeks) in avian liver.		

[a]Arithmetic mean concentration

AAS - Atomic Absorption Spectrometery

Table A-8 Background Concentrations of Molybdenum in Humans

Location	Number of Samples		Concentrations	Analytical Technique	Reference
19 blood collection sites in the United States	229		0.50 to 15.73 µg per 100 mL in whole blood	NA	Allaway et al., 1968
Zurich, Switzerland	110		0.44 µg/L[a], 3.00 µg/L[b] in whole blood	ICP-MS	Forrer et al., 2001
United States	1565	233 pregnant	44.4 to 53.4 µg/L 48.8 µg/L[c] in urine	ICP-MS	Jain, 2013 (NHANES)
		1323 nonpregnant	41.7 to 44.9 µg/L, 43.3 µg/L[c] in urine		
		nonsmoker-NR	43.6 to 47.1 µg/L, 45.3 µg/L[c] in urine		
		smoker-NR	37.1 to 43.1 µg/L, 40.0 µg/L[c] in urine		
Non-smoking adults (aged 33 to 64) from the west coast of Canada	61		8.03 to 37.00 nmol/L, 16.14 nmol/L[a], 15.36 nmol/L[d], 25.64[b] in whole blood	ICP-MS	Clark et al., 2007
	59		11.54 to 247.1umol per mol, 72.06 umol per mol[a], 58.41 umol per mol[d], 188.4 umol per mol[b] of creatinine in urine		
Canadians living at home and residing in the 10 provinces and 3 territories	5319 for whole blood, 5492 for urine (cycle 1, 2007-2009)		0.67 µg/L[d], 1.3 µg/L[b] in whole blood; 36 µg/L[d], 130 µg/L[b] in urine	ICP-MS	Health Canada, 2013 (Canadian Health Measures Survey)
	5575 for whole blood; 5738 for urine (cycle 2, 2009-2011)		0.65 µg/L[d], 1.4 µg/L[b] in whole blood; 44 µg/L[d], 170 µg/L[b] in urine		

[a]Arithmetic mean

[b]95th percentile

[c]adjusted geometric mean

[d]geometric mean

NA-not available

ICP-MS - inductively coupled plasma mass spectrometry

NR-number not reported

APPENDIX B: EXISTING ENVIRONMENTAL GUIDELINES FOR MOLYBDENUM

Jurisdiction	Guideline	Application	Receptors	Narrative Protection Goal	Operational Protection Goal	Reference
Soil	mg/kg					
Canada	**5; 10; 40; 40**	Agricultural; Residential/Parkland; Commercial;Industrial	Ecosystem function & human health	No unacceptable effects to key ecological receptors	Interim guideline	CCME, 1999-2006
Netherlands	**39**	MPC	All species	Minimal effects to most species	5th percentile of NOEC distribution	Verbuggen, et.al., 2001
Netherlands	**190**	Serious Risk Concentration	All species	Protective against serious harm to ecosystems	50th percentile of NOEC distribution	Verbuggen, et.al., 2001
New York	**2**	Soil Cleanup Objective	Ecological Resources	Protection of Ecological Resources	N/A	NYDEC, 2010
Ontario	**6.9; 40**	Surface soil, Residential/Parkland; Industrial/Commercial	Ecosystem function & human health	Protective of human health, groundwater leaching, migration to air, plants, soil-dwelling organism, mammals and avian	Lowest values selected from all receptor routes	MOE, 2011
Ontario	**1200**	Subsurface soils	Ecosystem function & human health	Protective of human health, groundwater leaching, migration to air, plants, soil-dwelling organism, mammals and avian	Lowest values selected from all receptor routes	MOE, 2011
Quebec	**40; 10**	Industrial/Non-Residential Commercial/Non-sensitive-use Recreational;Residential/Residential district Commercial/Sensitive-use Recreational/Institutional	Wildlife, flora, and the environment	To preserve the health of future users and protect the environment. May not be adequate for environments critical or sensitive for biodiversity, protected areas, and threatened or vulnerable species or those likely to be so designated, and their habitats	N/A	MDDEP, 2002
USA	**2**		Plants	Minimal phytotoxic effects to plant biota	10th percentile of LOEC distribution	ORNL, 1997b; EPA, 2001; Bachman, 2008; EPA, 2003
USA - DOE	**200**		Microbes	Minimal effects to microbial processes	10th percentile of LOEC distribution for microbial processes	ORNL, 1997a; Bachman, 2008
Sediment	mg/kg dw					
Netherlands	**25**	Maximum Permissible Concentration	Ecosystem Health	Minimal effects to most species	5th percentile of NOEC distribution	Verbuggen, et.al., 2001
Netherlands	**23**	Serious Risk Concentration	Ecosystem Health	Protective against serious harm to ecosystems	50th percentile of NOEC distribution	Verbuggen, et.al., 2001
Groundwater	μg/L					
British Columbia	**10000**		Aquatic life	No effects on important commercial species	Lowest EC20 for fish species with UF	BC Regs 375/96, 1996
British Columbia	**10- 30**		Irrigated crops- Standard varies with crop, soil drainage and Mo:Cu ratio.	N/A	N/A	BC Regs 375/96, 1996
British Columbia	**50**		Livestock	N/A	N/A	BC Regs 375/96, 1996
Canada	**0.073**	Interim Guideline	Ecosystem function & human health	No unacceptable effects to key ecological receptors	CCME SQG converted to water concentration with exposure estimate	Environment Canada, 2010
Michigan	**73**	Screening level	Human Health/Drinking Water	Concentrations of hazardous substances in drinking water that are safe for long-term consumption	Cancer risk 1 in 100,000 or Hazard Quotient < 1	MDEQ, 2012
Ontario	**9.20E+03**		Ecosystem health	No effects to aquatic or terrestrial receptors, including human health	Lower of GW concentration modeled to meet safe indoor air quality objectives and aquatic protection objectives	MOE, 2011
Quebec	**2000**	Seepage in to surface waters or infiltration into sewers	Aquatic life and piscivorous terrestrial fauna	N/A	The lowest of the following: 1X Acute aquatic life toxicity criterion, 100X Chronic aquatic life toxicity criterion, 100X Contamination of aquatic organisms prevention criterion, or 100X Piscivorous terrestrial fauna criterion, as derived Québec's surface water quality criteria (2001).	MENV, 2001
USA	**70**	Max Contaminant Level	Human Health/Drinking Water	No known or anticipated effects on persons	Relative water contribution to result in Hazard Index = 1	EPA, 2009
Porewater	mg/L					
USA	**0.5**		Plants	Minimal phytotoxic effects to plant biota	10th percentile of LOEC distribution	ORNL, 1997
Surface Water	μg/L					
British Columbia	**2000**	Acute	Freshwater aquatic organisms	Protect all forms of aquatic life and all aspects of aquatic life cycle	Acute LOAEL + UF	BC MOE, 2010
British Columbia	**1000**	Chronic	Freshwater aquatic organisms	Protect all forms of aquatic life and all aspects of aquatic life cycle	Chronic LOAEL + UF	BC MOE, 2010
British Columbia	**500**	Chronic	Irrigated crops	No effects to sensitive crop species at any life stage	Geometric mean of LOAEL and NOEC divided by UF for sensitive species (i.e.: lowest calculated)	BC MOE, 2010
British Columbia	**10**	Chronic	Irrigated crops	No effects to sensitive crop species at any life stage	Geometric mean of LOEC and NOEC divided by UF for sensitive species (i.e.: lowest calculated)	BC Regs 375/96, 1996
British Columbia	**10,000**	Chronic	Aquatic life	No effects to commercially important species	Lowest EC20 for fish species with UF	BC Regs 375/96, 1996
British Columbia	**50**	N/A	Livestock	N/A	N/A	BC Regs 375/96, 1996
Canada	**500**	Chronic	Livestock	No effects to sensitive livestock species and life stages	Lowest Tolerable Daily Intake (geomean of LOAEL and NOAEL divided by UF) for sensitive species	CCME, 1993; BC MOE, 2010; Saskatchewan MOE, 2006
Canada	**73**	Chronic	Freshwater aquatic organisms	Protect all forms of aquatic life and all aspects of aquatic life cycle	5th percentile of EC10/no-effect SSD	CCME, 2007; AE, 1999; EPA, 2005
Michigan	**3,200**	Chronic	Aquatic life	No injurious or debilitating effects to aquatic life	N/A	MDEQ, 2008
Michigan	**29,000**	Acute	Aquatic life	No unacceptable effects to aquatic life	N/A	MDEQ, 2008
Ontario	**40**	Chronic	Freshwater aquatic life & recreation	Protect from effects to human, aquatic or plant life and esthetic qualities	Lowest NOEC of aquatic toxicity, mutagenicity or bioaccumulation endpoints	MOE, 1994
USA/Canada (Great Lakes Initative)	**16,000**	Acute	Freshwater aquatic organisms	No unacceptable effects to aquatic organisms with less than 1 hour exposure	One half of the geometric mean of genus EC50 values divided by UF (data dependant)	EPA, 1995
USA/Canada (Great Lakes Initative)	**370**	Chronic	Fershwater aquatic organisms	No unacceptable effects to aquatic organisms	Geometric mean of genus EC50 values divided by UF and Acute to chronic ratio	EPA, 1995
Air	$\mu g/m^3$					
Ontario	**120**	24 hour average	Environmental and human health	No expected adverse health or environmental effects	NOAEL from animal study with uncertainty factors applied	MOE, 2008
Idaho	**500; 250**	24 hour average, acceptable ambient concentration for insoluble; soluble	Human health	No effects to human health	Hazard Index <1	IDEQ, n.d.a

APPENDIX C: ECOLOGICAL TOXICITY DATA

Table C-1 Plant Toxicity Data

Species	Endpoint	Soil	pH	Organic C %	Clay %	Sand %	Silt %	Fe oxides (mg/kg)		Added (mg Mo/kg)	Total (mg Mo/kg)	Reference	Qualification
Triticum aestivum L.	Plant yield	Haplic luvisol	6.4						EC10/EC50		15/42	Bueker et al., 2010	Sodium molybdate
											5/28	Bueker et al., 2010	Molybdenum oxide
											9/35	Bueker et al., 2010	Molybdenum oxide + CaCO3 for pH stabilization
Hodreum vulgare L.	Dry matter leaves and shoots	Silver sand							EC10	70	70	Davis et al., 1978	Molybdenum oxide
Bradyrhizobium japonicum	Seed yield and legume root nodule number and weight	Clay-loamy alluvial soil	8.05	0.84	54				NOEC	≥4		Yanni, 1990	Sodium molybdate, unbound NOEC
Pisum sativum, pea	Root yield	Calcareous chenozem	8.1	2.5					NOEC	0.1		Kevresan et al., 2001	Sodium molybdate, unbound NOEC. Application of Mo during plant growth without mixing, inconsistent dose spacing
	Shoot yield	Calcareous chenozem	8.1	2.5					NOEC	0.001			
Elytrigia elongata, wheat grass	Shoot yield	Halomorphic soil (typic natraquoll), poorly drained with high salt content	7.1	1.32					NOEC	≥1		De lorio et al., 1998	Sodium molybdate, unbound NOEC, correlated uptake with soil Cu content
Molybdenum Consortium Research Data (McGrath et al., 2010b)													
Brassica napus	Shoot yield	Zegveld	4.4	30.7	20	9	5	11.7	EC20		3301.5	Rothamsted Research, 2009	
		Kovlinge	5	2	3	78	9	1.9	EC20		51.32		
		Kasterlee	5.2	2.8	2	79	9	1.5	EC20		27.641		
		Zwijnaarde	5.2	1.8	2	81	8	1	EC20		46.361		
		Woburn	6.3	3.6	27	43	16	15.3	EC20		126.35		
		Ter Munck	6.7	0.9	12	8	70	2.2	EC20		11.758		
		Souli	6.8	0.6	33	51	11	0.7	EC20				below lowest added Mo dose, not used
		Rots	7.3	1.3	10	20	50	1.2	EC20		29.689		
		Nagyhorcsok	7.6	2.1	18	54	54	0.5	EC20		7.1248		
		Guadelajara	7.8	0.8	11	16	16	0.1	EC20		5.0208		
Trifolium pratense		Zegveld	4.4	30.7	20	9	5	11.7	EC20		1917.1		
		Kovlinge	5	2	3	78	9	1.9	EC20		49.932		
		Kasterlee	5.2	2.8	2	79	9	1.5	EC20		33.166		
		Zwijnaarde	5.2	1.8	2	81	8	1	EC20		46.122		
		Woburn	6.3	3.6	27	43	16	15.3	EC20		169.04		
		Ter Munck	6.7	0.9	12	8	70	2.2	EC20		45.374		
		Souli	6.8	0.6	33	51	11	0.7	EC20				below lowest added Mo dose, not used
		Rots	7.3	1.3	10	20	50	1.2	EC20		22.503		
		Nagyhorcsok	7.6	2.1	18	54	54	0.5	EC20		5.8226		
		Guadelajara	7.8	0.8	11	16	16	0.1	EC20		9.2143		
Lolium perenne		Zegveld	4.4	30.7	20	9	5	11.7	EC20		3917.3		
		Kovlinge	5	2	3	78	9	1.9	EC20		50.673		
		Kasterlee	5.2	2.8	2	79	9	1.5	EC20		152.75		
		Zwijnaarde	5.2	1.8	2	81	8	1	EC20		116.21		
		Woburn	6.3	3.6	27	43	16	15.3	EC20		444.52		
		Ter Munck	6.7	0.9	12	8	70	2.2	EC20		46.707		
		Souli	6.8	0.6	33	51	11	0.7	EC20		167.17		
		Rots	7.3	1.3	10	20	50	1.2	EC20		55.288		
		Nagyhorcsok	7.6	2.1	18	54	54	0.5	EC20		28.202		
		Guadelajara	7.8	0.8	11	16	16	0.1	EC20		40.516		
Lycopersicon esculentum		Zegveld	4.4	30.7	20	9	5	11.7	EC20		2118.2		
		Kovlinge	5	2	3	78	9	1.9	EC20		35.087		
		Kasterlee	5.2	2.8	2	79	9	1.5	EC20		37.64		
		Zwijnaarde	5.2	1.8	2	81	8	1	EC20		18.445		
		Woburn	6.3	3.6	27	43	16	15.3	EC20		175.45		
		Ter Munck	6.7	0.9	12	8	70	2.2	EC20		46.746		
		Souli	6.8	0.6	33	51	11	0.7	EC20		111.79		
		Rots	7.3	1.3	10	20	50	1.2	EC20		18.014		
		Nagyhorcsok	7.6	2.1	18	54	54	0.5	EC20		18.392		
		Guadelajara	7.8	0.8	11	16	16	0.1	EC20				below lowest added Mo dose, not used
Hordeum vulgare	root elongation	Zegveld	4.4	30.7	20	9	5	11.7	EC20		632.76		
		Kovlinge	5	2	3	78	9	1.9	EC20		28.926		below lowest added Mo dose, not used
		Kasterlee	5.2	2.8	2	79	9	1.5	EC20		82.642		
		Zwijnaarde	5.2	1.8	2	81	8	1	EC20		111.56		
		Woburn	6.3	3.6	27	43	16	15.3	EC20		411.68		
		Ter Munck	6.7	0.9	12	8	70	2.2	EC20		63.23		
		Souli	6.8	0.6	33	51	11	0.7	EC20		1323.5		
		Rots	7.3	1.3	10	20	50	1.2	EC20		37.728		
		Nagyhorcsok	7.6	2.1	18	54	54	0.5	EC20		53.8		
		Guadelajara	7.8	0.8	11	16	16	0.1	EC20				below lowest added Mo dose, not used

Underlined values were used for guideline calculation

Table C-2 Invertebrate Toxicity Data

Species	Soil	pH	Organic C %	Clay %	Sand %	Silt %	Fe oxides (mg/kg)		Added (mg Mo/kg)	Total (mg Mo/kg)
	Zegveld	4.4	30.7	20	9	5	11.7	EC20	>2719[a]	>2722
	Kovlinge	5	2	3	78	9	1.9	EC20	227.56	178
	Kasterlee	5.2	2.8	2	79	9	1.5	EC20	103.06	67
	Zwijnaarde	5.2	1.8	2	81	8	1	EC20	291.23	273
	Woburn	6.3	3.6	27	43	16	15.3	EC20	883.31	708
Enchytraeus crypticus	Ter Munck	6.7	0.9	12	8	70	2.2	EC20	784.84	617
	Souli	6.8	0.6	33	51	11	0.7	EC20	2489.747259	1663
	Rots	7.3	1.3	10	20	50	1.2	EC20	1127.6	922
	Nagyhorcsok	7.6	2.1	18	54	54	0.5	EC20	>2816[a]	>2817
	Guadelajara	7.8	0.8	11	16	16	0.1	EC20	1889.396921	1239
	OECD	7	5.8	20				EC20	567.02	413
	Zegveld	4.4	30.7	20	9	5	11.7	EC20	624.38	455
	Kovlinge	5	2	3	78	9	1.9	EC20	78.52	60
	Kasterlee	5.2	2.8	2	79	9	1.5	EC20	97.726	72
	Zwijnaarde	5.2	1.8	2	81	8	1	EC20	140.68	113
	Woburn	6.3	3.6	27	43	16	15.3	EC20	301.38	174
Eisenia andrei	Ter Munck	6.7	0.9	12	8	70	2.2	EC20	33.121	8.88
	Souli	6.8	0.6	33	51	11	0.7	EC20	1300.2	917
	Rots	7.3	1.3	10	20	50	1.2	EC20	31.06	9.21
	Nagyhorcsok	7.6	2.1	18	54	54	0.5	EC20	41.091	79
	Guadelajara	7.8	0.8	11	16	16	0.1	EC20	27.628	25
	OECD	7	5.8	20				EC20	378.01	244
	Zegveld	4.4	30.7	20	9	5	11.7	EC20	>2719[a]	>2722
	Kovlinge	5	2	3	78	9	1.9	EC20	47.999	39
	Kasterlee	5.2	2.8	2	79	9	1.5	EC20	1860.8	1865
	Zwijnaarde	5.2	1.8	2	81	8	1	EC20	798.75	728
	Woburn	6.3	3.6	27	43	16	15.3	EC20	>3395[a]	>3396
Folsomia candida	Ter Munck	6.7	0.9	12	8	70	2.2	EC20	>2895[a]	>2896
	Souli	6.8	0.6	33	51	11	0.7	EC20	>2742[a]	>2744
	Rots	7.3	1.3	10	20	50	1.2	EC20	>2843[a]	>2844
	Nagyhorcsok	7.6	2.1	18	54	54	0.5	EC20	>2816[a]	>2817
	Guadelajara	7.8	0.8	11	16	16	0.1	EC20	>2820[a]	>2821
	OECD	7	5.8	20	-	-	-	EC20	>2628[a]	>2628

a - no effect at largest Molybdenum dose tested

Underlined values were used for guideline calculation

Data produced by ARCHE (2012), all testing applied reproduction as the effect endpoint.

Table C-3 Microbial Toxicity Data

Table 1: Microbial Ecotoxicity data

Species	Endpoint	Soil	pH	Organic C %	Clay %	CEC pH soil ($cmol_c$/kg)	Al_{ox} (g/kg)	Fe_{ox} (g/kg)	Mn_{ox} (g/kg)	Cb (mg Mo/kg)		Added (mg Mo/kg)	Total (mg Mo/kg)	Reference	Qualification
Native microbial biomass	Basal respiration, reduced respiration	Mor layer of forest soil amended with Scot pine needles	unknown							2.5	EC10	75	77.5	Akerblom et al., 2007	Mo salt as $MoCl_5$
	Basal respiration, reduced respiration	Mor layer of forest soil amended with Scot pine needles	unknown							2.5	NOEC	4.5	7		
Native microbial biomass	Arylsulfatase activity	Natural soil (Nicollet)	6.2	2.73	29						EC63	2400		Al-Khafaji and Tabatabai, 1979	H_2MoO_4, only two test concentrations, cannot qualify EC
		Natural soil (Harps)	7.6	3.24	30						EC26	240			
		Natural soil (Harps)	7.6	3.24	30						EC60	2400			
		Natural soil (Webster)	6.5	2.91	26						EC40	240			
		Natural soil (Webster)	6.5	2.91	26						EC79	2400			
		Natural soil (Okoboji)	7	5.32	34						EC14	2400			
Native microbial biomass	Ethylene production	Handford soil	7.15	0.48	18	5.9					NOEC	0.5		Arshad and Frankenberger, 1991	
											LOEC	1			
											EC50	5			
	Nitrification	Haplic Luvisol	6.2								EC10/50	1522/3129		Buekers et al. 2010	sodium molybdate
												188/638			molybdenum oxide
												Stimulation			MoO3 + CaCO3 for pH stabilization
Native microbial biomass	Nitrate reductase	Typic Albaqualf (Ames)	6.7	2.99	10						EC20	240		Fu and Tabatabai, 1989	
		Typic Haplaquoll (Canisteo)	7.8	4.66	32						EC0	240			
		Cumulic Haptaquoll (Oboboji)	7.1	5.59	36						EC26	240			
		Cumulic Haptaquoll (Oboboji)	7.1	5.59	36						EC70	2400			
Native microbial biomass	L-glutaminase activity	Natural soil (Harps)	7.6	3.24	30						EC5	480		Frankenberger and Tabatabai, 1991a	
		Natural soil (Muscatine)	5.6	2.63	28						EC6	480			
		Natural soil (Okoboji)	7	4.7	34						EC6	480			
Native microbial biomass	L-asparaginase activity	Natural soil (Harps)	7.6	3.24	30						EC3	480		Frankenberger and Tabatabai, 1991b	
		Natural soil (Muscatine)	5.6	2.63	28						EC4	480			
		Natural soil (Okoboji)	7	4.7	34						EC6	480			
Native microbial biomass	Amidase activity	Natural soil (Harps)	7.6	3.24	30						EC2	480		Frankenberger and Tabatabai, 1991c	
		Natural soil (Muscatine)	5.6	2.63	28						EC0	48			
		Natural soil (Muscatine)	5.6	2.63	28						EC2	480			
		Natural soil (Okoboji)	7	4.7	34						EC4	480			
Native microbial biomass	Acid phosphatase activity	Clay loam (Harps)	7.8	3.74	30						EC41	2400		Juma and Tabatabai, 1977	H_2MoO_4
		Silty clay loam (Okoboji)	7.4	5.45	34						EC68	2400			
		Loam soil (Webster)	5.8	2.58	23						EC69	240			
		Loam soil (Webster)	5.8	2.58	23						EC93	2400			
		Clay loam (Harps)	7.8	3.74	30						EC25	2400			
		Silty clay loam (Okoboji)	7.4	5.45	34						EC12	240			
		Silty clay loam (Okoboji)	7.4	5.45	34						EC22	2400			
Native microbial biomass	Nitrogen mineralization	Loam soil (webster)	5.8	2.58	23						EC10	480		Liang and Tabatabai, 1977	H_2MoO_4, single dose tested, unable to qualify effect concentration
		Judson soil	6.6	2.95	45						EC22	480			
		Clay loam (Harps)	7.8	3.74	30						EC22	480			
		Silty clay loam (Okoboji)	7.4	5.45	34						EC54	480			
Native microbial biomass	Pyrophosphatase activity	Natural soil (Clarion)	4.6	1.99	24						EC62	480		Stott et al., 1985	
		Natural soil (Clarion)	4.6	1.99	24						EC75	2400			
		Natural soil (Nicollet)	6.2	2.73	29						EC83	2400			
		Natural soil (Okoboji)	7	5.32	36						EC81	2400			
		Natural soil (Clarion)	4.6	1.99	24						EC62	50			
		Natural soil (Nicollet)	6.2	2.73	29						EC31	50			
		Natural soil (Okoboji)	7	5.32	36						EC19	50			
Native microbial biomass	Urease activity	Natural soil (Weller)	5.1	1.51	17						EC7	480		Tabatabai, 1977	
		Natural soil (Nicollet)	6.1	3.32	30						EC16	480			
		Loam soil (Webster)	5.8	2.58	23						EC14	480			
		Clay loam (Harps)	7.8	3.74	30						EC11	48			
		Clay loam (Harps)	7.8	3.74	30						EC12	480			
		Natural soil (Luton)	6.8	4.35	42						EC4	480			
		Silty clay loam (Okoboji)	7.4	5.45	34						EC9	48			
		Silty clay loam (Okoboji)	7.4	5.45	34						EC16	480			
Native microbial biomass	Nitrification	Alluvial loamy soil	4.7	1.1							NOEC	≥466		Ueda et al., 1988	Na_2MoO_4
	Ammonification	Alluvial loamy soil	4.7	1.1							NOEC	≥466			
Bradyrhizobium japonicum	Nodulation	Clay-loamy alluvial soil	8.05	0.84	54						NOEC	≥4		Yanni, 1990	
Molybdenum Consortium Research Data															
Native microbial biomass	Substrate induced nitrification	Zegveld	4.4	30.7	58.8	41.7	3.5	11.7	0.09	3	EC20		1591	University of Leuven, 2009	
		Kovlinge	5	2	3.3	4.2	2.1	1.9	0.04	1	EC20		49		
		Kasterlee	5.2	2.8	2.2	6.3	0.6	1.5	0.06	<1	EC20		75		
		Zwijnaarde	5.2	1.8	2.2	4.1	1.2	1	0.06	1	EC20		108		
		Woburn	6.3	3.6	31.4	30	0.6	15.3	0.17	1	EC20		>10000		
		Ter Munck	6.7	0.9	13.3	12.2	0.6	2.2	0.35	1	EC20		3981		
		Souli	6.8	0.6	34.7	14.2	0.7	0.7	0.47	2	EC20		3990		
		Rots	7.3	1.3	12.5	14.3	0.4	1.2	0.21	1	EC20		3987		
		Nagyhorcsok	7.6	2.1	21.2	24.8	1.5	0.5	0.45	1	EC20		>10000		
		Guadelajara	7.8	0.8	18	14.1	0.3	0.1	0.05	1	EC20		3981		
	Substrate induced respiration	Zegveld	4.4	30.7	58.8	41.7	3.5	11.7	0.09	3	EC20		>10000		
		Kovlinge	5	2	3.3	4.2	2.1	1.9	0.04	1	EC20		>10000		
		Kasterlee	5.2	2.8	2.2	6.3	0.6	1.5	0.06	<1	EC20		50		
		Zwijnaarde	5.2	1.8	2.2	4.1	1.2	1	0.06	1	EC20		107		
		Woburn	6.3	3.6	31.4	30	0.6	15.3	0.17	1	EC20		>10000		
		Ter Munck	6.7	0.9	13.3	12.2	0.6	2.2	0.35	1	EC20		359		
		Souli	6.8	0.6	34.7	14.2	0.7	0.7	0.47	2	EC20		3660		
		Rots	7.3	1.3	12.5	14.3	0.4	1.2	0.21	1	EC20		1575		
		Nagyhorcsok	7.6	2.1	21.2	24.8	1.5	0.5	0.45	1	EC20		>10000		
		Guadelajara	7.8	0.8	18	14.1	0.3	0.1	0.05	1	EC20		8786		
	Plant residue mineralisation	Zegveld	4.4	30.7	58.8	41.7	3.5	11.7	0.09	3	EC20		>10000		
		Kovlinge	5	2	3.3	4.2	2.1	1.9	0.04	1	EC20		4107		
		Kasterlee	5.2	2.8	2.2	6.3	0.6	1.5	0.06	<1	EC20		1161		
		Zwijnaarde	5.2	1.8	2.2	4.1	1.2	1	0.06	1	EC20		1018		
		Woburn	6.3	3.6	31.4	30	0.6	15.3	0.17	1	EC20		>10000		
		Ter Munck	6.7	0.9	13.3	12.2	0.6	2.2	0.35	1	EC20		6102		
		Souli	6.8	0.6	34.7	14.2	0.7	0.7	0.47	2	EC20		>10000		
		Rots	7.3	1.3	12.5	14.3	0.4	1.2	0.21	1	EC20		>10000		
		Nagyhorcsok	7.6	2.1	21.2	24.8	1.5	0.5	0.45	1	EC20		>10000		
		Guadelajara	7.8	0.8	18	14.1	0.3	0.1	0.05	1	EC20		>10000		

Underlined values were used for guideline calculation

Table C-4 Livestock and Wildlife Toxicity Data

Species	Study Notes	Molybdenum Food Concentration	Copper Food Concentration	Total Daily Exposure	Endpoint	Toxicity Metric	Reference	Notes
Livestock Species								
Horse	12 fillies fed pasture amended with molybdenum for 84 days	0.6 to 1.2 mg/kg dry weight 8 to 15 mg/kg dry weight	6 to 9 mg/kg		copper deficiency	unbounded NOAEL	Pearce et al., 1998	
Horse	4.5 diet trial	20 mg/kg dry weight			blood plasma coppe content	unbound NOAEL	Strickland et al., 1987	
Horse	14 day	107 mg/kg				unbound NOAEL	Cymbaluk et al., 1981	
Goat	36 cashmere goats (1.5 yr) fed wild rye and alfalfa amend with copper and molybdenum for 84 days	0.16 mg/kg	4.72 mg/kg		serum lipid profiles	unbouned NOAEL	Zhang et al., 2012	
Goat	Oral administration, 30 days			20 mg/kg-bw/d	molybdenosis	unbounded LOAEL	Kusum et al., 2010	
Rabbit	Commercial pellets and carrots amended with molybdenum for 14 days	39, 40 mg/kg dry matter			growth	unbounded NOAEL	Bersenyi et al., 2008	
Rabbit	52 lab rabbits, oats and alfalfa amended with molydbenum (Na2MoO4) and 37 control rabbits	2,000 mg/kg	copper concentration not quantified		molybdenosis	unbounded LOAEL	McCarter et al., 1962	
Rabbit	12 week	500 mg/kg			growth retardation at 500 mg/kg deaths above 2000 mg/kg	LOAEL	Friberg et al., 1975	
Guinea pig		250 mg/kg - bw			mortality	unbound LOAEL	Chappell et al., 1979	calcium molybdate
Sheep		50 mg/d	5 ug/g		molybdenosis	unbounded LOAEL	Mills and Fell, 1960	
Sheep	Molybdenum amended pasture	5.5 - 12.5 g/kg dry weight	6 - 8.7		cartilage lesions and bone changes	unbound LOAEL	Pitt and Thurley, 1980	
Sheep	193 days	20, 40, 60 mg/kg	82 mg/kg		Renal effect: at 40 and 60 mg/kg both metals accumulated in kidney cortex no damage observed	unbound NOAEL	Van Ryssen et al., 1986	
Cattle	Aerial deposition onto pasture, 5000 grazing cows	2 to 20 mg/kg dry weight	pasture had slight copper deficiency (concentration unknown)		40% had molybdenosis	unbound LOAEL	Alary et al., 1981	
Cattle	84 weeks	5 mg/kg dry weight	4 mg/kg dry weight		decereased food intake, puberty onset delayed 10 weeks, decreased conception	unbound LOAEL	Phillippo et al., 1987a, b	
Cattle		15 to 20 mg/kg			84% of embryos developed abnormally	unbound LOAEL	O'Gorman et al., 1987	
Cattle	lactating cows for 9 weeks	40 mg/kg	6 mg/kg		30% reduction in milk yield, growth reduction nursing calves	unbound LOAEL	Wittenberg and Devlin, 1987	
Cattle		60 mg/kg dry weight		1,360 mg molybdate	brittle bones	unbound LOAEL	Penumarthy and Oehme, 1978	
Cattle	diary cow	140 mg/kg fresh weight	10 mg/kg fresh weight		molybdenosis	unbound LOAEL	Lloyd et al., 1976	
Cattle				141 mg	Anorexia, weight loss	unbound LOAEL	Friberg and Lener, 1986	
Cattle	96 yearling steers fed high fibre diets amended with Mo and drinking water amended with sulfur	187.5 mg/kg dry matter			Signs of Mo toxicity observed including anorexia, changes in hair colour, stiffness in joints	unbound LOAEL	Kessler et al., 2012	effects of sulfur addition on Mo toxicity hard to quantify
Cattle	dairy cow	173 ppm and higher in diet			reduced body weight gains	LOAEL	Huber et al., 1971	
Cattle	bull, n=2, increasing concentrations of molybdenum with age	4.11 to 7.84 mg/kg/d			molybdenosis	unbound LOAEL	Thomas and Moss, 1951	no controls
Wildlife Species								
Mule deer		2,500 mg/kg			reduced food intake	LOAEL	Nagy et al., 1975	
		200 to 1,000 mg/kg			no effect	NOAEL		
Bird Species								
Chicken	300, 1 day old broilers, fed diets amended with molybdenum for 6 weeks	13, 500, 1,000, 1,500			renal cell apoptosis at 1,000 mg/kg and higher	LOAEL	Xiao et al., 2011	
Chicken	300, 1 day old broilers, fed diets amended with molybdenum for 42 days	500, 1,000, 1,500			Concentrations of 1000 mg/kg and higher induced splenic lesions and lymphocyte apoptosis	LOAEL	Yang et al., 2010	
Chicken	300, 1 day old broilers, fed diets amended with molybdenum for 42 days	500, 1,000, 1,500 mg/kg sodium molybdate dihydrate			Concentrations of 1000 mg/kg and higher induced a decrease in t-cells, serum IL-2 contents and thymic lesions - cellularl immune function was injured.	LOAEL	Xiao et al., 2011	
Chicken	16 - 20 ppm resulted in embryo death	35.3 mg/kg/d			embyro death	LOAEL	Lepore and Miller, 195	dose used by ORNL to set their avian limit
Chicken	Increasing concentrations above 500 reduced egg laying, growth depression, anmeia at 4,000 mg/kg, and mortality at 6,000 mg/kg	500 mg/kg			reduced chick growth rate, 15% fewer eggs and all eggs has embyro death	LOAEL	Friberg et al., 1975	

APPENDIX D: DIETARY INTAKE OF MOLYBDENUM

Average dietary intakes (µg/kg bw/day) of trace elements for Canadians in different age/sex groups for Total Diet Study from 1993 to 1999

Trace element	0 - 1 months M & F	2 - 3 months M & F	4 - 6 months M & F	7 - 9 months M & F	10 - 12 months M & F	1 - 4 years M & F	5 - 11 years M & F	12 - 19 years M	20 - 39 years M	40 - 64 years M	65+ years M	12 - 19 years F	20 - 39 years F	40 - 64 years F	65+ years F	All ages Canadians M & F
Al	96.946	121.207	99.659	87.582	93.432	237.775	264.349	225.129	139.743	137.017	102.417	191.669	131.045	119.163	102.002	134.71
Ba	20.760	23.350	21.414	21.213	22.823	25.251	18.741	11.759	9.704	8.976	7.839	9.280	8.418	7.855	7.546	8.817
Bi	0.054	0.090	0.122	0.086	0.076	0.046	0.034	0.024	0.018	0.015	0.012	0.019	0.014	0.012	0.010	0.016
Cd	0.590	0.676	0.569	0.621	0.649	0.908	0.738	0.518	0.394	0.322	0.283	0.388	0.324	0.270	0.248	0.339
Ce	0.146	0.194	0.136	0.130	0.119	0.114	0.086	0.059	0.043	0.037	0.029	0.046	0.036	0.031	0.028	0.039
Co	0.674	0.821	0.697	0.653	0.625	0.656	0.493	0.350	0.279	0.240	0.202	0.263	0.231	0.211	0.184	0.241
Cu	62.025	77.494	41.391	49.592	39.785	45.742	36.309	25.084	21.140	17.496	14.289	18.831	17.423	14.961	13.364	17.651
La	0.154	0.190	0.118	0.115	0.090	0.075	0.054	0.036	0.027	0.023	0.019	0.029	0.023	0.021	0.018	0.025
Mn	76.538	91.589	72.986	80.851	104.231	127.875	105.304	71.094	67.182	73.376	66.731	54.769	63.098	63.921	64.501	61.344
Mo	9.228	12.451	10.848	9.172	8.002	8.223	5.994	3.779	2.867	2.524	2.269	2.970	2.409	2.248	2.251	2.659
Pb	0.445	0.543	0.418	0.454	0.496	0.492	0.368	0.250	0.223	0.205	0.162	0.198	0.185	0.168	0.144	0.189
Rb	156.820	142.767	201.120	149.987	155.188	133.094	84.136	56.661	50.712	44.012	35.630	43.406	43.560	40.298	32.704	43.458
Sr	101.716	106.707	82.014	79.161	76.888	72.784	52.430	33.660	32.202	29.182	24.264	29.032	29.230	29.725	23.669	28.276
Tl	0.026	0.024	0.024	0.043	0.061	0.088	0.067	0.044	0.032	0.028	0.024	0.034	0.027	0.022	0.019	0.029
Y	0.274	0.339	0.166	0.171	0.109	0.096	0.070	0.057	0.044	0.035	0.030	0.040	0.039	0.031	0.026	0.037
Zn	751.553	803.220	649.428	602.037	503.511	558.553	398.213	310.047	272.150	205.189	155.394	208.705	190.871	160.170	122.645	203.94