UPDATED ECOTOX DATABASE
AND REVISED ECOLOGICAL
DIRECT CONTACT SOIL STANDARD
FOR SOLUBLE BARIUM

Project Prepared for:
British Columbia Ministry of Energy, Mines and Petroleum Resources
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1. INTRODUCTION

The British Columbia Ministry of the Environment (BCE), assisted by the Barite-Barium Issues Subgroup of the BC Upstream Petroleum Environmental Task Group is in the process of developing matrix numerical soil standards for barium. BCE has used the CSST Protocols (BCE, 1996) to develop a draft set of standards for discussion. The draft standard value for the toxicity to soil invertebrates and plants exposure pathway was calculated based on the existing CSST (BCE, 1996) protocol and the database in the Environment Canada (1999) scientific supporting document for barium. Additional data have become available since the Environment Canada data were compiled. This report is funded by the BC Ministry of Energy, Mines, and Petroleum Resources (BC MEMPR), and provides and describes:

- the procedures used and the results of a literature search to identify barium toxicity data for plants and soil invertebrates;
- the screening criteria used to select relevant studies with useable data, and to reject other studies; and,
- the methodology used to develop a revised soil standard for this exposure pathway for barium.

Ecotoxicological data from selected studies are summarized in Tables 1 to 4. Appendix A provides references and a one page summary of each of the selected studies. Appendix B provides references for the studies that were excluded, with the rationale for screening each out.

2. LITERATURE STUDY

2.1 Study Parameters

The literature study used existing relevant data compilations, searches of the open literature, and available information in the "grey" literature to compile as much as possible of the available plant and soil invertebrate ecotoxicity data for barium compounds. The following sources were consulted.

Data Compilations

- Canadian Soil Quality Guidelines for Barium (Environmental Effects), Scientific Supporting Document. Environment Canada (1999). This study included a literature review and commissioned new barium ecotoxicological data (effect of barium chloride on lettuce and radish growth, and earthworm survival) from Hydroqual Laboratories Ltd.
- The Alberta Environment Barite Soil Quality Guidelines (AENV, 2004a,b). This study also included a literature review and commissioned new barium ecotoxicological data (effects of barium acetate and barium sulphate on the growth of alsike clover, perennial ryegrass, and orchard grass, and collembola and earthworm reproduction and survival) from Stantec Consulting Ltd.
- The United States Environmental Protection Agency (USEPA, 2005) Ecological Soil Screening Levels for Barium, February, 2005.
- Oak Ridge National Laboratory. Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision. (Efroymson et al., 1997a)
- Oak Ridge National Laboratory. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision. (Efroymson et al., 1997b).

Databases

- The United States Environmental Protection Agency (USEPA, 2006) ECOTOX Database.
- CSA Illumina Database:
    - Environmental Sciences and Pollution Management;
    - Plant Science;
    - Biological Sciences;
    - Agricultural and Environmental Biotechnology Abstracts;

- Biology Digest;
- Health and Safety Science Abstracts;
- Toxline;
- Medline;
- Aqualine; and,
- Bioengineering Abstracts.

Search Terms Used

In searches of the open literature and databases, data were sought for plant and soil invertebrate ecotoxicological data on the following barium compounds.

CAS Numbers and Chemical Terms

- 513779 Barium carbonate
- 543806 Barium acetate
- 115216778 Barium nitrate hydrate
- 10326279 Barium chloride hydrate
- 7440393 Barium
- 7727437 Barium sulfate
- 10022318 Barium nitrate
- 10361372 Barium chloride
- 13462867 Barite (barium sulfate)
- 21109955 Barium sulfide

2.2 Screening Criteria

Some of the sources indicated above may produce results that are not relevant to the effort to develop soil standards. Studies were screened out if they failed to meet any of the conditions below:

- Studies must involve a single toxicant that is a barium compound. Studies involving simultaneous exposure to multiple toxicants are screened out.
- Studies must identify a toxic response in growth, reproduction, or mortality to terrestrial plants or soil invertebrates that is associated with the presence of a barium compound. Ideally, a dose-response relationship should be evident.

- Studies must have been conducted in a natural or artificial soil. Studies conducted in other media such as hydroponic vessels or on filter paper are screened out.

Studies that satisfy the screening criteria are listed in Appendix A. Studies that are identified, but screened out, are listed in Appendix B, together with the reason for their exclusion.

2.3 Data Extraction

All the studies that remained after the screening process were obtained and reviewed. For each study, summary information was compiled in a single page format. These summaries are provided in Appendix A, ordered alphabetically. From the summaries in Appendix A, key toxicological data were identified that would be carried forward to the standard derivation process. Selected toxicological data for plants and invertebrates for soluble barium compounds (acetate, chloride, nitrate) are provided in Tables 1 and 2, respectively. Selected toxicological data for plants and invertebrates for insoluble barium compounds (sulphate) are provided in Tables 3 and 4, respectively.

2.3.1 Treatment of Redundant Data

Where multiple datapoints were available for the same species and test conditions, these were retained if it was felt that there was a reasonable degree of independence between the datapoints, or combined or eliminated where it was felt that they were essentially redundant. The way that various data redundancy issues was handled is summarized below:

- ***Wet and Dry Mass Data***. Where wet and dry root or shoot mass data were available, only the dry mass data were carried forward to Tables 1-4, since it is felt that these two endpoints are essentially redundant, and the wet mass data tend to be more variable.
- ***Non-Redundant Data in Plant Tests***. Shoot length, shoot mass, root length, root mass and nodule production endpoints were retained as independent datapoints.
- ***Invertebrate Reproductive Fecundity***. Adult fecundity was considered essentially redundant with juvenile production, and not reported in Tables 2 or 4.
- ***Multiple Repetitions***. Where multiple repetitions of the same test were reported, only the geometric mean of the data was retained (Table 1).

2.3.2 Analytical Basis for Barium Data

The majority of the selected studies on the ecotoxicity of soluble barium compounds used analytical techniques to confirm the exposure concentration of barium in the test soils. Analytical methods varied (see individual entries in Appendix A), however, all used some variation on a strong acid digestion followed by an appropriate analytical technique, typically inductively coupled plasma. Where possible, all data for soluble barium compounds were presented on the basis of measured barium concentrations, based on analytical data provided in the study. Typically, analytical recovery of barium was close to quantitative in the studies on soluble barium salts. No analytical data were available in the Chaudry et al. (1977) study, and those data were presented on a nominal basis.

Note that a less aggressive analytical method, based on $CaCl_2$ extraction, has been developed in an associated study, to approximate the concentration of soluble barium in a soil sample. The implications of using the soluble barium analytical technique are discussed in Section 3.1.2.

Barium analysis of barium sulphate-containing soils using conventional strong acid extraction techniques has proved unreliable at higher barium concentrations. The data in ESG (2003) confirm this, and indicate that the technique used in that report (strong acid digestion/ICP analysis) appeared to saturate at a measured total barium concentration of between 1,000 and 2,000 mg/kg, even when analyzing pure barite. Considering the uncertainty in using measured barium concentrations for insoluble barium compounds, all data for studies on insoluble barium compounds are presented on the basis of nominal barium concentration.

All data in Tables 1-4 are presented in terms of mg of barium per kg dry soil.

2.3.3 Preferred Effect Levels

Two effect levels are provided in Tables 1-4. The “low effects level” is an estimate of the concentration that produces a 20-25% reduction in the endpoint of interest (i.e., the IC20 or IC25). Where IC (or EC or LC) data were not available, the lowest observed effect concentration (LOEC) was included. Failing that, the no observed effect concentration (NOEC) was reported. The “median effects level” is the IC50, EC50, or LC50, where available. IC, EC, and LC are abbreviations for inhibition concentration, effect concentration, and lethal concentration, respectively.

3. STANDARD DERIVATION

In this section, a toxicity to soil invertebrates and plants standard was calculated for soluble barium compounds, using the 1996 CSST protocol. In addition the ecotoxicity data for insoluble barium compounds (i.e., barium sulphate) are discussed.

3.1 Soluble Barium Compounds

3.1.1 Standard Calculation

The CSST 1996 procedure for deriving the "toxicity to soil invertebrate and plants standard" is as follows:

> *"Toxicity to soil invertebrates and plants" soil quality standards were calculated for all land uses to protect plants and soil dependent invertebrates from the adverse effects of direct contact with contaminants in soil. As described below, both LC20 and EC50-NL values were estimated for each substance. For Agricultural, Residential and Urban Parkland uses, the concentration corresponding to the more stringent of the LC20 and the EC50-NL values was chosen as the appropriate "Toxicity to soil invertebrates and plants" soil quality matrix standard. For Commercial and Industrial land uses, the concentration representing the less stringent of the LC20 and the EC50-NL values was chosen as the appropriate "Toxicity to soil invertebrates and plants" matrix standard.*
>
> *The "Toxicity to soil invertebrates and plants" standard is derived according to the five step procedure below:*
>
> 1. *Consider all appropriate invertebrate and plant toxicity data from CCME "Substance Assessment" documents*
> 2. *Separate data into discrete lethal and non-lethal effect distributions*
> 3. *Calculate median effects concentrations for lethal and non-lethal distributions*
> 4. *Fit linear regression lines to lethal and non-lethal median distributions. If lethal or non-lethal regression correlation coefficient < 0.25 use "Empirical Exception" rule[1].*
> 5. *Determine regression intercepts for EC50-NL and LC20 and apply appropriate level of protection rule for:*
>   - *A/R/P - lesser of EC50-NL or LC20*
>   - *C/I - greater of EC50-NL or LC20*
>
> [1] *"Empirical Exception" rule: Estimate EC50-NL and/or LC20 via empirical extrapolation from median effects distributions.*

Following the CSST 1996 procedure for the soluble barium database:

1. All applicable date for soluble barium compounds are summarized in Tables 1 and 2.

2. The data are separated into non-lethal (i.e., growth and reproduction endpoints) and lethal (mortality) data in Tables 5 and 6, respectively, and sorted into rank order.
3. Tables 5 and 6 include only the median effects concentrations (EC50, IC50, or LC50, as appropriate.
4. Linear regression lines are fitted to the non-lethal and lethal distributions in Figures 1 and 2, respectively. The regression correlation coefficients are 0.73 and 0.94, (Figures 1 and 2, respectively), which are greater than 0.25, and accordingly, the "Empirical Exception" rule is not required.
5. The regression intercepts for non-lethal and lethal distributions are illustrated in Figures 1 and 2, respectively, and are:
    - EC50-NL = 1,406 mg/kg; and,
    - LC20 = 1,218 mg/kg.

   The lower of these two values is adopted as the soil quality standard for Agricultural/Residential/Parkland use, while the higher is adopted for Commercial/Industrial land use.

Soil quality standards developed under the CSST protocol are rounded to "1.5 significant figures" – the first significant figure of the calculated standard is used, and the second significant figure is rounded to either 0 or 5. Thus, the "toxicity to soil invertebrates and plants" soil quality standards are:

Land Use	Standard, mg/kg
Agricultural/Residential/Parkland	1,000
Commercial/Industrial	1,500

3.1.2 Applicability of Standard to Measured Soluble Barium

The soil quality standards for the "toxicity to soil invertebrates and plants" exposure pathway calculated in Section 3.1.1 are based entirely on the toxic responses of plants and soil invertebrates to soluble barium compounds (acetate, chloride, nitrate). The data presented in Section 3.2 indicate that barium sulphate (representing an insoluble form of barium) is essentially non-toxic to plants. The barium in a soil sample may contain a mixture of soluble and insoluble forms of barium, but only the soluble fraction will contribute to the plant and invertebrate toxicity, and therefore the concentration of soluble barium is the appropriate measure to compare against the standard value. As noted in Section 2.3.2, the toxicity data used in the derivation of the standard were based on chemical analyses that yielded essentially quantitative recovery of soluble barium salts from soils.

In a parallel study (BCLQAAC, 2007a,b,c), an analytical method, based on extraction with 1.0 M $CaCl_2$, ("the BC Soluble Barium Method") was developed to determine the concentration of soluble barium in a soil sample. Use of the standards calculated in Section 3.1.1 with data for soluble barium is valid so long as the BC Soluble Barium Method returns essentially quantitative results for measurements of soluble barium compounds in soil. Eight laboratories used the BC Soluble Barium Method to analyze 10,000 mg/kg barium chloride spiked into a sandy soil (BCLQAAC, 2007c). The mean recovery for the eight laboratories was 87% (range 75% to 103%).

Alberta Environment have developed a similar, but less aggressive extraction using 0.1 M $CaCl_2$. Regression of the results of using the less aggressive Alberta Soluble Barium Method to extract barium from a clay loam soil spiked with barium acetate (AENV, 2004) indicated a recovery of 82% for this soluble barium compound.

It is noted that applying either of these recovery figures (82% or 87%) to the calculated barium standards of 1,218 mg/kg or 1,406 mg/kg prior to rounding to 1.5 significant figures would not alter the final, rounded values for the revised barium standards of 1,000 mg/kg or 1,500 mg/kg, and accordingly the BC Soluble Barium Method is deemed to be essentially quantitative for soluble barium compounds, and therefore, the standards calculated in Section 3.1.1 are applicable to measurements of barium obtained using the BC Soluble Barium Method.

3.2 Insoluble Barium Compounds

Available ecotoxicity data for insoluble barium compounds (all available data are for barium sulphate) for plants and soil invertebrates are presented in Tables 3 and 4. The majority of the available plant data indicate no growth inhibition at high concentrations up to and including 100% barite (Table 3). The most sensitive endpoint among the data appears to be the effect of barium sulphate on the dry mass of corn shoots, which showed a 20% reduction in shoot mass relative to the controls at a concentration of approximately 312,000 mg/kg (Appendix A).

Available invertebrate data for insoluble barium compounds are limited (Table 4), but show no effect on earthworm or springtail survival at concentrations as high as 100% barite.

Overall, the available ecotoxicological data indicate that barium sulphate is effectively non-toxic to plants and soil invertebrates.

4. CLOSURE

The information presented in this report was compiled and interpreted exclusively for the purpose of assisting the British Columbia Ministry of the Environment and the Barite-Barium Issues Subgroup of the BC Upstream Petroleum Environmental Task Group in the development of soil standards for barium.

Axiom has exercised reasonable skill, care and diligence to assess the information acquired during the preparation of this report, but makes no guarantees or warranties as to the accuracy or completeness of this information. The information contained in this report is based upon, and limited by, the circumstances and conditions acknowledged herein, and upon information available at the time of its preparation. The information provided by others is believed to be accurate but cannot be guaranteed.

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5. GENERAL REFERENCES

(REFERENCES FOR INDIVIDUAL STUDIES ARE INCLUDED IN APPENDICES)

Alberta Environment, 2004a. Soil Quality Guidelines for Barite: Environmental Health and Human Health. Pub No: T/738.

Alberta Environment, 2004b. Technical Appendices for Barite Soil Quality Guidelines. February 2004.

BCE (British Columbia Ministry of the Environment), 1996. Overview of CSST Procedures for the Derivation of Soil Quality Matrix Standards for Contaminated Sites. Risk Assessment Unit, Environmental Protection Department, BC Environment. January 31, 1996.

Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten, 1997a. Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision. November 1997. Report prepared for the Oak Ridge National Laboratory, U.S. Department of Energy, Office of Environmental Management.

Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten, 1997b. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision. November 1997. Report prepared for the Oak Ridge National Laboratory, U.S. Department of Energy, Office of Environmental Management.

Environment Canada, 1999. Canadian Soil Quality Guidelines, Barium, Environmental Effects. Scientific Supporting Document prepared by National Guidelines and Standards Office. Environment Canada. December 1999.

US EPA (United States Environmental Protection Agency), 2005. Ecological Soil Screening Levels for Barium, Interim Final. US EPA Office of Solid Waste and Emergency Response. February 2005.

US EPA (United States Environmental Protection Agency), 2006. US EPA ECOTOX Database.

TABLES

Table 1. Plant Toxicity - Soluble Barium Compounds

Organism	Compound	Test duration (days)	Effect	Low Effects Level: Effect Level	Low Effects Level: Concentration (mg/kg)	Median Effects Level: Effect Level	Median Effects Level: Concentration (mg/kg)	Reference
Growth Endpoints								
Alsike clover	barium acetate	21	shoot length	IC20	1,157	IC50	1,468	Stantec (2003)
Alsike clover	barium acetate	21	shoot dry mass	IC20	583	IC50	1,030	Stantec (2003)
Alsike clover	barium acetate	21	root length	IC20	948	IC50	1,220	Stantec (2003)
Alsike clover	barium acetate	21	root dry mass	IC20	767	IC50	966	Stantec (2003)
Alsike clover	barium acetate	21	nodule formation	IC20	na	IC50	1,300	Stantec (2003)
Orchard grass	barium acetate	14	shoot length	IC20	1,407	IC50	1,485	Stantec (2003)
Orchard grass	barium acetate	14	shoot dry mass	IC20	na	IC50	1,301	Stantec (2003)
Orchard grass	barium acetate	14	root length	IC20	772	IC50	1,503	Stantec (2003)
Orchard grass	barium acetate	14	root dry mass	IC20	na	IC50	1,283	Stantec (2003)
Perennial ryegrass	barium acetate	14	shoot length	IC20	511	IC50	2,206	Stantec (2003)
Perennial ryegrass	barium acetate	14	shoot dry mass	IC20	536	IC50	995	Stantec (2003)
Perennial ryegrass	barium acetate	14	root length	IC20	945	IC50	1,456	Stantec (2003)
Perennial ryegrass	barium acetate	14	root dry mass	IC20	850	IC50	1,248	Stantec (2003)
Letuce	barium chloride	5	seedling emergence [a]	IC25	325	IC50	868	Environment Canada (2003)
Radish	barium chloride	5	seedling emergence [a]	IC25	1,064	IC50	2,944	Environment Canada (2003)
Bush bean	barium nitrate	14	shoot dry mass	IC25	1,244	IC50	1,739	Chaudry et al. (1977)
Barley	barium nitrate	14	shoot dry mass	IC25	328	IC50	813	Chaudry et al. (1977)

Notes:
All data presented as mg(barium) per kg(dry weight soil), on the basis of measured barium except for Chaudry et al. (1977) data which are presented as nominal barium.
a. Geometric mean of 3 tests

Table 2. Invertebrate Toxicity - Soluble Barium Compounds

				Low Effects Level		Median Effects Level		
Organism	Compound	Test duration (days)	Effect	Effect Level	Concentration (mg/kg)	Effect Level	Concentration (mg/kg)	Reference
Mortality Data								
Earthworm (*Eisenia andrei)*	barium acetate	14	mortality	LOEC	8,404	LC50	7,560	Stantec (2003)
Earthworm (*Eisenia fetida*)	barium chloride	14	mortality	LC20	2,869	LC50	3,617	Environment Canada, 1996
Earthworm (*Eisenia fetida*)	barium nitrate	14	mortality	LOEC	433	LC50	1,723	Simini et al. (2002)
Potworm (*Enchytraeus crypticus*)	barium nitrate	28	mortality	LOEC	2,000	LC50	nd	Kuperman et al. (2002)
Springtail (*Folsomia candida*)	barium nitrate	28	mortality	LOEC	375	LC50	1,196	Phillips et al. (2002)
Springtail (*Onychiurus folsomii*)	barium acetate	35	mortality	LC20	6,370	LC50	8,734	Stantec (2003)
Reproduction Endpoints								
Earthworm (*Eisenia fetida*)	barium nitrate	21	cocoon production	EC20	370	EC50	664	Simini et al. (2002)
Potworm (*Enchytraeus crypticus*)	barium nitrate	42	juvenile production	EC20	585	EC50	947	Kuperman et al. (2002)
Springtail (*Folsomia candida*)	barium nitrate	28	juvenile production	EC20	165	EC50	478	Simini et al. (2002)
Springtail (*Onychiurus folsomii*)	barium acetate	35	juvenile production	EC20	1,461	EC50	3,636	Stantec (2003)

Notes:
All data presented as mg(barium) per kg(dry weight soil), on the basis of measured barium.
a. Geometric mean of 3 tests

Table 3. Plant Toxicity - Insoluble Barium Compounds

Organism	Compound	Test duration (days)	Effect	Low Effects Level: Effect Level	Low Effects Level: Concentration (mg/kg)	Median Effects Level: Effect Level	Median Effects Level: Concentration (mg/kg)	Reference
Growth Endpoints								
Alsike clover	barium sulphate	21	shoot length	LOEC	589,000	-	na	ESG (2003)
Alsike clover	barium sulphate	21	shoot dry mass	NOEC	589,000	-	na	ESG (2003)
Alsike clover	barium sulphate	21	root length	NOEC	589,000	-	na	ESG (2003)
Alsike clover	barium sulphate	21	root dry mass	NOEC	589,000	-	na	ESG (2003)
Alsike clover	barium sulphate	21	nodule formation	NOEC	589,000	-	na	ESG (2003)
Orchard grass	barium sulphate	14	shoot length	NOEC	589,000	-	na	ESG (2003)
Orchard grass	barium sulphate	14	shoot dry mass	NOEC	589,000	-	na	ESG (2003)
Orchard grass	barium sulphate	14	root length [a]	IC20	500,000	-	na	ESG (2003)
Orchard grass	barium sulphate	14	root dry mass	NOEC	589,000	-	na	ESG (2003)
Perennial ryegrass	barium sulphate	14	shoot length	NOEC	589,000	-	na	ESG (2003)
Perennial ryegrass	barium sulphate	14	shoot dry mass	NOEC	589,000	-	na	ESG (2003)
Perennial ryegrass	barium sulphate	14	root length [a]	IC20	565,000	-	na	ESG (2003)
Perennial ryegrass	barium sulphate	14	root dry mass	NOEC	589,000	-	na	ESG (2003)
Bush bean	barium sulphate	56	shoot dry mass	NOEC	312,000 [b]	-	na	Miller et al. (1980)
Corn	barium sulphate	56	shoot dry mass	LOEC	312,000 [b]	-	na	Miller et al. (1980)

Notes:
All data presented as mg(barium) per kg(soil), on the basis of nominal barium concentration.
589,000 mg(barium) per kg(soil) corresponds to 100% barite (no soil).
a. ESG (2003) postulated that the reduction in root length in 100% barite may have been due to the dense nature of barite as a growing medium rather than any toxicological effect
b. The study design was not suitable to determining whether a dose response relationship existed (control + 2 concentrations only)

Table 4. Invertebrate Toxicity - Insoluble Barium Compounds

Organism	Compound	Test duration (days)	Effect	Low Effects Level		Median Effects Level		Reference
				Effect Level	Concentration (mg/kg)	Effect Level	Concentration (mg/kg)	
Mortality Data								
Earthworm (*Eisenia fetida*)	barium sulphate	14	mortality	NOEC	589,000	-	na	ESG (2003)
Springtail (*Onychiurus folsomii*)	barium sulphate	7	mortality	NOEC	589,000	-	na	ESG (2003)

Notes:
All data presented as mg(barium) per kg(soil), on the basis of nominal barium concentration.
589,000 mg(barium) per kg(soil) corresponds to 100% barite (no soil).

Table 5. Ranked Median Toxicity Data for Soluble Barium, Non-Lethal Endpoints

Organism	Compound	Test duration (days)	Effect	Median Effect Concentration (mg/kg)	Rank Percentile	Rank
Springtail (*Folsomia candida*)	barium nitrate	28	juvenile production	478	5%	1
Earthworm (*Eisenia fetida*)	barium nitrate	21	cocoon production	664	9%	2
Barley	barium nitrate	14	shoot dry mass	813	14%	3
Letuce	barium chloride	5	seedling emergence	868	18%	4
Potworm (*Enchytraeus crypticus*)	barium nitrate	42	juvenile production	947	23%	5
Alsike clover	barium acetate	21	root dry mass	966	27%	6
Perennial ryegrass	barium acetate	14	shoot dry mass	995	32%	7
Alsike clover	barium acetate	21	shoot dry mass	1,030	36%	8
Alsike clover	barium acetate	21	root length	1,220	41%	9
Perennial ryegrass	barium acetate	14	root dry mass	1,248	45%	10
Orchard grass	barium acetate	14	root dry mass	1,283	50%	11
Alsike clover	barium acetate	21	nodule formation	1,300	55%	12
Orchard grass	barium acetate	14	shoot dry mass	1,301	59%	13
Perennial ryegrass	barium acetate	14	root length	1,456	64%	14
Alsike clover	barium acetate	21	shoot length	1,468	68%	15
Orchard grass	barium acetate	14	shoot length	1,485	73%	16
Orchard grass	barium acetate	14	root length	1,503	77%	17
Bush bean	barium nitrate	14	shoot dry mass	1,739	82%	18
Perennial ryegrass	barium acetate	14	shoot length	2,206	86%	19
Radish	barium chloride	5	seedling emergence	2,944	91%	20
Springtail (*Onychiurus folsomii*)	barium acetate	35	juvenile production	3,636	95%	21

Notes:
All data presented as mg(barium) per kg(soil), on the basis of measured barium,
except for barley and bush bean data (from Chaudry et al., 1977) which are presented on a nominal basis.
However, note that analytical recovery of these soluble barium cmpounds was essentially quantitative.

Table 6. Ranked Median Toxicity Data for Soluble Barium, Mortality Endpoints

Organism	Compound	Test duration (days)	Effect	Median Effect Concentration (mg/kg)	Rank Percentile	Rank
Springtail (*Folsomia candida*)	barium nitrate	28	mortality	1,196	17%	1
Earthworm (*Eisenia fetida*)	barium nitrate	14	mortality	1,723	33%	2
Earthworm (*Eisenia fetida*)	barium chloride	14	mortality	3,617	50%	3
Earthworm (*Eisenia andrei)*	barium acetate	14	mortality	7,560	67%	4
Springtail (*Onychiurus folsomii*)	barium acetate	35	mortality	8,734	83%	5

Notes:

All data presented as mg(barium) per kg(soil), on the basis of measured barium.

nd = not determined

FIGURES

Figure 1. Regression of Non-Lethal Ecotoxicity Data for Soluble Barium Compounds

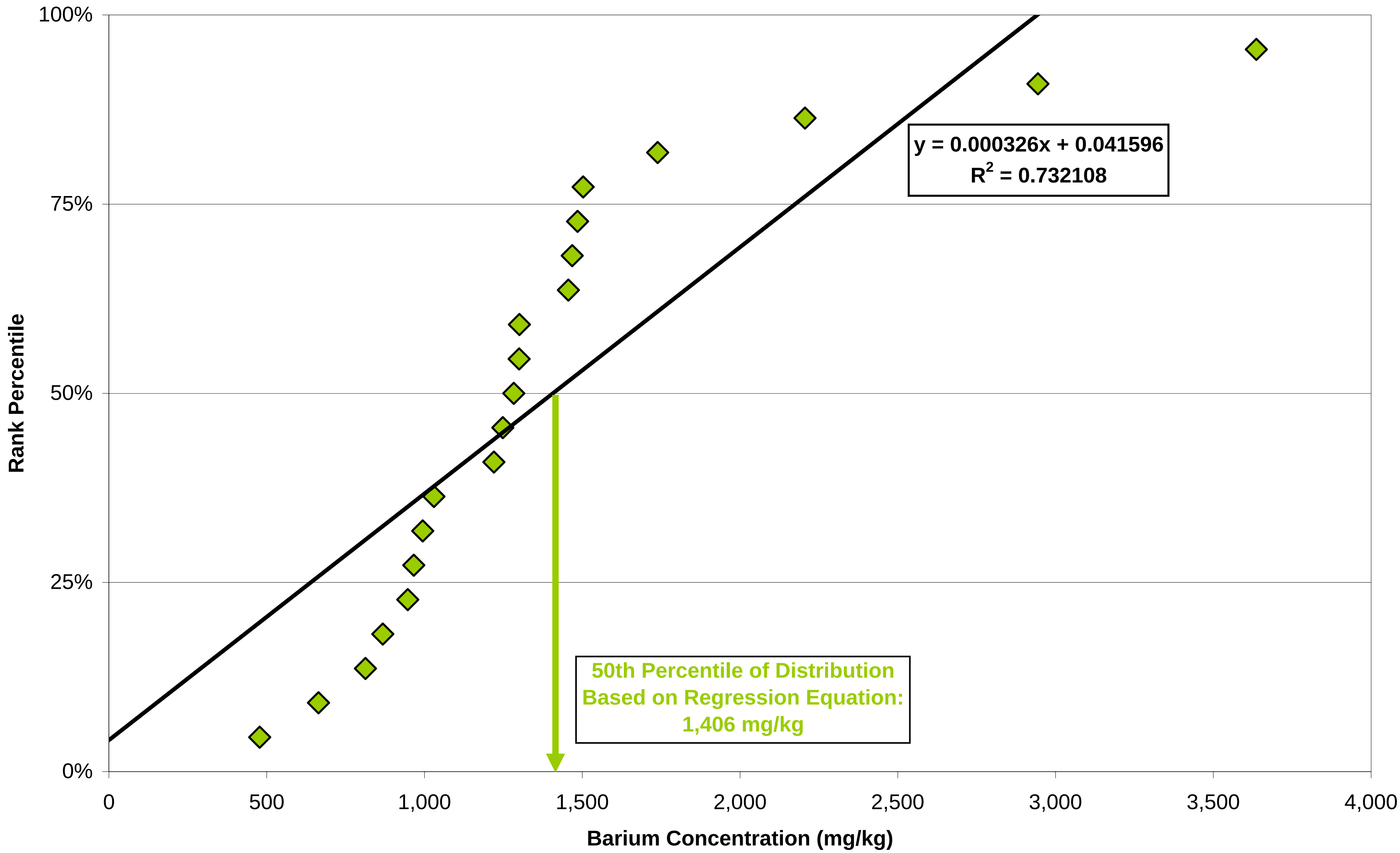
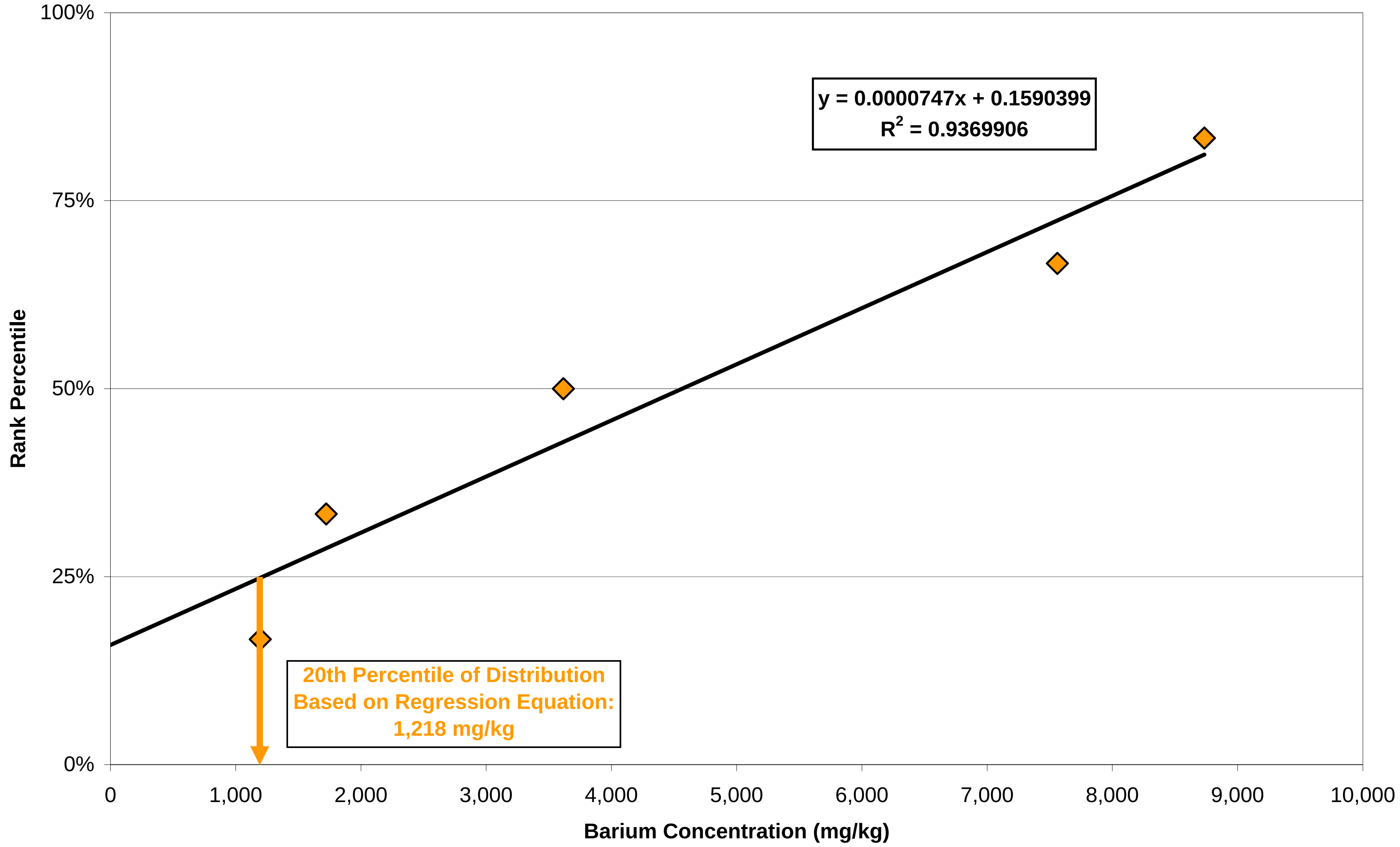


Figure 2. Regression of Mortality Data for Soluble Barium Compounds



APPENDIX A

SELECTED STUDIES

APPENDIX A –SELECTED STUDIES

This Appendix provides references for the studies that were selected in the screening process, and provides a one page compilation of the key points of each, including all the relevant toxicity data.

Chaudhry, F. M., Wallace, A., and Mueller, R. T. 1977. Barium Toxicity in Plants. Commun. Soil Sci. Plant Anal. 8[9], 795-797

Environment Canada, 1996. Seedling emergence and earthworm toxicity tests on barium and thallium. Prepared for the Science Policy and Environmental Quality Branch, Environment Canada by Hydroqual Laboratories Ltd., Calgary, Alberta.

ESG (ESG International Inc.), 2003. Ecotoxicity evaluation of reference site soils amended with barium sulphate. File # G2144. Unpublished report prepared for the Alberta Barite Soil Quality Guidelines Project. January 2003.

Kuperman, R.G., Checkai, R.T., Phillips, C.T., Simini, M., Speicher, J.A., Barclift, D.J. 2002. Toxicity Assessments of Antimony, Barium, Beryllium, and Manganese for Development of Ecological Soil Screening Levels (Eco-SSL) Using Enchytraeid Reproduction Benchmark Values. Technical Report No. ECBC-TR-324. U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Miller, R. W., Honarvar, S., and Hunsaker, B. 1980. Effects of Drilling Fluids on Soils and Plants 1. Individual Fluid Components. J. Environ. Qual. 9[4]: 547-552. Eco-SSL for Barium 12 February 2005.

Phillips, C.T., Checkai, R.T., Kuperman, R.G., Simini, M., Speicher, J.A., Barclift, D.J. 2002. Toxicity Assessments of Antimony, Barium, Beryllium, and Manganese for Development of Ecological Soil Screening Levels (Eco-SSL) Using Folsomia Reproduction Benchmark Values. Technical Report No. ECBC-TR-326. U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Simini, M., Checkai, R.T., Kuperman, R.G., Phillips, C.T., Speicher, J.A., Barclift, D.J. 2002. Toxicity Assessments of Antimony, Barium, Beryllium, and Manganese for Development of Ecological Soil Screening Levels (Eco-SSL) Using Earthworm (Eisenia fetida) Benchmark Values. Technical Report No. ECBC-TR-325. U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.

Stantec (Stantec Consulting Ltd.), 2003. Ecotoxicity evaluation of reference site soils amended with barium acetate. File # 626 03291. Unpublished report prepared for the Alberta Barite Soil Quality Guidelines Project. September 2003.

Chaudry et al. (1977)

Summary of Toxicity Study				
Full reference	Chaudhry, F. M., Wallace, A., and Mueller, R. T. 1977. Barium Toxicity in Plants. Commun. Soil Sci. Plant Anal. 8[9], 795-797			
Species tested	Bush bean, barley			
Form of barite	Barium nitrate, $BaNO_3$			
Soil				
Soil type	Yolo loam			
Soil properties	sand (%)	silt (%)	clay (%)	
	na	na	na	
Soil chemistry	pH	EC (dS/m)	organic matter (%)	
	na	na	na	
Chemical Analysis				
Analytical method	none			
Analytical recovery	na			
Analytical basis for results	Toxicological data on this sheet presented on a nominal concentration basis			
Toxicity Tests (all values in mg/kg, presented on nominal basis)				
Test	**bush bean, *Phaseolus vulgaris* var Tendergreen, 14 day growth, no standard method referenced**			
Endpoint	NOEC	LOEC	IC25 [b]	IC50 [b]
shoot dry mass	1,000	2,000	1,244	1,739
Test	**BARLEY, *Hordeum vulgare* var Atlas 57, 14 day growth, no standard method referenced**			
Endpoint	NOEC	LOEC	IC25 [b]	IC50 [b]
shoot dry mass	0	500 [a]	328	813

Notes:

a. LOEC is unbounded

b. IC25 and IC50 calculated from data in source paper using linear interpolation

Environment Canada, 1996

Summary of Toxicity Study				
Full reference	Environment Canada (1996). Seedling emergence and earthworm toxicity tests on barium and thallium. Unpublished report prepared for Environment Canada by Hydroqual Laboratories Ltd. September, 1996.			
Species tested	Earthworm, lettuce, radish			
Form of barite	Barium chloride dihydrate $BaCl_2.2H_2O$			
Soil				
Soil type	Artificial soil (70%sand, 20% kaolinite clay, 10% peat moss)			
Soil properties	sand (%)	silt (%)	clay (%)	
	72	9	19	
Soil chemistry	pH	EC (dS/m)	organic matter (%)	
	4.2	0.3	6.1	
Chemical Analysis				
Analytical method	Nitric/perchloric/hydrochloric acid digestion + ICP (EPA 3050A)			
Analytical recovery	Analytical recovery was calculated as effectively quantitative (26 samples analyzed, recovery ranged from 69% to 125% with a mean of 97%)			
Analytical basis for results	Toxicological data on this sheet presented on a measured concentration basis			
Toxicity Tests (all values in mg/kg, presented on measured concentration basis)				
Test	**lettuce, *Lactuca sativa*, 5 day seedling emergence, Green et al. (1989)**			
Endpoint	NOEC	LOEC	IC25	IC50
sedling emergence, test #1	165	391	283	604
sedling emergence, test #2	439	903	657	1,206
sedling emergence, test #3	77	199	184	898
geometric mean of 3 tests	177	413	325	868
Test	**radish, *Raphanus sativa*, 5 day seedling emergence, Green et al. (1989)**			
Endpoint	NOEC	LOEC	IC25	IC50
sedling emergence, test #1	1,523	3,015	1,393	2,953
sedling emergence, test #2	486	952	777	3,709
sedling emergence, test #3	1,585	3,073	1,112	2,329
geometric mean of 3 tests	1,055	2,066	1,064	2,944
Test	**earthworm, Eisenia fetida, 7 day survival, Green et al. (1989)**			
Endpoint	NOEC	LOEC	IC25	IC50
mortality, test #1	2,475	4,814	3,160	3,869
mortality, test #2	2,474	4,786	2,737	3,525
mortality, test #3	2,230	5,086	2,974	3,879
geometric mean of 3 tests	2,390	4,893	2,952	3,754
Test	**earthworm, Eisenia fetida, 14 day survival, Green et al. (1989)**			
Endpoint	NOEC	LOEC	IC25	IC50
mortality, test #1	2,475	4,814	3,081	3,688
mortality, test #2	2,474	4,786	2,639	3,465
mortality, test #3	2,230	5,086	2,903	3,703
geometric mean of 3 tests	2,390	4,893	2,869	3,617

Notes:

ESG (2003)

Summary of Toxicity Study

Full reference	ESG (ESG International Inc.), 2003. Ecotoxicity evaluation of reference site soils amended with barium sulphate. File # G2144. Unpublished report prepared for the Alberta Barite Soil Quality Guidelines Project. January 2003.					
Species tested	Earthworm, springtail, alsike clover, orchard grass, perennial ryegrass					
Form of barite	Barium sulphate, $BaSO_4$					
Soil						
Soil type	Clay loam					
Soil properties	Sand (%)	Silt (%)	Clay (%)	OM (%)	CEC (meq/100g)	pH
	29.9	40.7	29.5	1.2	23	7.7
Soil chemistry	Ba (mg/kg)	SO_4 (mg/kg)	EC (dS/m)			
	250 [a]	54 [a]	0.54			
Chemical Analysis						
Analytical method	Nitric/hydrochloric acid digestion + ICP					
Analytical recovery	Analytical method appeared to be unable to distinguish between barite concentrartions above 10,000 mg(barium)/kg(soil)					
Analytical basis for results	Toxicological results presented on the basis of nominal concentrations, since analytical method is not reliable for higher barite concentrations.					
Toxicity Tests (all values in mg(barium)/kg(soil), presented on nominal basis)						
Test	**Alsike clover, *Trifolium hybridum*, 21 day definitive growth, EC (1998a)**					
Endpoint	NOAEC	LOAEC	IC20	IC50		
Emergence	177,000	589,000	na	na		
Shoot length	177,000	589,000	na	na		
Shoot dry mass [b]	589,000	na	na	na		
Root length	589,000	na	na	na		
Root dry mass [b]	589,000	na	na	na		
Nodules	589,000	na	na	na		
Test species, test	**Orchard grass, *Dactylis glomerate*, 14 day definitive growth, EC (1998a)**					
Endpoint	NOAEC	LOAEC	IC20	IC50		
Emergence	589,000	na	na	na		
Shoot length	589,000	na	na	na		
Shoot dry mass [b]	589,000	na	na	na		
Root length	589,000	na	500,000	>589,000		
Root dry mass [b]	589,000	na	na	na		
Test species, test	**Perennial ryegrass, *Loleum perenne,* 14 day definitive growth, EC (1998a)**					
Endpoint	NOAEC	LOAEC	IC20	IC50		
Emergence	589,000	na	na	na		
Shoot length	589,000	na	na	na		
Shoot dry mass [b]	589,000	na	na	na		
Root length	177,000	589,000	565,000	>589,000		
Root dry mass [b]	589,000	na	na	na		
Test species, test	**Springtail, *Onychiurus folsomii,* 35 day survival and reproduction, EC (1998b)**					
Endpoint	NOAEC	LOAEC	EC20	EC50		
Adult survival	589,000	na	na	na		
Test species, test	**Earthworm, *Eisenia andrei*, 14 day survival, EC (2002) [d]**					
Endpoint	NOAEC	LOAEC	EC20	LC50		
Adult survival	589,000	na	na	na		

Notes:
na = not available or not applicable
Reports for rangefinding tests also presented in source document.
Only the longest valid test results for each species included here.
a. 589,000 mg(barium)/kg(soil) is equivalent to 100% barite (no soil)
b. wet mass data also provided in source report, but not reproduced here due to the inherent variability in this measure and redundancy with dry weight

Kuperman et al. (2002)

Summary of Toxicity Study						
Full reference	Kuperman, R.G., Checkai, R.T., Phillips, C.T., Simini, M., Speicher, J.A., Barclift, D.J. 2002. Toxicity Assessments of Antimony, Barium, Beryllium, and Manganese for Development of Ecological Soil Screening Levels (Eco-SSL) Using Enchytraeid Reproduction Benchmark Values. Technical Report No. ECBC-TR-324. U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.					
Species tested	Potworm (*Enchytraeus crypticus*)					
Form of barite	Barium nitrate $Ba(NO_3)_2$					
Soil						
Soil type	Sassafras sandy loam					
Soil properties	Sand (%)	Silt (%)	Clay (%)	OM (%)	CEC (meq/100g)	pH
	71	18	11	1.2	4.27	5
Soil chemistry	Ba (mg/kg)	SO_4 (mg/kg)	EC (dS/m)			
	34	na	na			
Chemical Analysis						
Analytical method	USEPA Method 200.8 (USEPA, 1994); (Digestion of 1 g of soil by 4 ml of "1+1" nitric acid and 10 ml of "1+4" hydrochloric acid on a hotplate, followed by ICP-MS)					
Analytical recovery	Analytical recovery ranged from 88% to 134%, mean of 110%.					
Analytical basis for results	Toxicological data on this sheet presented on a measured concentration basis					

Toxicity Tests (all values in mg/kg, presented on a measured concentration basis)				
Test	**Potworm, *Enchytraeus crypticus*), 28 day adult survival, ISO/CD 16387**			
Endpoint	NOAEC	LOAEC	LC20	LC50
adult survival	1,798	2,000	na	nd [a]
Test	**Potworm, *Enchytraeus crypticus*), 42 day juvenile production, ISO/CD 16387**			
Endpoint	NOAEC	LOAEC	EC20	EC50
adult survival	433	689	585	947

Notes:
na = not available or not applicable
nd = not defined
All test concentrations and negative controls were subjected to 3 weeks of simulated aging/weathering involving multiple cycles of weting and air drying.
Reports for rangefinding tests with the sulphate, oxide, and acetate salts were also presented in source document.
The rangefinding test with the sulphate salt yielded an unbounded NOEC for adult survival at 10,000 mg/kg
The rangefinding tests with the soluble salts (acetate, oxide and nitrate), indicated broadly similar results for adult survival and juvenile production, with the nitrate salt being the most toxic and hence carried forward for definitive testing.
a. Highest concentration tested achieved a mortality of <50%, therefore LC50 is not defined in this test.

Miller et al. (1980)

Summary of Toxicity Study				
Full reference	1. Individual Fluid Components. J. Environ. Qual. 9[4]: 547-552. Eco-SSL for Barium 12 February 2005.			
Species tested	Bush bean, corn.			
Form of barite	Barium sulphate $BaSO_4$			
Soil				
Soil type	Dagor silt loam			
Soil properties	sand	silt	clay	CEC
Soil properties	(%)	(%)	(%)	(meq/100g)
	na	na	10	34.3
Soil chemistry	pH	EC	OM	
Soil chemistry	(_)	(dS/m)	(%)	
	6.2	na	8.1	
Chemical Analysis				
Analytical method	none			
Analytical recovery	na			
Analytical basis for results	Toxicological data on this sheet are presented on a nominal concentration basis			
Toxicity Tests (all values in mg/kg, presented on nominal basis)				
Test	**bush bean, *Phaseolus vulgaris*, 56 day growth, no standard method referenced**			
Endpoint	NOEC	LOEC	IC25	IC50
shoot dry mass	312,000	na	na	na
Test	**Corn, *Zea mays* 56 day growth, no standard method referenced**			
Endpoint	NOEC	LOEC	IC25 [b]	IC50 [b]
shoot dry mass	119,000	312,000 [a]	na	na

Notes:

a. Growth at this level was 80% of controls, which was significant at tht 95% level, but not the 99% level

Phillips et al. (2002)

Summary of Toxicity Study						
Full reference	Phillips, C.T., Checkai, R.T., Kuperman, R.G., Simini, M., Speicher, J.A., Barclift, D.J. 2002. Toxicity Assessments of Antimony, Barium, Beryllium, and Manganese for Development of Ecological Soil Screening Levels (Eco-SSL) Using Folsomia Reproduction Benchmark Values. Technical Report No. ECBC-TR-326. U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.					
Species tested	Springtail (*Folsomia candida*)					
Form of barite	Barium nitrate $Ba(NO_3)_2$					
Soil						
Soil type	Sassafras sandy loam					
Soil properties	Sand (%)	Silt (%)	Clay (%)	OM (%)	CEC (meq/100g)	pH
	71	18	11	1.2	4.27	5
Soil chemistry	Ba (mg/kg)	SO_4 (mg/kg)	EC (dS/m)			
	34	na	na			
Chemical Analysis						
Analytical method	USEPA Method 200.8 (USEPA, 1994); (Digestion of 1 g of soil by 4 ml of "1+1" nitric acid and 10 ml of "1+4" hydrochloric acid on a hotplate, followed by ICP-MS)					
Analytical recovery	Analytical recovery ranged from 89% to 139%, mean of 114%.					
Analytical basis for results	Toxicological data on this sheet presented on a measured concentration basis					
Toxicity Tests (all values in mg/kg, presented on a measured concentration basis)						
Test	**Springtail (*Folsomia candida*), 28 day adult survival, ISO/FDIS/ 11267:1998(E)**					
Endpoint	NOAEC	LOAEC	LC20	LC50		
adult survival	211	375	na	1196 [a]		
Test	**Springtail (*Folsomia candida*), 28 day juvenile production, ISO/FDIS/ 11267:1998(E)**					
Endpoint	NOAEC	LOAEC	EC20	EC50		
adult survival	211	375	165	478		

Notes:

na = not available or not applicable

All test concentrations and negative controls were subjected to 3 weeks of simulated aging/weathering involving multiple cycles of weting and air drying.

Reports for rangefinding tests were also presented in source document.

a. Calculated by linear interpolation from data in source paper.

Simini et al. (2002)

Summary of Toxicity Study						
Full reference	Simini, M., Checkai, R.T., Kuperman, R.G., Phillips, C.T., Speicher, J.A., Barclift, D.J. 2002. Toxicity Assessments of Antimony, Barium, Beryllium, and Manganese for Development of Ecological Soil Screening Levels (Eco-SSL) Using Earthworm (Eisenia fetida) Benchmark Values. Technical Report No. ECBC-TR-325. U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD.					
Species tested	Earthworm (*Eisenia fetida*)					
Form of barite	Barium nitrate $Ba(NO_3)_2$					
Soil						
Soil type	Sassafras sandy loam					
Soil properties	Sand (%)	Silt (%)	Clay (%)	OM (%)	CEC (meq/100g)	pH
	71	18	11	1.2	4.27	5
Soil chemistry	Ba (mg/kg)	SO_4 (mg/kg)	EC (dS/m)			
	34	na	na			
Chemical Analysis						
Analytical method	USEPA Method 200.8 (USEPA, 1994); (Digestion of 1 g of soil by 4 ml of "1+1" nitric acid and 10 ml of "1+4" hydrochloric acid on a hotplate, followed by ICP-MS)					
Analytical recovery	Mean analytical recovery: 109% (survival test), 112% (cocoon test).					
Analytical basis for results	Toxicological data on this sheet presented on a measured concentration basis					

Toxicity Tests (all values in mg/kg, presented on a measured concentration basis)				
Test	**Earthworm (*Eisenia fetida*), 14 day adult survival, Greene et al. (1989)**			
Endpoint	NOAEC	LOAEC	LC20	LC50
adult survival	1,348	1,585	na	1723 [a]
Test	**Earthworm (*Eisenia fetida*), 21 day cocoon production, no method reference.**			
Endpoint	NOAEC	LOAEC	EC20	EC50
adult survival	258	433	370	664

Notes:
na = not available or not applicable
All test concentrations and negative controls were subjected to 3 weeks of simulated aging/weathering involving multiple cycles of weting and air drying.
Reports for rangefinding tests were also presented in source document.
a. Calculated by linear interpolation from data in source paper.

Stantec (2003)

Summary of Toxicity Study				
Full reference	Stantec (Stantec Consulting Ltd.), 2003. Ecotoxicity evaluation of reference site soils amended with barium acetate. Unpublished report prepared for the Alberta Barite Soil Guidelines Technical Steering Committee. September, 2003.			
Species tested	Earthworm, springtail, alsike clover, orchard grass, perennial ryegrass			
Form of barite	Barium acetate $Ba(C_2H_3O_2)_2$			

Soil

Soil type	Clay loam					
Soil properties	Sand (%)	Silt (%)	Clay (%)	OM (%)	CEC (meq/100g)	pH
	29.9	40.7	29.5	1.2	23	7.7
Soil chemistry	Ba (mg/kg)	SO_4 (mg/kg)	EC (dS/m)			
	250 [a]	54 [a]	0.54			

Chemical Analysis

Analytical method	Nitric/hydrochloric acid digestion + ICP
Analytical recovery	Analytical recovery was calculated as effectively quantitative (regression from 36 datapoints gave a recovery of 101%, R=0.996)
Analytical basis for results	Toxicological results presented on the basis of measured concentrations. Analytical data confirmed that analytical recovery was within about 1% of nominal (allowing for background). Nominal values were converted to measured basis by applying the regression y = 1.0148x+285.4

Toxicity Tests (all values in mg/kg, presented on measured basis)

Test	**Alsike clover, *Trifolium hybridum*, 21 day definitive growth, EC (1998a)**			
Endpoint	NOAEC	LOAEC	IC20	IC50
Shoot length	793	1,300	1,157	1,468
Shoot dry mass [b]	na	na	583	1,030
Root length	na	na	948	1,220
Root dry mass [b]	793	1,300	767	966
Nodules	793	1,300	na	1,300
Test species, test	**Orchard grass, *Dactylis glomerate*, 14 day definitive growth, EC (1998a)**			
Endpoint	NOAEC	LOAEC	IC20	IC50
Shoot length	na	na	1,407	1,485
Shoot dry mass [b]	na	na	na	1,301
Root length	na	na	772	1,503
Root dry mass [b]	na	na	na	1,283
Test species, test	**Perennial ryegrass, *Loleum perenne*, 14 day definitive growth, EC (1998a)**			
Endpoint	NOAEC	LOAEC	IC20	IC50
Shoot length	na	362	511	2,206
Shoot dry mass [b]	590	793	536	995
Root length	793	1,300	945	1,456
Root dry mass [b]	793	1,300	850	1,248
Test species, test	**Springtail, *Onychiurus folsomii*, 35 day survival and reproduction, EC (1998b)**			
Endpoint	NOAEC	LOAEC	LC20/EC20	LC20/EC20
Adult survival	3,330	6,374	6,370	8,734
# juveniles [c]	3,330	6,374	1,461	3,636
Test species, test	**Earthworm, *Eisenia andrei*, 14 day survival, EC (2002)** [d]			
Endpoint	NOAEC	LOAEC	LC20	LC50
Adult survival	6,374	8,404	na	7,560

Notes:
na = not available or not applicable
Reports for rangefinding tests also presented in source document.
Only the longest valid test results for each species included here.
a. mean value
b. wet mass data also provided in source report, but not reproduced here due to the inherent variability in this measure and redundancy with dry weight
c. adult fecundity was also reported in the source document, but is not reproduced here on account of being considered redundant with # juveniles
d. a 35/63 day survival/reproduction test was also carried out, but resulting data were not amenable to statistical analysis.

APPENDIX B

EXCLUDED STUDIES

APPENDIX B – EXCLUDED STUDIES

This Appendix lists the studies that were identified, but subsequently screened out, and provides the rationale for screening each out.

Exclusion Rationale	Study
FL	Bruinsma, J. R. 1940. Field Tests with Potassium, Sodium, and Barium. Meded.Inst.Suikerbiet., Bergen op Zoom, Netherlands 10, 141-167 *Eco-SSL for Barium* 11 February 2005
Media	Chaney, W. R. and Strickland, R. C. 1984. Relative toxicity of heavy metals to red pine pinus resinosa pollen germination and germ tube elongation. *J Environ Qual.* 13[3]: 391-394**.**
No Dose	Cipollini, M. L. and Pickering, J. L. 1986. Determination of the Phytotoxicity of Barium in Leach-Field Disposal of Gas Well Brines. *Plant Soil*. 92[2]: 159-169**.**
Media	Clark, R. B., Pier, P. A., Knudsen, D., and Maranville, J. W. 1981. Effect of Trace Element Deficiencies and Excesses on Mineral Nutrients in Sorghum. *J. Plant Nutr.* 3[1-4]: 357-374**.**
Media	Davis, R.D., P.H.T. Beckett, and E. Wollan, 1978. Critical levels of twenty potentially toxic elements in young spring barley. Plant and Soil 49: 395-408.
Media	Debnath, R. 1982. Toxic Action of Barium Chloride on Germination, Growth and Metabolism of Rice (*Oryza sativaL.*). *Environ Exp Bot.* 22[2]: 203-210**.**
Media	Debnath, R. Bpaba and Mukherji, S. 1982. Barium effects in Phaseolus aureus, Cephalandra indica, Canna indica, Beta vulgaris, Triticum aestivum and Lactuca sativa (mung beans, beets, wheat, lettuce, air pollutants deleterious concentration influencing growth and respriation). *Biol. Plant.* 24[6]: 423- 429**.**
Mix	En, Z., A. Vasidov, V.V. Tsipin, T. Tillaev, G.I. Jumaniyazova, 2003. Study of element uptake in plants from the soil to assess environmental contamination by toxic elements. Nuclear Instruments and Methods in Physics Research A 505: 462–465
No COC	Grace, J. K. 1990. Oral toxicity of barium metaborate to the eastern subterranean termite Isoptera Rhinotermitidae. *Journal of Entomological Science.* 25 (1): 112-116.
Media	Grace, J.K., and A. Abdallay, 1990. Termiticidal activity of boron dusts (Isoptera, Rhinotermitidae). J. Appl. Ent. 109: 283-288.
No Dose	Guyette, R. P. and Cutter, B. E. 1994. Barium and manganese trends in tree-rings as monitors of sulfur deposition. *Water Air Soil Pollut*. 73[1/4]: 213-223**.**
No Dur	Hope, B., Loy, C., *and Miller, P. 1996. Uptake and Trophic Transfer of Barium in a Terrestrial Ecosystem. Bull. Environ. Contam. Toxicol.* 56[5]: 683-689.
Media	Iqbal, J. and Rafique, N. 1987. Toxic Effects of $BaCl_2$ on Germination, Early Seedling Growth, Soluble Proteins and Acid Phosphatases in *Zea mays* L. *Pak. J. Bot.* 19[1]: 1-8**.**
Media	Ke, Hueli Yang David, Anderson, Wendy L., Moncrief, Robyn M., Rayson, Gary D., and Jackson, Paul J. 1994. Luminescence studies of metal ion-binding sites on *Datura inoxia* biomaterial. *Environ. Sci. Technol*. 28[4]: 586-591**.**
Media	Lane, I. and Puckett, K. J. 1979. Responses of the Phosphatase Activity of the Lichen Cladina rangiferina to Various Environmental Factors Including Metals. *Can. J. Bot.* 57: 1534-1540.
Mix	Lawrey, J. D. 1979. Boron, Strontium, and Barium Accumulation in Selected Plants and Loss During

	Leaf Litter Decomposition in Areas Influenced by Coal Strip Mining. *Can J Bot.* 57[8]: 933-940**.**
Media	Llugany, M., Poschenrieder, C., and Barcelo, J., 2000. Assessment of barium toxicity in bush beans. Arch. Environ. Contam. Toxicol. 39: 440-444.
OM, pH	Marsh, C. D. 1912. Absorption of Barium Chloride by *Aragallus lamberti*. *Bot. Gaz.* 54: 250-252**.**
Species	Marsh, C. D., Alsberg, C. L., and Black, O. F. 1912. The Relation of Barium to Loco-Weed Disease 37997. U.S. Dep. Agric. Bur. Plant Ind. Bull. No**.** 246.
OM, pH	McFarland, M. L., Ueckert, D. N., Hons, F. M., and Hartmann, S. 1992. Selective-placement burial of drilling fluids ii. Effects on buffalograss and fourwing saltbush. *J Environ Qual.* 21[1]: 140-144.
Mix	McFarland, M.L., 1988. Selective placement disposal of drilling fluids in West Texas. PhD thesis. Texas A&M University, December 1988.
OM, pH	McHargue, J. S. 1919. Effect of Certain Compounds of Barium and Strontium on the Growth of Plants. *J. Agric. Res.* 16: 183-194**.**
Score	Miller, R. W., Honarvar, S., and Hunsaker, B. 1980. Effects of Drilling Fluids on Soils and Plants 1. Individual Fluid Components. *J. Environ. Qual.* 9[4]: 547-552**.** *Eco-SSL for Barium* 12 February 2005
Media	Minton, G. A. and Wilson, R. H. 1973. Effect of Ba Ions on the Growth and Mitochondrial Metabolism of Mung Bean Seedlings. *Plant Soil.* 39[3]: 611-617**.**
pH	Nyarai-Horvath, F., Szalai, T., Kadar, I., and Csatho, P. 1997. Germination characteristics of pea seeds originating from a field trial treated with different levels of harmful elements. *Acta Agron. Hung.* 452[147-154].
Mix **No COC**	Pichtel, J., K. Kuroiwa, and H.T. Sawyerr, 2000. Distribution of Pb, Cd and Ba in soils and plants of two contaminated sites. Environmental Pollution 110: 171-178.
Mix **No COC**	Raghu, V., 2001. Accumulation of elements in plants and soils in and around Mangampeta and Vemula barite mining areas, Cuddapah District, Andhra Pradesh, India. Environmental Geology, 40: 1265-1277
Ecol, Mix	Ravikovitch, S. and Margolin, M. 1959. The Effect of Barium Chloride and Calcium Sulphate in Hindering Selenium Absorption by Lucerne. *Emp.J.Exp.Agric*. 27, 235-240
Ecol, Mix	Ravikovitch, S. and Margolin, M. 1959. The Effect of Barium Chloride and Calcium Sulphate in Hindering Selenium Absorption by Lucerne. *Emp. J. Exp. Agric*. 27: 235-240**.**
Media	Reddy, T. and Vaidyanath, K. 1978. Mutagenic Potentiating and Antimutagenic Activity of Certain Metallic Ions in the Rice Genetic System. *Curr Sci.* 47[14]: 513-515**.**
In Vit	Siegel, S. M. 1977. The Cytotoxic Response of Nicotiana Protoplast to Metal Ions: A Survey of the Chemical Elements. *Water Air Soil Pollut.* 8[1-4]: 293-304**.**
Mix	Smith, K. A. 1971. The Comparative Uptake and Translocation by Plants of Calcium, Strontium, Barium and Radium. II. *Triticum vulgare* (Wheat). *Plant Soil.* 34[3]: 643-651.
Media	Steinberg, R. A. 1936. Effects of Barium Salts upon *Aspergillus niger*, and Their Bearing upon the Sulphur and Zinc Metabolism of the Fungus in an Optimum Solution. *Bot. Gaz.* 97: 666-671.
Media	Tatara, C.P., M.C. Newman, J.T. McCloskey, and P.L. Williams, 1998. Use of ion characteristics to predict relative toxicity of mono-, di- and trivalent metal ions: Caenorhabditis elegans LC50, Aquatic Toxicology 42: 255–269.
Mix	Tolle, Duane A., Arthur, Mickey F., Chesson, Jean, and Van Voris, Peter. 1985. Comparison of pots versus microcosms for predicting agroecosystem effects due to waste amendment. *Environ. Toxicol. Chem*. 4[4]: 501-509.
Mix	Vandenhove, H., T. Eyckmans, and M. Van Hee (2005). Can barium and strontium be used as tracers for radium in soil-plant transfer studies? Journal of Environmental Radioactivity 81:255-

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Rev	Vanselow, A. P. 1966. Barium. In: H.D.Chapman (Ed.), *Diagnostic Criteria for Plants and Soils*, University of California, Berkeley, CA , 24, 31-24, 32**.**
OM, pH	Voelcker, J. A. 1917. Pot-Culture Experiments, 1917. I. The Hills' Experiments - The Influence of Barium Compounds on Wheat. *J. R. Agric. Soc.* 78: 232-248.
Media	Wallace, A. and Romney, E. M. 1971. Some Interactions of Ca, Sr, and Ba in Plants. *Agron. J.* 63[2]: 245-248.
Media	Watanabe, T, and K. Okada, 2005. Interactive effects of Al, Ca, and other cations on root elongation of rice cultivars under low pH. Annals of Botany, 95: 379-385.
Media	Wettlaufer, S. H., Osmeloski, J., and Weinstein, L. H. 1991. Response of polyamines to heavy metal stress in oat seedlings. *Environ Toxicol Chem.* 10[8]: 1083-1088.
Media	Wilson, R. H. and Minton, G. A. 1974. The comparative uptake of barium ions and other alkaline earth metals by plant mitochondria. *Biochim. Biophys. Acta*. 333[1]: 22-27**.**

Key To Exclusion Criteria	
Exclusion Rationale	**Description**
MIXTURE **(Mix)**	Studies that report data for combinations of single toxicants (e.g. cadmium and copper) are excluded.
NO CONTAMINANT OF CONCERN **(No COC)**	Studies that do not examine the toxicity of the contaminant of concern.
NO DOSE or CONC **(No Dose)**	Studies with no usable dose or concentration reported, or an insufficient number of doses/concentrations are used.
NO DURATION **(No Dur)**	Studies with no exposure duration.
FOREIGN LANGUAGE **(FL)**	Studies in languages other than English.
IN VITRO **(In Vit)**	In vitro studies, including exposure of cell cultures, excised tissues and/or excised organs.
MEDIA **(Media)**	Authors must report that the study was conducted using natural or artificial soil. Studies conducted in pore water or any other aqueous phase (e.g., hydroponic solution), filter paper, petri dishes, manure, organic or histosoils (e.g., peat muck, humus), are not considered suitable for use in defining soil standards.
ECOLOGICAL INTERACTIONS **(Ecol)**	Studies of ecological processes that do not investigate effects of contaminant exposure.
REVIEW **(Rev)**	Studies in which the data reported in the article are not primary data from research conducted by the author. The publication is a compilation of data published elsewhere. These publications are reviewed manually to identify other relevant literature.