



Equilibrium Environmental Inc.



### New Tier 1 Boron Guideline for Alberta: Overall Guideline Development

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Remediation Technologies Symposium Banff, Alberta, October 16<sup>th</sup> 2015

# Acknowledgements

- Exova
- Petroleum Technology Alliance of Canada (PTAC)
- PTAC Boron Working Group
- Environment Canada
- Alberta Environment

## **Presentation Overview**

- Background
- Boron Sorption and K<sub>d</sub> Values
- Guideline Derivation for Soil Dependent Biota
- Livestock and Wildlife Toxicity
- Groundwater Pathways and Guidelines
- Other Soil Pathways and Guidelines
- Summary of Proposed Tier 1 Soil Remediation Guidelines

# Background

- Current Tier 1 guideline of 2 mg/kg HWS ('hot water soluble') boron an 'interim' guideline from 1991 based on professional judgment
- Good plant growth has been observed in the field and lab at levels above the current Tier 1 guideline

- e.g, 4-10 mg/kg HWS or higher for typical soils - see previous Exova presentation

• Saturated paste B (in mg/L) is more closely correlated to plant toxicity than HWS B over a range of soil textures

- HWS B test was designed to diagnose deficiency, not toxicity

- Saturated paste B represents boron dissolved in soil solution, HWS B captures large amounts of adsorbed boron
- Cases with background soils above the Tier 1 HWS guideline can be distinguished from impacted soils using saturated paste B
- Saturated paste B also relevant to groundwater transport and various groundwater pathways

→Other background information summarized in previous Exova presentation (Remtech, 2015)

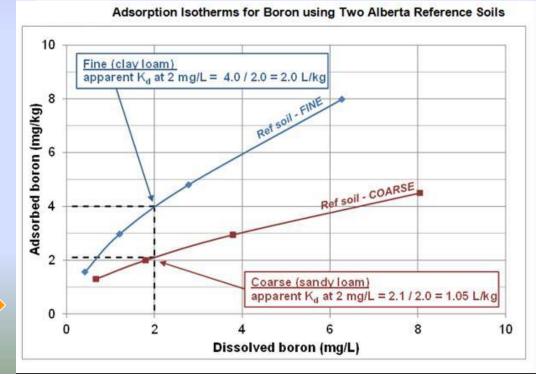
# **Boron Sorption and K<sub>d</sub> Values**

#### **Boron Adsorption in Soil – K**d **Aspects** K<sub>d</sub> is related to partitioning of boron between soil and pore

- K<sub>d</sub> is related to partitioning of boron between soil and pore water (soil solution)
- Soils with high clay content or organic matter content have greater surface area and thus higher sorptive ability
  - Adsorption is thus correlated to soil texture
- Sorption is commonly explored via a distribution coefficient, K<sub>d</sub> which is defined as:

K<sub>d</sub> = <u>adsorbed boron (mg/kg)</u> dissolved boron (mg/L)

K<sub>d</sub> often measured with batch adsorption isotherm experiments (example for Alberta reference soils)



## Boron Adsorption in Soil – K<sub>d</sub> Aspect

- Sorbed B cannot easily be measured directly, but the HWS test is a good proxy
  - HWS B  $\rightarrow$  measures sorbed B <u>plus</u> dissolved B
  - − Sat paste  $B \rightarrow$  measures dissolved B

 $= K_d + <u>Sat</u>%$ 

100

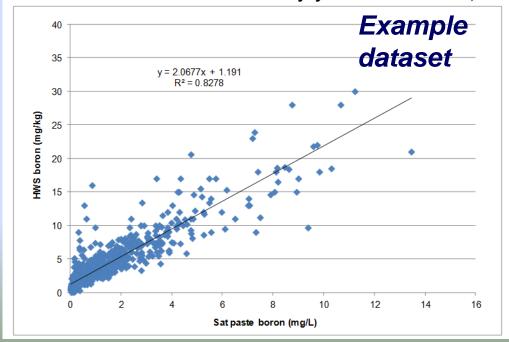
K<sub>d</sub> can be estimated

from slope:

HWS B (mg/kg)

sat paste B (mg/L)

 Often useful to plot HWS B (mg/kg) vs sat paste B (mg/L) for site data as indicator of soil sorption and allows estimation of K<sub>d</sub>

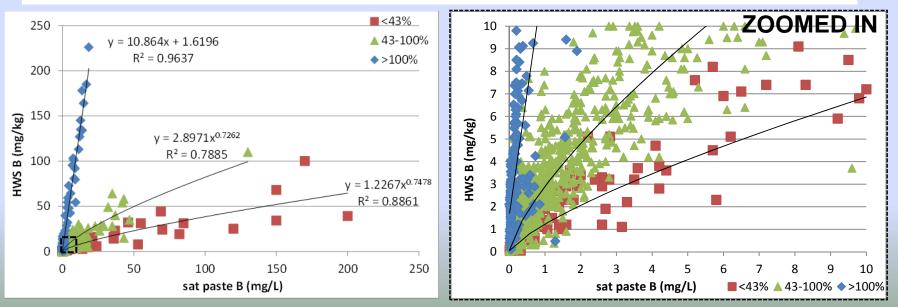


HWS vs Saturated Paste Boron for Clayey Soils Near Armena, Alberta

#### **Boron Adsorption in Soil – K<sub>d</sub> Aspect** Used this technique for over 2,300 data points from over 40

- Used this technique for over 2,300 data points from over 40 sites across Alberta spanning a range of soil textures
- K<sub>d</sub> correlated to texture via saturation percentage (sat % a proxy for texture, see Equilibrium 2014 PTAC presentation)

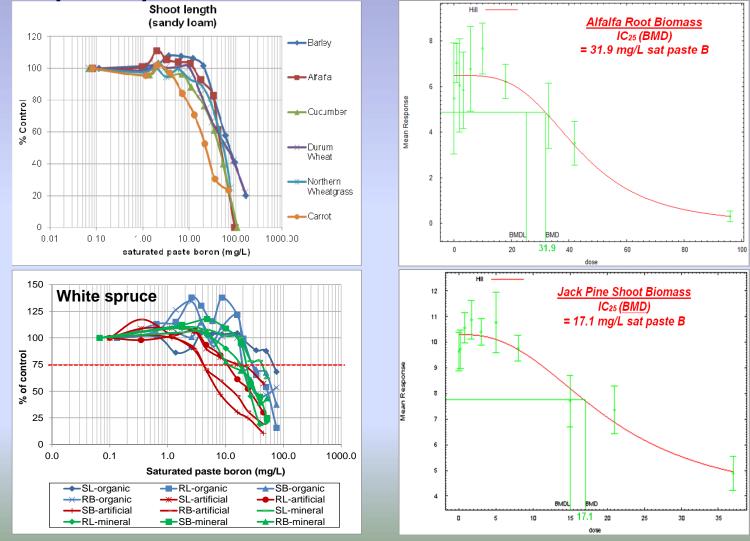
Estimated K <sub>d</sub> values for Typical Alberta Soils										
Saturation	Typical texture	Average K <sub>d</sub>	Average saturation							
percentage range		(L/kg)	percentage							
>100%	Heavy clay or organic soils	8.5	374%							
43-100%	Fine clayey soils	2.1	61%							
<43%	Coarser or silty soils	0.8	34%							



## Guideline Derivation for Soil Dependent Biota

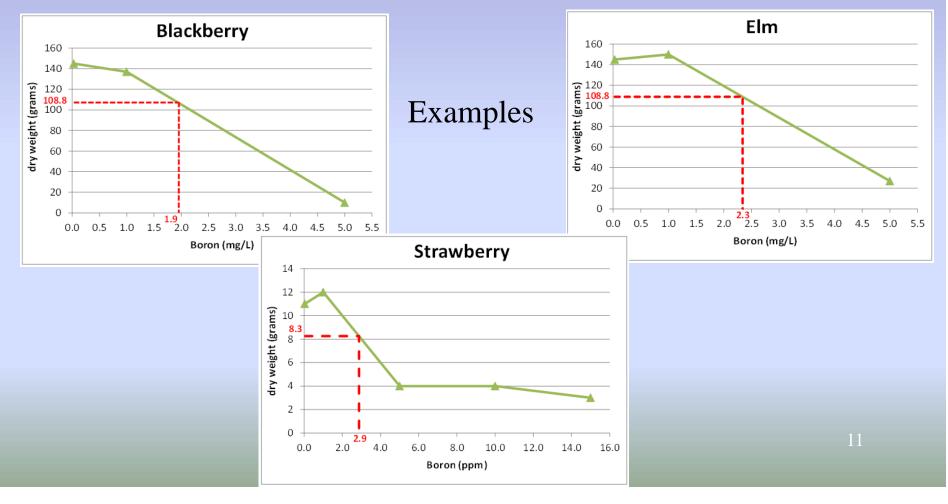
### Soil Dependent Biota - Plants (Exova)

 Recent toxicity studies carried out by Exova on Agricultural and Boreal plant species (See Exova 2015 Remtech presentation).
 Example responses and 25% effect levels shown below



## Soil Dependent Biota - Plants (literature)

- Toxicity research in California by Eaton (1944) on various fruit, vegetable and grass/grain species in sand cultures irrigated with boron at 0, 1, 5, 10, 15 mg/L.
- Visual effects and changes in biomass recorded
- IC<sub>25</sub>'s estimated for cases where clear dose-response observed



## Soil Dependent Biota - Plants (literature)

- More recent sand culture experiments carried out on additional foodcrops, and to refine threshold levels from the 1944 results
- Slopes and thresholds useful for estimating 25% effect levels (IC<sub>25</sub>'s)

Summary of Plant Species Thresholds, Slopes and Calculated IC<sub>25</sub>'s from Newer Sand Culture Experiments

Summary of Flant Species Thresholds, Slopes and Calculated 1025's non-Newer Sand Culture Experiments												
Common Name	Botanical Name	Tolerance Based on	Threshold B (mg/L)	Slope (%/mg·L <sup>-1</sup> )	Calculated IC <sub>25</sub> (mg/L)	Sensitivity Rating	Reference	Test Duration				
Barley	Hordeum vulgare	Grain yield	3.4	4.4	9.1	moderately tolerant	Bingham et al., 1985	6 months				
Bean, snap	Phaseolous vulgaris	Pod yield	1	12	3.1	sensitive	Francois, 1989	2.5 months				
Broccoli	Brassica oloracea (Botrytis group)	Head fresh weight	1	1.8	14.9	moderately sensitive	Francois, 1986	3.5 months				
Cauliflower	Brassica oloracea (Botrytis group)	Curd fresh weight	4	1.9	17.2	moderately tolerant	Francois, 1986	3.5 months				
Celery	Apium graveolens var. dulce (Mill.) Pers	Petiole fresh weight	9.8	3.2	17.6	very tolerant	Francois, 1988	4.5 months				
Cowpea	Vigna unguiculata Walp.	Seed yield	2.5	12	4.6	moderately tolerant	Francois, 1989	2-3 months				
Garlic	Allium sativum	Bulb yield	4.3	2.7	13.6	tolerant	Francois, 1991	7.5 months				
Lettuce	Lactuca sativa	Head fresh weight	1.3	1.7	16.0	moderately sensitive	Francois, 1988	3.5 months				
Onion	Allium cepa	Bulb yield	8.9	1.9	22.1	very tolerant	Francois, 1991	7.5 months				
Radish	Raphanus sativus	Root fresh weight	1	1.4	18.9	moderately sensitive	Francois, 1986	1.5 months				
Sorghum	Sorghum bicolor Moench	Grain yield	7.4	4.7	12.7	very tolerant	Bingham et al., 1985	4 months				
Squash, Scallop	<i>Cucurbita pepo</i> var melopepo Alef	Fruit yield	4.9	9.8	7.5	tolerant	Francois, 1992	1.5 months				
Squash, Winter	<i>Cucurbita moschata</i> Poir	Fruit yield	1	4.3	6.8	moderately sensitive	Francois, 1992	3 months				
Squash, zucchini	<i>Cucurbita pepo</i> var melopepo Alef	Fruit yield	2.7	5.2	7.5	moderately tolerant	Francois, 1992	1.5 months				
Sugar beet	Beta vulgaris	Storage Root fresh weight	4.9	4.1	11.0	tolerant	Vlamis & Ulrich, 1973	1.5 months				
Tomato	Lycopersicon lycopersicum Karst. Ex Farw.	Fruit yield	5.7	3.4	13.1	tolerant	Francois, 1984b	3-4 months				
Wheat	Triticum aestivum	Grain yield	0.75-1.0 <sup>1</sup>	3.3	8.3	sensitive	Bingham et al., 1985; Khudairi, 1961	6 months				

### Soil Dependent Biota – Soil Invertebrates

- Soil invertebrates such as earthworms, springtails and mites are important receptors in soil, along with plants
- Recent Exova research in combination with toxicity data from published literature and method development studies was combined to derive IC<sub>25</sub>'s across species and soil types
  - Substantial work done by Environment Canada, Method Development Unit
- Reproductive endpoints used to derive IC<sub>25</sub>'s are shown below as an example of the invertebrate dataset
- In many cases sat paste boron estimated from spiked levels and regressions. For Exova tests, sat paste B measured directly

				<b>_</b>						
	Species	Test	Duration	Soil	Measure	Boron (B) added	sat paste Boron	Reference		
						(mg/kg)	(mg/L)			
Earthworm	Esenin andrei	reproduction	63 days	sandy loam	IC25	*	26.4	* Exova, 2013		
Earthworm	Dendrodrilus rubidus	reproduction	56 days	artificial	IC25	47	13.5	Environment Canada, 2008-2010		
Earthworm	Eisenia andrei	reproduction	84 days	clay loam	IC25	28	13.1	Ingraldi, 2004		
Oribatid mite	Oppia nitens	reproduction	28 days	artificial	IC25	44	12.0	Environment Canada, 2006-2010		
Springtail	Proisotoma minuta	reproduction	21 days	artificial	EC25	37	9.4	Environment Canada, 2010-2012		
Earthworm	Eisenia andrei	reproduction	63 days	sandy loam	IC25	*	5.4	* Exova, 2013		
Springtail	Folsomia candida	reproduction	28 days	artificial	IC25	27	5.6	Environment Canada, 2007c		
Oribatid mite	Oppia nitens	reproduction	28 days	loam with 2-7% OM	IC25	13	5.1	Princz, 2010		
Springtail	Folsomia fimetaria	reproduction	21 days	clay loam	clay loam IC25 13 4.7		CECOTOX, 2005			
Earthworm	Eisenia andrei	reproduction	84 days	clay loam	clay loam IC25 12 4.4		Ingraldi, 2004			
Springtail	Folsomia fimetaria	reproduction	21 days	artificial	IC25	15	2.4	CECOTOX, 2005		
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Invertebrate Boron Toxicity – 25% Effect Data on Reproductive Endpoints

### **Guideline to Protect Soil Dependent Biota**

- Direct eco-contact guideline derived based on the ranked IC<sub>25</sub>s for all soil dependent biota which includes:
  - -Agricultural plants (crops, grasses, trees, fruits, vegetables)

-Boreal plants (trees, grasses, other plants)

- -Soil invertebrates (earthworms, mites, springtails)
- Coarse and fine grained soil generally combined since similar responses on sat paste B basis
- The IC<sub>25</sub>s for soil dependent biota were plotted in a species sensitivity distribution (SSD). Guidelines determined from best fit to toxicity data SSD (log-linear distribution):

Agricultural, Natural, Residential/Parkland (25<sup>th</sup> percentile):

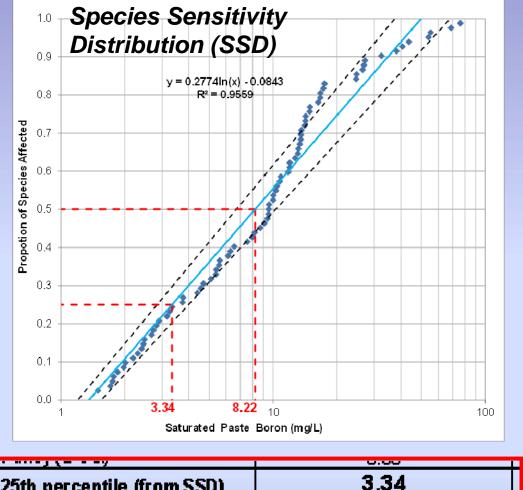
<u>Direct eco-contact guideline = 3.3 mg/L sat paste B</u> Commercial/Industrial (50<sup>th</sup> percentile):

Direct eco-contact guideline = 8.2 mg/L sat paste B

\*Subject to final regulatory approval

Sector (A) Fears (A model (C) Back (model (C) C) Fears (A model (C) C) Alex (A model (C) C) C) Alex (A model (C) C) C) C) Alex (A model (C) C) C) C) Alex (A model (C) C) C) C) C) C) C) C) C) C) C) C) C) C	Descript	tion	IC <sub>a</sub> (mg/L sat paste B)	Rank	CCME rank percentile	So	bil	Γ
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Name         Stage         Colo         Stage         Colo           Stage         Stage<							2	
Countrier - shote (3. 8)       8.2       33       0.44         Path (6 C n)       7.98       35       0.44         Bade nt - rote (11 N)       7.68       34       0.41         Common whee (8 Out)       6.52       33       0.40         Bade nt - rote (11 N)       6.52       33       0.40         Bade nt - rote (11 N)       6.52       33       0.40         Bade nt - rote (11 N)       6.52       33       0.40         Bade nt - rote (11 N)       6.53       32       0.35         Chan (13 C U)       6.62       23       0.33       0.37         Attin (13 C U)       6.63       23       0.33       0.17         Attin (13 C U)       6.63       23       0.33       0.17         Attin (13 C U)       6.63       23       0.33       0.1         Beenia and (21 U)       6.40       28       0.33       0.1         Chan (13 C U)       1.47       20       0.20       0.1         Chan (13 C U)       1.77       22       0.22       0.1         Chan (13 C U)       1.33       13       0.23       0.1         Devel and (21 U)       1.42       14       0.17       0.1							<u>م</u>	
Countrier - shote (3. 8)       8.2       33       0.44         Path (6 C n)       7.98       35       0.44         Bade nt - rote (11 N)       7.68       34       0.41         Common whee (8 Out)       6.52       33       0.40         Bade nt - rote (11 N)       6.52       33       0.40         Bade nt - rote (11 N)       6.52       33       0.40         Bade nt - rote (11 N)       6.52       33       0.40         Bade nt - rote (11 N)       6.53       32       0.35         Chan (13 C U)       6.62       23       0.33       0.37         Attin (13 C U)       6.63       23       0.33       0.17         Attin (13 C U)       6.63       23       0.33       0.17         Attin (13 C U)       6.63       23       0.33       0.1         Beenia and (21 U)       6.40       28       0.33       0.1         Chan (13 C U)       1.47       20       0.20       0.1         Chan (13 C U)       1.77       22       0.22       0.1         Chan (13 C U)       1.33       13       0.23       0.1         Devel and (21 U)       1.42       14       0.17       0.1	Summer bent /S Cult	13 441		37			0.2	
Potor(8 Cml         7.98         35         0.43           Badom - rook f/H         7.65         34         0.41           Common whee( (3 Cut)         6.65         33         0.40           Budom - rook f/H         6.23         32         0.33           Common whee( (3 Cut)         6.60         33         0.40           Budom - rook f/H         6.60         33         0.40           Common whee( (3)         6.40         6.60         33         0.33           Price marks (A         6.60         33         0.33         0.33           Price marks (A         6.60         33         0.33         0.33           Price marks (Cut)         6.61         33         0.33         0.33           Price marks (Cut)         6.62         29         0.33         0.33           Price marks (Cut)         4.77         25         0.33         0.33           Courting mark (Cut)         4.47         22         0.22         0.1           Courting Circl         3.77         22         0.22         0.27           Courting Circl         3.77         22         0.22         0.27           Court (S Cut)         3.13         13         <		CL SU		36			0.5	
Common views (6 Cu)         6.63         33         0.40           Bing in - stack (4)         6.23         33         0.38           Control condul (4)         6.63         33         0.38           Followin (20 - condul (4)         6.63         33         0.37           Affeit (5 Cu)         6.66         23         0.35           Breek andel (8)         6.43         28         0.34           Breek (3)         6.43         28         0.32           Court for the fination (1)         6.13         28         0.32           Court for the fination (1)         6.17         28         0.32           Court for the fination (1)         6.17         20         0.27           Court for the fination (1)         3.17         22         0.27           Court for (1)         3.13         10         0.24           Lambor (1)         2.23         14         0.24           Line (2)         13         0.16         0.17 </td <td></td> <td></td> <td>7.98</td> <td>35</td> <td></td> <td></td> <td></td> <td></td>			7.98	35				
Budgent - decki (SN)         6.33         32         0.39           Call (S Cut         6.13         31         0.38           Falscrin candid (A         6.60         33         0.37           Main (S Cut)         6.60         33         0.37           Sevel acadid (A         6.60         33         0.37           Main (S Cut)         6.60         33         0.35           Bevel acadid (A)         6.60         33         0.34           Specent (CL)         6.13         28         0.32           Count new (D)         6.13         28         0.32           Count new (D)         6.13         28         0.32           Count new (D)         6.47         24         0.29           Count (S Cut)         3.77         22         0.27           Count (S Cut)         3.78         21         0.26           Count (S Cut)         3.13         13         0.22           Date (S Cut)         2.27         15         0.16           Lambour (S Cut)         2.43         13         0.12           Jambe (S Cut)         2.27         15         0.16           Jambe (S Cut)         2.23         11 <td< td=""><td></td><td></td><td></td><td>34</td><td></td><td></td><td></td><td></td></td<>				34				
Folionin condition         6.60         30         0.37           Afrife SC 00         6.68         29         0.35           Benefit andref (01)         6.40         29         0.34           Speech (3 Cub)         6.63         27         0.33           Code in meeting (CL)         6.77         22         0.32           Course in meeting (CL)         4.77         25         0.30           Course in meeting (CL)         4.77         22         0.29           Course in meeting (CL)         4.47         24         0.29           Course in meeting (CL)         4.47         24         0.29           Course in meeting (CL)         4.47         24         0.29           Course in meeting (CL)         4.17         21         0.20           Course ing (CC u)         3.25         13         0.20           Course ing (CC u)         2.23         13         0.22           Street pare if S Cub         2.27         0.21         0.01           Lanieour (SC Cub         2.23         13         0.20         14           Street pare if S Cub         2.45         12         0.16         255th per (15           Street pare if S Cub         2.45	Common wheet (S	Cuij		30			0.0	
Folionin condition         6.60         30         0.37           Afrife SC 00         6.68         29         0.35           Benefit andref (01)         6.40         29         0.34           Speech (3 Cub)         6.63         27         0.33           Code in meeting (CL)         6.77         22         0.32           Course in meeting (CL)         4.77         25         0.30           Course in meeting (CL)         4.77         22         0.29           Course in meeting (CL)         4.47         24         0.29           Course in meeting (CL)         4.47         24         0.29           Course in meeting (CL)         4.47         24         0.29           Course in meeting (CL)         4.17         21         0.20           Course ing (CC u)         3.25         13         0.20           Course ing (CC u)         2.23         13         0.22           Street pare if S Cub         2.27         0.21         0.01           Lanieour (SC Cub         2.23         13         0.20         14           Street pare if S Cub         2.45         12         0.16         255th per (15           Street pare if S Cub         2.45	Code /S Cuit			32			0.2	-
Ministry (SCu)         6.62         29         0.35           Bevel (SCu)         6.43         29         0.34           Squeeh (SCu)         6.43         27         0.33           Opein neuro (C)         6.13         22         0.32           Pederin finaturis (CL)         6.13         22         0.33           Opein neuro (C)         0.1         4.77         22         0.32           Develo nello(CL)         0.47         24         0.29         0.1           Count Store (C)         0.1         4.77         22         0.27           Corn (S Cu)         3.35         22         0.27         0.0           Corn (S Cu)         3.35         22         0.27         0.0           Corn (S Cu)         3.35         22         0.24         1           Latispur (S Cu)         3.35         23         0.24         1           Latispur (S Cu)         2.73         15         0.18         1           Jame (S Cu)         2.43         13         0.12         2         2           Jame (S Cu)         2.44         13         0.18         2         2         5           Jame (S Cu)         2.02		6		31				
Bends and/el (31)         5.40         27         0.34           Breek (32 Cub         6.38         27         0.38           Oracle mitter (1)         6.13         28         0.32           Followin mitter (1)         6.13         28         0.32           Count mitter (1)         6.13         28         0.32           Count mitter (1)         6.13         28         0.32           Count mitter (1)         6.47         28         0.30           Count mitter (1)         6.47         28         0.32           Count mitter (1)         6.47         28         0.29           Count (1)         6.47         22         0.27           Count (1)         3.38         21         0.24           Lambour (1) Cub         3.38         23         0.24           Lambour (1) Cub         2.27         13         0.22           Break pine (1) Cub         2.27         13         0.20           Break pine (1) Cub         2.27         13         0.20           Break pine (1) Cub         2.23         13         0.22           Image Cub         2.27         13         0.20           Break pine (1) Cub         2.45	Afaire (SCub			29				
Open in Norm (1)         6.17         28         0.32           Feborin Reserve (1)         4.77         28         0.30           Courtie method (21)         4.47         22         0.29           Courtie method (21)         4.47         22         0.27           Court (2 Coll         3.77         22         0.27           Court (2 Coll         3.77         22         0.27           Court (2 Coll         3.77         22         0.27           Court (2 Coll         3.78         20         0.24           Lambour (3 Coll         3.25         13         0.22           Sevet see (3 Coll         230         17         0.21           Line been (3 Coll         230         17         0.21           Line been (3 Coll         230         17         0.21           Line been (3 Coll         243         13         0.16           Data (5 Coll         2.43         13         0.16           State (5 Coll         2.43         13         0.16           Data (5 Coll         2.45         12         0.16           Data (5 Coll         2.17         6         0.07           State see (1)         1.77         4	Geenis endel (SL)			23	0.34		<b>.</b> .	
Folionic finature (CL)         4.72         25         0.30           Countine - react (C - 0L)         4.67         28         0.28           Countine - react (C - 0L)         4.67         20         0.28           Countine - react (C - 0L)         4.67         20         0.28           Countine - react (C - 0L)         4.67         20         0.28           Countine - react (C - 0L)         4.67         20         0.20           Davis andel (CL)         3.77         22         0.27           Corror (S Cul)         3.77         22         0.27           Corror (S Cul)         3.78         20         0.24           Lambour (S Cul)         3.25         13         0.20           Paulo (S Cul)         2.28         13         0.20           Davis (S Cul)         2.28         13         0.20           Davis (S Cul)         2.28         13         0.18           Inno been (S Cul)         2.23         15         0.16           Inno been (S Cul)         2.43         13         0.18           Inno been (S Cul)         2.73         11         0.13           Cours as (R Cul)         2.73         12         0.4	Squeeh (3 Cui)						0.1	
Oscuritor - resta (C_00)         4.47         94         0.28           Oscuritor - resta (C_00)         4.47         20         0.20           Oscuritor - resta (C_00)         4.47         22         0.20           Oscuritor - resta (C_00)         3.77         22         0.27           Cernol (C 00)         3.78         22         0.27           Cernol (C 00)         3.25         20         0.24           Lambur (S Cu0)         3.26         13         0.22           Sweet per (S Cu0)         2.27         13         0.22           Sweet per (S Cu0)         2.27         13         0.22           Data (S Cu0)         2.27         13         0.20           Line teen (S Cu0)         2.27         13         0.20           Line teen (S Cu0)         2.27         13         0.20           Line teen (S Cu0)         2.27         13         0.16           Breachard Artich (S Cu0)         2.43         13         0.16           Grave per (S Cu0)         2.23         0         0.10           Conv per (S Cu0)         1.07         6         0.00           Breachard Arch (G Cu0)         1.77         4         0.00           <								
Control and/01         4.43         22         0.20           Durky (100)         3.77         22         0.27           Cerrol (100)         3.77         22         0.27           Cerrol (100)         3.78         21         0.26           Corn (100)         3.25         13         0.26           Corn (100)         3.25         13         0.26           Street pee (100)         3.25         13         0.22           Breet pee (100)         2.27         0.27         0.21           Line ban (100)         2.27         15         0.16           Breet pee (100)         2.43         13         0.17           Mate pee (100)         2.45         12         0.16           Breet pee (100)         2.45         12         0.16           Breet pee (100)         1.02         6         0.07           Grame (1010)         1.77         6         0								· ,
Budyr(80-6)         3.77         22         0.27           Carna (30-6)         3.78         21         0.26           Carna (30-6)         3.35         22         0.27           Latispur (30-0)         3.25         22         0.27           Latispur (30-0)         3.25         22         0.24           Latispur (30-0)         3.25         14         0.22           Breed pee (50-0)         2.30         17         0.24           Latispur (30-0)         2.273         15         0.16           Line been (50-0)         2.273         15         0.16           Line been (50-0)         2.43         13         0.17           Line been (50-0)         2.43         13         0.18           Line been (50-0)         2.43         13         0.18           Line been (50-0)         2.43         13         0.18           Corr sen (%C16)         2.73         11         0.13           Corr sen (%C16)         2.73         11         0.13           Corr sen (%C16)         1.45         7         0.00           Chevr (60-0)         1.45         7         0.00           Chevr (60-0)         1.45         2	Cucurnoer - roece ru							1
Complete         174         21         0.26           Com 18 Gui         1.05         20         0.34           Latieur (SCu)         1.25         13         0.22           Res (SGui         2.33         13         0.22           Street pee (S Cu)         2.23         13         0.22           Line been (S Cui         2.23         13         0.22           Line been (S Cui         2.28         13         0.20           Date (S Cu)         2.273         15         0.16           Line been (S Cui         2.28         13         0.20           Bate leen (S Cui         2.43         13         0.17           Mate leen (S Cui         2.43         13         0.16           Bate leen (S Cui         2.43         13         0.16           Core sen (G Cu)         2.43         13         0.16           Core sen (G Cu)         2.43         11         0.13           Bate leen (S Cu)         2.03         6         0.09           Charry (G Cu)         1.77         6         0.09           Charry (G Cu)         1.77         3         0.04           Bate leen (G Cu)         1.44         2 <t< td=""><td>Budar/S Cal</td><td></td><td></td><td></td><td></td><td></td><td>0.0</td><td>- / /</td></t<>	Budar/S Cal						0.0	- / /
Com (S Cut)         1.35         20         0.24           Lambur (S Cut)         1.25         13         0.22           Rev(S Cut)         2.25         13         0.22           Brevel pee (S Cut)         2.20         17         0.21           Line been (S Cut)         2.22         13         0.20           Zoole (S Cut)         2.282         13         0.20           Zoole (S Cut)         2.282         13         0.20           Zoole (S Cut)         2.282         13         0.20           Ameeting Aftich (S Cut)         2.283         14         0.17           Kit heam (S Cut)         2.43         13         0.18           Stans been (S Cut)         2.43         13         0.18           Branch SCut)         2.43         13         0.16           Cour see (R Cut)         2.43         13         0.16           Cour see (R Cut)         2.13         9         0.11           Motet (S Cut)         1.20         6         0.00           Brewlery (S Cut)         1.20         6         0.00           Brewlery (S Cut)         1.25         6         0.00           Brewlery (S Cut)         1.77								1
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Com (5 Cui)			2	0.24			1
Break part (S Cu)         250         17         0.21           Una base (S Cu)         2.82         13         0.20           Data (S Cu)         2.82         13         0.20           Marken (S Cu)         2.73         15         0.16           Marken (S Cu)         2.43         13         0.17           Marken base (S Cu)         2.43         13         0.18           Brew base (S Cu)         2.43         13         0.18           Brew base (S Cu)         2.43         13         0.18           Chruzen (S Cu)         2.43         13         0.18           Chruzen (S Cu)         2.43         13         0.18           Chruzen (S Cu)         2.43         13         0.19           Chruzen (S Cu)         2.43         13         0.19           Visit (S Cu)         2.02         6         0.10           Brewlarry (S Cu)         1.45         7         0.00           Grave (S Cu)         1.77         6         0.00           Grave (S Cu)         1.77         3         0.04           Marken (S Cu)         1.44         2         0.04           Marken (S Cu)         1.43         0.04         <	Leriepur (SCul)		12					
Line ben (8 Cu)         282         13         0.20           Zmak (3 Cu)         273         15         0.16           Amseur Arch (8 Cu)         283         14         0.17           Md ben (8 Cu)         2.43         13         0.18           Sma ben (8 Cu)         2.43         13         0.18           Sma ben (8 Cu)         2.43         13         0.16           Cour and (3 Cu)         2.43         13         0.16           Cour and (3 Cu)         2.13         9         0.11         0.12           Mokel (8 Cu)         2.02         6         0.00         500th per (           Browleary (8 Cu)         1.02         6         0.00         500th per (           Churr (8 Cu)         1.02         6         0.00         500th per (           Using (2 Cu)         1.77         3         0.00         500th per (           Using (2 Cu)         1.71         3<								
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Sweet pee (S Cup							
Arresolur, Artich 8 Gul     288     14     0.17       Add bann RG Gul     2.43     13     0.18       Brain bann G Gul     2.43     12     0.16       Grain bann (G Gul)     2.43     11     0.13       Grain bann (G Gul)     2.43     11     0.13       Chur and (G Gul)     2.73     11     0.13       Branch (G Gul)     2.13     0     0.11       Branch (G Gul)     2.13     0     0.11       Branch (G Gul)     1.02     0     0.09       Churry (G Gul)     1.02     0     0.09       Churry (G Gul)     1.07     6     0.09       Chur (G Gul)     1.77     4     0.06       Chur (G Gul)     1.77     4     0.06       Chur (G Gul)     1.44     2     0.04       Masser (K Cub)     0.63     -     -       Zifn sercentle from SSD)     3.34     -     -	Zinele (2 Cul)							
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Jamesium Atlah (3	Cuf						
Base bein (3 Cut.         2.45         12         0.16         25         12         0.16         25         12         0.16         25         11         0.13         13         0.13         13         0.13         13         0.13         13         0.11         0.13         13         0.11         0.13         0.11         0.13         0.11         0.13         0.11         0.13         0.11         0.11         0.13         0.10         0.11	Kid been (SCui)							
Circums (RC(1))         2.11         11         112           Parech (SC 4)         2.02         9         0.11           Model (S Cu)         2.02         9         0.10           Brownbary (S Cu)         1.02         9         0.10           Brownbary (S Cu)         1.02         9         0.00           Churry (S Cu)         1.02         9         0.00           Churry (S Cu)         1.02         9         0.00           Brownbary (S Cu)         1.73         6         0.00           Lughe (S Cu)         1.71         3         0.04           Listed (Cu)         1.65         2         0.05           Lughe (S Cu)         0.65         0.05         0.05           Zifn sercentle (rom SSD)         3.34         -         -			2.45			26	iéh me	
Circums (RC(1))         2.11         11         112           Parech (SC 4)         2.02         9         0.11           Model (S Cu)         2.02         9         0.10           Brownbary (S Cu)         1.02         9         0.10           Brownbary (S Cu)         1.02         9         0.00           Churry (S Cu)         1.02         9         0.00           Churry (S Cu)         1.02         9         0.00           Brownbary (S Cu)         1.73         6         0.00           Lughe (S Cu)         1.71         3         0.04           Listed (Cu)         1.65         2         0.05           Lughe (S Cu)         0.65         0.05         0.05           Zifn sercentle (rom SSD)         3.34         -         -	Folornia finatoria (	<b>A</b>				Z;	յա թւ	31 CU
Visit (S Cu)         202         9         0.10           Brownery (S Cu)         1.89         7         0.00           Brownery (S Cu)         1.00         9         0.00           Churry (S Cu)         1.00         9         0.00           Churry (S Cu)         1.00         9         0.00           Churry (S Cu)         1.77         6         0.00           Dark (S Cu)         1.71         3         0.04         *         Subject           Lughts (S Cu)         1.71         3         0.04         *         Subject           Zifn sercentle from SSD)         3.34         -         -         -								
Charm (G Crit)         1.00         0         0.007           Graw (G Crit)         1.73         6         0.008           Enr (G Crit)         1.73         6         0.008           Lumin (G Crit)         1.71         3         0.04           Lister (G Crit)         1.44         2         ULL2           Lister (G Crit)         0.63         -         0.01           Z5th sercentile (from SSD)         3.34         -         -						E1	14h	
Charm (G Crit)         1.00         0         0.007           Graw (G Crit)         1.73         6         0.008           Enr (G Crit)         1.73         6         0.008           Lumin (G Crit)         1.71         3         0.04           Lister (G Crit)         1.44         2         ULL2           Lister (G Crit)         0.63         -         0.01           Z5th sercentile (from SSD)         3.34         -         -	Branchory & Cut					<b>1</b> 0	JULI PE	si cei
Owner(BCu)         173         6         0.08           Br (8 Cu)         1.73         4         0.05           Lught (C cu)         1.71         3         0.04           Lister (C cu)         1.44         2         ULL           Lister (C cu)         0.63         -         -           Z5h sercentle (ron SSD)         3.34         -         -	Cherry (C Cal)							_
Er (8 Cu) 1.75 4 0.06 **********************************	Grass (SCub							
Zifn sercentile from SSD) 3.34			1.75			+0		
Zifn sercentile from SSD) 3.34							In	
Zifn sercentile from SSD) 3.34			1.49	2				
aven perceitae promisiau) 0.222				-				
	oun percentile (r	om 550)	8.22		-			

# Soil Dependent Biota -Combined Ranked IC<sub>25</sub>s



-	(from SSD)	8.22

Subject to final regulatory approval

# Livestock and Wildlife Toxicity

#### Livestock and Wildlife Soil & Food Ingestion Grazing animals may be exposed to elevated boron and other metals

- Grazing animals may be exposed to elevated boron and other metals which have accumulated from soil into consumed vegetation
- Boron is less toxic to grazers than some other metals such as molybdenum and selenium, but in some cases naturally occurring boron can be ingested at potentially toxic levels. <u>Examples:</u>
- Sheep in Kazakhstan grazing on soils with highly-elevated natural boron were observed to have symptoms of toxicity (enteritis)
- Lambs in the Kulundinsk Steppe in Russia grazing on soils with highly-elevated natural boron also observed to have symptoms of toxicity
- Mallards in the San Joaquin Valley in California exposed to high boron (and selenium) levels in surface waters in irrigated regions



Image from: 'http://californiaagriculture.ucanr.org/landingpage.cfm?Article=ca.v063 n01p 41&fulltext=yes

### Livestock and Wildlife Soil & Food Ingestion

- Toxicity data from literature reviewed for rats, mice, cattle, chickens, mallards, rabbits, etc
- Variability of data between the studies poses challenges in deriving IC<sub>25</sub>s. For example: limited dose ranges, study duration, unavailable feed rate or body weight information, lack of reproductive data, lack of clear dose response relationships, etc.

→ toxicity data deemed more appropriate for identifying general ranges or the absence/onset/presence of effects, but is insufficient for identifying quantitative  $EC_{25}$  levels for a sufficient range of sensitive endpoints and relevant species as per CCME (2006) protocol.

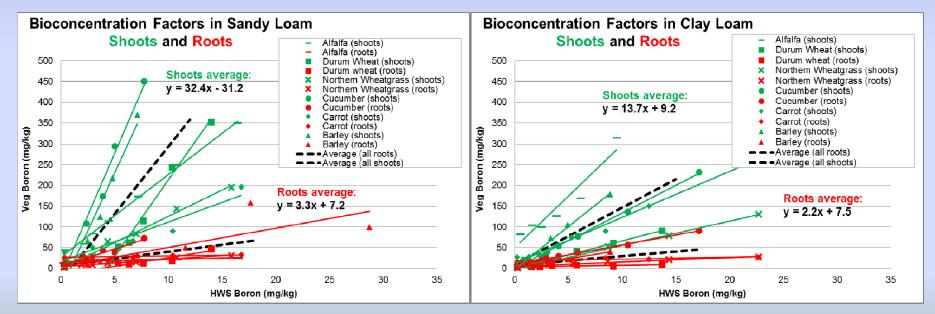
Thus, a guideline for protection of livestock and wildlife soil and food ingestion is not explicitly derived, rather exposures and risks have been evaluated for typical species assuming soils at the direct ecocontact guideline for plants/invertebrates

### Livestock and Wildlife Soil & Food Ingestion

- B uptake into plants described by 'bioconcentration factors' (BCF's)
- Estimated daily exposures to B calculated from soil at 3.3 mg/L sat paste using vegetation BCF's

BCF = vegetation boron (mg/kg) / soil boron (mg/kg HWS boron)

• BCF's vary with soil texture if using HWS B. Differences become less if using sat paste B (mg/L) instead, but BCF's typically calculated on mg/kg basis and thus retained here



 Average BCF (roots and shoots combined) is 15.5 for coarse soil and 9.6 for fine soil, consistent with other AB field and tub studies

## Livestock and Wildlife Soil & Food Assuming soil at 3.3 mg/L sat paste B, typical HWS values estimated as

- Assuming soil at 3.3 mg/L sat paste B, typical HWS values estimated as 4.8 mg/kg (coarse soil) or 7.0 mg/kg (fine soil) HWS
  - based on reference soils will vary site-to-site depending on soil type
- Vegetation boron concentrations of 74 mg/kg (coarse) and 67 mg/kg (fine) estimated from the BCF's from previous slide
- Expected daily exposures for various livestock/wildlife species calculated, and compared to various estimated toxicity thresholds from literature

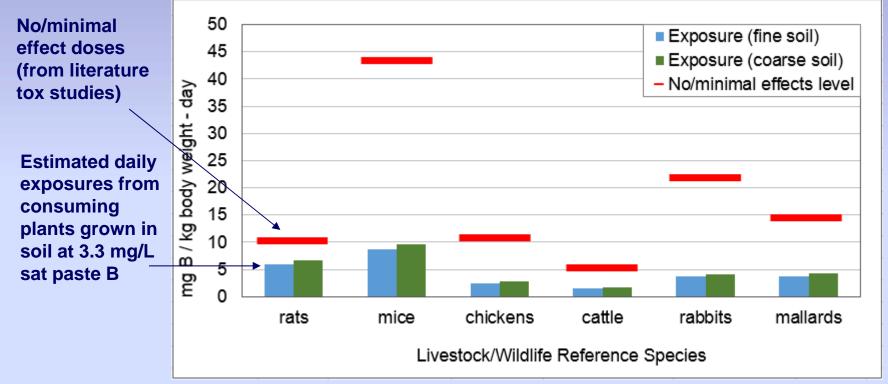
#### • Relative exposures shown as exposure ratios

Species	Body	Food Ingestion	Expo	osure	Daily dose for no/minimal	Toxicity endpoint	Primary	-	osure atio		
opecies	Weight	Rate	fine	coarse	effects		reference	fine	coarse	All	
	kg	kg/day	mg/kg-day	mg/kg-day	mg/kg-day			-	-	ovposuro	
rats	0.24	0.021	6.0	6.6	10.3	BMDL <sub>05</sub> (reduced fetal weight)	US EPA, 2004a,b	0.58	0.64	exposure ratios <1	
mice	0.028	0.0036	8.8	9.7	43	NOAEL (reduced fetal success, body weight, malformations)	Heindel, 1992, 1994	0.20	0.22		
chickens	3.7	0.14	2.5	2.7	10.9	NOAEL/LOAEL (reduced hatchability, damaged sperm cells)	Rossi, 1993a	0.23	0.25		
cattle	550	12.3	1.5	1.7	5.5	NOAEL (increased phosphate excretion)	Weeth, 1981	0.27	0.30		
rabbits	3.5	0.19	3.7	4.1	22	NOAEL (reduced fetal success, malformations)	Heindel, 1994	0.17	0.19		
mallards	1.1	0.062	3.8	4.2	14.6	NOAEL (reduced brain ATP levels and activity levels)	Hoffman, 1990	0.26	0.29	20	

### Livestock and Wildlife Soil & Food Ingestion

Shown graphically, all exposures ratios are <1</li>

(*i.e.*, below thresholds) –implies minimal risk from food



- Exposure to B from soil ingestion negligible compared to food
- Exposure to B in drinking water assumed to be 25% of threshold
- All exposure ratios below 0.75 (75%), indicating minimal risk to livestock and wildlife from food, soil, and water

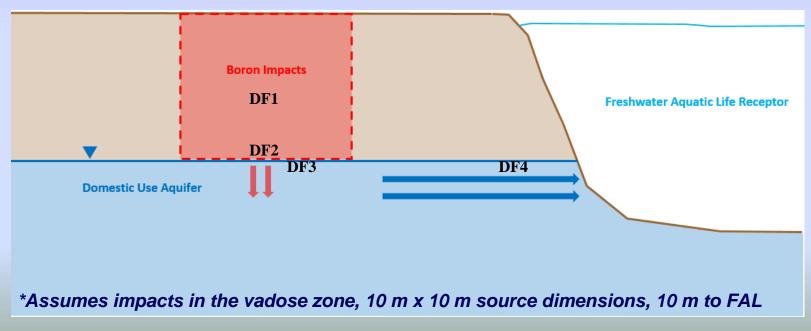
# Groundwater Pathways and Guidelines

## **SRGs to Protect Groundwater Pathways**

- Groundwater boron guidelines can be converted to generate SRGs in mg/L sat paste, to protect groundwater pathways such as:
  - Irrigation water

- Human drinking water
- Aquatic life
   Livestock drinking water
- Uses Alberta Environment Tier 1 methodology;
   →GW guideline x DF1 x DF2 x DF3 X DF4

#### AENV Dilution Factors (DF1, DF2, DF3, DF4):



## **SRGs to Protect Groundwater Pathways**

#### **DF1: Partitioning:**

- The DF1 equation below has been modified from the Tier 1 protocol to express the ratio between saturated paste boron and soil solution boron at a given soil moisture content. It is based on estimated K<sub>d</sub> values
- A typical DF1 for fine soil is 0.823 and for coarse soil is 0.767

$$DF1 = \frac{Saturated \ paste \ B \ (mg/L)}{Soil \ solution \ B \ (mg/L)} = \frac{K_d + \frac{\theta_w}{\rho_b}}{K_d + \frac{saturation \ \%}{100}}$$

where:

DF1	=	modified dilution factor 1 (dimensionless)
$K_d$	=	distribution coefficient (L/kg)
$\theta_w$	=	water-filled porosity (dimensionless);
$ ho_b$	=	dry soil bulk density (kg/L);

#### **DF2: Vertical transport through vadose zone:**

- =1, assumes impacts immediately above water table
- **DF3:** Dilution into fine or coarse groundwater:
- ~3-5, depends on pathway and soil texture. Higher for DUA pathway

#### **DF4: Lateral biodegradation/dispersion to aquatic life:**

• ~1, very little dispersion during 10 m travel. No degradation

## **Guideline for Irrigation Water**

- Alberta Tier 1 and surface water documents show a range of 0.5-6 mg/L for irrigation water B thresholds based on older sand culture experiments
  - Irrigation water <1 mg/L appears to pose minimal risk</li>
- Assuming a groundwater boron guideline of 1 mg/L, fine and coarse SRGS shown below:

Irrigation water pathway	Fine texture	Coarse texture
Groundwater guideline	1 mg/L	1 mg/L
DF1	0.823	0.767
DF2	1	1
DF3	3.86	4.64
Soil guideline (saturated paste boron)	3.18 mg/L	3.56 mg/L

- Since similar for both textures, average of the fine and coarse guidelines used as overall guideline for irrigation water:
   Irrigation water guideline = 3.4 mg/L saturated paste B
- \* Tier 2 adjustments may be required if source length is >10 m

# **Guideline for Aquatic Life**

- Alberta Tier 1 guideline for aquatic life is 1.5 mg/L for surface water / groundwater
- Soil guideline for protecting aquatic life derived similarly as for irrigation water using DF equations
  - Assumes 10 m to receptor

Aquatic life pathways	Fine texture	Coarse texture
Groundwater guideline	1.5 mg/L	1.5 mg/L
DF1	0.823	0.767
DF2	1	1
DF3	3.86	4.64
DF4	1	1
Soil guideline (saturated paste)	4.76 mg/L	5.34 mg/L

 Since similar for the two textures, average of the fine and coarse guidelines used as overall guideline: <u>Aquatic life guideline = 5.0 mg/L saturated paste B</u>

\* Tier 2 adjustments may be required if source length is >10 m

### Guidelines for Livestock and Wildlife Water

- Alberta Tier 1 guideline for livestock and wildlife water is 5 mg/L for groundwater / surface water
- Soil guideline derived in same manner using DF equations:

Livestock watering pathways	Fine texture	Coarse texture
Groundwater guideline	5 mg/L	5 mg/L
DF1	0.823	0.767
DF2	1	1
DF3	3.86	4.64
DF4	1	1
Soil guideline (saturated paste)	15.88 mg/L	17.78 mg/L

 Since similar for the two textures, average of the fine and coarse guidelines is the overall guideline: <u>Livestock / wildlife water guideline = 16.8 mg/L sat paste B</u>

\* Tier 2 adjustments may be required if source length is >10 m

# **Guideline for DUA**

- Alberta Tier 1 guideline for DUA (human drinking water) is 5 mg/L for groundwater
- Soil guideline derived in same manner using DF equations:

Human drinking water pathways	Fine texture	Coarse texture
Groundwater guideline	5 mg/L	5 mg/L
DF1	0.823	0.767
DF2	1	1
DF3	15.93	30.87
Source concentration (saturated paste)	65.5 mg/L	118.3 mg/L

 The fine and coarse soil guidelines are maintained separately for the DUA pathway since values differ by approximately 2-fold:

> DUA guideline = 66 mg/L sat paste B (fine) DUA guideline = 118 mg/L sat paste B (coarse)

\* Tier 2 adjustments may be required if source length is >10 m and has <u>substantial</u> effects on DUA pathway<sup>28</sup>

## Other Soil Pathways and Guidelines

## **Guideline for Human Direct Soil Contact**

- Boron a reproductive toxin in humans and other animals
- Boron toxicity to humans via occupational exposure or accidental poisoning described in literature, but data is sparse/anecdotal
- Detailed toxicity studies commonly performed on proxy laboratory species such as rats, mice, and rabbits



- mice, and rabbits – rats found to be the most sensitive species based on decreased fetal weight
- A human health oral reference dose of 0.2 mg/kg-day has been developed by the US EPA (2004) based on rat toxicity data and uncertainty/safety factors
  - more recent than Health Canada value from 1990
- Human direct soil contact guidelines estimate exposure from ingested, inhaled, and dermally absorbed boron from soil
- Relatively low-risk pathways under typical circumstances:

**Agricultural, Residential / Parkland:** 

<u>Human direct soil contact guideline = 7,500 mg/L sat paste B</u> Commercial / Industrial:

Human direct soil contact guideline = 234,000 mg/L sat paste B

## **Guidelines for Offsite Migration**

- Soil guidelines derived to protect soil dependent biota and humans from offsite migration of boron from commercial/industrial land to more sensitive adjacent land uses such as agricultural
  - Migration considered to be via wind-blown soil
  - Guidelines applicable to commercial/industrial land only

**Ecological soil contact:** derived from agricultural eco-contact SRG of 3.3 mg/L saturated paste.

**Off-site migration (eco-contact) = 45.9 mg/L sat paste B** 

Human soil contact: derived from agricultural human direct soil contact SRG of 7,500 mg/L saturated paste.

Off-site migration (human contact) = 107,000 mg/L sat paste B

#### Summary of Proposed Tier 1 Boron Guidelines

- Constrained by ecological direct soil contact (plants and invertebrates) for most land uses including agricultural
- Constrained by aquatic life for commercial/industrial land use
- Groundwater pathways may require Tier 2 adjustments, could alter constraining pathways

Overall (	Guideline		Hu	uman		Ecological												
		Direct Soil Contact	Dome	stic Use	Off-Site Migration		Contact and Food and Food		Freshwater		Protection of Livestock Water		Protection of Wildlife Water		Protection of Irrigation Water		Off-Site Migration	
Fine	Coarse		Fine	Coarse		Fine	Coarse			Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
3.3	3.3	-	65	118	-	3.3	3.3	-	-	5.0	5.0	-	-	17	17	-	-	-
3.3	3.3	7,500	65	118	-	3.3	3.3	-	-	5.0	5.0	17	17	17	17	3.4	3.4	-
3.3	3.3	7,500	65	118	-	3.3	3.3	-	-	5.0	5.0	-	-	-	-	-	-	-
5.0	5.0	230,000	65	118	110,000	8.2	8.2	-	-	5.0	5.0	-	-	-	-	-	-	46
5.0	5.0	230,000	65	118	110,000	8.2	8.2	-	-	5.0	5.0	-	-	-	-	-	-	46
	Fine mg/L 3.3 3.3 3.3 3.3 5.0	Fine         Coarse           mg/L         mg/L           3.3         3.3           3.3         3.3           3.3         3.3           3.3         3.3           5.0         5.0	Contact           Fine         Coarse           mg/L         mg/L         mg/L           3.3         3.3         -           3.3         3.3         7,500           3.3         3.3         7,500           5.0         230,000         100	Direct Soil Contact         Prote Dome Action           Fine         Coarse         Fine           mg/L         mg/L         mg/L         mg/L           3.3         3.3         -         65           3.3         3.3         7,500         65           3.3         3.3         7,500         65           3.3         3.3         230,000         65	Direct Soil Contact         Protection of Domestic Use Aquifer           Fine         Coarse         Fine         Coarse           mg/L         mg/L         mg/L         mg/L         mg/L         mg/L           3.3         3.3         -         65         118           3.3         3.3         7,500         65         118           3.3         3.3         7,500         65         118           3.3         3.3         230,000         65         118	Direct Soil Contact         Protection of Domestic Use Aquifer         Off-Site Migration           Fine         Coarse         Fine         Coarse           mg/L         mg/L         mg/L         mg/L         mg/L         mg/L           3.3         3.3         -         65         118         -           3.3         3.3         7,500         65         118         -           3.3         5.0         230,000         65         118         110,000	Direct Soil Contact         Protection of Domestic Use Aquifer         Off-Site Migration         Direct Contact           Fine         Coarse         Fine         Coarse         Fine           mg/L         3.3	Direct Soil Contact         Protection of Domestic Use Aquifer         Off-Site Migration         Direct Soil Contact           Fine         Coarse         Fine         Coarse         Fine         Coarse           mg/L         3.3         3.3         3.3         3.3         3.3         3.3         3.3         3.3         3.3         3.3         3.3         3.	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Note: all boron guidelines expressed on a mg/L saturated paste boron basis

\* Subject to final regulatory approval

## **Thank You**

# **Questions**?

## Acknowledgements

- Exova
- Petroleum Technology Alliance of Canada (PTAC)
- PTAC Boron Working Group
- Environment Canada
- Alberta Environment