Investigation of Cause of Effects on Benthic Communities Downstream of the Flin Flon Site

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HUDBAY

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Outline

1 Site (history, operations, plume)

2 Context and objectives of the study

3 Experimental design

4 Results

5 Conclusions and recommendations

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Site History and Operations

- The Flin Flon Mining and Metallurgical complex is located in northern Manitoba
- Operations for over 90 years
- Process ore from various mines in area

- This large complex is currently comprised of:
  -Triple 777 Mine
  -copper and zinc concentrator
  -copper smelter (shut down June 2010)
  -zinc pressure leach plant (significant upgrades and closed loop)
  -tailings management facility (expanded 2005-2008)

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North Weir Discharge

- FFTIS receives several discharges from the complex:
  -tailings and other waste products from the facility
  -process water from the Metallurgical Complex
  -mine dewater from Triple 777 Mine
  -surface runoff and stormwater
  -drainage from the town of Creighton

- The North Weir is the key discharge from the FFTIS
- Mean monthly discharge volume is over 30,000 m^3 per month, plume extending almost 150 km
- Discharge meets the Metal Mining Effluent Regulatory (MMER) limits

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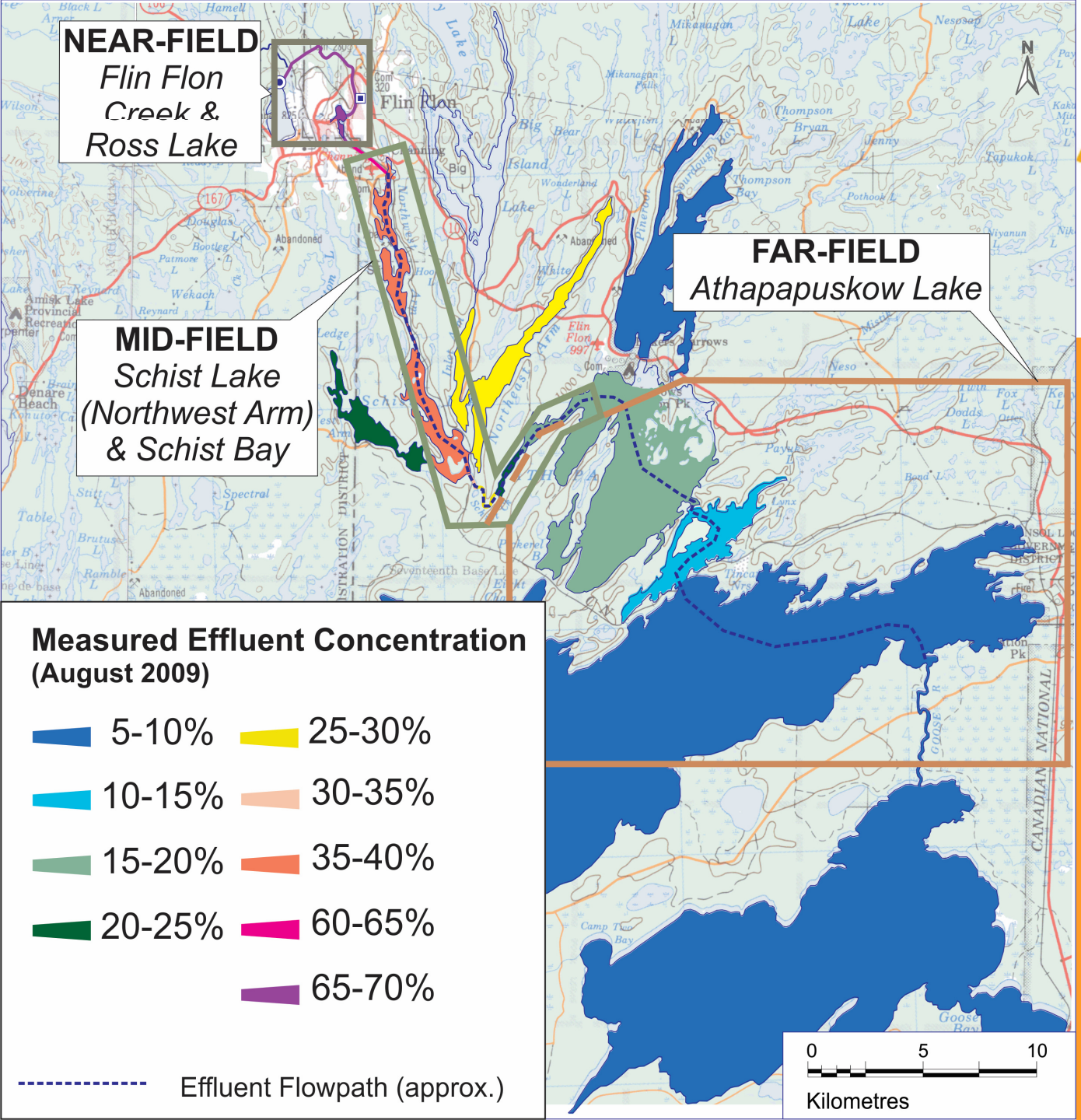

-Study Areas and Effluent Plume

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Context and Objectives

- Three rounds of Environmental Effects Monitoring (EEM/MMER) have shown clear and consistent impacts on downstream benthic invertebrate communities and fish
- This is the fourth study in the EEM program at the site

Objectives:

1. Determine what (if any) metals are causing impacts on benthic communities.

2. Determine whether impacts are associated with historical contamination or current receiving water quality.

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Summary of Effects on Benthic Invertebrate Communities

Benthic Index	Near-field		Mid-field (Schist Lake, NW Arm)		Far-field (Athapapuskow Lake)	
	Flin Flon Creek	Ross Lake	North half	South half	Upper	Lower
Density						
Richness						
Bray Curtis						
Simpsons Evenness						

2005, 2007, 2009, 2012

Exposure significantly different / impacted = significantly different at $p \leq 0.10$ 2 SD = difference greater than ± 2 SD of the Reference Mean

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Hyalella azteca – freshwater amphipod commonly found in the wild and used in toxicity testing to look at the effects of metals

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Study Design - Lab Based Toxicity & Bioaccumulation

- **Laboratory testing:** Sediment toxicity tests using *Hyalella* in the lab with various combinations of contaminated and reference sediment and surface water
- **Water Only:** *Hyallela* toxicity tests with no sediment only lab and receiving waters
- 100% final effluent

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Laboratory Testing

Study Design – Field Based Toxicity and Bioaccumulation

- **Toxicity Tests:** Sediment toxicity tests conducted *in situ* using caged *Hyalella* with various combinations of sediment and surface water, used *Hyalella* collected from reference

- **Wild**: *Hyalella* collected throughout the receiver

Field Toxicity Testing

SAMPLING ARRAY

- Various sediment / water body combinations
- 5 replicates for each combination
- 20 *Hyalella* in each vial
- 10 day exposures

Hyalella in situ cage with sediment

In situ cage placement

Hyalella Studies and Water & Sediment Combinations: Flin Flon

TEST	SEDIMENT	OVERLYING WATER
LABORATORY	Exposure Site Sediment No. 1 **Schist Lake**	Lab Dilution Water
		Reference Water
		Exposure Site Water #1: Schist Lake
	Exposure Site Sediment No. 2 **Flin Flon Creek**	Lab Dilution Water
		Reference Water
		Exposure Site Water #2: Flin Flon Creek
	Field Reference Sediment **First Cranberry Lake**	Lab Dilution Water
		Reference Water
		Exposure Site Water #1: Schist Lake
		Exposure Site Water #2: Flin Flon Creek
	Laboratory Reference Sediment	Lab Dilution Water
		Reference Water
		Exposure Site Water #1: Schist Lake
		Exposure Site Water #2: Flin Flon Creek
***IN SITU* CAGED (FIELD)**	Exposure Site Sediment No. 1 **Schist Lake**	Reference Water
		Exposure Site Water #1: Schist Lake
	Exposure Site Sediment No. 2 **Flin Flon Creek**	Reference Water
		Exposure Site Water #2: Flin Flon Creek
	Exposure Site Sediment No. 3 **Lower Athapapuskow Lake**	Reference Water
		Exposure Site Water #3: Lower Lake Athapapuskow
	Field Reference Sediment **First Cranberry Lake**	Reference Water
		Exposure Site Water #1: Schist Lake
		Exposure Site Water #2: Flin Flon Creek
		Exposure Site Water #3: Lower Lake Athapapuskow
WILD (FIELD)	**ALL FIELD SITES**	**ALL FIELD SITES**

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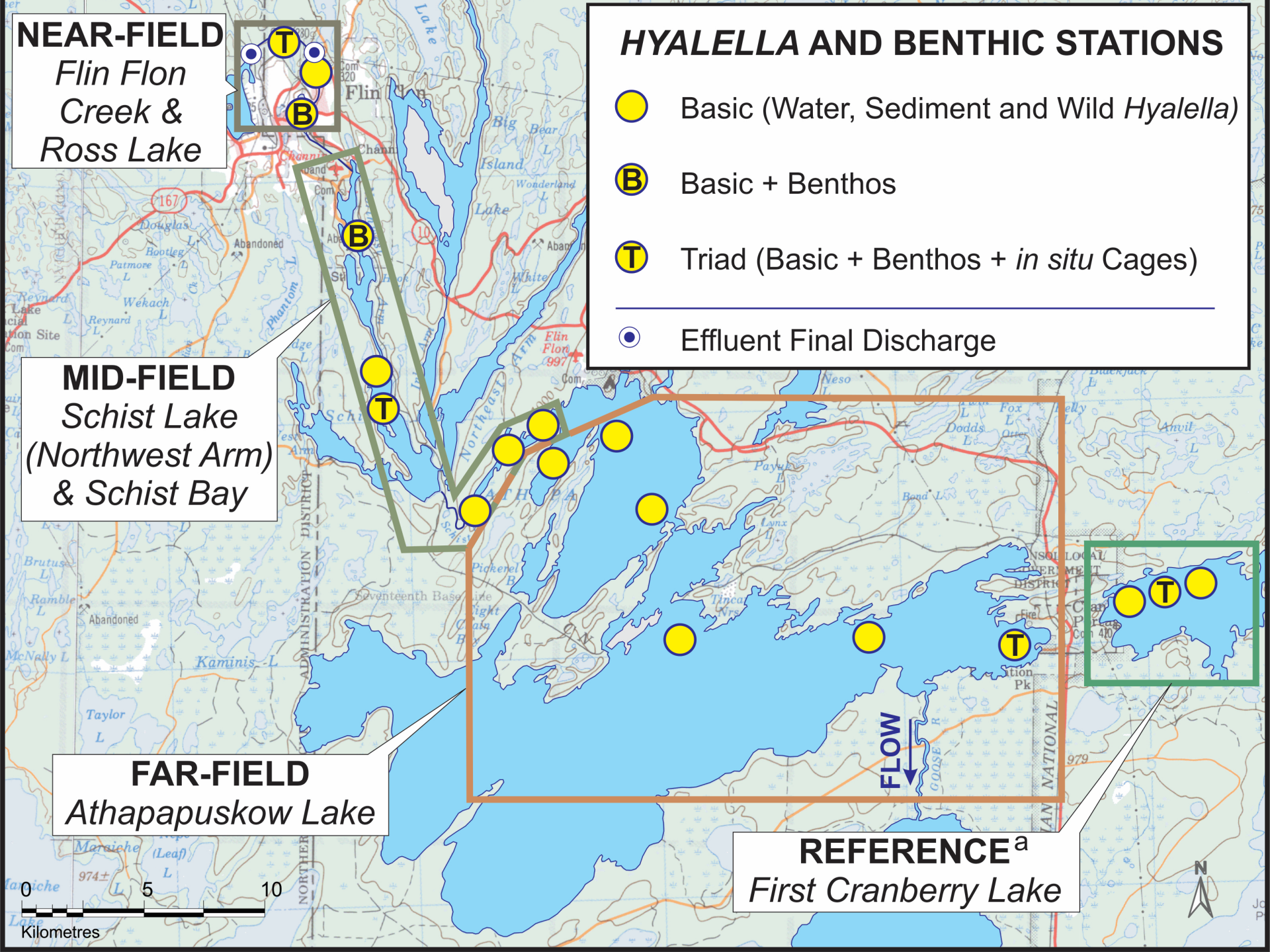
Hyalella Toxicity Test Methods

Environment Canada's standard (1997) test method (EPS 1/RM/33) was used with several modifications:

1. Older organisms were used (6-9 days)
2. Solutions were not aerated, instead overlying water was renewed 2x daily
3. In field, tests were terminated at 10 days
4. *Hyalella* were not rinsed in EDTA

Once dried, *Hyalella* from all treatments (if they survived) were analyzed by RPC Laboratories in Fredericton, New Brunswick using ICP-MS.


NEAR-FIELD
Flin Flon Creek & Ross Lake
MID-FIELD
Schist Lake (Northwest Arm) & Schist Bay
FAR-FIELD
Athapapuskow Lake
REFERENCE[a]
First Cranberry Lake
HYALELLA AND BENTHIC STATIONS
Basic (Water, Sediment and Wild Hyalella)
Basic + Benthos
Triad (Basic + Benthos + in situ Cages)
Effluent Final Discharge
FLOW
0
5
10
Kilometres
N

Supporting Analyses & Modeling

- **Water Quality:** collected comprehensive water quality data including factors required for the **Biotic Ligand Modeling (BLM)**

- **Sediment Quality:** collected comprehensive sediment quality data

- **Analysis is metals (bioaccumulation) in Hyalella**, to compare to lethal body concentrations (LBCs) established in literature and to conduct **Metal Effects Addition Modeling (MEAM)**.

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Metals in Surface Water

	Aluminum	Arsenic	Cadmium	Copper	Iron	Selenium	Zinc
Guideline[a] (uL/L)	100	150	Variable[b]	Variable	300	1	Variable
Flin Flon Creek	47	8.0	**0.92**	**30**	**870**	**11.9**	**123**
Ross Lake	41.1	4.4	**2.86**	**30.2**	238	**10.2**	**387**
Schist Lake	14.2	2.0	**0.286**	5.1	30	**2.9**	**78.7**
Schist Bay	32.6	2.0	0.078	3.1	38	**1.6**	27.8
Little Athapap Lake	28.2	1.8	**0.079**	2.8	30	0.81	17.1
Lower Athapap Lake	44.2	1.2	0.045	2.0	54	0.25	12.1
Cran & Mirond (REF)	**180**	0.8	0.025	**2.2**	**320**	0.14	4.1

[a] CCME Water Quality Guidelines for the Protection of Aquatic Life

[b] Water Quality Guideline is Hardness dependant

Exceeds CCME Water Quality Guideline

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Metals in Sediment

	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc
Guideline[a] (mg/kg)	**17**	**3.5**	**90**	**197**	**91.3**	**0.486**	**2[b]**	**315**
Flin Flon Creek	**188**	**221**	78.2	**7540**	**512**	**2.71**	**727**	**15300**
Ross Lake	**206**	**93.2**	29.0	**4540**	**266**	**23.0**	**280**	**11100**
Schist Lake	5.74	**7.61**	13.5	80.2	10.3	0.127	**8.14**	**1480**
Schist Bay	9.98	**5.26**	32.3	98.8	26.4	0.120	**10.1**	**2150**
Little Athapap Lake	9.13	**5.47**	14.5	98.5	25.6	**0.966**	**4.4**	**1320**
Lower Athapap Lake	4.1	1.63	25.3	38.0	10.1	0.09	0.963	142
Cran & Mirond (REF)	3.99	0.83	24.7	31.3		0.096	0.9	98.4

[a] CCME (2002) Sediment Quality Guidelines for the Protection of Aquatic Life; PEL (Probable Effects Level)

[b] BCMoE (2014)

Exceeds CCME Water / Sediment Quality Guideline

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Weight of Evidence With BLM

Areas	Waterbody	Water COCs	Sediment COCs	Benthic Impacts	BLM
Near-field (60-75%)	Flin Flon Creek	As, Cd, Cu, Se, Zn	As, Cd, Cu, Pb, Se, Zn	++++	Cu
	Ross Lake	As, Cd, Cu, Se, Zn	As, Cd, Cu, Pb, Se, Zn	++++	Cu
Mid-field (25-40%)	Schist Lake	Cd, Cu, Se, Zn	As, Cd, Cu, Se, Zn	++	
	Schist Bay	Cd, Cu, Se, Zn	As, Cd, Cu, Se, Zn	Not sampled	
Far-field (5-25%)	Upper Athapap	Zn	As, Cd, Cu, Se, Zn	+	
	Lower Athapap	No exeedences		0	

Effect of Flin Flon Creek on *Hyalella*

Test	Sediment	Overlying Water	Metal	Background-Corrected Concentration (ng/mol)						*Hyalella* Survival (%)	
				As	Cd	Cu	Pb	Se	Zn		
			$LBC25_{x24hr}$	83	585	1850	650	72.4	938	Predicted	Actual
Lab	FF Creek	Lab	-	No Survival in Lab Experiments						n/a	n/a
		Cran-REF	-							n/a	n/a
		FF Creek	-							n/a	n/a
	Cran Lake	FF Creek	-	26	0.8	**1992**	5.8	**178**	150	22.5	94.0
	Lab	FF Creek	-	4.7	0	**1685**	0.1	**220**	0	16.3	76.0
In Situ	FF Creek	FF Creek	-	No Survival in Field Toxicity Test						n/a	n/a
Caged	Cran Lake	FF Creek	-	No Survival in Field Toxicity Test						n/a	n/a
Wild	FF Creek	FF Creek	-	No Wild Specimens Captured						n/a	n/a

- Predicted survival based on 28d test
- Actual survival based on a14d test

Hyalella did not survive experiments OR were not found in the wild

Mean result exceeds LBC25

Mean result approaches LBC25

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Impact of Schist Lake on *Hyalella*

Test	Sediment	Overlying Water	Metal	Background-Corrected Concentration (ng/mol)						*Hyalella* Survival (%)	
				As	Cd	Cu	Pb	Se	Zn		
			$LBC25_{x24hr}$	**83**	**585**	**1850**	**650**	**72.4**	**938**	Predicted	Actual
Lab	Schist L.	Lab	-	6.8	0	0	5.5	34.6	337	70.7	86.0
		Cran-REF	-	8.9	0.2	663	1.5	41.4	45.7	69.5	64.0
		Schist L.	-	6.2	7.7	428	1.7	**90.4**	398	53.0	97.8
	Cran. L.	Schist L.	-	5.3	5.9	0	1.6	35.1	320	72.4	93.3
	Lab	Schist L.	-	0	0	0	0	33.8	0	72.7	77.8
In-Situ Caged	Schist L.	Cran-REF	-	14.4	0	140	8.8	6.8	0	80.4	63.0
		Schist L.	-	14.3	0	855	16.5	54.7	**1017**	23.6	85.0
	Cran. L.	Schist L.	-	15	0	180	6.1	29	368	74.1	60.0
Wild	Schist L.		-	14.9	3.4	201	71.7	**108**	**430**	n/a	n/a
	Schist Bay		-	11.4	0	75	0.2	**71.4**	80.8	n/a	n/a
	1st Cranberry L. REF		-	10.9	0	86.6	2	0.6	0	n/a	n/a

Combination of Schist Lake sediment and Schist Lake water

Mean result exceeds LBC25

Mean result approaches LBC25

Mean result less than LBC25 but at least one test result exceeded LBC25

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Weight of Evidence Using MEAM

Areas	Waterbody	Water COCs	Sediment COCs	Benthic Impacts	BLM	MEAM
Near-field (60-75%)	Flin Flon Creek	As, Cd, Cu, Se, Zn	As, Cd, Cu, Pb, Se, Zn	++++	Cu	Cu, Se
	Ross Lake	As, Cd, Cu, Se, Zn	As, Cd, Cu, Pb, Se, Zn	++++	Cu	Cu, Se
Mid-field (25-40%)	Schist Lake	Cd, Cu, Se, Zn	As, Cd, Cu, Se, Zn	++		Zn, Se
	Schist Bay	Cd, Cu, Se, Zn	As, Cd, Cu, Se, Zn	Not sampled		Zn, Se
Far-field (5-25%)	Little Athapap	Zn	As, Cd, Cu, Se, Zn	+		
	Lower Athapap	No exeedences		0		Pb (in one replicate)

Conclusions

1. **Flin Flon Creek/Near-field Area:** Cu and Se due to historical contamination and current receiving water causing toxicity
2. **Schist Lake/Mid-field Area:** Zn and Se are causing toxicity, however, toxicity due moreso to historical contamination in sediment
3. **Athapapuskow Lake/Far-field Area:** showed no toxicity due to metals despite a 5-10% effluent concentration
4. MEAM model added significant information regarding causes of effects.
5. The novel toxicity testing design helped tease out effects due to current effluent/receiving water quality or historical contamination.

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Recommendations

1. Make sure you pretest toxicity at the reference site.
2. Conduct the water only tests in conjunction with the various exposure treatments.
3. Try to gather the dead or dying organisms to analyze for metals.

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Acknowledgements

Hudbay Minerals

Warren Norwood, Environment Canada

Aquatox Testing and Consulting Inc.

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Background-Corrected Concentration of Selected Metals in *Hyalella at Flin Flon/TLM*

Test	Sediment	Overlying Water	Metal	Background-Corrected Concentration (ng/mol)						*Hyalella* Survival (%)	
				As	Cd	Cu	Pb	Se	Zn		
			$LCB25_{x24hr}$	**83**	**585**	**1850**	**650**	**72.4**	**938**	Predicted	Actual
Lab	Schist L.	Lab	-	6.8	0	0	5.5	34.6	337	70.7	86.0
		Cran-REF	-	8.9	0.2	663	1.5	41.4	45.7	69.5	64.0
		Schist L.	-	6.2	7.7	428	1.7	**90.4**	398	53.0	97.8
	FF Creek	Lab	-	**No Survival**						n/a	n/a
		Cran-REF	-							n/a	n/a
		FF Creek	-							n/a	n/a
	First Cranberry Lake REF	Lab	-	10.9	0	0	13.4	8.5	18.9	67.7	98.4
		Cran-REF	-	14.2	0	341	12.7	9.8	39.1	71.7	67.5
		Schist L.	-	5.3	5.9	0	1.6	35.1	320	72.4	93.3
		FF Creek	-	26	0.8	**1992**	5.8	**178**	150	22.5	94.0
	Lab	Lab	-	0	0	0	0.7	0	0	75.5	90.4
		Cran-REF	-	10	0	725	0.4	11	464	72.9	28.0
		Schist L.	-	0	0	0	0	33.8	0	72.7	77.8
		FF Creek	-	4.7	0	**1685**	0.1	**220**	0	16.3	76.0
In-Situ Caged	Schist L.	Cran-REF	-	14.4	0	140	8.8	6.8	0	80.4	63.0
		Schist L.	-	14.3	0	855	16.5	54.7	**1017**	23.6	85.0
	FF Creek	Cran-REF	-	16.1	0	0	**23**	20	111	63.4	32.0
		FF Creek	-	**No Survival**						n/a	n/a
	LOAL	Cran-REF	-	34.2	0	184	9.9	9.7	283	76.7	39.0
		LOAL	-	20.8	0	327	**36**	13.8	43.3	61.1	66.0
	First Cranberry Lake REF	Cran-REF	-	14.3	0	0	17	1.7	0	77.7	45.0
		Schist L.	-	15	0	180	6.1	29	368	74.1	60.0
		FF Creek	-	**No Survival**						n/a	n/a
		LOAL	-	16.3	0	230	13.8	10.4	0	76.1	66.0
Wild	Flin Flon Creek		-	**No Specimens Captured**						n/a	n/a
	Ross Lake		-							n/a	n/a
	Schist Lake		-	14.9	3.4	201	71.7	**108**	**430**	n/a	n/a
	Schist Bay		-	11.4	0	75	0.2	**71.4**	80.8	n/a	n/a
	Little Athapap L.		-	13.3	0	151	2.4	45.3	0	n/a	n/a
	Lower Athapap. L		-	16.2	7.4	121	**33.5**	32.7	17.1	n/a	n/a
	1st Cranberry L. REF		-	10.9	0	86.6	2	0.6	0	n/a	n/a

No hyalella survived experiments OR were not found in the wild

Mean result exceeds LCB25

Mean result below LBC25 but at least 1 result exceed LCB25

Approaching LCB25

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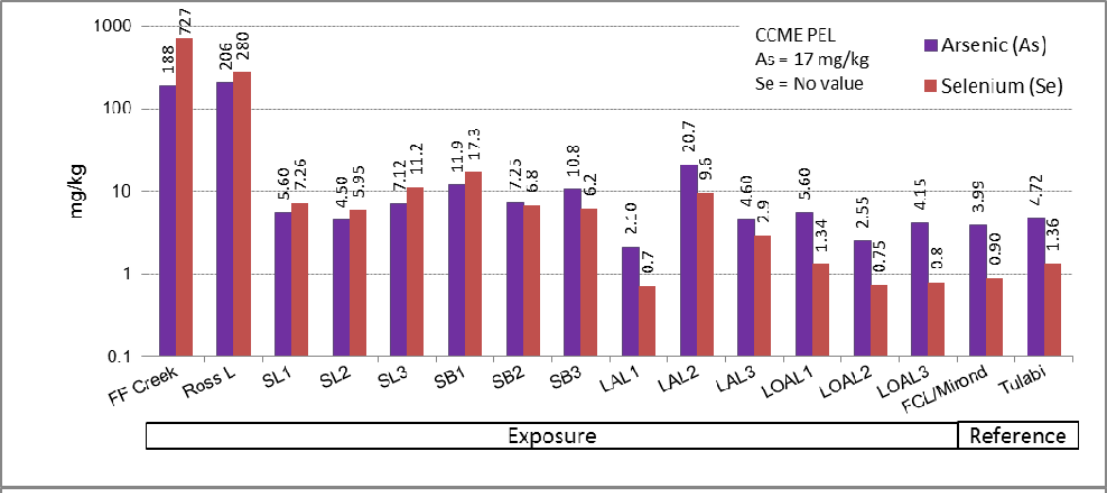
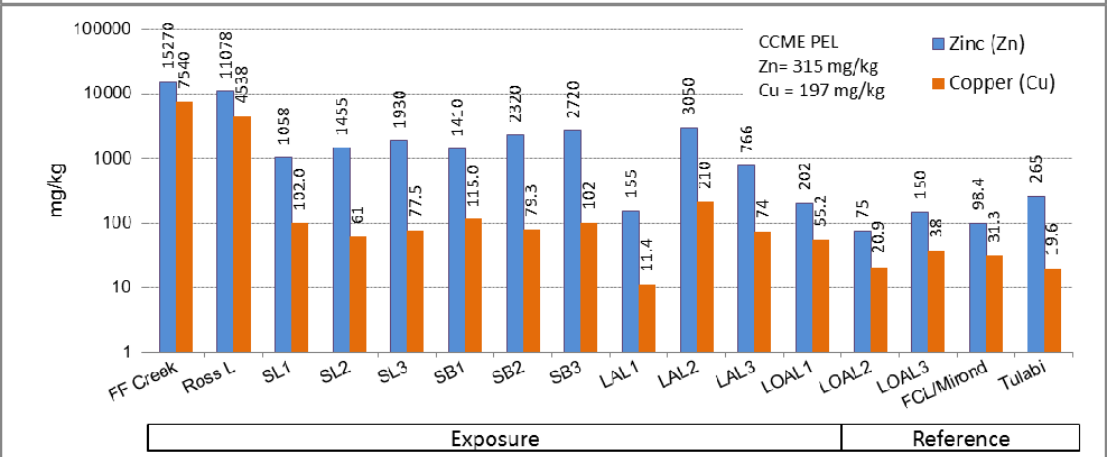
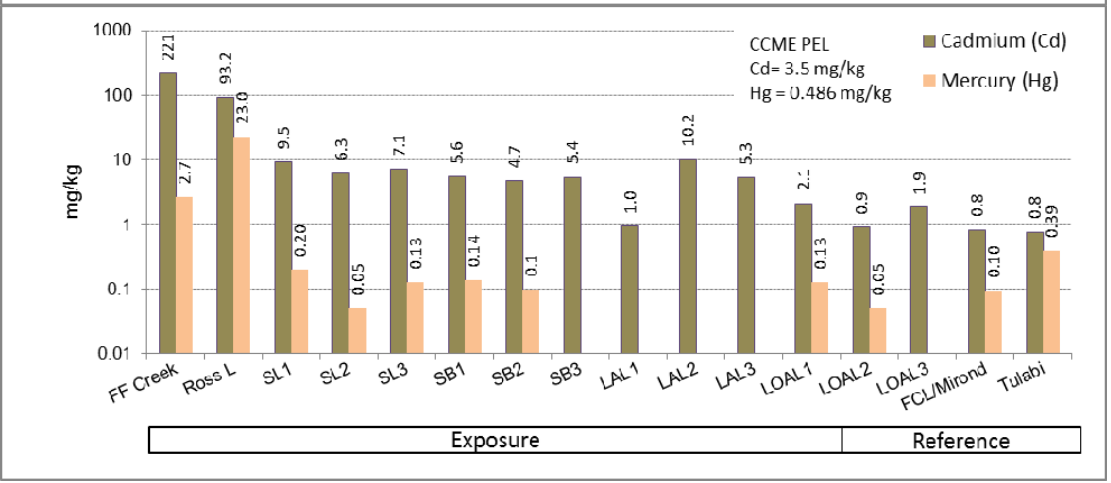
Metals in Sediment







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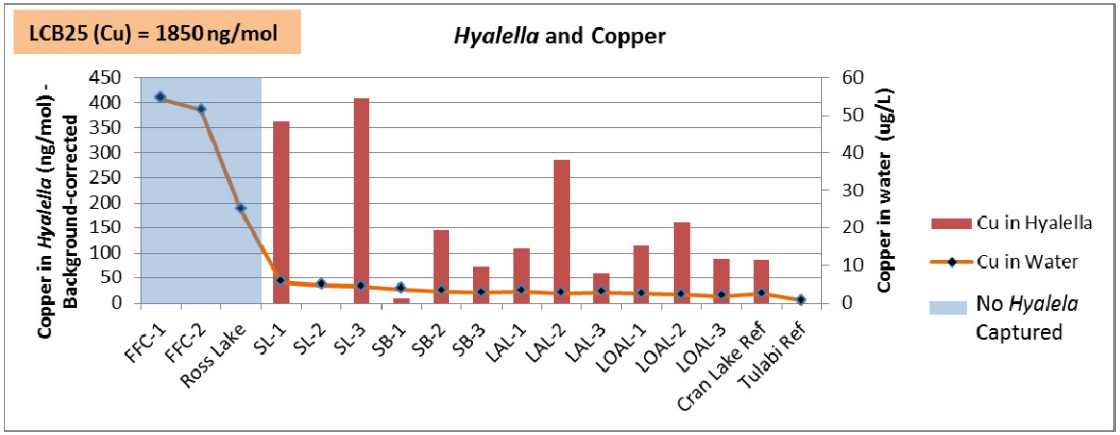
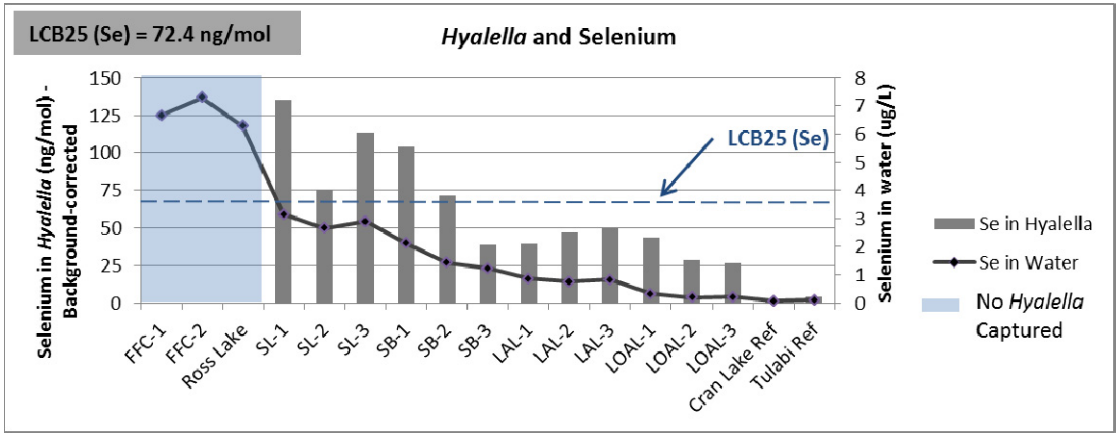
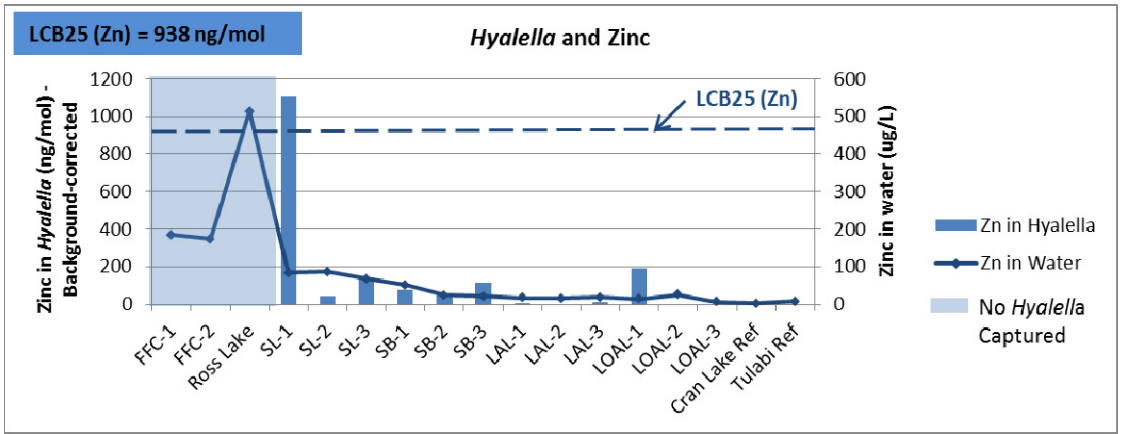
Copper, Selenium and Zinc in *Hyalella* and surface water at Flin Flon/TLM







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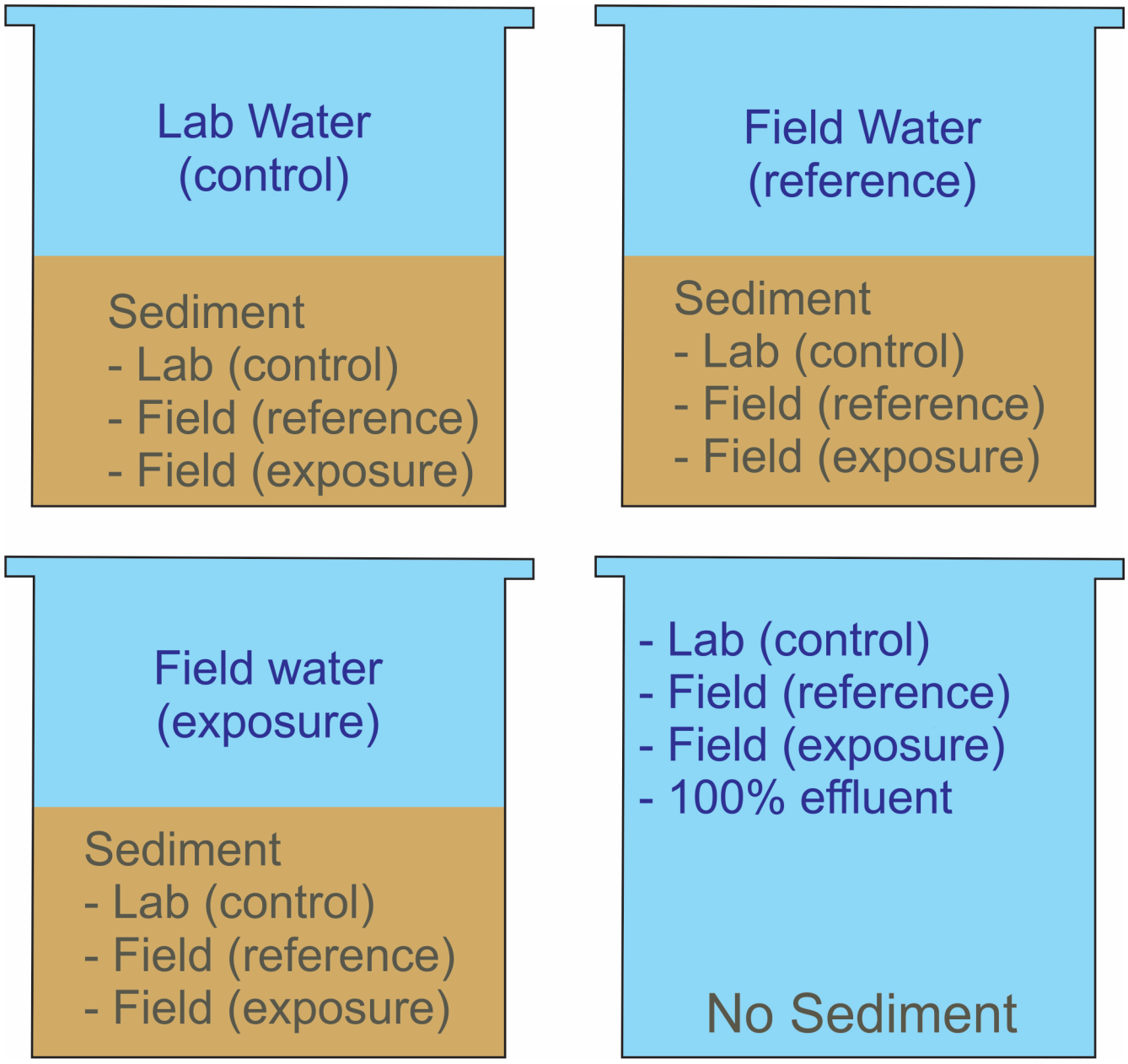
Lab Water
(control)
Sediment
- Lab (control)
- Field (reference)
- Field (exposure)
Field Water
(reference)
Sediment
- Lab (control)
- Field (reference)
- Field (exposure)
Field water
(exposure)
Sediment
- Lab (control)
- Field (reference)
- Field (exposure)
- Lab (control)
- Field (reference)
- Field (exposure)
- 100% effluent
No Sediment

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MEAM Modeling

Background correction using three different background metals concentrations in *Hyalella:*

- **Field Specimens from Mirond Lake and Kisseynew Lake**
- **Environment Canada (Norwood, *et al*, 2003)**
- **Laboratory *Hyalella* exposed to Laboratory Water**

MEAM results using EC data largely consistent with field background concentrations, with minor exceptions. Therefore local background values were used.

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Background Metals in *Hyalella*

Metal	Background Metals Concentration (ng/mol)		
	Field Hyalella[a]	Laboratory Hyalella[b]	Environment Canada[c]
Arsenic	23.4	18.6	13.8
Cadmium	8.96	3.80	3.64
Cobalt	6.47	7.20	2.25
Chromium	12.8	4.58	-0.100
Copper	1336	1035	1539
Manganese	1660	321	107
Nickel	16.0	19.3	16.0
Lead	5.25	1.59	0.199
Selenium	14.4	12.2	6.68
Thallium	0.122	0.137	0.124
Zinc	1050	925	924

[a] Mirond Lake and Kisseynew Lake; [b] Hardness = 265 and 130; [c] Norwood (*et al*) 2013.

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