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Anaerobic Biochemical Reactor (BCR) Treatment of Mining-Influenced Water (MIW): Evaluation of Reduction in Concentrations of Metals and Aquatic Toxicity

Presented in Webinar Series:

FRTR Presents...Heavy Metals-Mining Site Characterization and Treatment Session 2

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Presentation Outline

- BCR Treatment
- Research Questions
- Study Sites
- Methods
- Metals Removal
- Aquatic Toxicity (Acute)
- Concluding Remarks

BCR Treatment

- Passive / semi-passive treatments
  - May be completely anaerobic, aerobic, or combination of both
  - Natural processes
  - Minimal or no energy requirement
    - Solar power has been used
- Anaerobic biochemical reactor
  - Previously (and sometimes still) called sulfate-reducing bioreactor
    - A primary mechanism is microbial sulfate reduction to sulfide that precipitates metal sulfides
  - Sometimes called anaerobic wetland
    - But, no vegetation

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BCR Treatment

- Chemical, biological, and physical processes
  - Reduction, precipitation, adsorption, retention
- Hay, straw, wood chips, sawdust, compost, limestone, manure, ethanol, waste milk…
- Aerobic polishing
  - Increase oxygen
  - Decrease biochemical oxygen demand (BOD)
  - Settle solids
    - Some release of sulfide precipitates, which will oxidize and re-precipitate as metal oxyhydroxides
  - Degas sulfide and ammonia

BCR Treatment

- Overall goal of remediation is to minimize environmental and human health impacts

- Evaluation of BCR treatment generally through metal removal efficiency
  - Percentage of dissolved metals removed by the system
    - 100% * [(influent concentration – effluent concentration) / influent concentration]

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Research Questions Asked

- Are the effluents from the different pilot BCRs toxic (i.e., are there adverse effects to either test species that is statistically different from control water)?

- Is the toxicity reduced, relative to the influent?

- If effluents are toxic, is a toxicant identifiable?

Study Sites

- Luttrell Repository, Helena, MT
- Peerless Jenny King, Helena, MT
- Park City Biocell, Park City, UT
- Standard Mine, Crested Butte, CO

Luttrell Repository, MT

- Upper Ten-Mile Creek Superfund site
- 7,644 ft AMSL
- 2002
- 1.5 gpm treated
- Al, As, Cd, Co, Cu, Fe, Mn, Zn

Peerless Jenny King, MT

- Upper Ten-Mile Creek Superfund site
- 7,600 ft AMSL
- 2003
- 20-25 gpm treated
- Cd, Fe, Zn

Peerless Jenny King, MT

- Upper Ten-Mile Creek Superfund site
- 7,600 ft AMSL
- 2003
- 20-25 gpm treated
- Cd, Fe, Zn

Park City Biocell, UT

- Prospector drain in Silver Creek Watershed
- 2002
- 6,900 ft AMSL
- 29 gpm treated
- Cd, Zn

Park City Biocell, UT

- Prospector drain in Silver Creek Watershed
- 2002
- 6,900 ft AMSL
- 29 gpm treated
- Cd, Zn

Standard Mine, CO

- Crested Butte
- 2007
- 11,000 ft AMSL
- 1.2 gpm treated
- Cd, Cu, Fe, Pb, Mn, Zn

Standard Mine, CO

- Crested Butte
- Aerobic polishing cells added in 2008

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Methods

Methods

- Triplicate influent and effluent samples from Luttrell, PJK, and Park City
- Duplicate influent and effluent samples from the Standard Mine BCR and from the APC

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Methods

- Filtered metals (0.45 µm) – inductively coupled plasma – optical emission spectroscopy (ICP-OES)
- Sulfate – ion chromatography
- Total sulfide – ion selective electrode
- Total ammonia – gas sensing electrode

Methods

- Whole effluent toxicity tests [WET]
  - Series of dilutions of the influent and effluent water samples
- Acute 48-hr LC50
  - Percentage of water mixed with moderately hard dilution water
- *Ceriodaphnia dubia* [water flea]
- *Pimephales promelas* [fathead minnow]
  - Control survival > 90%

Results - Metals

Influent Metals Concentrations

Analyte	Site			
	Luttrell	PJK	Park City	Standard Mine
Al (mg/l)	28 ± 0.3	BMDL	BMDL	BMDL
As (mg/l)	2.5 ± 0.03	BMDL	BMDL	BMDL
Cd (mg/l)	1.6 ± 0.11	BMDL	0.1 ± 0.01	0.18 ± 0.003
Cu (mg/l)	27 ± 0.1	BMDL	BMDL	0.24 ± 0.006
Fe (mg/l)	27 ± 0.3	0.27 ± 0.015	BMDL	0.12 ± 0.008
Ni (mg/l)	0.31 ± 0.003	BMDL	BMDL	BMDL
Pb (mg/l)	BMDL	BMDL	BMDL	0.21 ± 0.025
Zn (mg/l)	270 ± 25	1.2 ± 0.03	8.4 ± 0.15	27 ± 0.6
SO_4 (mg/l)	4.6 ± 1.1 (g/l)	49 ± 15.8	642 ± 39	254 ± 9

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Influent & Effluent pH and DO

	Parameter (average)	Luttrell	PJK	Park City	SM-BCR	SM-APC
Influent	pH	3.6 ± 0.23	6.7 ± 0.08	6.2 ± 0.13	6.1 ± 0.06	
	DO (mg/l)	4 ± 0.8	3 ± 0.1	5 ± 0.1	6 ± 0	
Effluent	pH	6.4 ± 0.02	7.8 ± 0.04	7.1 ± 0.03	6.7 ± 0.06	8.6 ± 0.07
	DO (mg/l)	0.3 ± 0.24	3 ± 0.3	2 ± 0.1	0.6 ± 0.45	1 ± 0

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Percentage of Metals Removed

Analyte	Site				
	Luttrell	PJK	Park City	SM-BCR	SM-APC
Al	99 ± 1	n/a	n/a	n/a	n/a
As	98 ± 2	n/a	n/a	n/a	n/a
Cd	99 ± 10	n/a	96 ± 12	100 ± 2	100 ± 2
Cu	100 ± 0.3	n/a	n/a	94 ± 9	94 ± 9
Fe	99 ± 2	90 ± 12	n/a	-266 ± -518	100 ± 10
Ni	94 ± 5	n/a	n/a	n/a	n/a
Pb	n/a	n/a	n/a	94 ± 16	91 ± 17
Zn	100 ± 13	94 ± 11	100 ± 3	100 ± 3	100 ± 3
SO_4	72 ± 29	-78 ± -137	-1 ± -8	39 ± 4	72 ± 5

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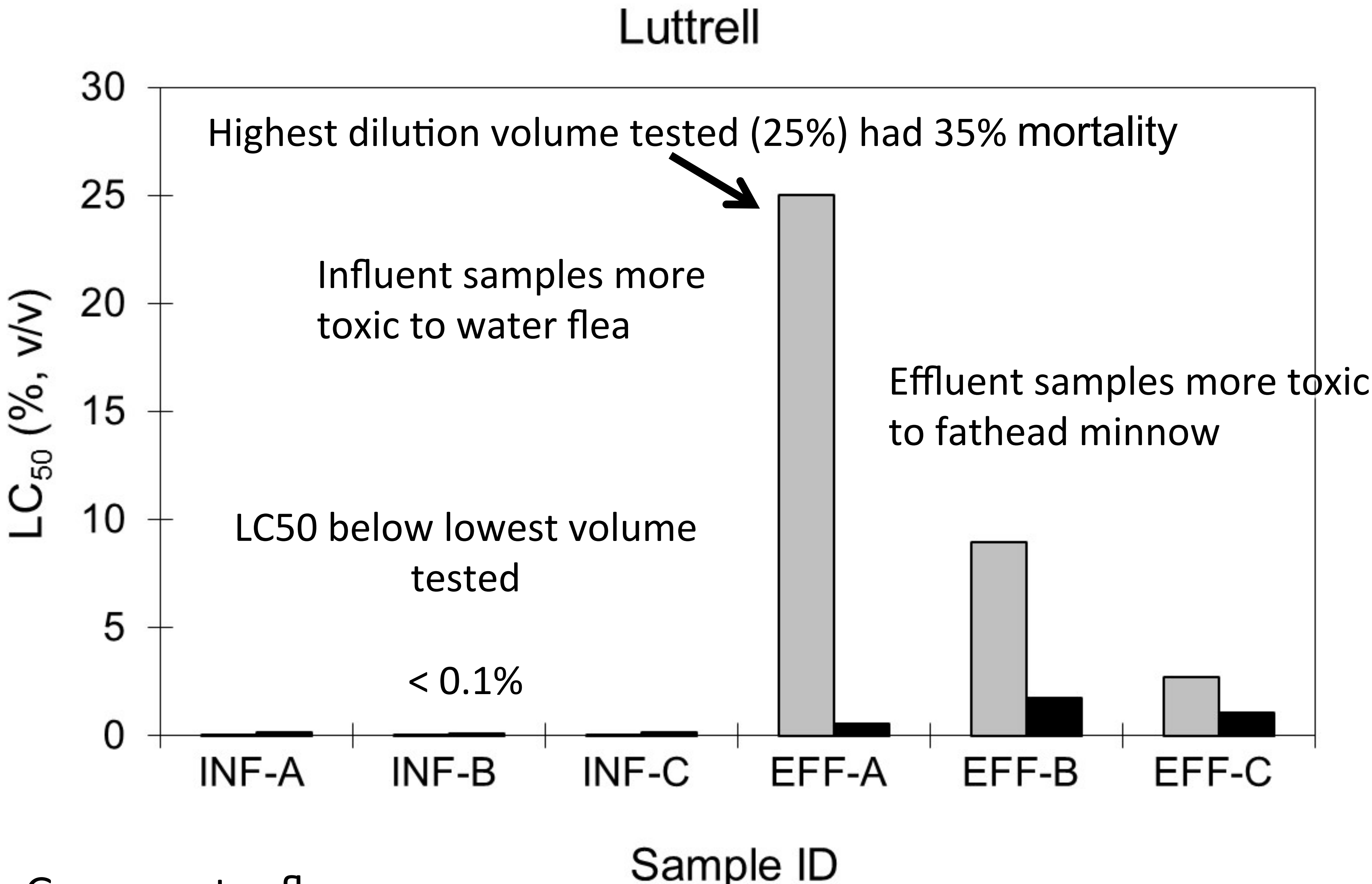
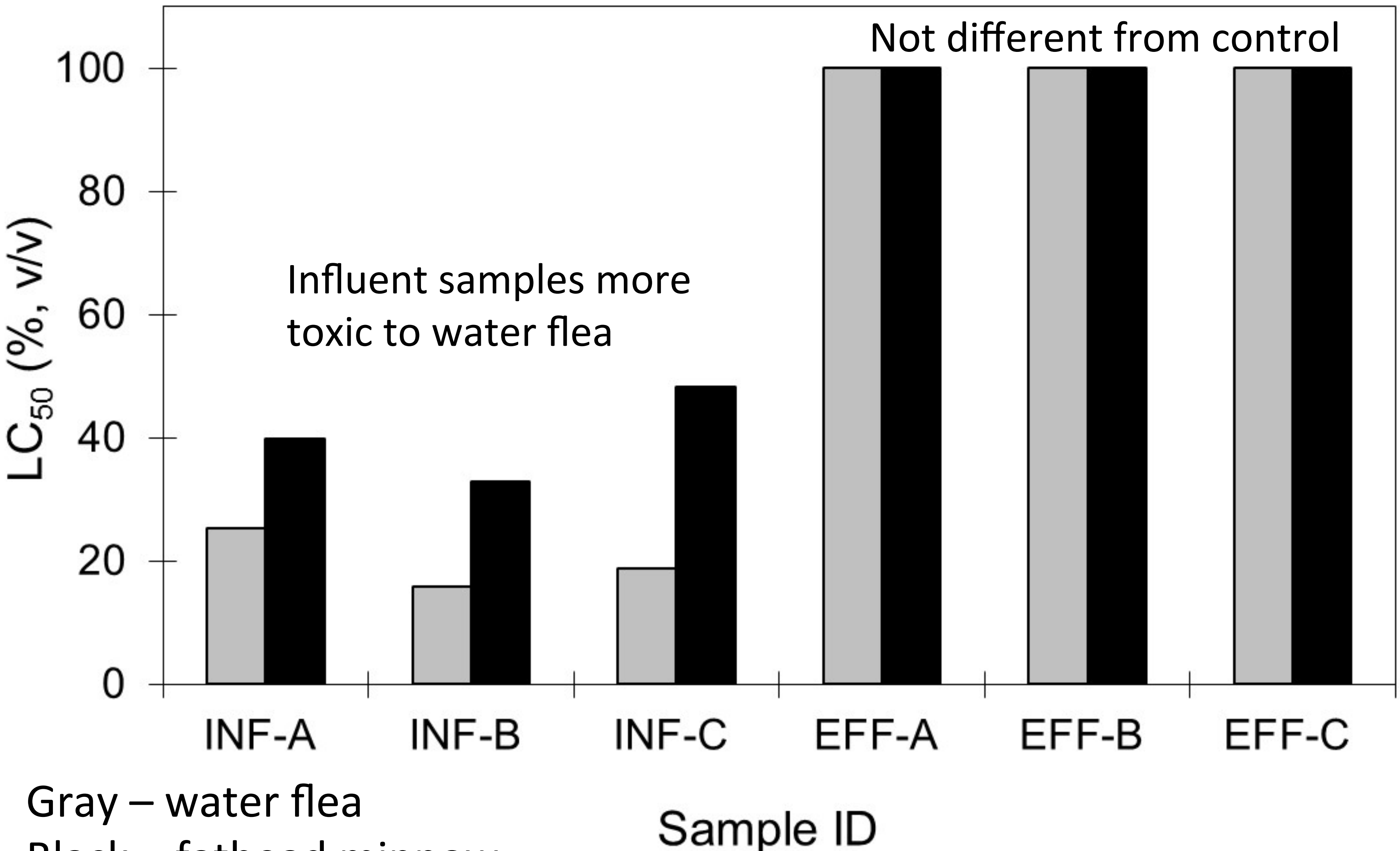
Results - Acute Aquatic Toxicity



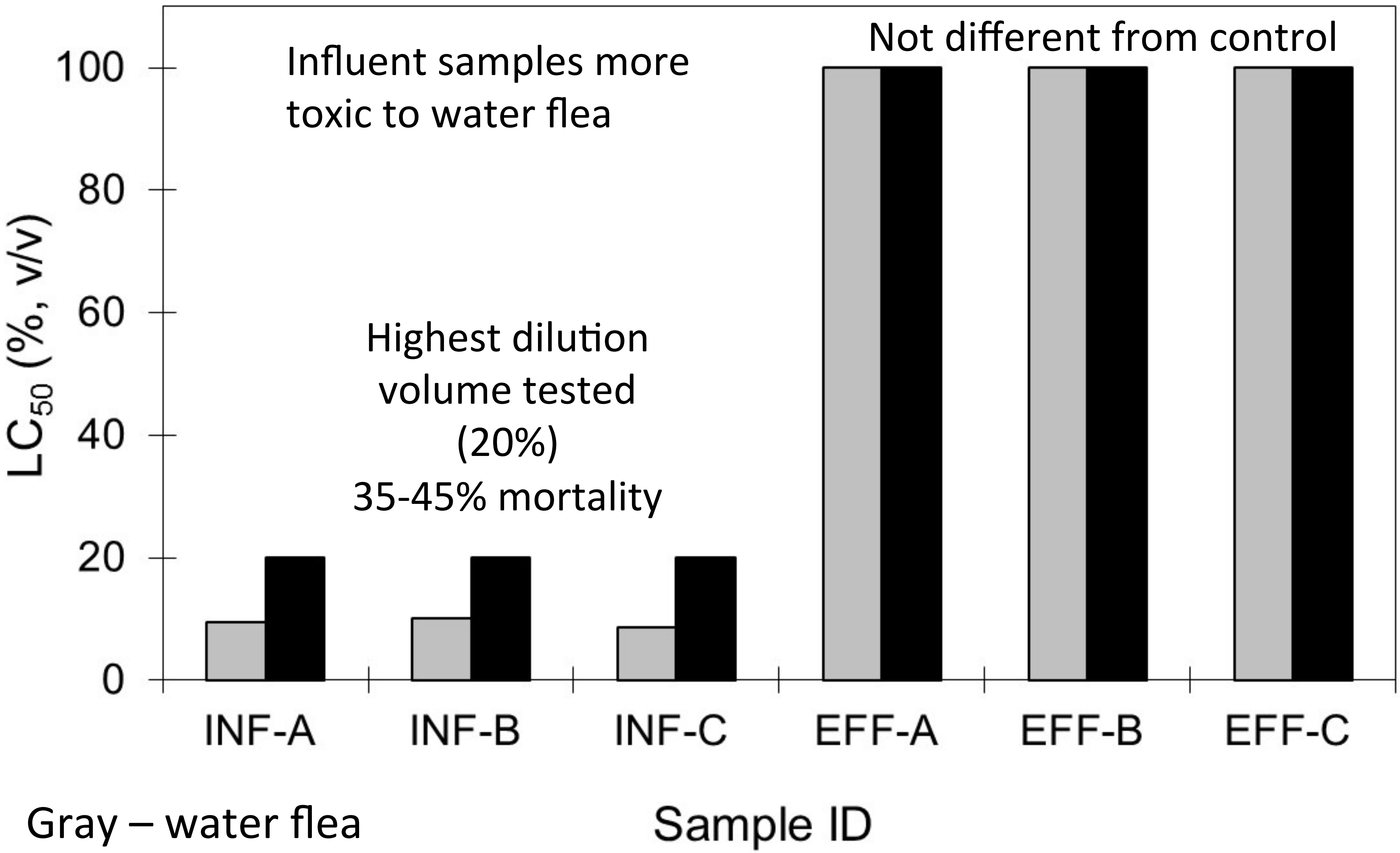
Gray – water flea
Black – fathead minnow

Peerless Jenny King



Gray – water flea
Black – fathead minnow

Park City



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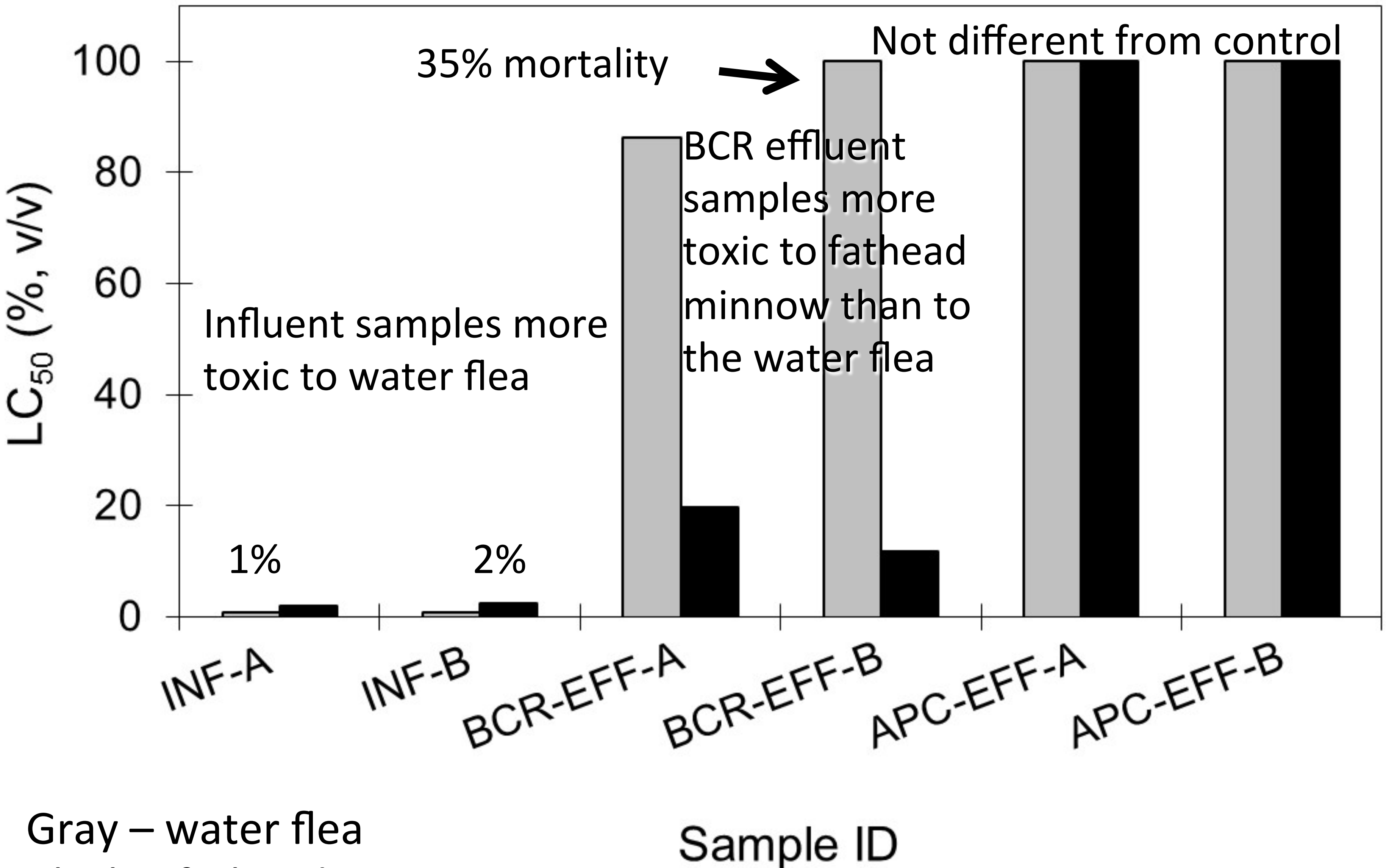
Standard Mine



Gray – water flea
Black – fathead minnow

Acute Aquatic Toxicity

- What caused acute toxicity in Luttrell and Standard Mine BCR effluent samples?
- Low dissolved oxygen?
  - SM-BCR field average 0.6 mg/l DO; Luttrell field average 0.3 mg/l DO
  - Test units must have > 4 mg/l
    - Generally > 6 mg/l
- Metals, sulfide, ammonia?

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Acute Aquatic Toxicity

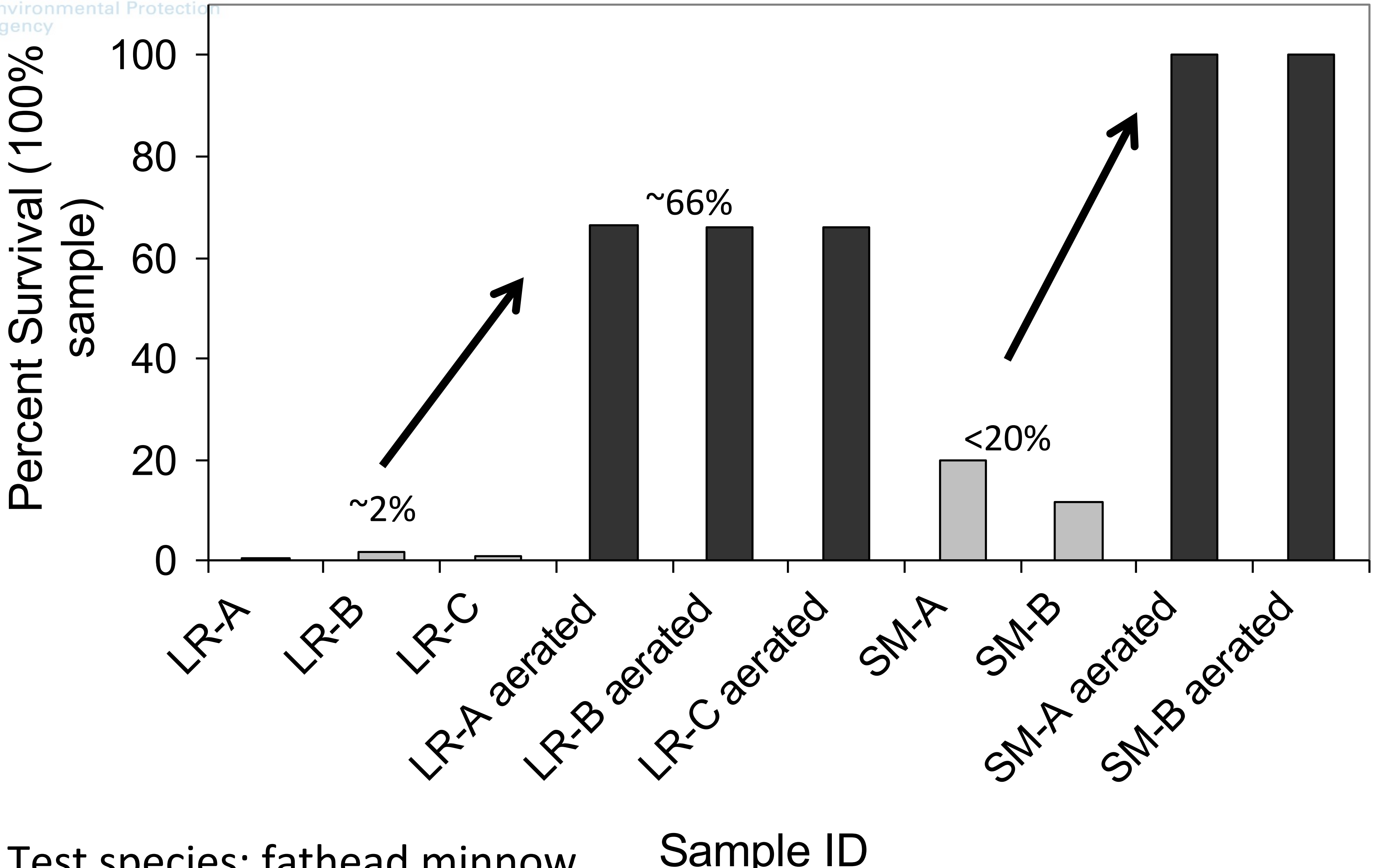
Sample ID	*Ceriodaphnia dubia*				
	Cd (ug/l)	Cu (ug/l)	Zn (ug/l)	H_2S (mg/l)	NH_3 (ug/l)
LR-EFF-A	NA	NA	61	26	5
LR-EFF-B	NA	NA	27	9.3	2
LR-EFF-C	NA	NA	NA	3.2	0.5
SM-BCR-A	NA	NA	NA	1.29	0.06
SM-BCR-B	NA	NA	NA	0.74	0.1
Comparison Value	31.4	6	425	0.002	500 - 5000

Sample ID	*Pimephales promelas*				
	Cd (ug/l)	Cu (ug/l)	Zn (ug/l)	H_2S (mg/l)	NH_3 (ug/l)
LR-EFF-A	NA	NA	0.13	0.58	0.1
LR-EFF-B	NA	NA	0.53	1.83	0.4
LR-EFF-C	NA	NA	NA	1.28	0.2
SM-BCR-A	NA	NA	NA	0.298	0.01
SM-BCR-B	NA	NA	NA	0.087	0.01
Comparison Value	29.2	69.6	725	0.002	200 - 3400

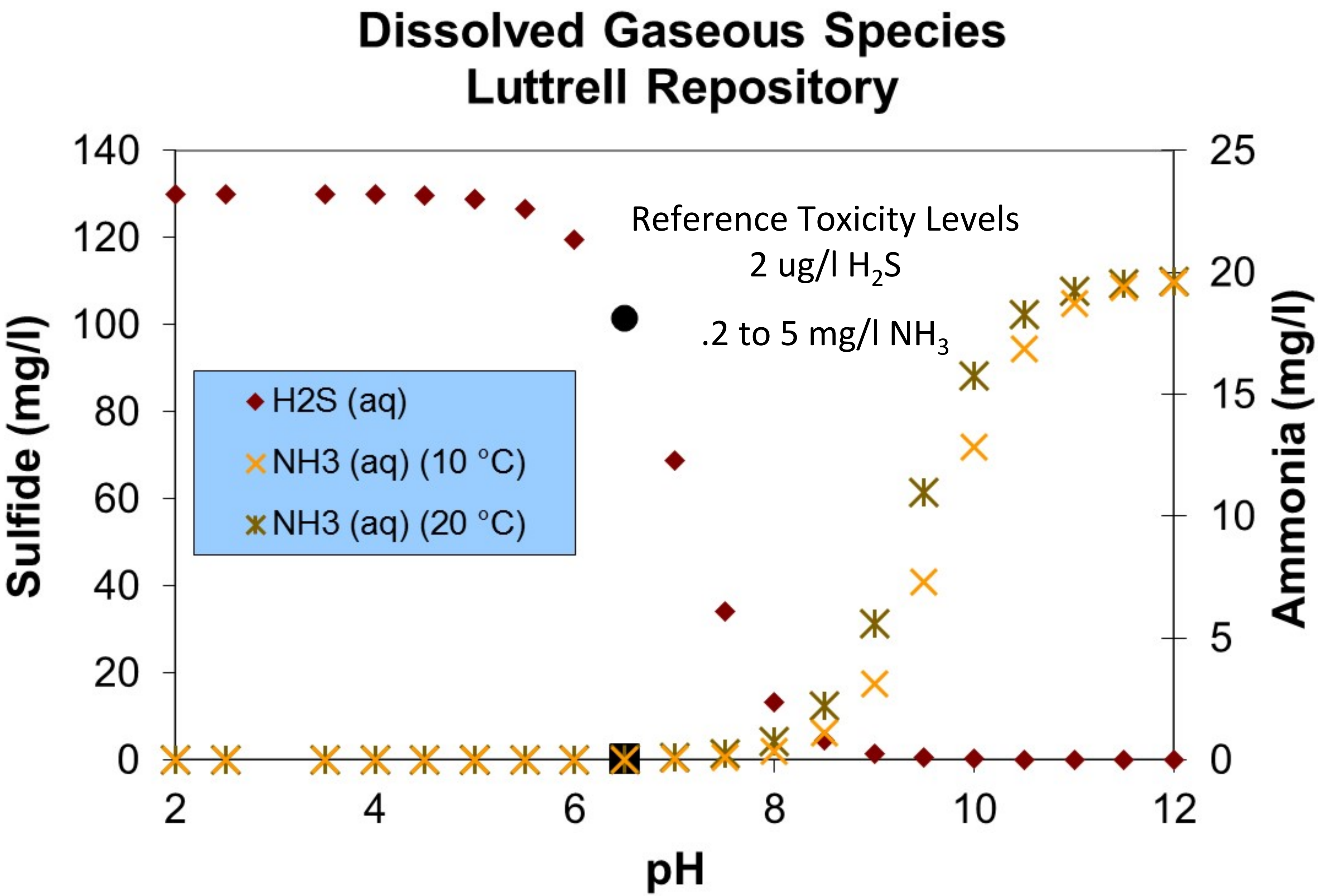
NA = none detected in undiluted sample

Dissolved H_2S and NH_3 calculated from total values, temp, and pH

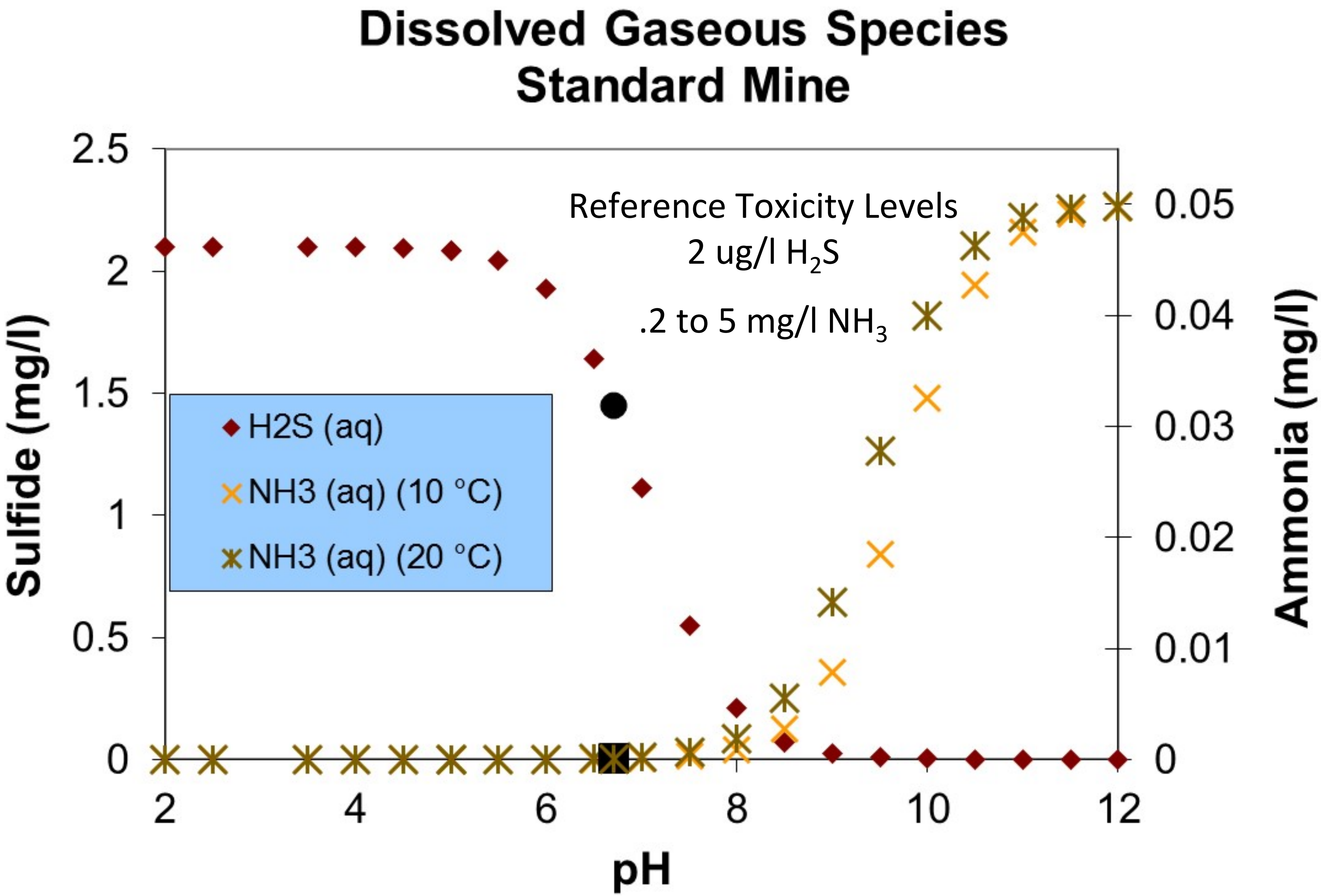
Effect of Aeration



Test species: fathead minnow



Dissolved Gaseous Species
Luttrell Repository
Reference Toxicity Levels
2 ug/l H_2S
.2 to 5 mg/l NH_3
H2S (aq)
NH3 (aq) (10 °C)
NH3 (aq) (20 °C)
Sulfide (mg/l)
Ammonia (mg/l)
pH
0
20
40
60
80
100
120
140
0
5
10
15
20
25
2
4
6
8
10
12



Dissolved Gaseous Species
Standard Mine
Reference Toxicity Levels
2 ug/l H_2S
.2 to 5 mg/l NH_3
H2S (aq)
NH3 (aq) (10 °C)
NH3 (aq) (20 °C)
Sulfide (mg/l)
Ammonia (mg/l)
pH
2.5
2
1.5
1
0.5
0
0.05
0.04
0.03
0.02
0.01
0
2
4
6
8
10
12

Concluding Remarks

- Results suggest toxicity from dissolved hydrogen sulfide gas
  - Effluents more toxic to fathead minnow than to the *C. dubia*
  - Fathead minnow known to be more sensitive to dissolved gases than *C. dubia*
  - Dissolved H_2S concentrations above species mean acute values
  - Toxicity from 100% sample removed with aeration at Standard Mine and reduced at Luttrell

- Other BCRs may have different toxicants, depending on:
  - Contaminants present and efficiency of removal
  - Concentrations of dissolved gases and pH of the effluent

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Concluding Remarks

- BCR treatment is effective at removing significant proportions of metals from MIW, but aquatic toxicity may still be present

- Sufficient in-field aeration following BCR treatment is an important step to remove potential toxicants resulting from the processes occurring within the BCR cells

- Combining chemical and biological monitoring can lead to better treatment system designs
  - To meet the goal of minimizing environmental and human health impacts

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  - Regional RPM's
  - City of Park City, UT

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Butler, BA, Smith, ME, Reisman, DJ, Lazorchak, JM. 2011. Metal removal efficiency and ecotoxicological assessment of field-scale passive treatment biochemical reactors. Environmental Toxicology & Chemistry. 30(2):385-392.