# Passive Co-Treatment of Polymetallic Acid Mine Drainage at Cerro Rico de Potosí, Bolivia


Rebecca Peer, *Saint Francis University*

Julie LaBar, *University of Oklahoma*

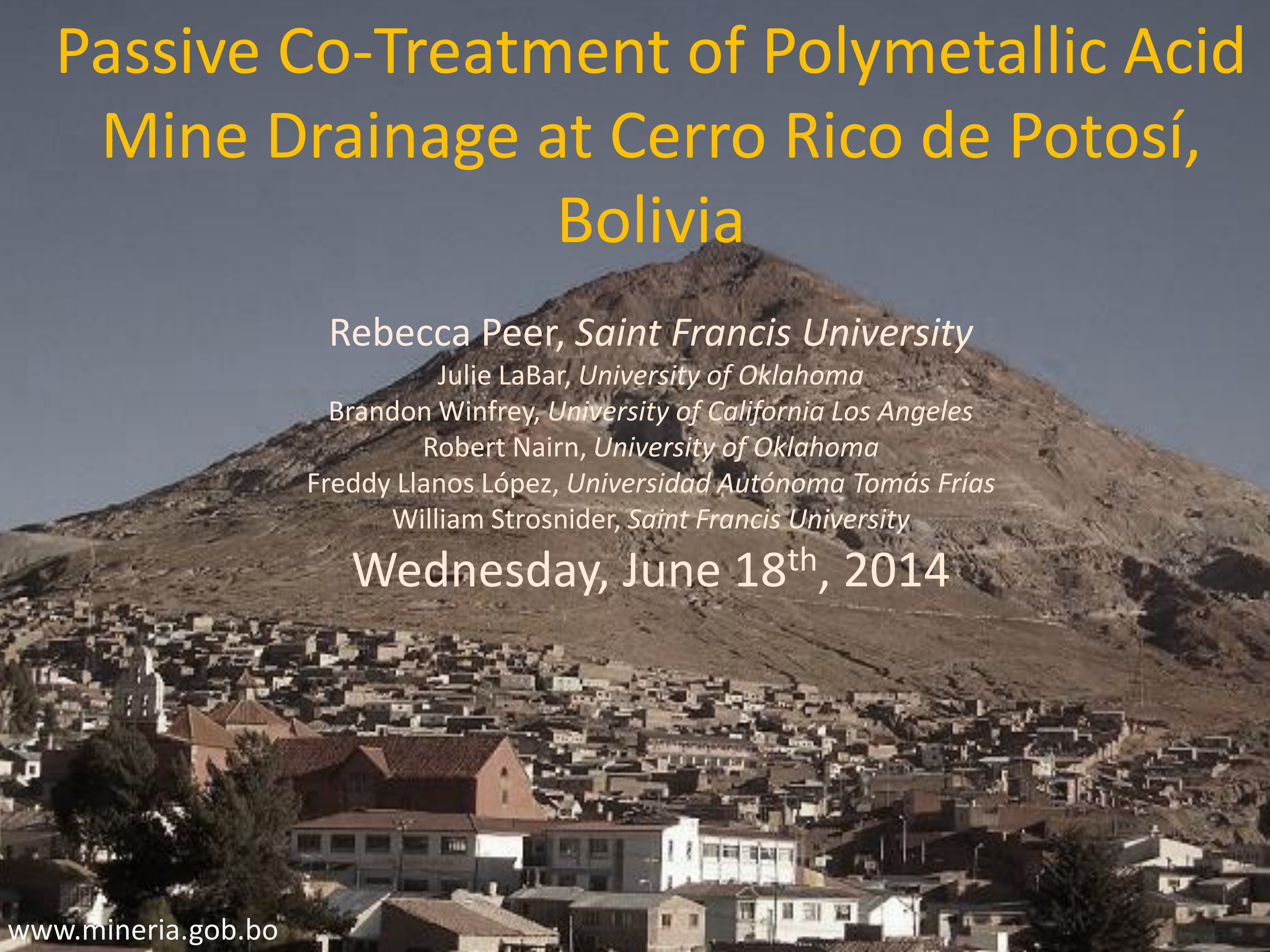
Brandon Winfrey, *University of California Los Angeles*

Robert Nairn, *University of Oklahoma*

Freddy Llanos López, *Universidad Autónoma Tomás Frías*

William Strosnider, *Saint Francis University*


Wednesday, June 18th, 2014



www.mineria.gob.bo


The methods

The study


Results

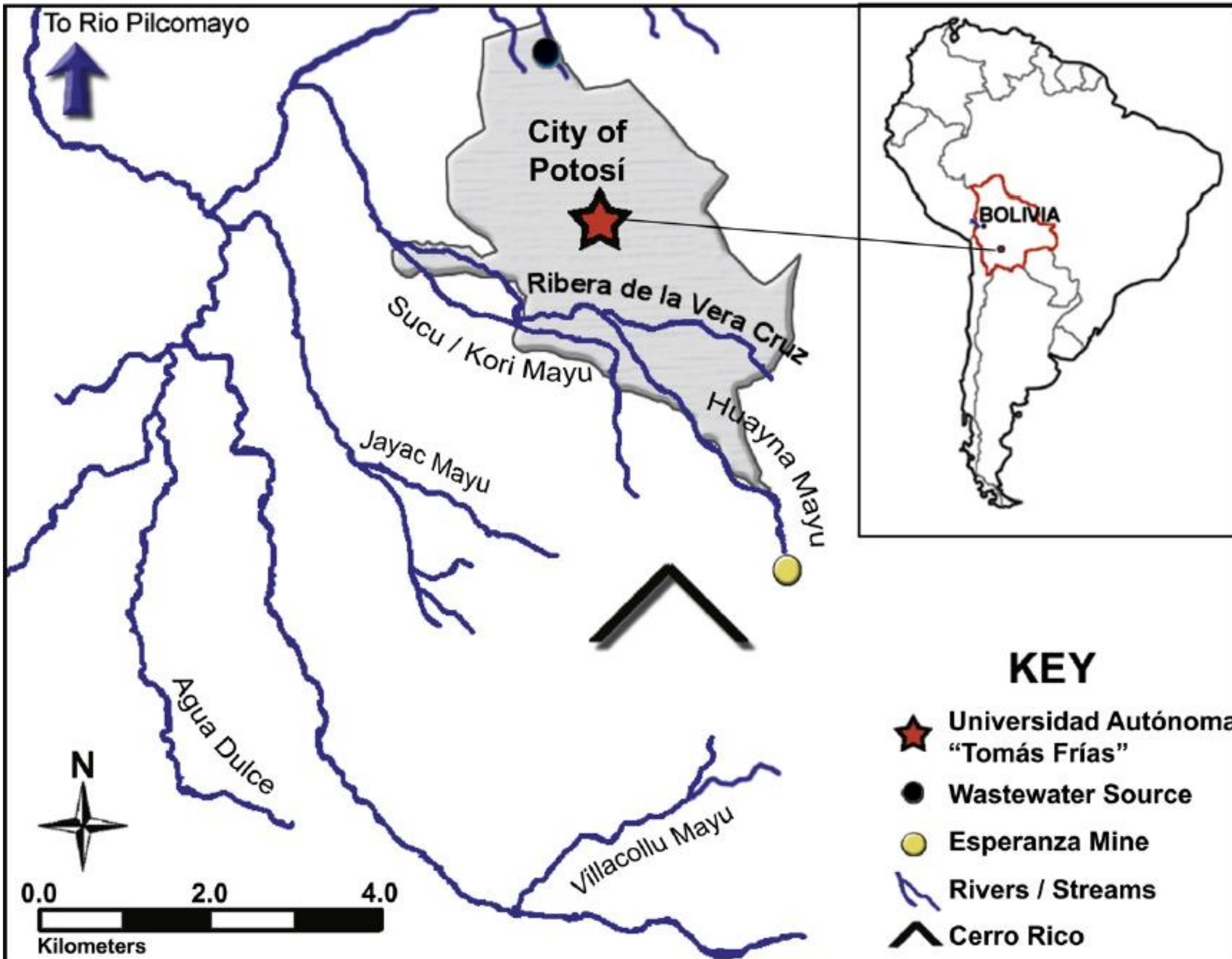
Conclusions


The methods

The study


Results

Conclusions



To Rio Pilcomayo
City of Potosí
Ribera de la Vera Cruz
Sucu / Kori Mayu
Huayna Mayu
Jayac Mayu
Agua Dulce
Villacollu Mayu
BOLIVIA
N
0.0
2.0
4.0
Kilometers
KEY
Universidad Autónoma "Tomás Frías"
Wastewater Source
Esperanza Mine
Rivers / Streams
Cerro Rico

# Co-Treatment Theory

- Acid Mine Drainage
  - Needs $e^-$ donors for bacterial reduction
- Municipal Waste Water
  - Needs $e^-$ acceptors for bacterial oxidation
  - Need to remove of solids
  - Need to remove pathogens

# Previous Co-Treatment Studies

- First suggested by Roetman (1932)
- Algal-based systems
  - Short term removal
- Many microcosm-scale experiments
  - Bacterial sulfate reduction
  - Sànchez-Andrea et al. (2012), McCullough et al. (2008), Kumar et al. (2011)
- Activated sludge
  - Active co-treatment
  - Hughes and Gray (2012a, 2012b, 2013)

# Previous Co-Treatment Studies

- Simple incubations
  - Strosnider and Nairn (2010), Strosnider et al. (2011, 2013), Deng and Lin (2013)
- Full-scale wetland treatment system
  - Johnson and Younger (2006), Younger and Henderson (2014)
- Three-stage batch reactor
  - Strosnider et al. (2013)


The methods

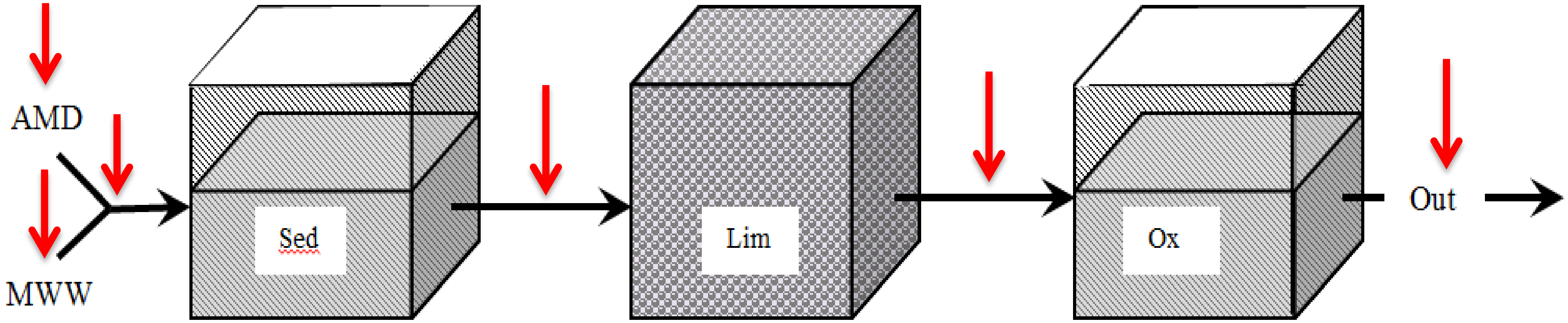
The study


Results

Conclusions

# Experimental Design

- Three-stage batch reactor
  - Removal of metal contaminants
  - Alkalinity generation, Acidity consumption
  - Raise pH
  - Increase dissolved oxygen




The methods

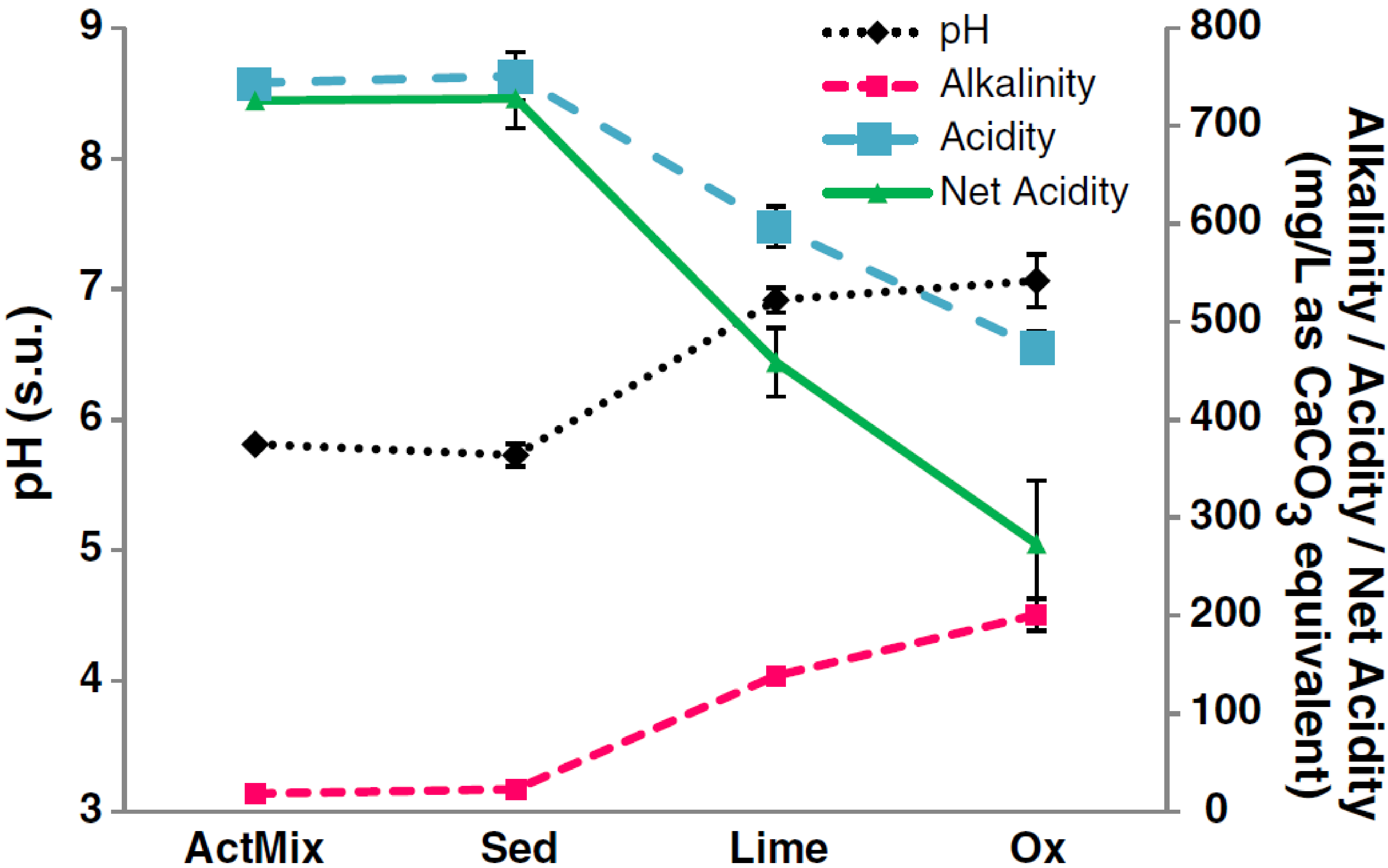
The study


Results

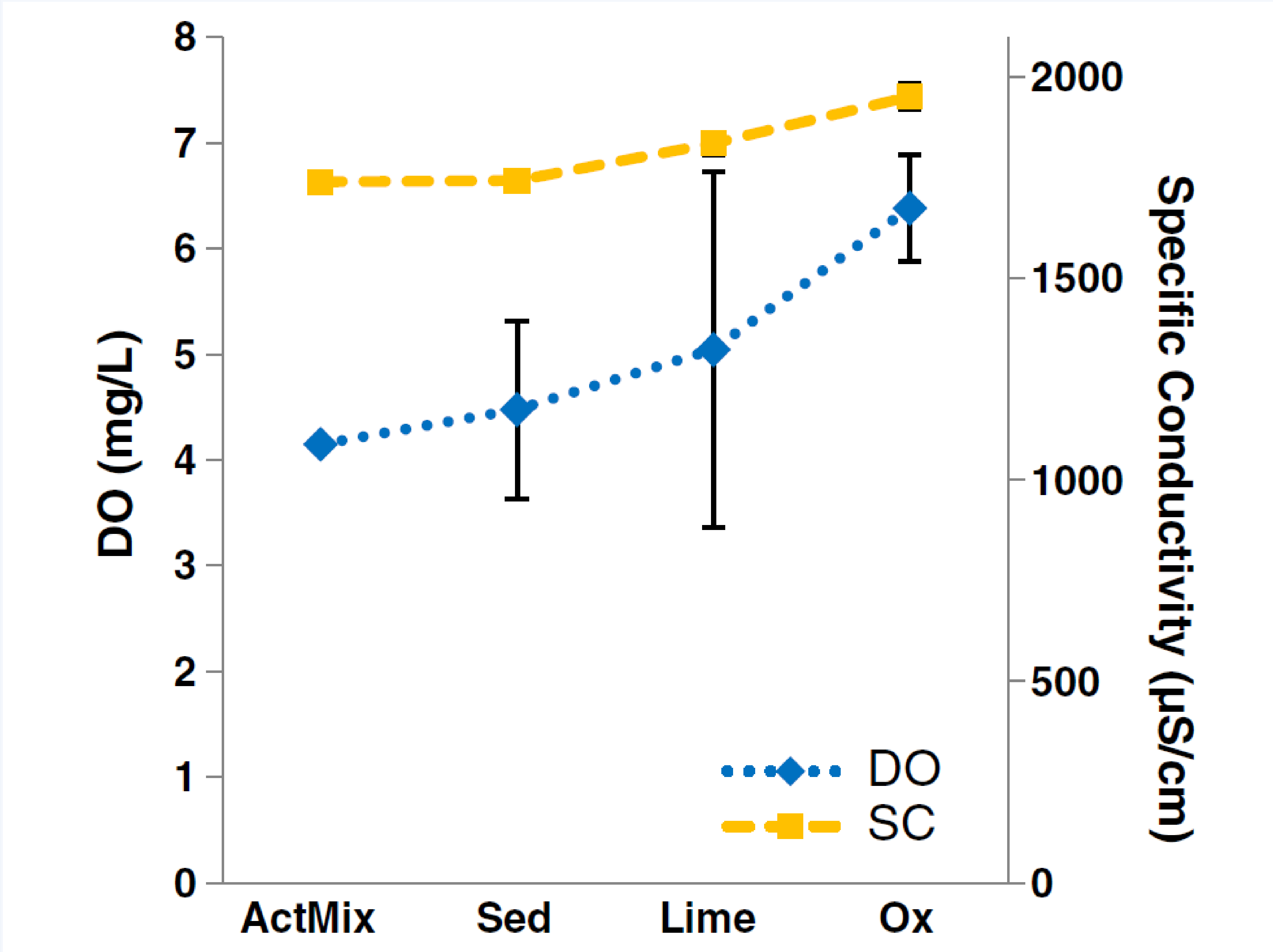
Conclusions

# Physicochemical Data

| | Units | MWW | AMD | TheoMix | ActMix | Sedimentation | Limestone | Oxidation |
|---|---|---|---|---|---|---|---|---|
| pH | s.u. | 9.05 | 3.58 | 3.68 | 5.81 | 5.73 | 6.91 | 7.06 |
| SC | µs/cm | 1315 | 1915 | 1795 | 1741 | 1744 | 1837 | 1953 |
| T | °C | 10 | 8.4 | 8.7 | 8.2 | 8.15 | 7.63 | 10.3 |
| DO | mg/L | 2.3 | 9.2 | 7.8 | 4.2 | 4.5 | 5 | 6.4 |
| Alkalinity | mg/L | 418 | 0 | - | 18 | 23 | 139 | 201 |
| Acidity | mg/L | 1.2 | 1083 | 866 | 744 | 750 | 597 | 474 |
| Net Acidity | mg/L | -417 | 1083 | - | 726 | 728 | 459 | 273 |



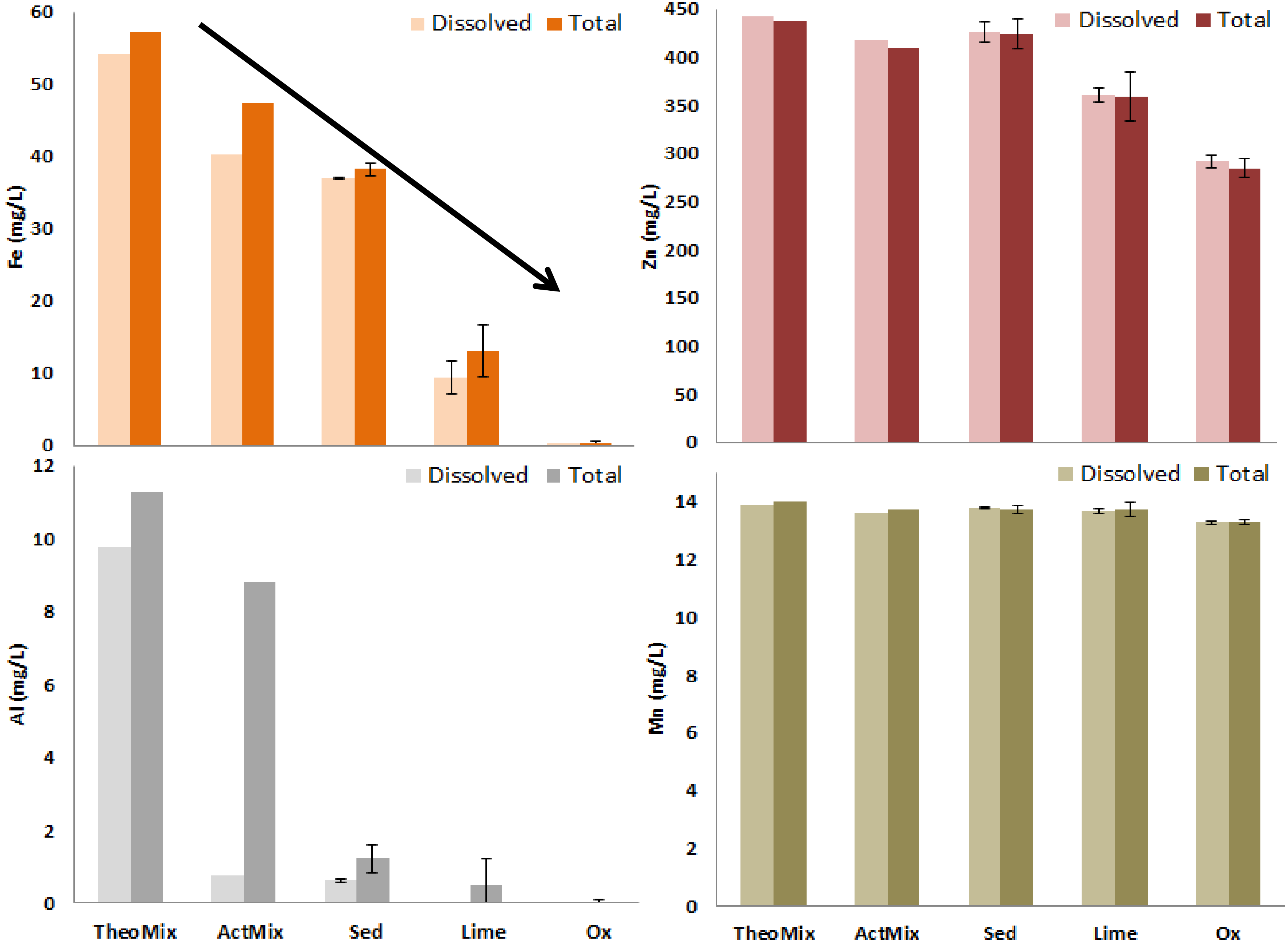
pH
Alkalinity
Acidity
Net Acidity
9
8
7
6
5
4
3
pH (s.u.)
800
700
600
500
400
300
200
100
0
Alkalinity / Acidity / Net Acidity
(mg/L as $CaCO_3$ equivalent)
ActMix
Sed
Lime
Ox



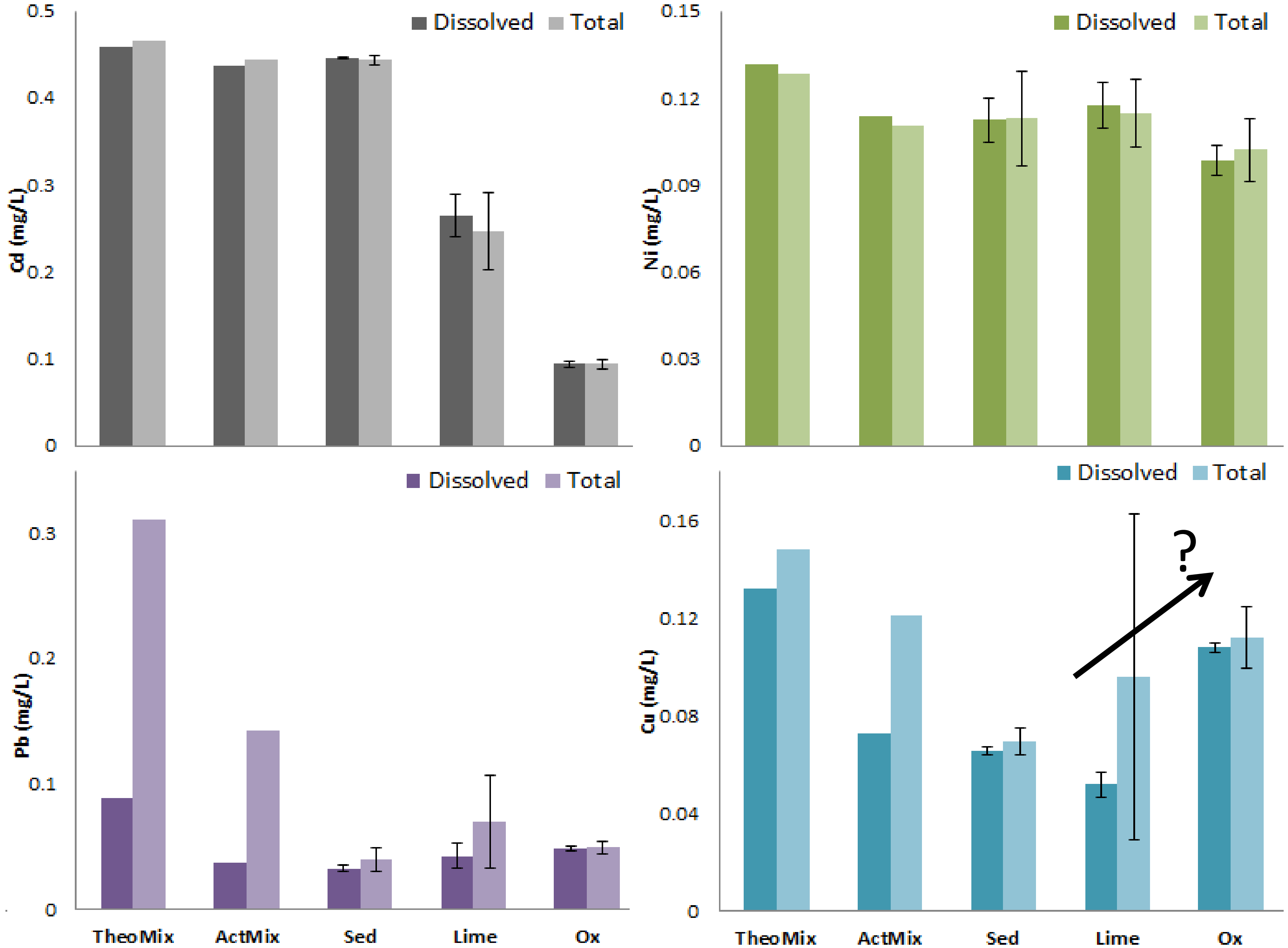
DO (mg/L)
Specific Conductivity (µS/cm)
8
7
6
5
4
3
2
1
0
2000
1500
1000
500
0
ActMix
Sed
Lime
Ox
DO
SC

# Dissolved Metal Concentrations (mg/L)

| | MWW | AMD | TheoMix | ActMix | Sedimentation | Limestone | Oxidation | %Change |
|---|---|---|---|---|---|---|---|---|
| Al | 0.0598 | 12.2 | 9.77 | 0.763 | 0.626 | 0.0297 | 0.0326 | **-99.7** |
| Ag | <0.0016 | 0.003 | 0.0025 | 0.0025 | 0.0025 | 0.0029 | 0.0034 | **34.3** |
| As | <0.022 | <0.022 | <0.022 | <0.022 | <0.022 | <0.022 | <0.022 | 0 |
| B | 0.270 | 0.176 | 0.195 | 0.187 | 0.186 | 0.264 | 0.293 | **50.3** |
| Ba | 0.0302 | 0.0237 | 0.025 | 0.026 | 0.027 | 0.0867 | 0.100 | **300** |
| Ca | 43.5 | 136 | 117 | 113 | 115 | 212 | 312 | **166** |
| Cd | 0.0006 | 0.574 | 0.459 | 0.436 | 0.445 | 0.264 | 0.0936 | **-78.5** |
| Ce | <0.0028 | 0.0518 | 0.0417 | 0.0316 | 0.0322 | 0.0088 | 0.009 | **-78.5** |
| Cr | 0.0014 | 0.0015 | 0.002 | <0.001 | 0.0014 | 0.0011 | 0.0012 | **-100** |
| Cu | 0.0152 | 0.1616 | 0.132 | 0.0729 | 0.0655 | 0.0519 | 0.108 | **-18.3** |
| Fe | 0.1609 | 67.7 | 54.2 | 40.2 | 37.0 | 9.38 | 0.0095 | **-100** |
| Gd | 0.0042 | 0.011 | 0.0096 | 0.0068 | 0.0067 | 0.0032 | <0.0028 | **-100** |
| K | 58.1 | 12.3 | 21.5 | 21.1 | 21.3 | 23.7 | 25.2 | **17.2** |
| La | 0.0023 | 0.0149 | 0.0124 | 0.0102 | 0.0105 | 0.0045 | 0.0045 | **-63.8** |
| Li | 0.205 | 0.138 | 0.114 | 0.115 | 0.115 | 0.115 | 0.119 | **4.22** |
| Mg | 8.36 | 19.0 | 16.9 | 16.8 | 17.1 | 18.5 | 21.6 | **28.1** |
| Mn | 0.118 | 17.3 | 13.9 | 13.6 | 13.8 | 13.7 | 13.3 | **-4.52** |
| Na | 91.8 | 14.3 | 29.8 | 34.8 | 35.1 | 35.6 | 37.4 | **25.7** |
| Ni | 0.0273 | 0.158 | 0.132 | 0.114 | 0.112 | 0.117 | 0.0983 | **-25.5** |
| Nd | 0.0232 | 0.0589 | 0.0518 | 0.0483 | 0.0492 | 0.0514 | 0.0568 | **9.76** |
| Pb | <0.011 | 0.111 | 0.090 | 0.0379 | 0.0326 | 0.0431 | 0.0485 | **-45.9** |
| Pr | 0.0888 | 0.181 | 0.162 | 0.173 | 0.172 | 0.234 | 0.263 | **62.0** |
| Sr | 0.287 | 1.24 | 1.05 | 1.06 | 1.07 | 1.10 | 1.16 | **10.1** |
| Zn | 0.211 | 552 | 441 | 418 | 426 | 361 | 292 | **-33.9** |



60
50
40
30
20
10
0
Fe (mg/L)
Dissolved
Total
450
400
350
300
250
200
150
100
50
0
Zn (mg/L)
Dissolved
Total
12
10
8
6
4
2
0
Al (mg/L)
Dissolved
Total
14
12
10
8
6
4
2
0
Mn (mg/L)
Dissolved
Total
TheoMix
ActMix
Sed
Lime
Ox
TheoMix
ActMix
Sed
Lime
Ox



Dissolved
Total
Cd (mg/L)
0.5
0.4
0.3
0.2
0.1
0
Ni (mg/L)
0.15
0.12
0.09
0.06
0.03
0
Pb (mg/L)
0.3
0.2
0.1
Cu (mg/L)
0.16
0.12
0.08
0.04
?
TheoMix
ActMix
Sed
Lime
Ox

# First-Order Removal Rates (K)

| | Sedimentation | Limestone | Oxidation | Overall |
|---|---|---|---|---|
| Al | 2.7 | 6.1 | -0.05 | 1.4 |
| Cd | -0.02 | 1.0 | 0.5 | 0.4 |
| Ce | 0.3 | 2.6 | -0.008 | 0.4 |
| Cu | 0.7 | 0.5 | -0.4 | 0.05 |
| Fe | 0.08 | 2.7 | 3.5 | 2.1 |
| Gd | 0.4 | 1.5 | - | - |
| La | 0.2 | 1.7 | 0.004 | 0.3 |
| Mn | 0.008 | 0.02 | 0.02 | 0.01 |
| Ni | 0.2 | -0.09 | 0.09 | 0.07 |
| Pb | 1.0 | -0.6 | -0.04 | 1.2 |
| Zn | 0.04 | 0.3 | 0.1 | 0.1 |

# Geochemical Modeling

- Using PHREEQC 2.14.03 with MinteqV4 database
  - Evaluating possible precipitates via saturation indices
    - $Al(OH)_3$, $FeOOH$, $Fe_2O_3$, $MnOOH$, $ZnCO_3$ …

# Versatility of a Treatment System

- Dominant metals in AMD treatment:
  - Al, Fe, Mn (Younger et al. 2002)
- Trace metals becoming of greater concern:
  - New toxic effects constantly being discovered
    - Effects even at low concentrations
  - Not typically addressed in treatment
  - As, Ba, Cd, Cu, Ni, Pb


The methods

The study


Results

Conclusions

# Conclusions

- Passive co-treatment is applicable
  - Treat a wider range of contaminants
  - Removes metals/metalloids that are health concerns:
    - Al, As, Cd, Fe, Pb, Mn (Nordberg et al. 2007)
  - Solution to chronic water problems
  - Inexpensive and low-maintenance

# Conclusions

- A pilot-scale system is necessary
  - Sustainability, longevity, and maintenance
  - Importance of each unit process


QUESTIONS?