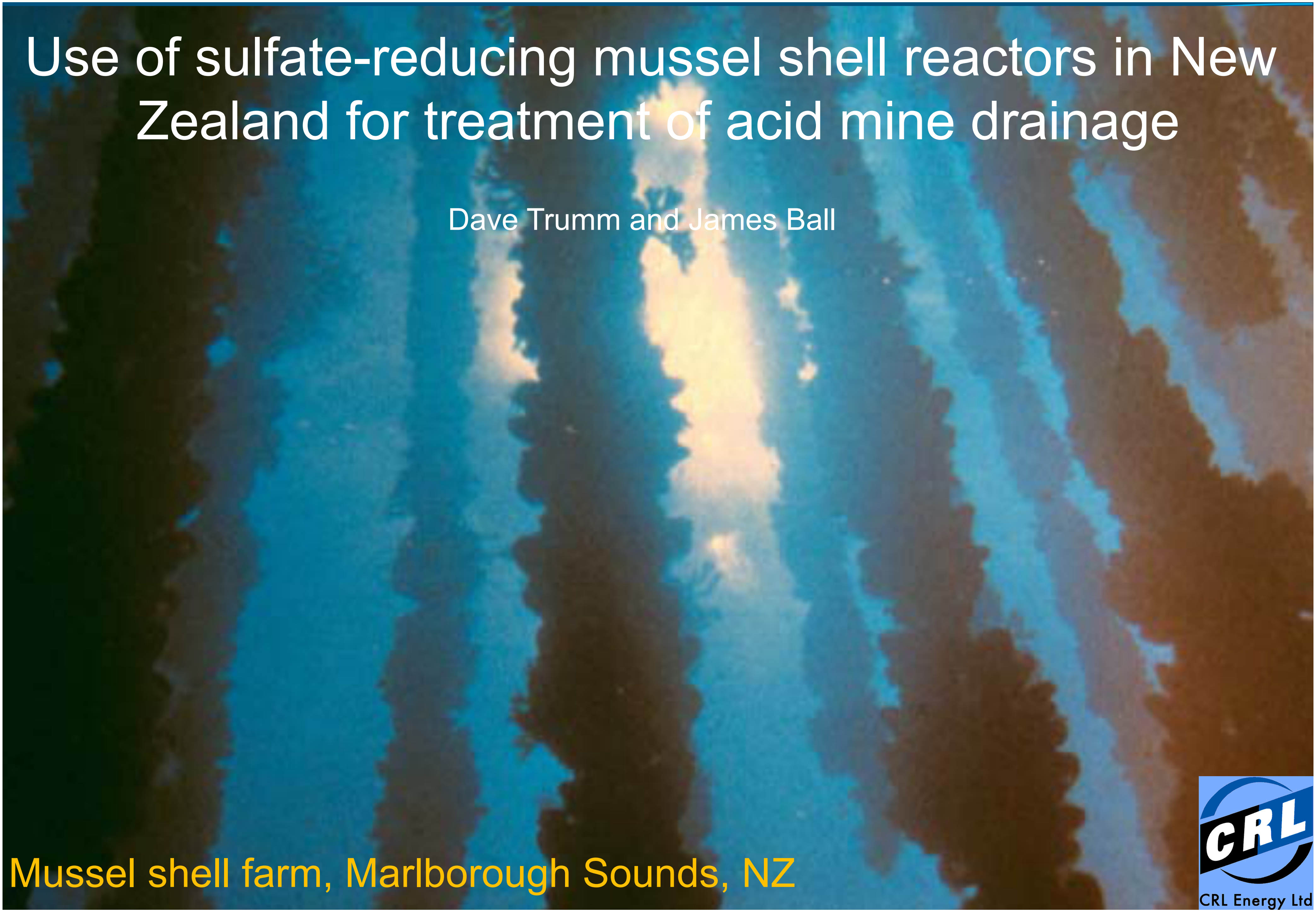
Use of sulfate-reducing mussel shell reactors in New Zealand for treatment of acid mine drainage

Dave Trumm and James Ball



Mussel shell farm, Marlborough Sounds, NZ

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Sub-bituminous coal

Bituminous coking coal

Lignite

Epithermal gold

Mesothermal gold

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Coal production

- 15 billion tonnes reserves
- 5 UG mines, 16 opencast mines
- 5.3 Mt/yr
  - 49% bituminous coking coal
  - 45% sub-bituminous thermal coal
  - 6% lignite
- Almost all coking coal exported to India, Japan, China
- Remaining coal used in NZ (electricity, factories, steel making, commercial, residential)

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Coal Mining

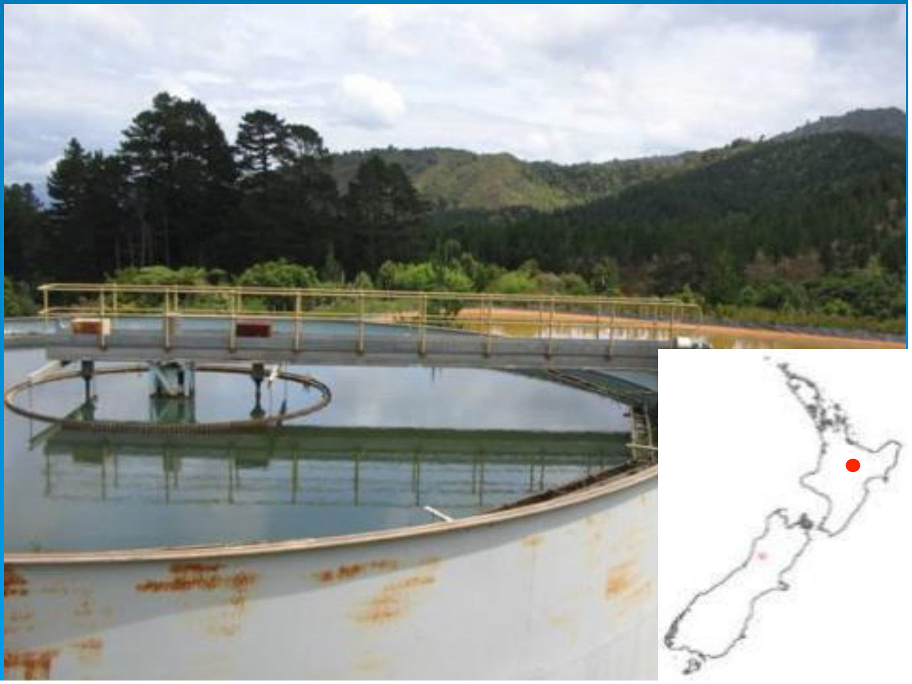

2004 10 29

Gold Mining

Active Treatment

- Neutral pH, high Fe, Mn
  - pH 6.0
  - Fe 25 mg/L
  - Mn 18 mg/L
- Treatment with
  - CaO, $Ca(OH)_2$, $CaCO_3$

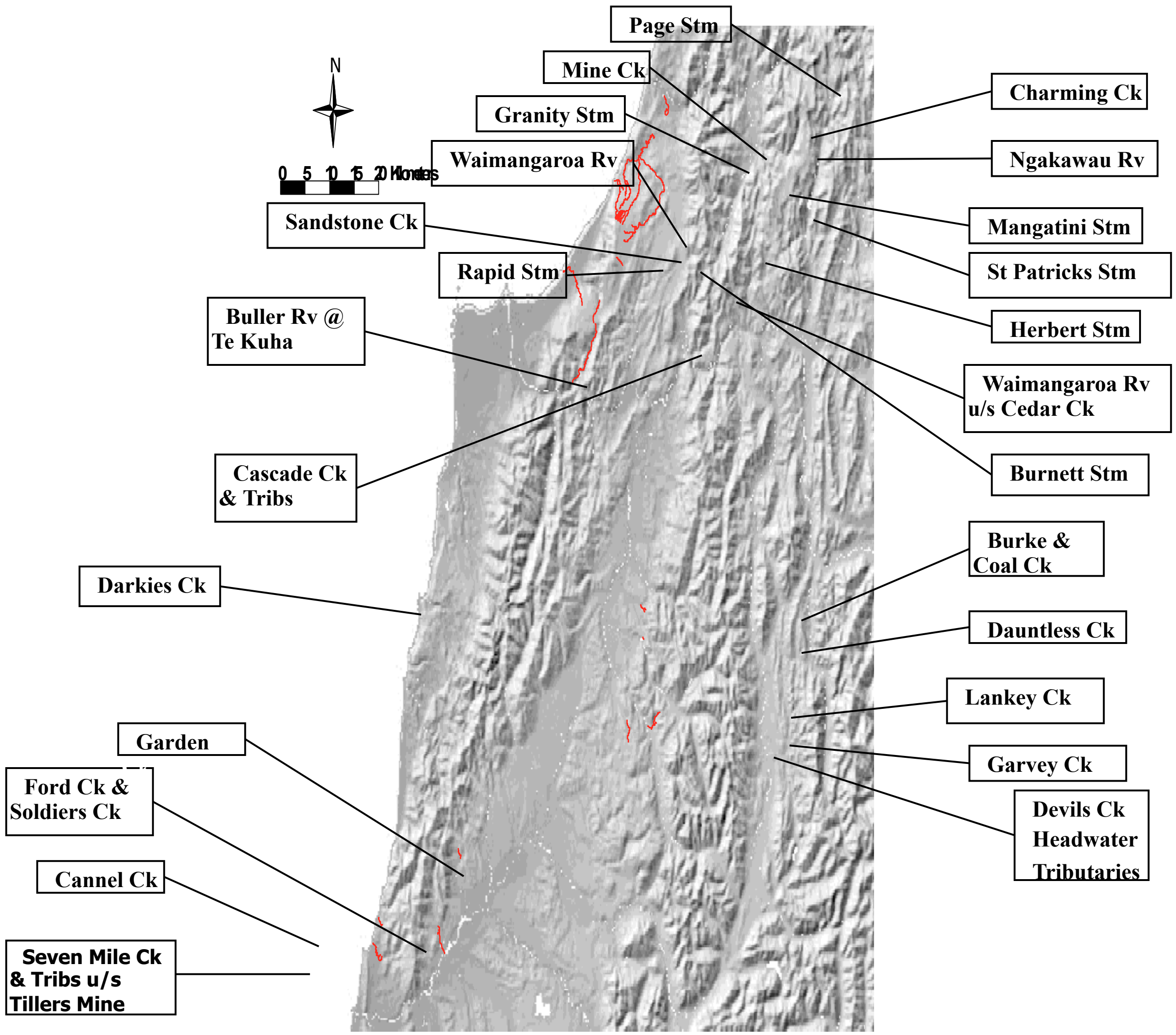
Golden Cross Gold Mine,
Waihi, NZ



Stockton Coal Mine, West Coast

- Low pH, high Fe, Al
  - pH 3.1
  - Fe 35 mg/L
  - Al 50 mg/L
- Treatment with
  $Ca(OH)_2$, $CaCO_3$

The legacy



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Blackball Mine

pH 3.1

Fe 11 mg/L

Al 14 mg/L

60 L/s

Bellvue Mine

pH 2.7

Fe 100 mg/L

Al 41 mg/L

2 L/s

Golden Cross Mine

pH 6.0

Fe 25 mg/L

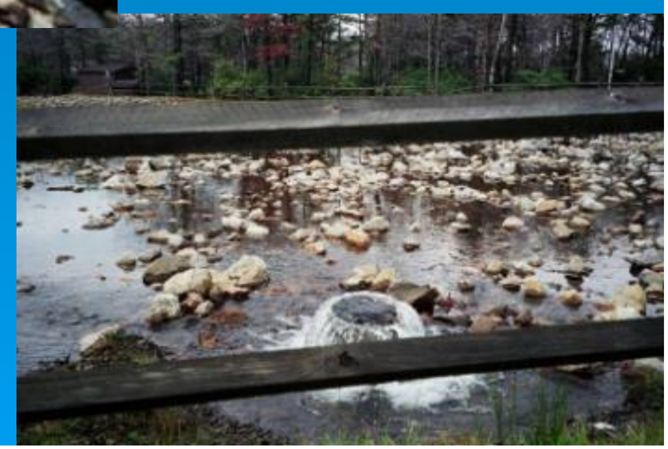
Mn 18 mg/L

20 L/s


Sullivan Mine
pH 2.8
Fe 42 mg/L
Al 14 mg/L
40 L/s

Visit to WV, 2003

Limestone leaching bed, Ohiopyle, PA



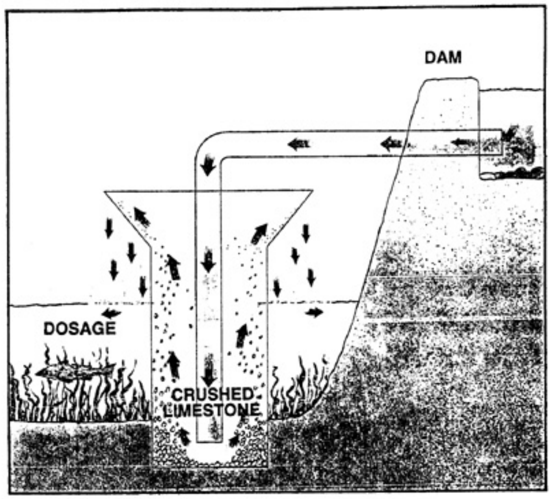


Figure 1. Schematic arrangement of a typical diversion well (from Cementa Movab 1983).

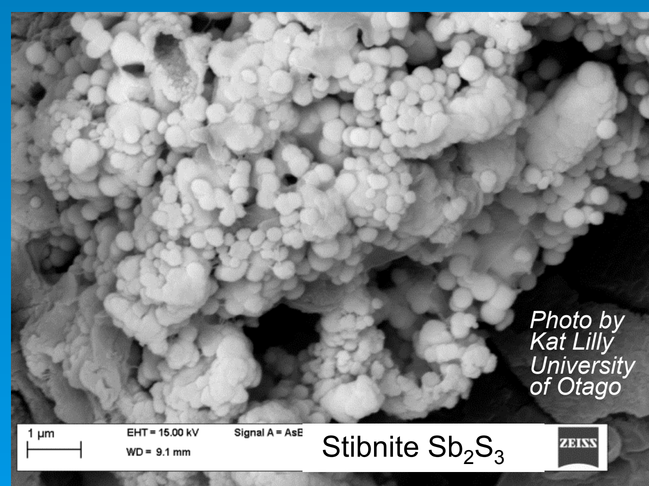
Passive Treatment Experiments

Herbert Stream 2005 (AMD)

Golden Cross 2006 (NMD)

Pike River 2007 (AMD)

Bellvue Mine 2013 (AMD)



Globe Progress 2012 (Sb)

Waiuta 2010 (As)

Framework document

- Main text
  - 9 chapters
  - Checklists
  - Worked example
- Appendices with detailed technical information

Available at:

http://www.crl.co.nz/research/mine_drainage_framework.asp

A framework for predicting and managing water quality impacts of mining on streams: a user's guide

JE Cavanagh[1], J Pope[2], JS Harding[3], D Trumm[2], D Craw[4], R Rait[2]
H Greig[3], D Niyogi[3], R Buxton[1], O Champeau[1], A Clemens[2]

[1] Landcare Research
[2] CRL Energy
[3] School of Biological Sciences, University of Canterbury
[4] School of Geological Sciences, University of Otago

June 2010

Landcare Research Manaaki Whenua

CRL Energy Ltd

University of Otago

UC University of Canterbury

Outline

- The New Zealand mussel
- History of mussel shell reactors in New Zealand
  - Laboratory studies, field trials, full-scale systems
- Current field trials

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The Green-lipped mussel
(Perna canalicula)

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Japanese Longline system

#1 seafood export

(>$200 M/year)

Mostly fully shelled

12,000 tons shell waste / month

10% waste mussel meat

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10% waste mussel meat

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It is an alkalinity source? What about the mussel meat?

- Amendment to bioreactors
  - Craig McCauley (PhD student, 2007)
  - Andy Mackenzie (MSc student, 2010)
  - Ben Uster (PhD student, current)
- Shell-only reactors
  - Manchester Street (Solid Energy, 2010)
  - Whirlwind (Solid Energy, 2012)
  - Rae West (MSc student, current)
  - This study (Trumm, 2013)

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Case study 1
(Craig McCauley 2007)

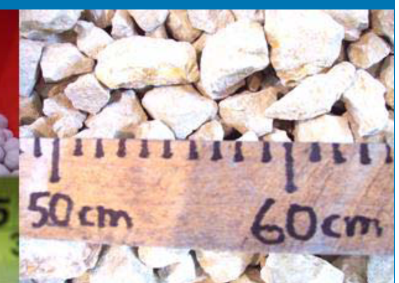
Flow (L/s)	1.82
pH	2.8
DO (% sat)	82
Fe (mg/L)	63 (140 max)
Al (mg/L)	33 (57 max)
Zn (mg/L)	0.99
Ni (mg/L)	0.18

Manchester Street, Stockton Coal Mine

- Laboratory study (PhD)
- Mussel shell vs. limestone
  - Amendment in bioreactors
- Drum vs. trapezoidal shape reactor

mussel shells

stack dust

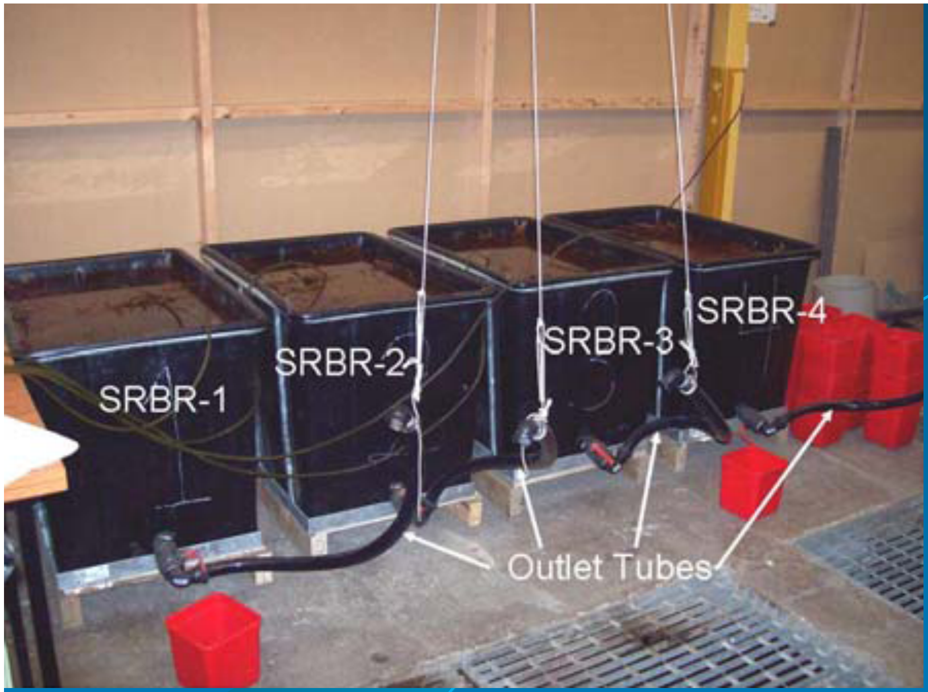


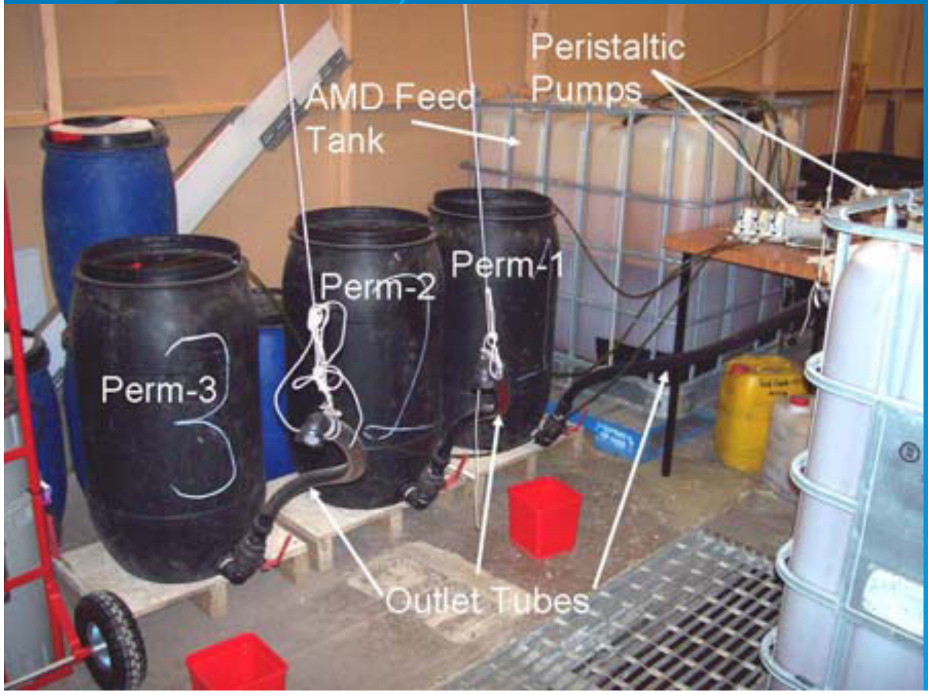
limestone

post peel

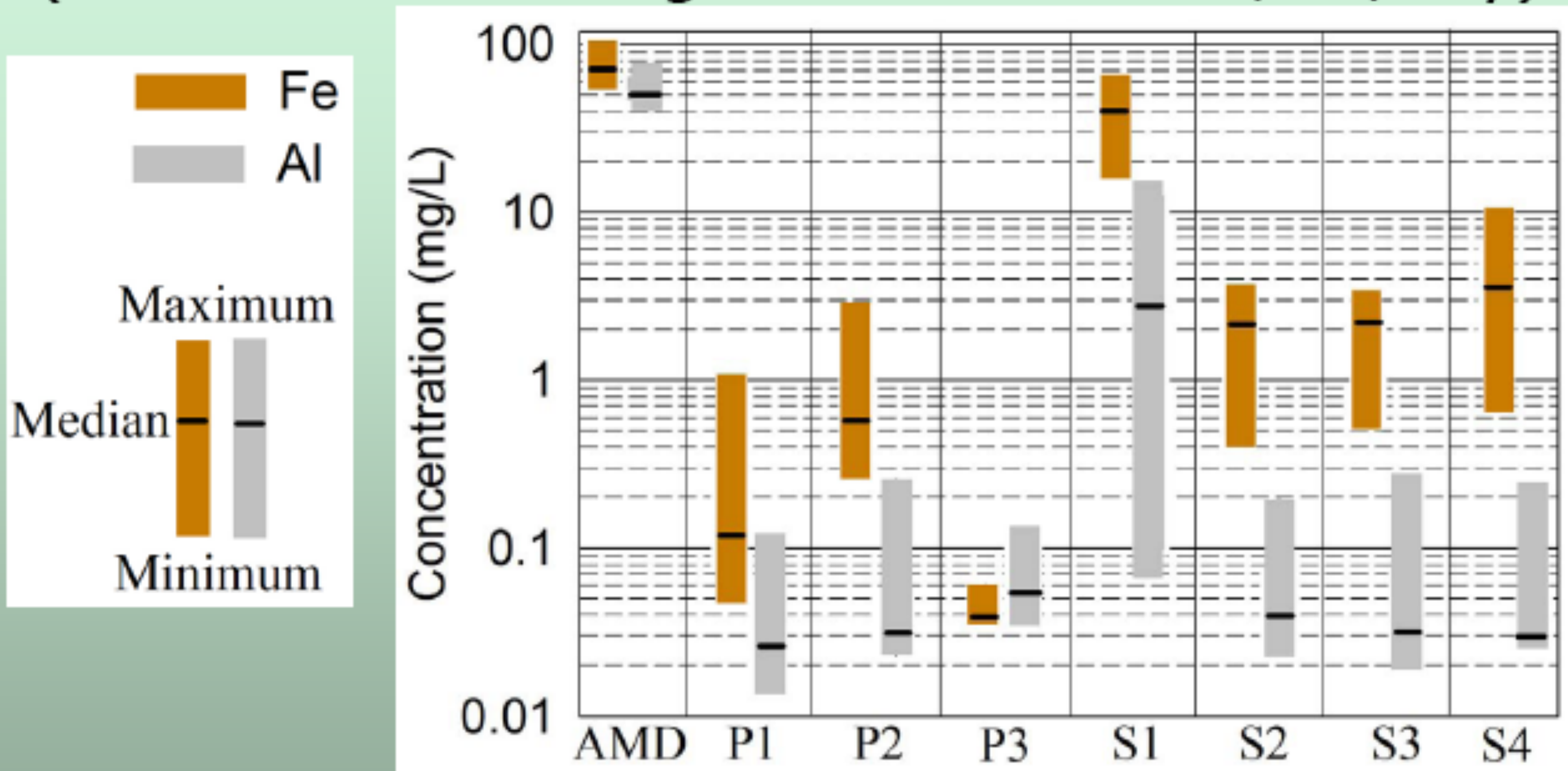
bark chips

compost


SRBR-1
SRBR-2
SRBR-3
SRBR-4
Outlet Tubes


Peristaltic Pumps
AMD Feed Tank
Perm-1
Perm-2
Perm-3
Outlet Tubes

Influent and Effluent Fe and Al Concentrations (Total Metal Loading = 0.23-0.83 mol/m^3/day)



	Drum			Trapezoidal			
% Limestone	0	5	2.5	12.5	0	0	5.0
% Mussel Shells	30	12	12	0	20	20	12
% NSD	0	0	5	0	0	0	0

(McCauley C, O'Sullivan A, Weber P, Trumm D, Brough A, Milke M (2008) Research Initiatives for Developing Passive-Treatment Systems for Ameliorating Acid Mine Drainage in New Zealand. ASMR 2008 Conference)

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Removal efficiency in bioreactors with 20-30 vol.% mussel shells

- metal loading rates 0.23 to 0.83 mol/m^3/substrate/day
- acidity loading rates 25 to 80 g $CaCO_3$/m^2/day

Parameter	Removal efficiency (%)
Fe	98.3
Al	99.9
Cu	99.9
Ni	99.7
Zn	99.9
Cd	98.5
Pb	99.7

McCauley C, O'Sullivan A, Weber P, Trumm D (2010) Variability of Stockton Coal Mine drainage chemistry and its treatment potential with biogeochemical reactors. New Zealand Journal of Geology and Geophysics 53:211-226.

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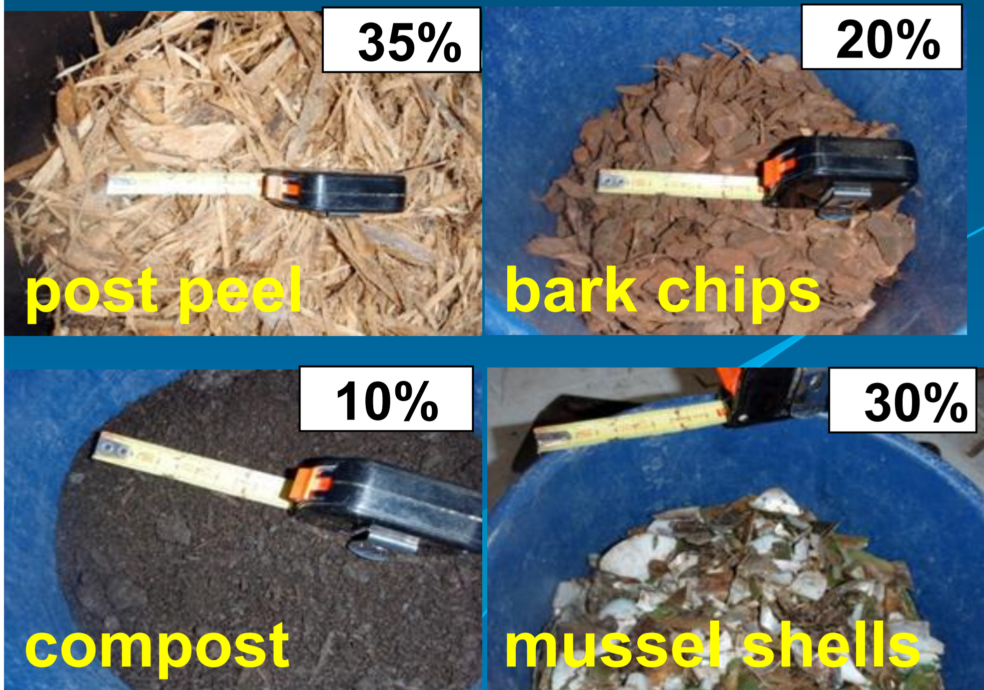
Case study 2

(Andy Mackenzie 2010)

Flow (L/s)	12
pH	3.6
DO (% sat)	80
Fe (mg/L)	1.3
Al (mg/L)	6
Mn (mg/L)	3.1
Zn (mg/L)	0.49
Ni (mg/L)	0.14
Cu (mg/L)	0.0071

Fanny Creek, Island Block Coal Mine



- Laboratory study (MSc)
- Mussel shell bioreactor vs:
  - Open limestone channel
  - Limestone leaching bed

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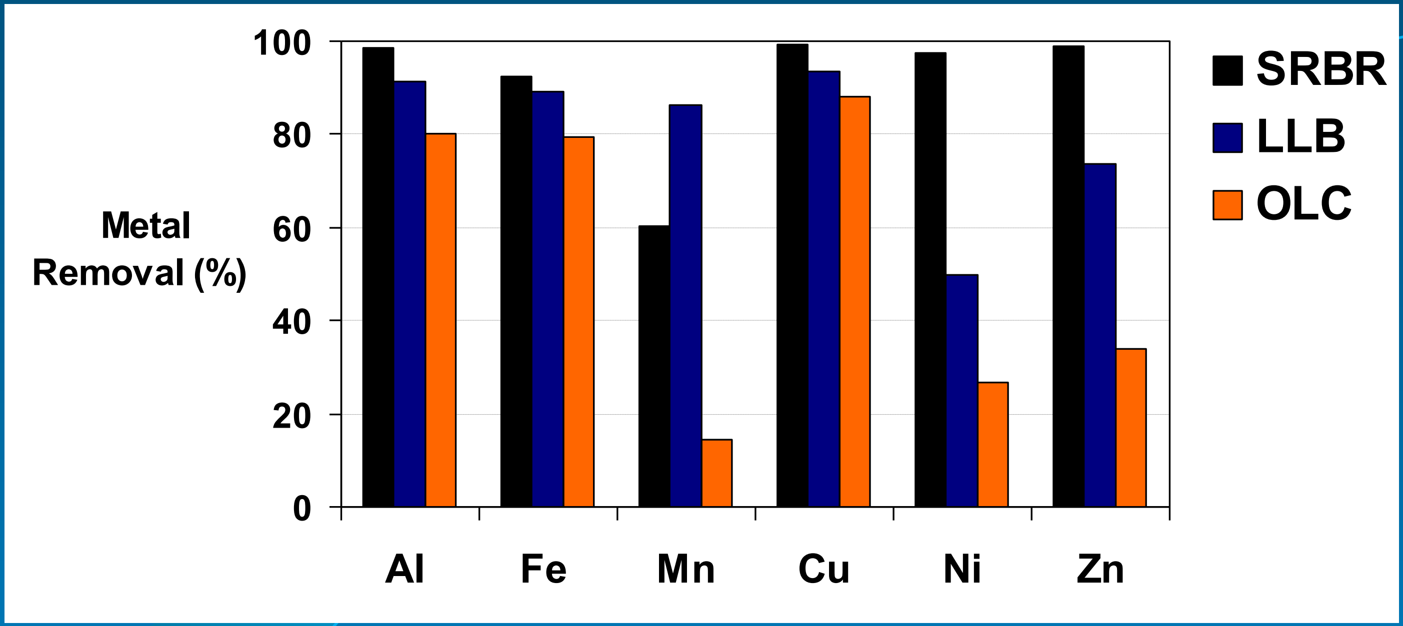

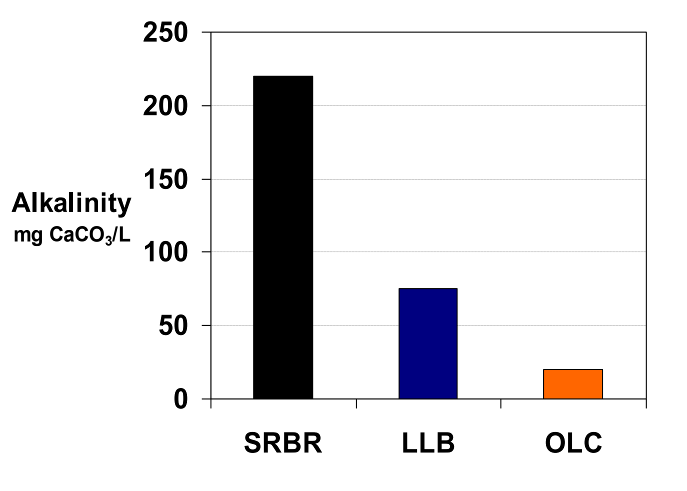

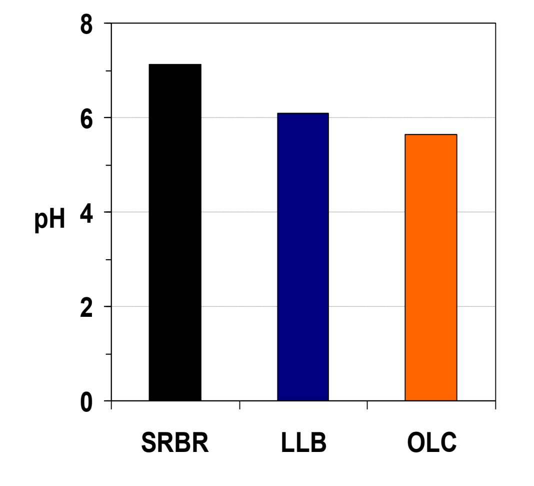

Mackenzie A, Pope J, Weber P, Trumm D, Bell D (2011) Characterisation of Fanny Creek catchment acid mine drainage and optimal passive treatment remediation options. AusIMM Conference, Queenstown, New Zealand

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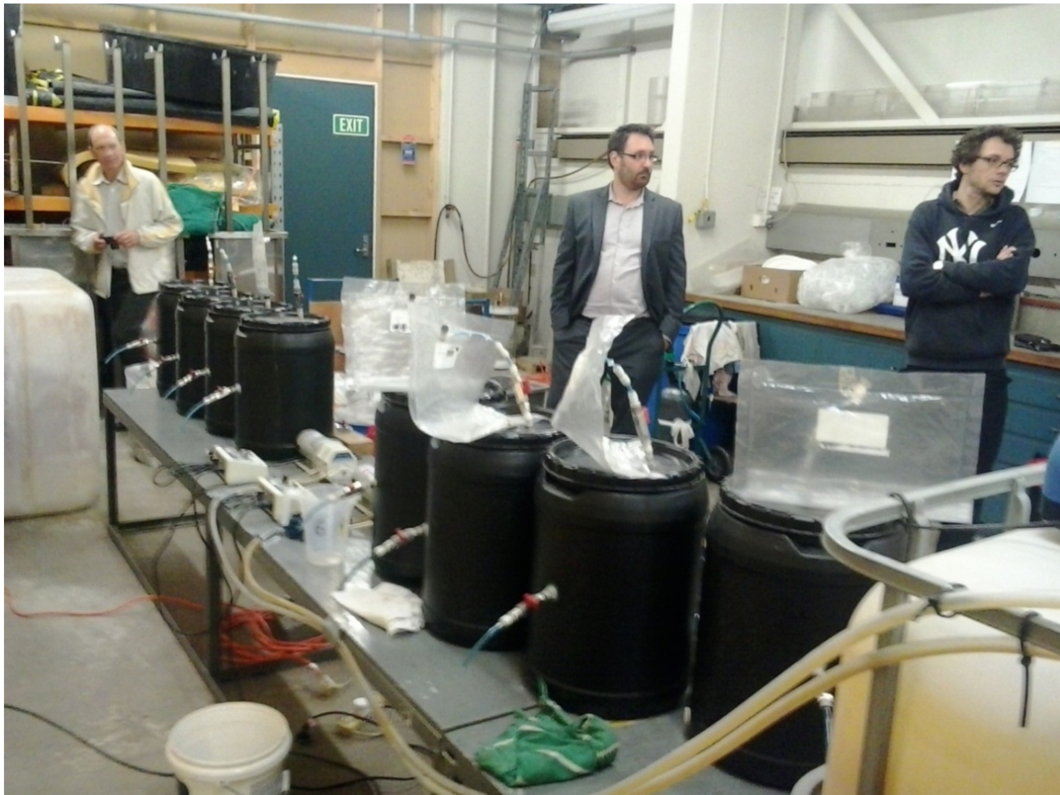
Case study 3
(Ben Uster - current)

pH	2.7
DO (% sat)	90
Fe (mg/L)	42
Al (mg/L)	18
Zn (mg/L)	4.2
Ni (mg/L)	1.2
Cu (mg/L)	0.35

Coal Mine X



- Laboratory study (PhD)
- Mussel shell vs. limestone
  - Amendment in bioreactors
- Long vs. short HRT (10, 3 dy)
  - **Upflow reactors**

Mussel shells or Limestone	30 %
Bark	30 %
Bark mulch	20 %
Compost	20 %

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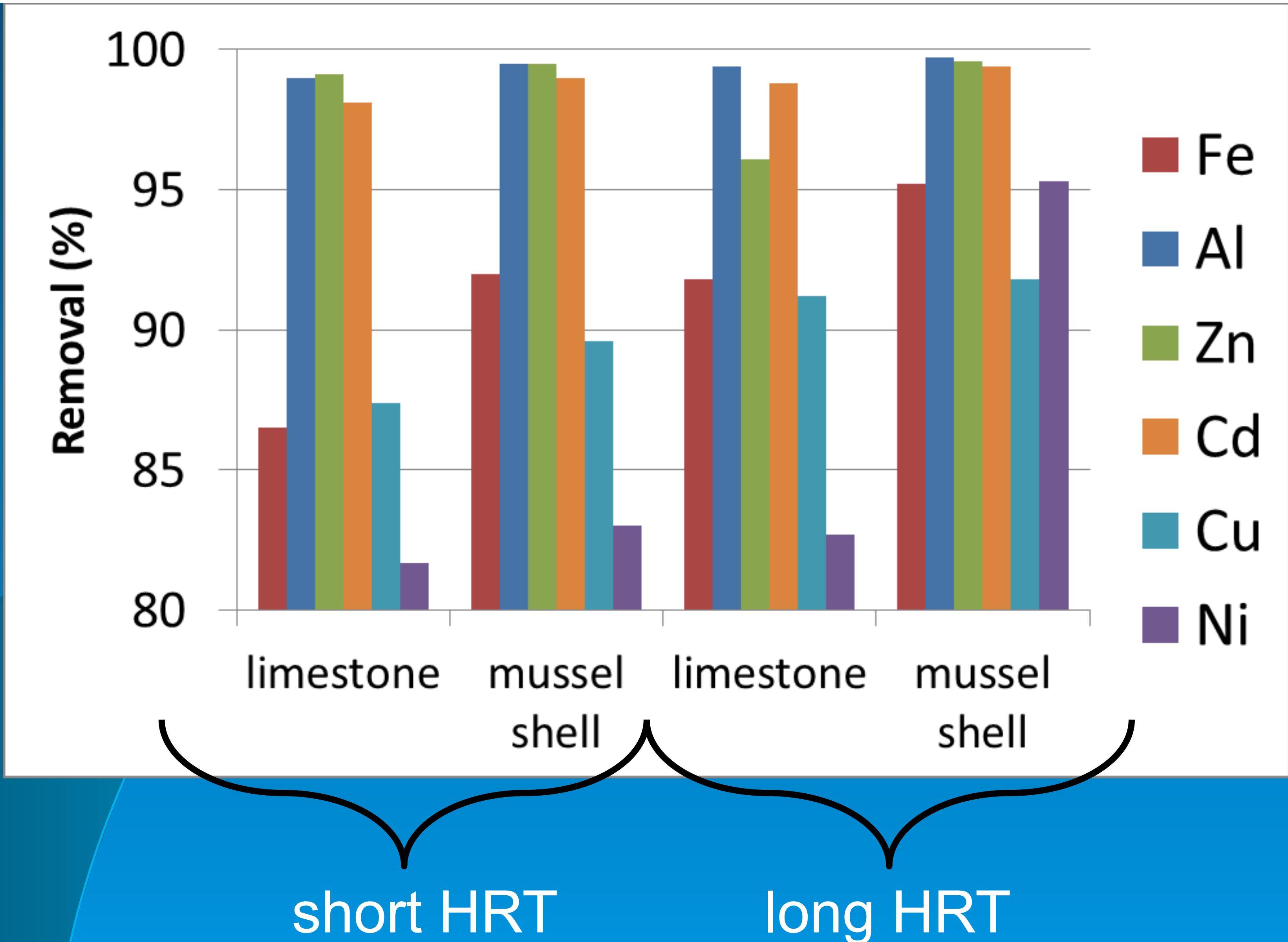

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Uster B, O'Sullivan A, Ko S, Evans J, Pope J, Trumm D, Caruso B (in press) The use of mussel shells in upward-flow sulfate-reducing bioreactors treating acid mine drainage. Accepted by Mine Water and the Environment, 2014

Shell-only reactors
Case study 1 - Manchester St.

- Second part of Craig McCauley's PhD:
  - Full scale bioreactor
- Mine plans change…
- After Craig finished:
  - Mining company installed reactor with only mussel shells

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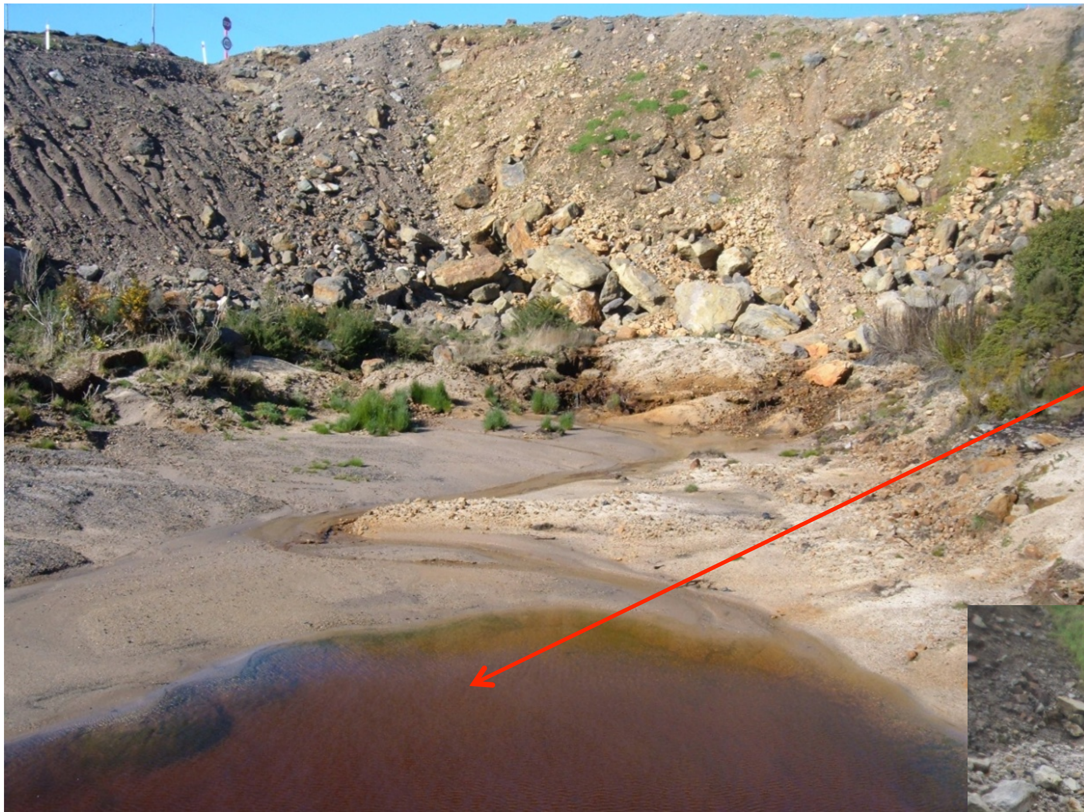
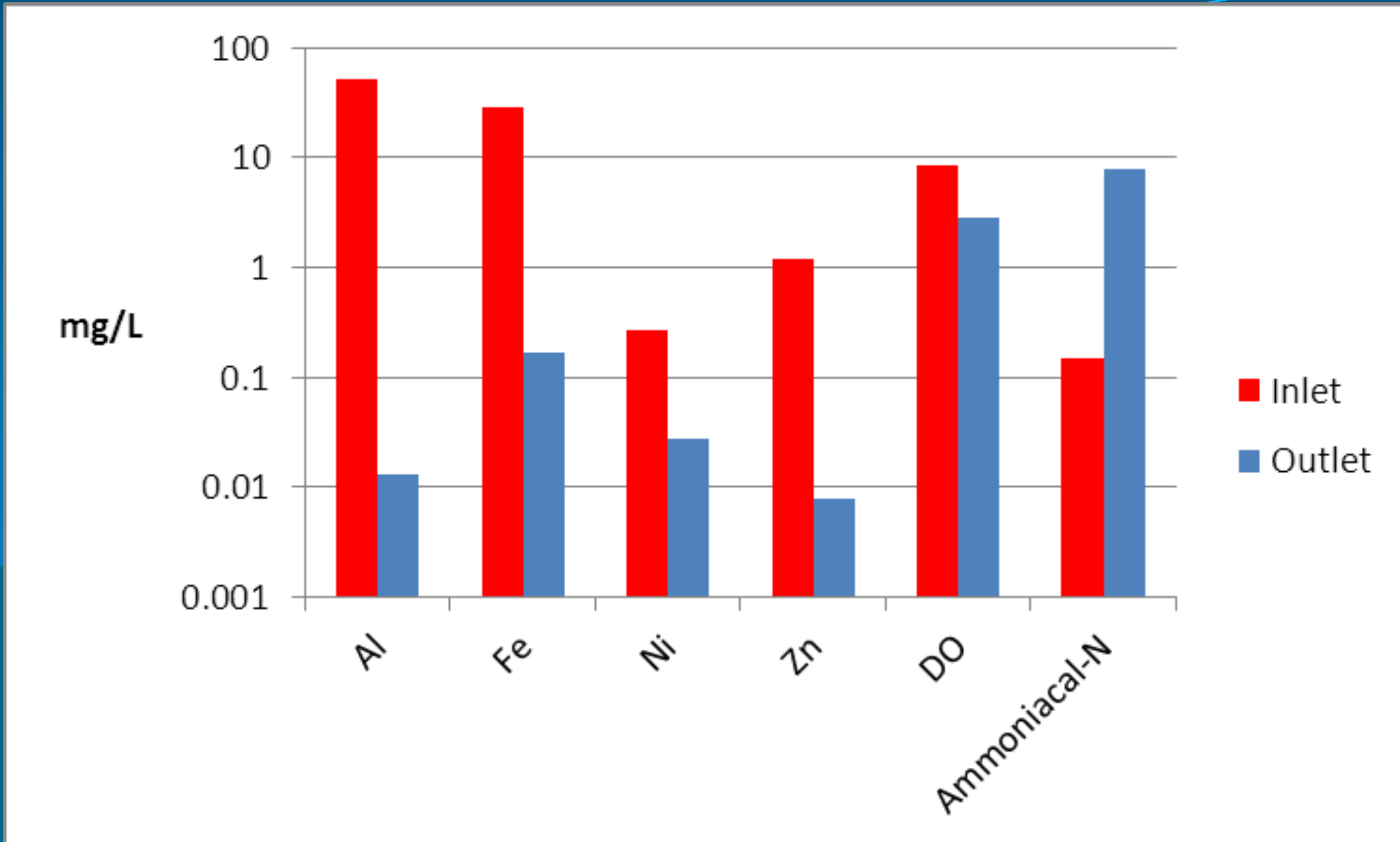
Manchester Street AMD



Filled with mussel shells



Crombie F, Weber P, Lindsay P, Thomas D, Rutter G, Shi P, Rossiter P, Pizey M (2011) Passive treatment of acid mine drainage using waste mussel shell, Stockton Coal Mine, New Zealand. Seventh Australian Workshop on Acid and Metalliferous Drainage, Darwin, Australia

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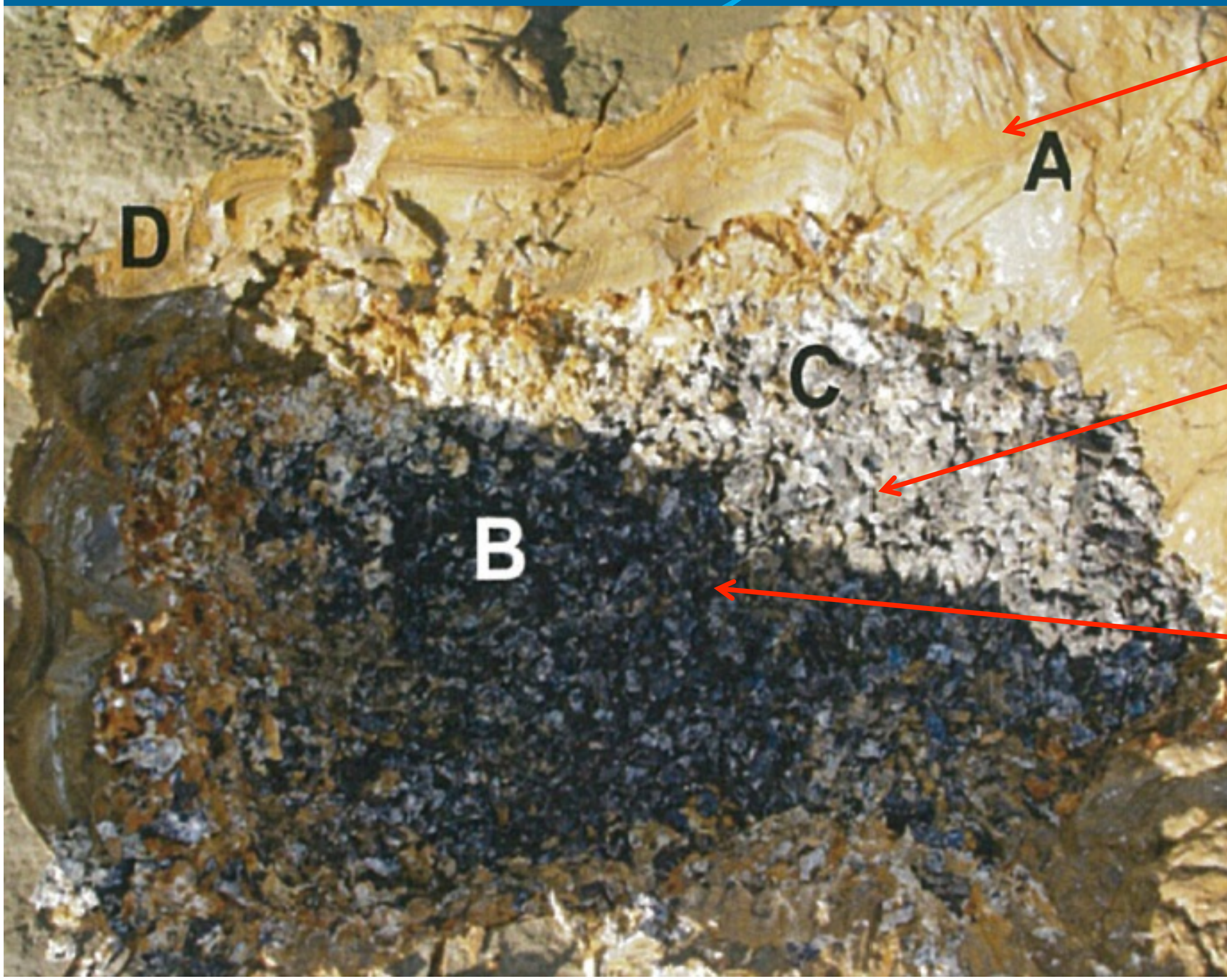


Fe

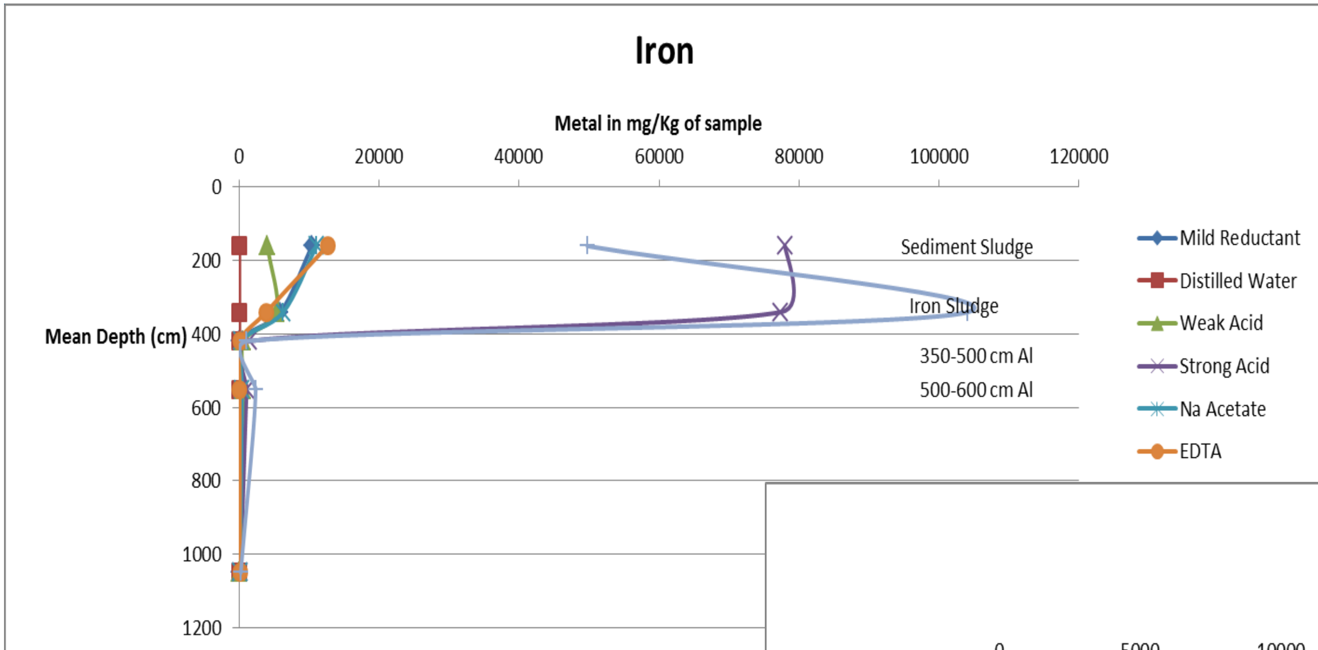
Al

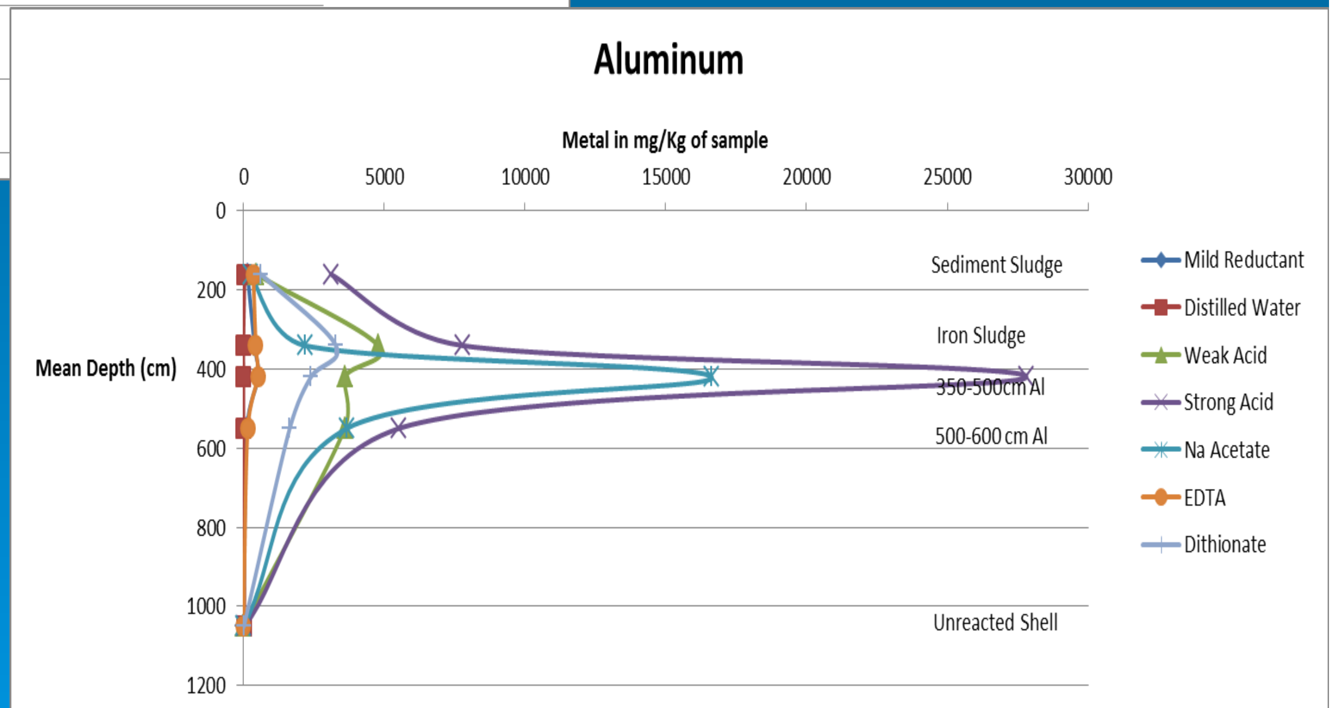
Anaerobic zone

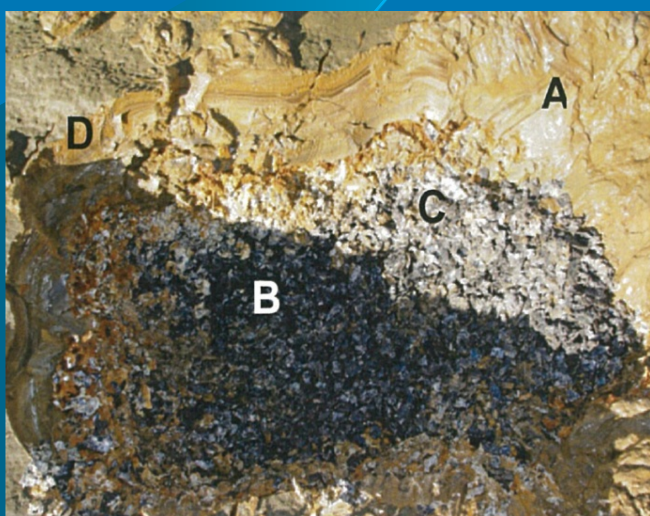
Zn, Ni

Intact shells

Hydroxides







Diloreto Z, Weber P, Weisener CG (In Press 2014) Passive treatment of acid mine drainage using bioreactors: Investigating redox gradients and metal stability. Submitted to Applied Geochemistry

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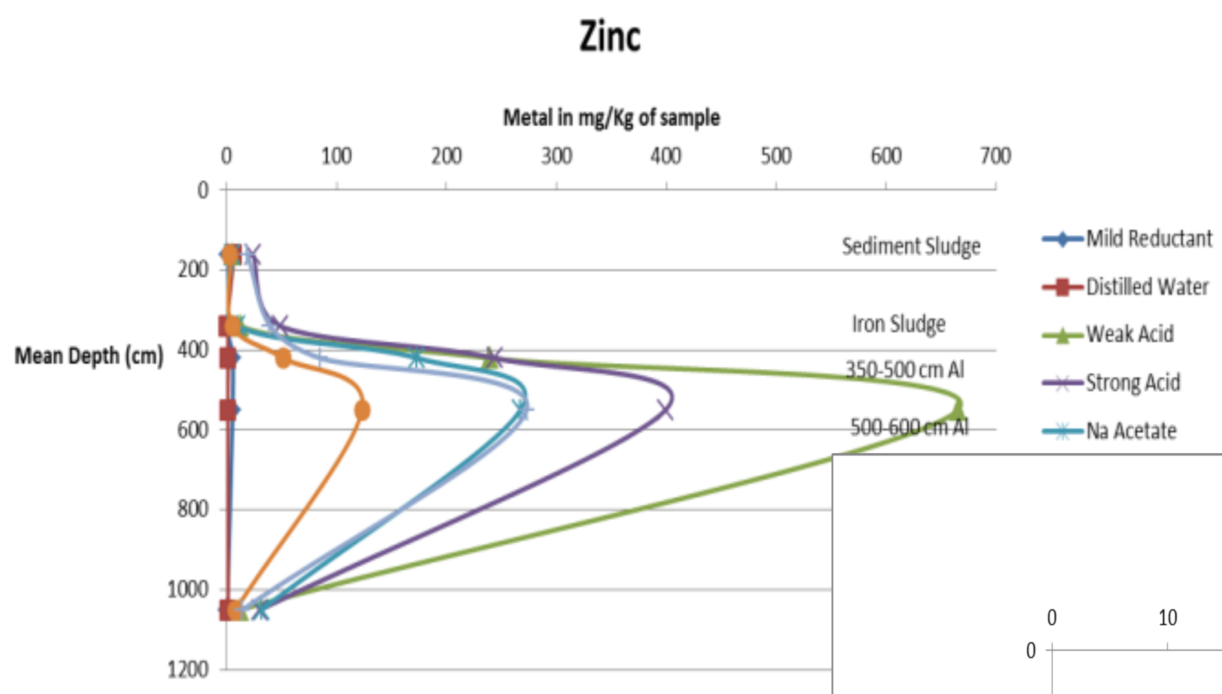
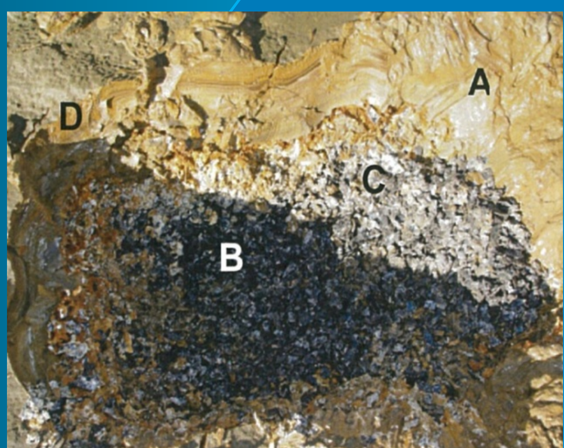
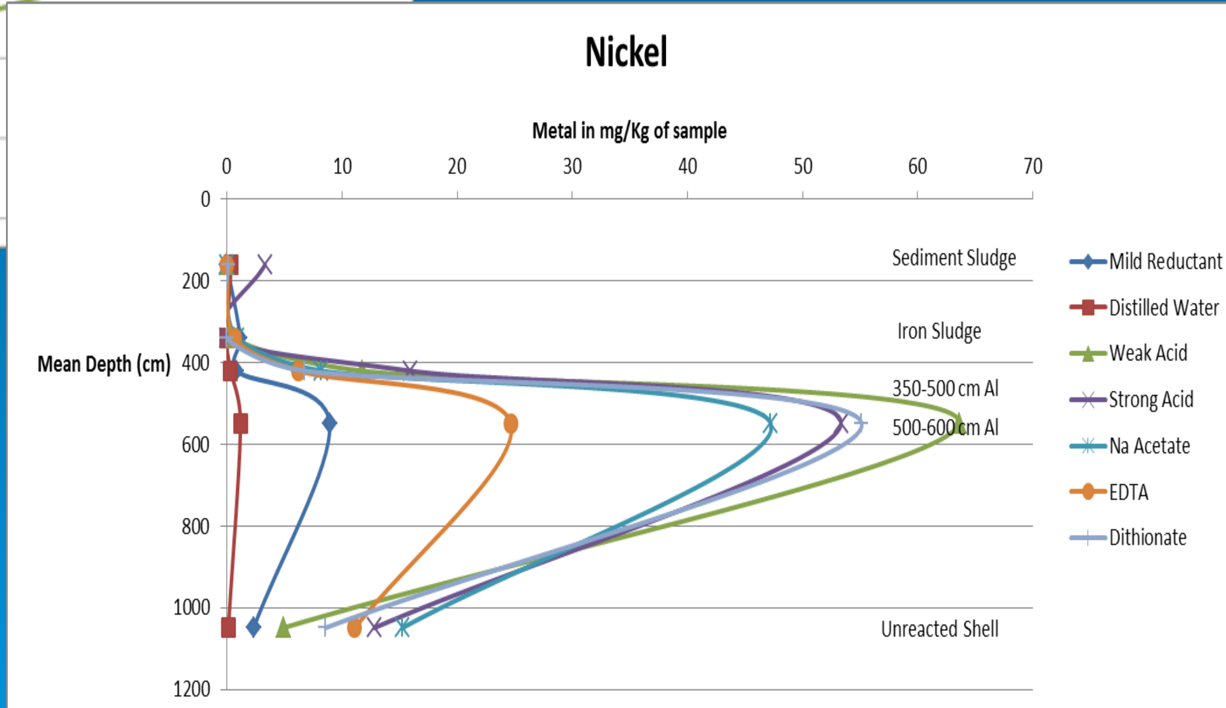
Sulphides







Diloreto Z, Weber P, Weisener CG (In Press 2014) Passive treatment of acid mine drainage using bioreactors: Investigating redox gradients and metal stability. Submitted to Applied Geochemistry

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Shell-only reactors
Case study 2 – Whirlwind AMD

Full-scale mussel shell reactor

- Same mine site – different AMD
- Downflow reactor

Flow (L/s)	3
pH	3.4
Fe (mg/L)	2.6
Al (mg/L)	22
Zn (mg/L)	0.33
Ni (mg/L)	0.096

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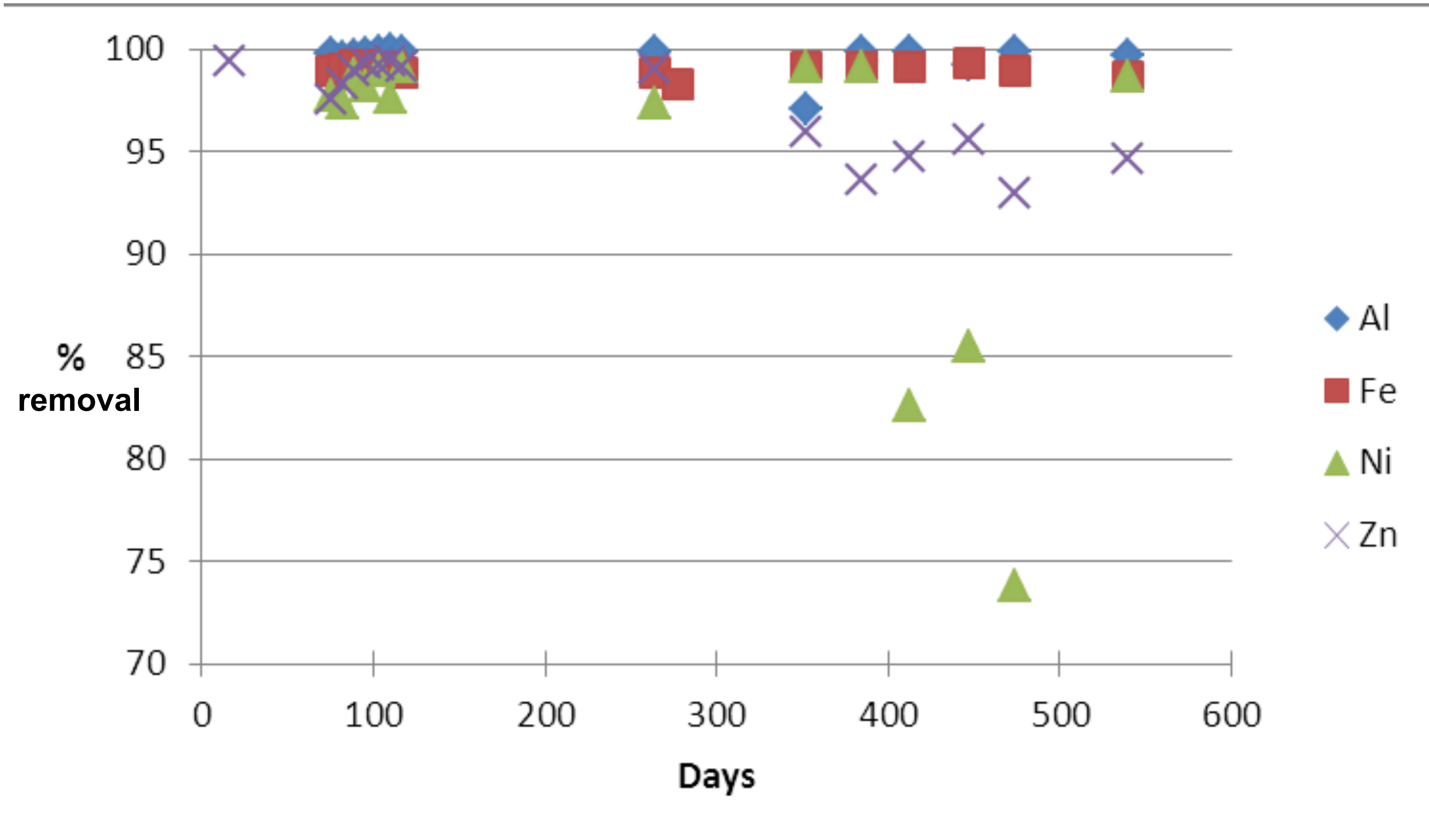

% removal
Days
Al
Fe
Ni
Zn
100
95
90
85
80
75
70
0
100
200
300
400
500
600

Shell-only reactors
Current field trials – Coal Mine Y

- Upflow configuration tested:
  - Sulphate reduction throughout reactor?
  - Prevent Fe hydroxides forming?
  - Prevent release of Ni, Zn?
  - Produce bicarbonate alkalinity and extend lifespan of mussel shells?

- Methods:
  - Install upflow at site
  - Three systems in series

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pH	3.1
Fe (mg/L)	123
Al (mg/L)	29
Mn (mg/L)	27
Zn (mg/L)	6.0
Ni (mg/L)	1.5

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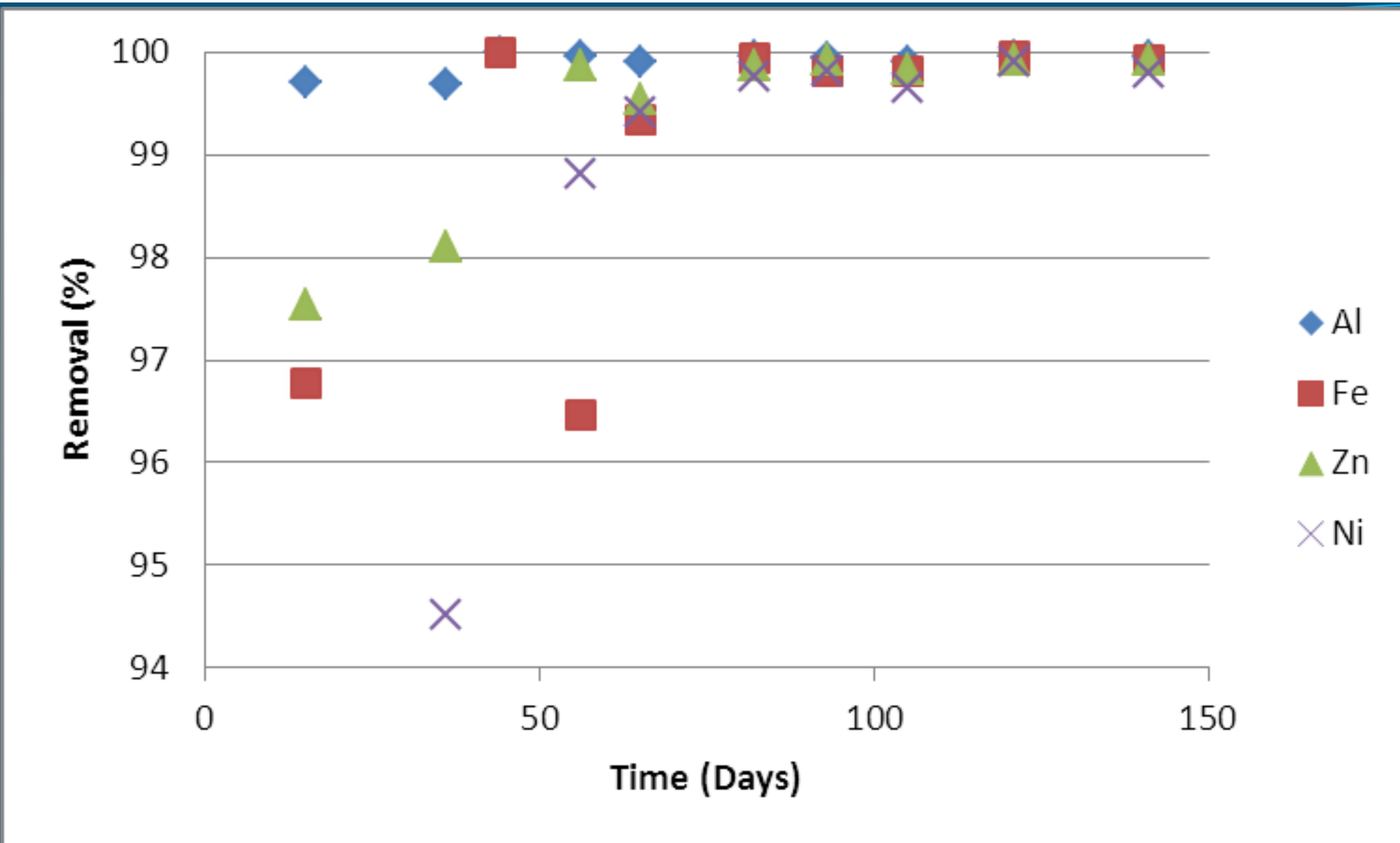
NEW ZEALAND MADE
RECYCLABLE PVC



HRT mostly 14 – 95 hours in each of the three systems

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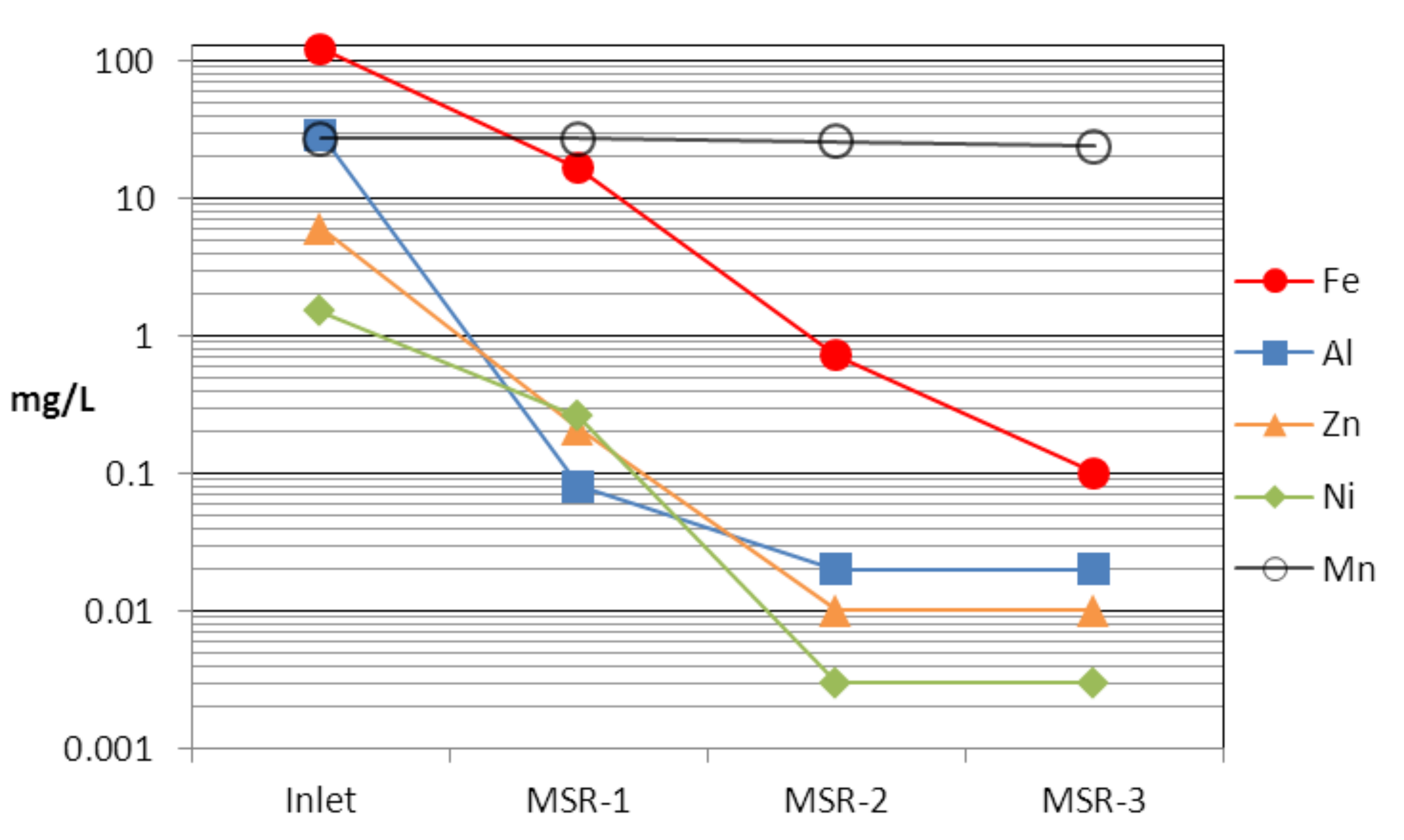

28 hr HRT

- Nearly total removal Fe, Al, Zn, Ni
- Majority of metal removal in first reactor
- Insignificant Mn removal

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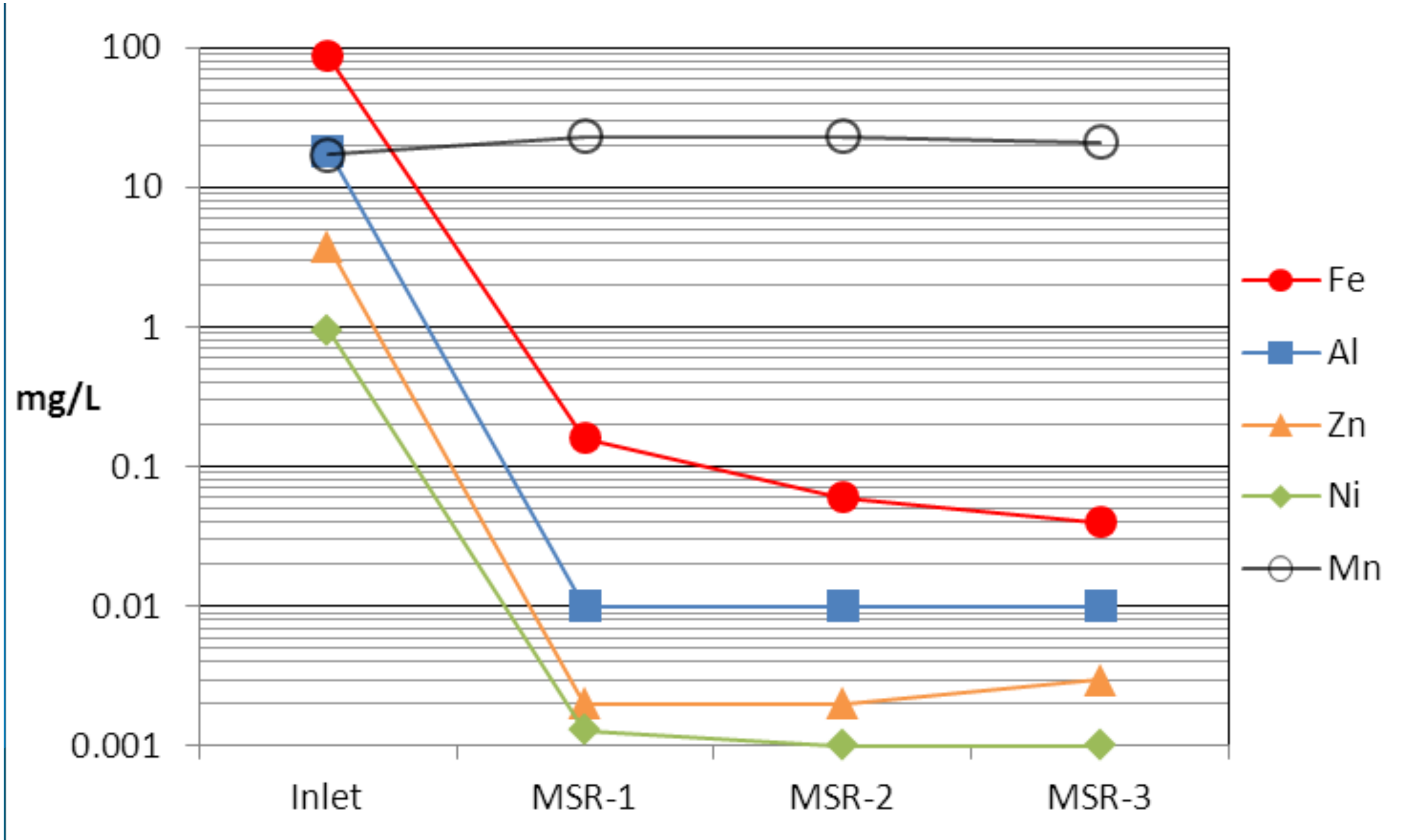

95 hr HRT

- Nearly total removal Fe, Al, Zn, Ni
- Majority of metal removal in first reactor
- Insignificant Mn removal

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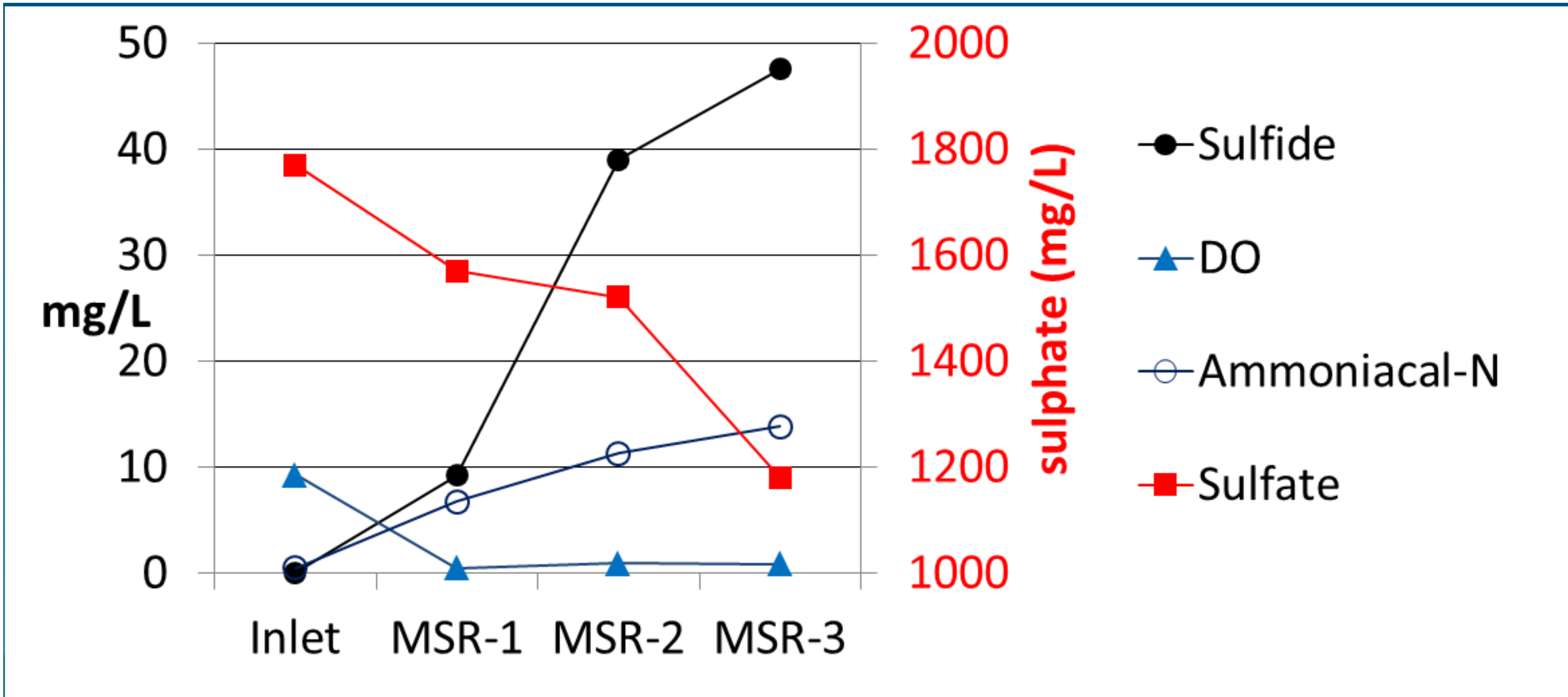

<u>Reducing conditions</u>

56 hr HRT

- DO decreases
- Sulphate decreases
- Sulphide increases
- Ammoniacal-Nitrogen increases

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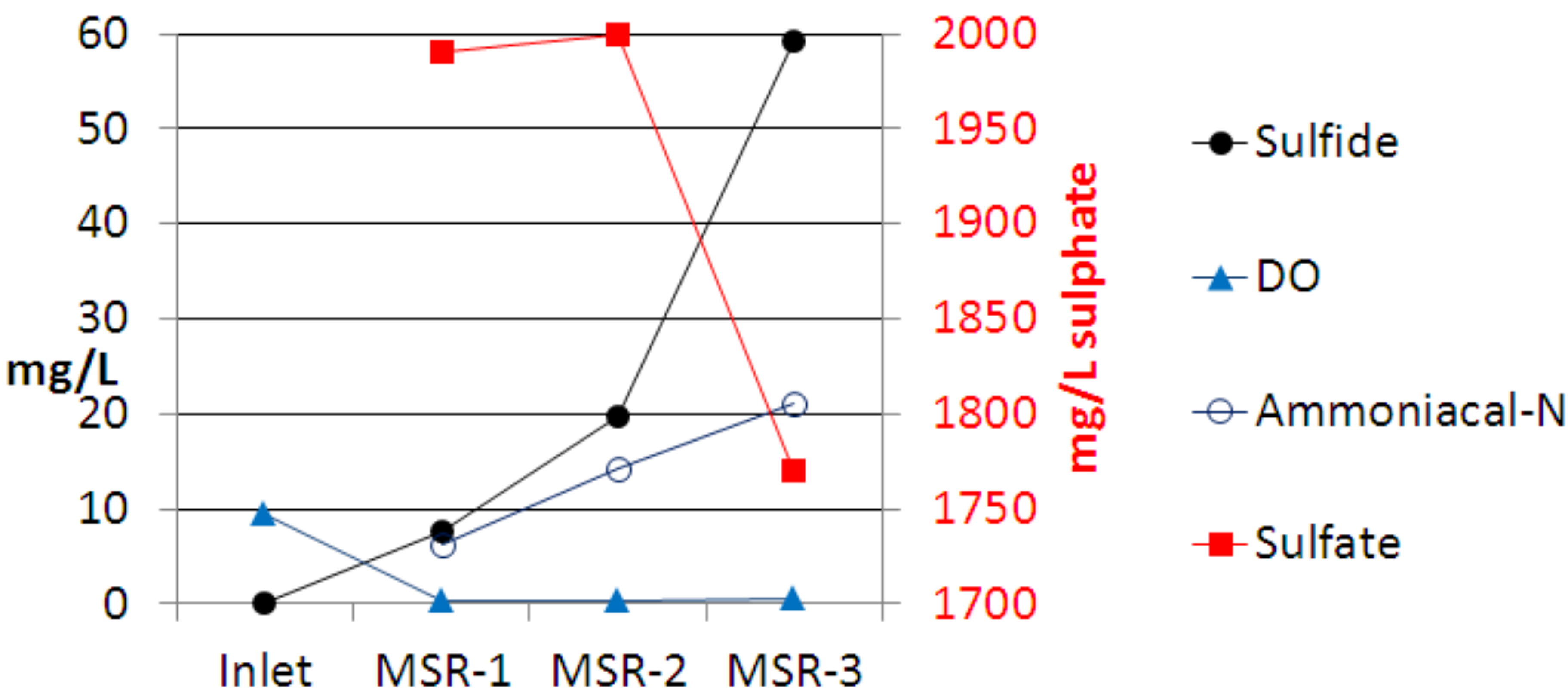

Reducing conditions

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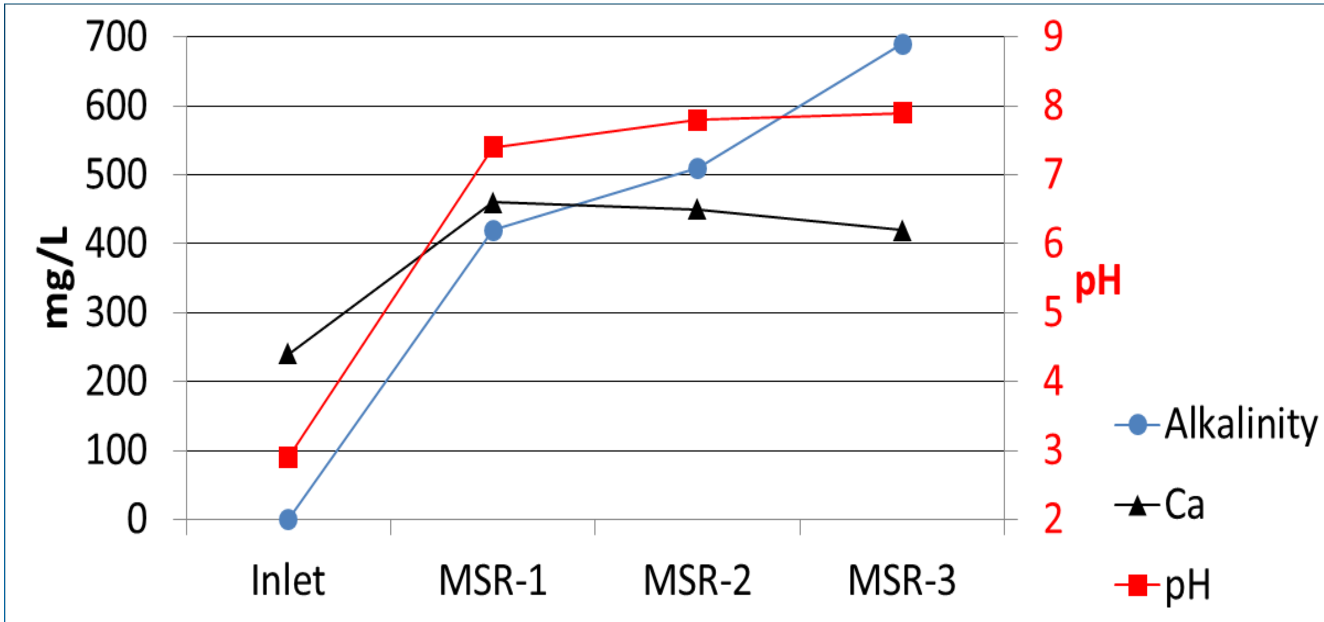
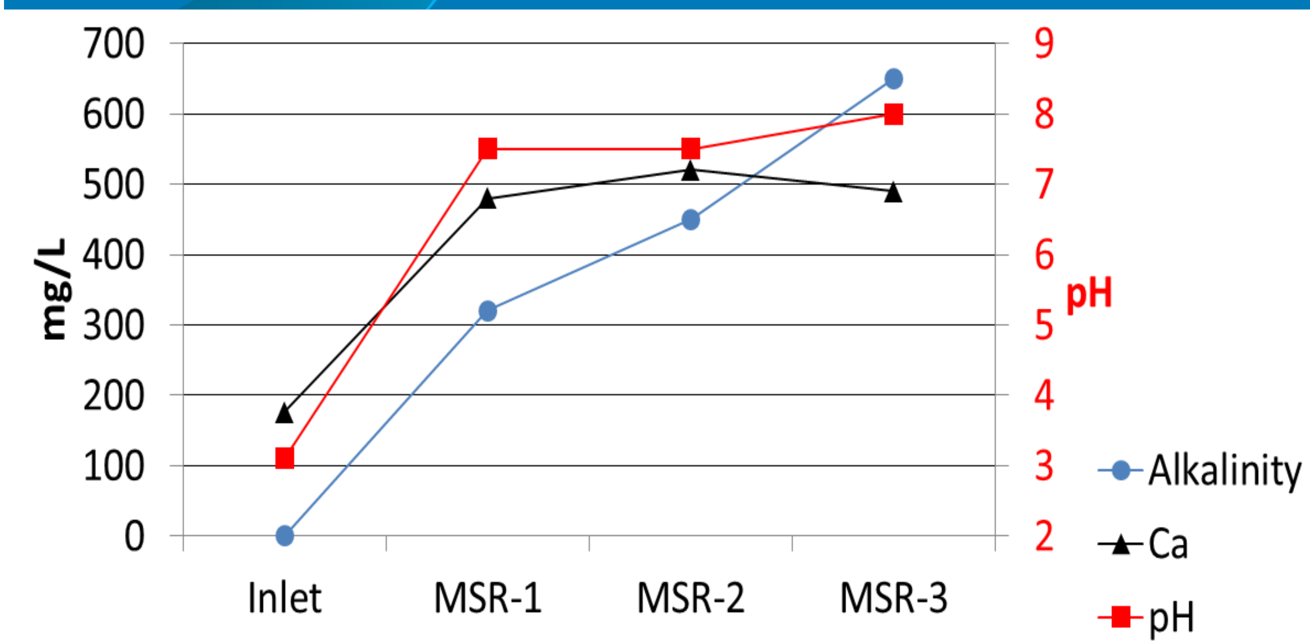


56 hr HRT



95 hr HRT

Reactor 1

- Increase pH
- Increase Ca
- Increase alkalinity

Reactors 2 and 3

- Little change pH
- Little change Ca
- Increase alkalinity

Bicarbonate alkalinity from sulphate reduction?

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Metal removal mechanisms Downflow vs. Upflow reactors

- DOWNFLOW

Oxidised Zone
Fe hydroxide layer
Al hydroxide layer
Unreacted shell boundary
Reduced Zone
Zn, Ni sulphides
Bicarbonate alkalinity

- UPFLOW

Reduced Zone
Fe sulphide layer?
Al hydroxide layer
Zn, Ni sulphides
Bicarbonate alkalinity
Mn hydroxides/carbonates

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mussel shell reactor 1

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mussel shell reactor 1

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mussel shell reactor 1

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mussel shell reactor 2

CRL

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mussel shell reactor 3

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Conclusions

- Mussel shell reactors can treat AMD
  - Effective metal removal: Fe, Al, Zn, Ni, (Mn)
  - Used as an amendment to bioreactors or in shell-only reactors
- Shell-only reactors contain sufficient organic matter to reduce metals to sulphides
  - DO, sulphate decrease; sulphide, ammoniacal-N increase
  - Upflow setup more effective at maintaining reducing conditions?
- Metal removal for upflow reactors better in long term?
  - Fe, Zn, Ni = sulphides
  - Al = hydroxides
  - Mn = hydroxides / carbonates (rhodochrosite / kutnahorite)

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Acknowledgements

Thank you to Jeff Skousen and the West Virginia Mine Drainage Task Force for the funding to attend Symposium

Financial support from the Ministry for Business, Innovation and Employment (contract CRL1202)

We acknowledge the anonymous mining company for allowing systems to treat their AMD

Mussel shells were donated by Sanford Limited, Christchurch

Preparation of graphs by Patrick Turner, CRL

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And now….
for something completely different

DVT (direct vegetation transfer)

Careful removal of vegetation

Animals and all

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Placed in nursery
Stored until closure
KT07

gy Ltd

Thank you