Operation and maintenance of downwards flow compost systems for mine drainage treatment: Experiences from 3 full-scale systems in the UK

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Introduction

Downwards flow compost-based passive treatment systems

- Nomenclature
- Principles
- Layout
- Design
- Perfomance
- Maintenance

Nomenclature

SAPS: **S**uccessive **A**lkalinity **P**roducing **S**ystems

RAPS: **R**educing and **A**lkalinity **P**roducing **S**ystems

VFP: **V**ertical **F**low **P**ond

Principles

SAPS/RAPS:

•Primarily designed for alkalinity generation / elevating pH, with Fe / Al removal in subsequent units (e.g. aerobic wetlands)
•Overcome shortcomings of ALDs - limestone armouring due to Fe^{3+} and Al^{3+}

- Pass water downwards through **compost layer** to **strip dissolved O_2** from water
- **Bacterial Sulfate Reduction** (BSR) in compost may simultaneously immobilise divalent metals and generate alkalinity (but not explicitly designed for this)
- Water then passes through **limestone layer** at base of system to generate alkalinity via **calcite dissolution**, but no armouring
- **Perforated pipe network** at base of system takes water to effluent pipe, which is raised to maintain **saturated conditions** in SAPS/RAPS

Principles

VFPs:

VFP / RAPS terms somewhat interchangeable, but in context of this presentation:

•Primarily designed for **metal removal via Bacterial Sulfate Reduction** in compost layer i.e. formation of solid metal sulphides in compost

•For circum-neutral mine waters, limestone included above perforated pipe network to prevent clogging, not for alkalinity generation

Principles

Key chemical reactions:

Main target reactions in VFPs for divalent metal removal

$$2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO_3^-$$

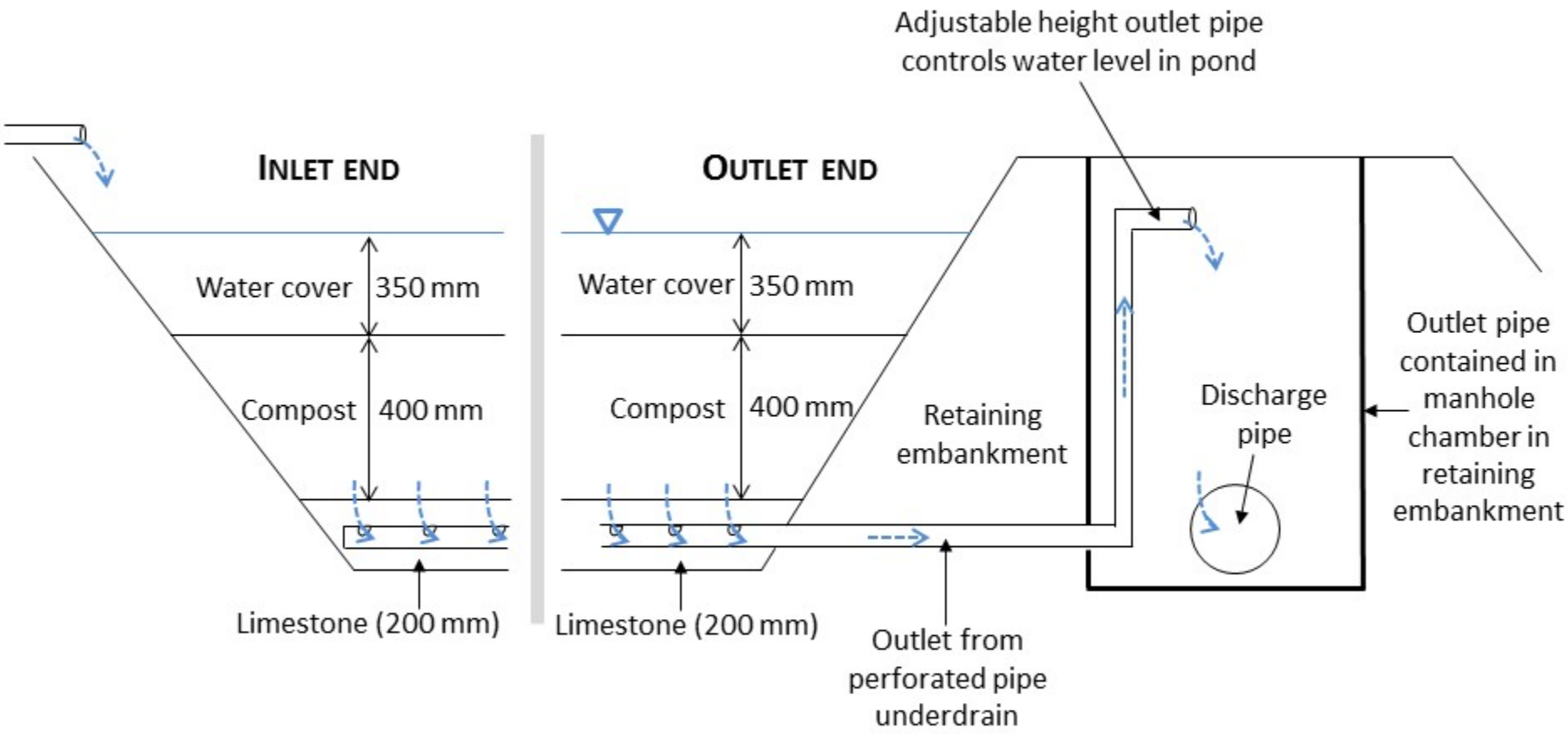
$$M^{2+} + H_2S + 2HCO_3^- \rightarrow MS + 2H_2O + 2CO_2$$

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2O + CO_2 \quad \text{[at pH < 5]}$$

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^- \quad \text{[at pH > 5]}$$

Main target reactions in RAPS for alkalinity generation (once DO stripped)

RAPS / VFP Treatment system layout



RAPS / VFP Treatment system layout

A. Under drainage perforated pipe network being laid

B. Limestone (200 mm) and compost (400 mm) being placed over drainage network

Treatment system design

- ~ 200 mm limestone
- ~ 200 – 500 mm compost
- ~ 300 mm water cover
- Therefore require 1 m + of hydraulic head to avoid pumping

- RAPS: **14 hour HRT** in limestone for optimum alkalinity generation

- VFP: **~ 15 hour HRT** in compost for immobilisation of divalent metals in form MS (but may vary)

RAPS Treatment systems

From Smail and Thorn (2016)

Tan-y-Garn, Wales:

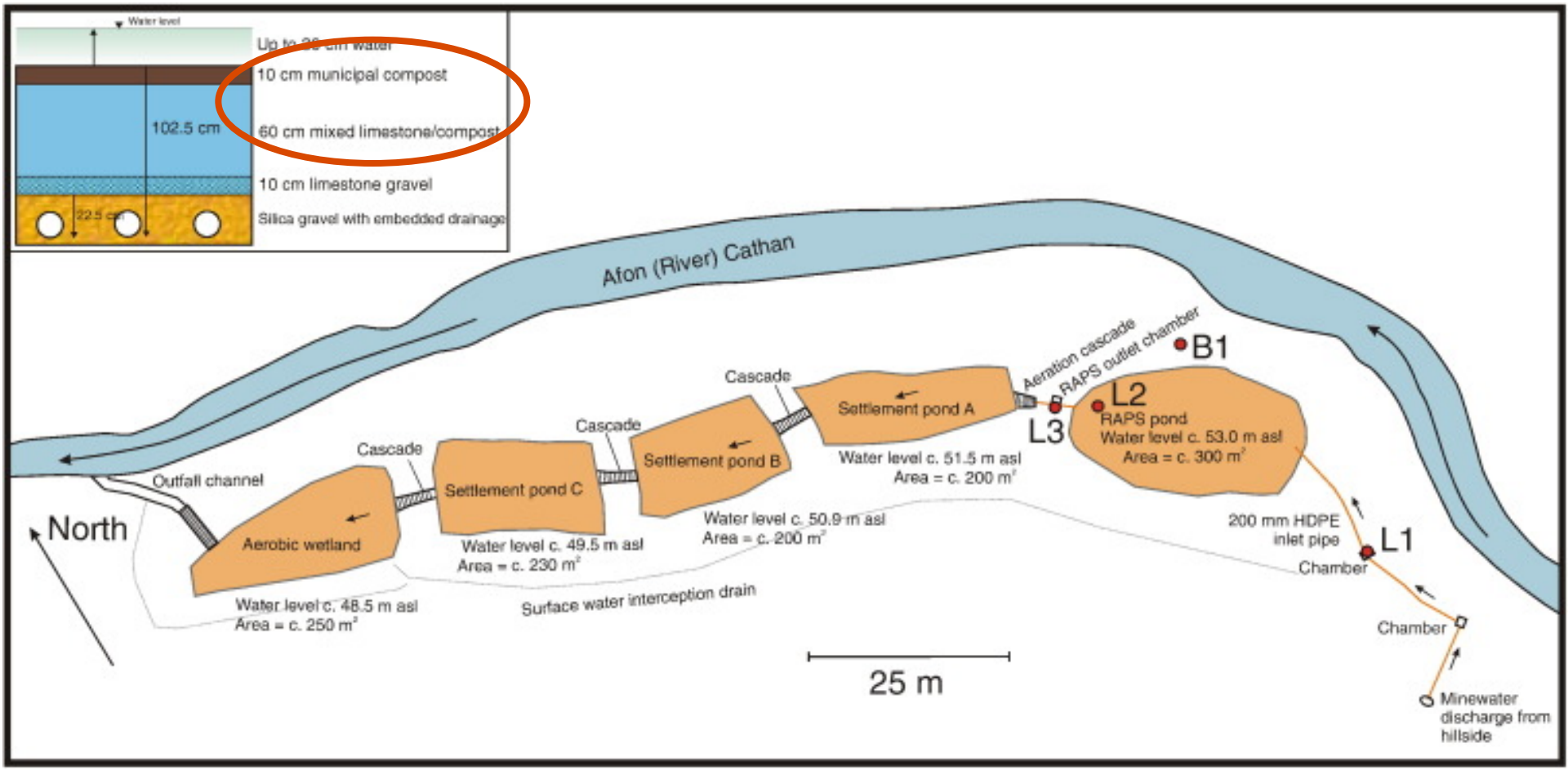
Flow	~ 2 L/s
pH	5.9 (6.5)
Alkalinity	~ 50 mg/L as $CaCO_3$
Fe (total)	47 (36) mg/L

From Fabian et al. (2006)

Bowden Close, north east England

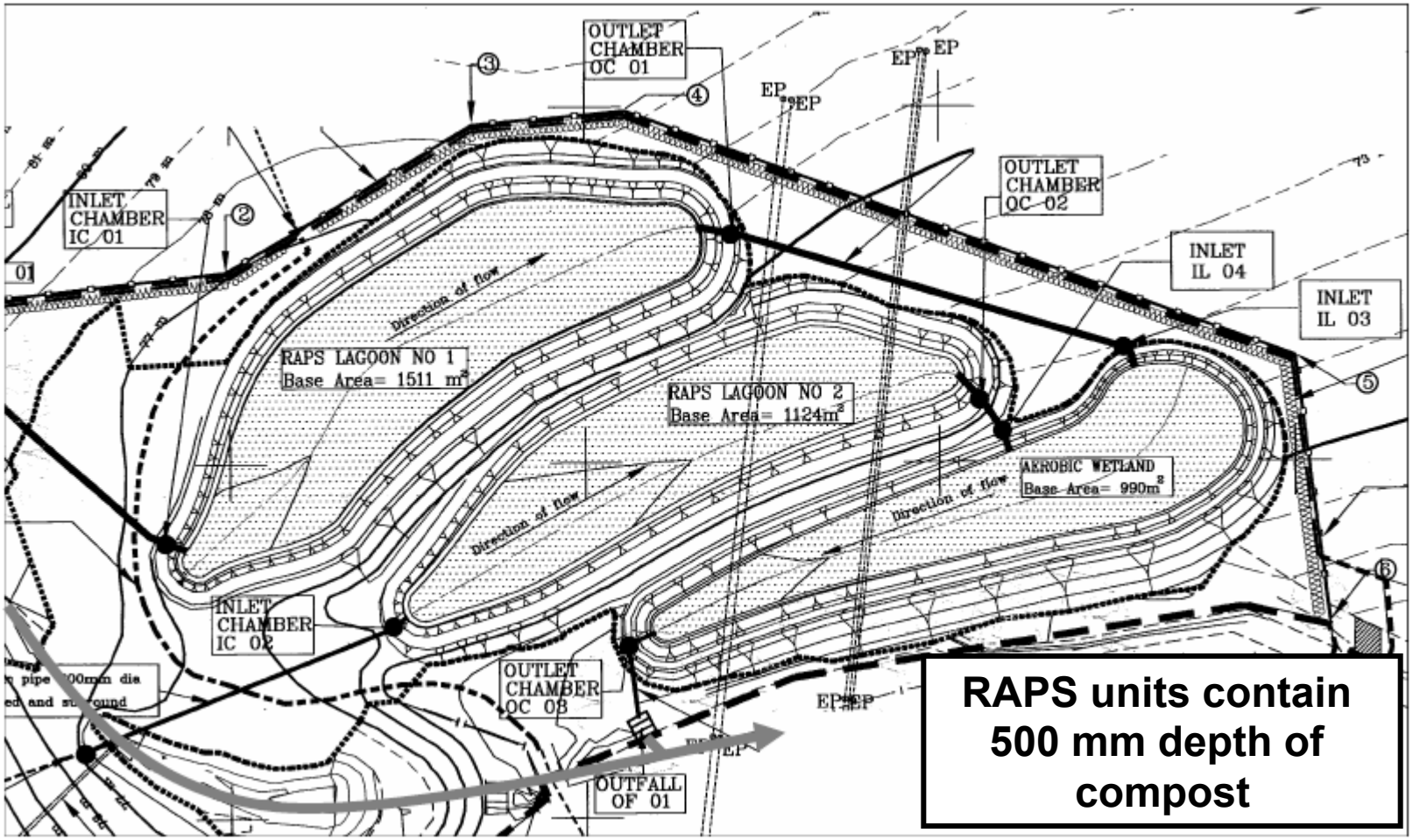
Flow	3.3 L/s
pH	4.0
Alkalinity	0 mg/L as $CaCO_3$
Fe (total)	80 mg/L

Tan-y-Garn RAPS Treatment systems



From: Taylor, K, Banks, D. and Watson, I. (2016) Characterisation of hydraulic and hydrogeochemical processes in a reducing and alkalinity-producing system (RAPS) treating mine drainage, South Wales, UK. *International Journal of Coal Geology*, **164**, 35-47.

Bowden Close RAPS Treatment systems



From Fabian, D., Jarvis, A.P., Younger, P.L. and Harries, N.D. (2006) *A Reducing and Alkalinity Producing System (RAPS) for Passive Treatment of Acidic, Aluminium Rich Mine Waters.* CL:AIRE Technology Demonstration Project Report: TDP5.

Force Crag VFP Treatment system

Force Crag, north west England

Flow	6.0 L/s
pH	6.4
Alkalinity	14.2 mg/L as $CaCO_3$
Zn (total)	3.25 mg/L

Force Crag VFP Treatment system

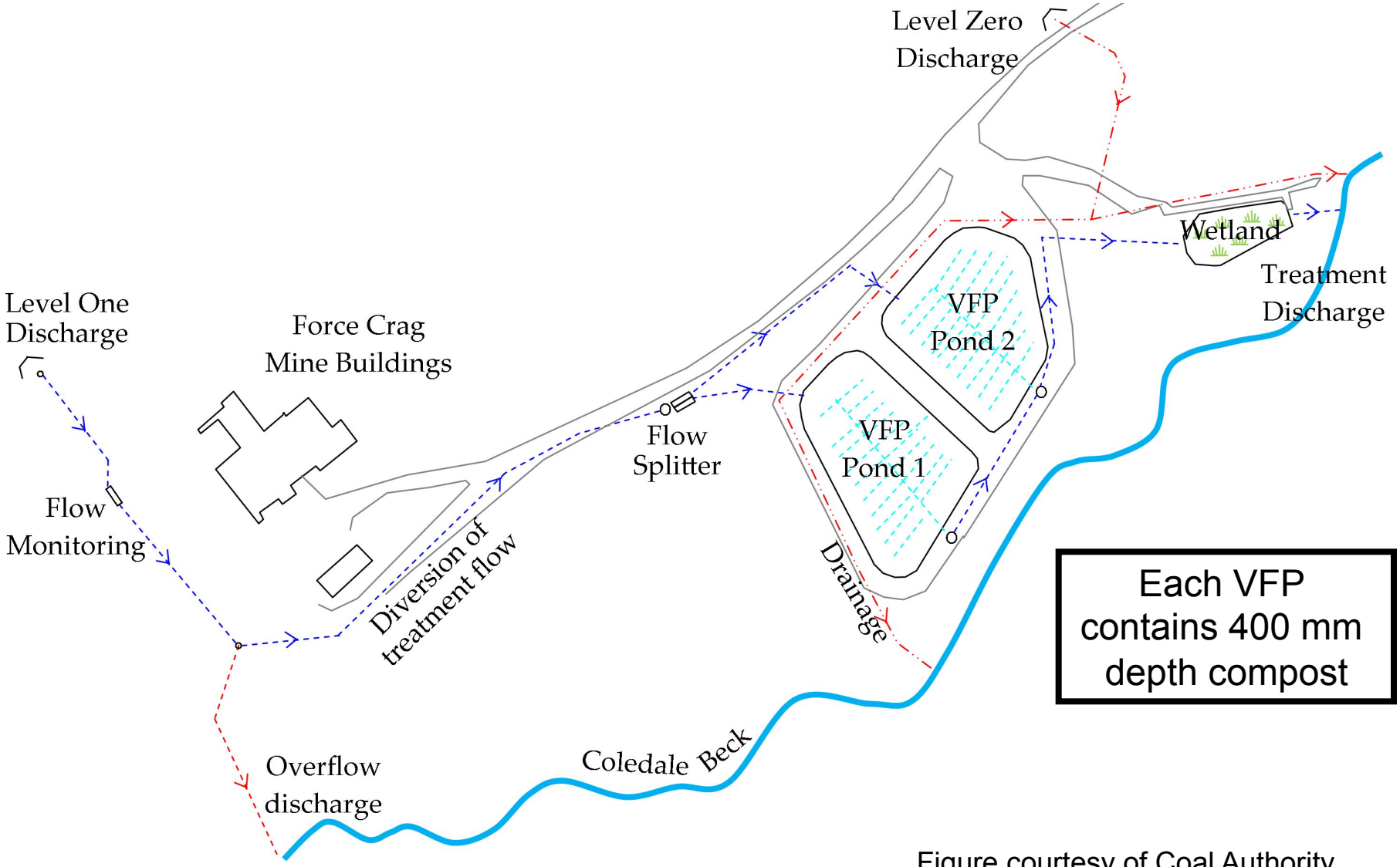


Figure courtesy of Coal Authority

Force Crag VFP Treatment system

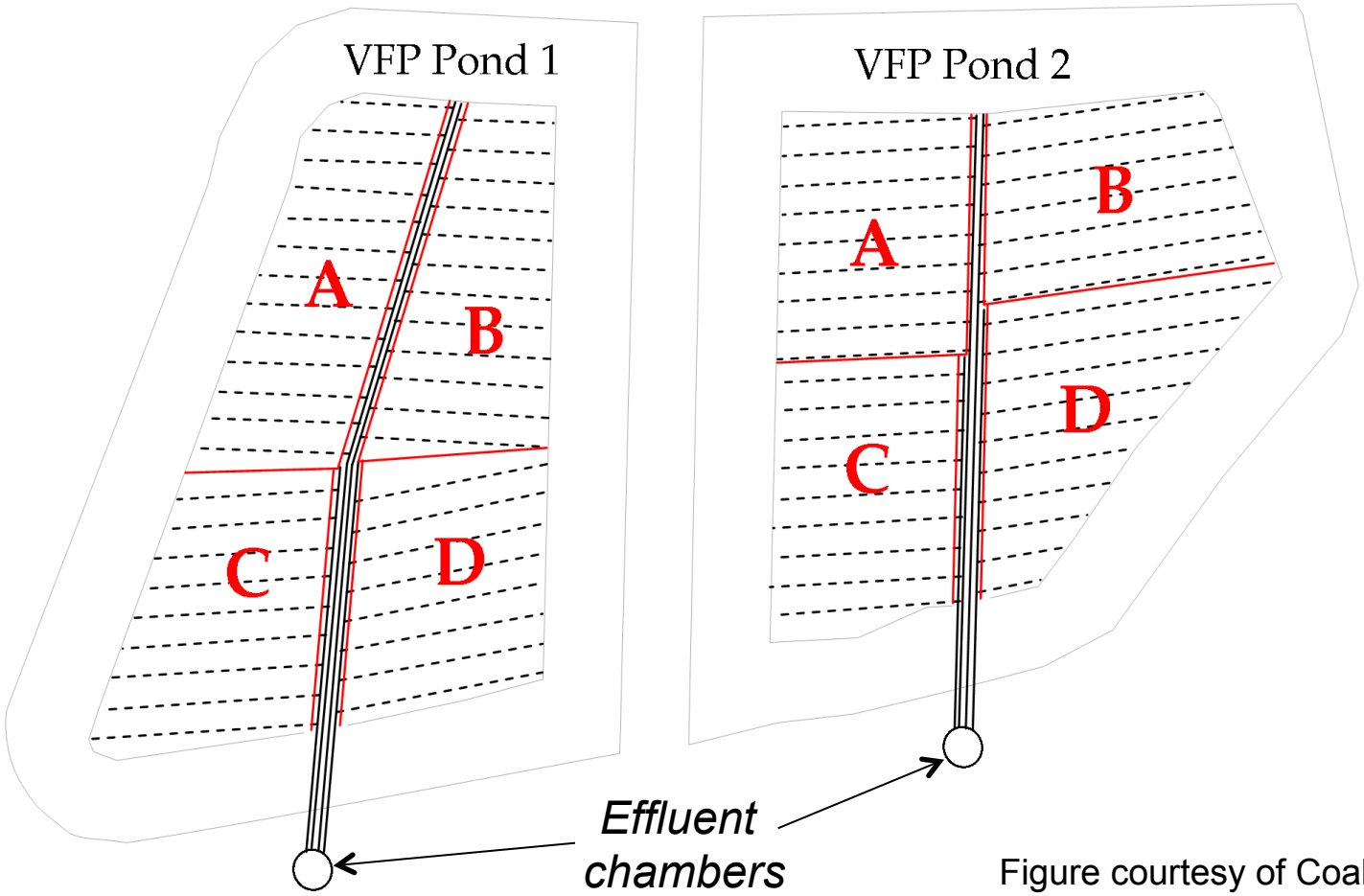
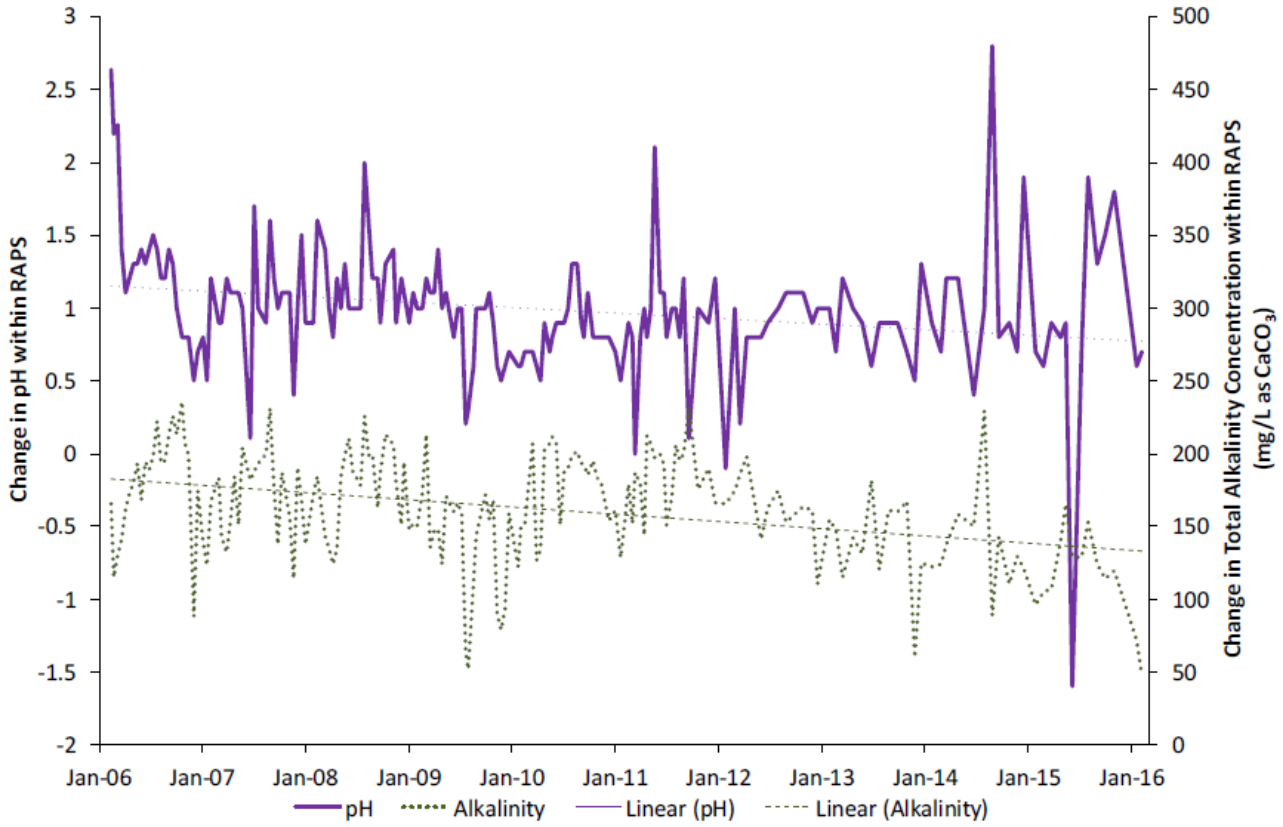


Figure courtesy of Coal Authority

•Within each VFP have 4 independent perforated pipe drainage networks of equal area

RAPS Treatment system performance

Tan-y-Garn

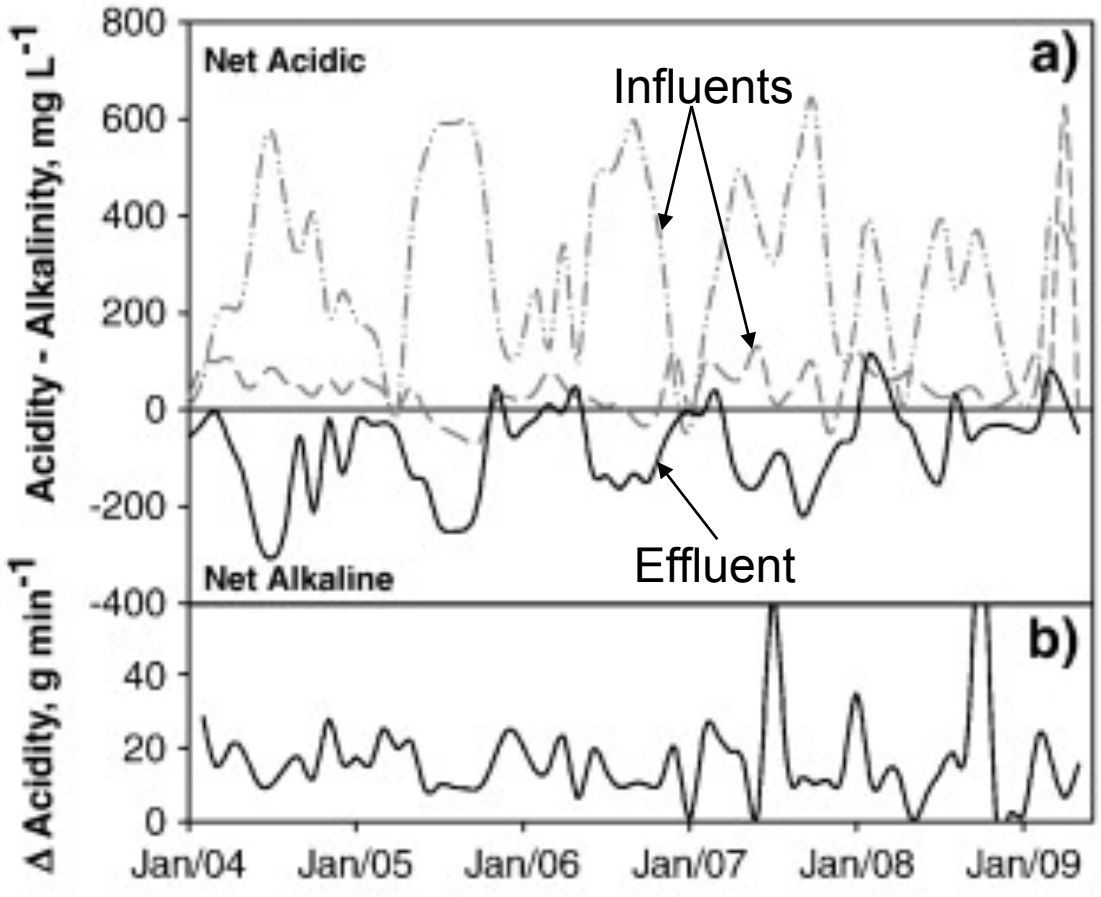


- Generation of 50 – 200 mg/L as $CaCO_3$ alkalinity, though decreasing over 10 years
- Elevation of pH by ~ 1 unit on average, but decreasing

From: Smail, I. and Thorn, P. (2016) Performance of an operation Reducing Alkalinity Producing System (RAPS) treating coal mine waters at Tan-y-Garn, Wales. *Proceedings of IMWA 2016*, Leipzig, Germany

RAPS Treatment system performance

Bowden Close

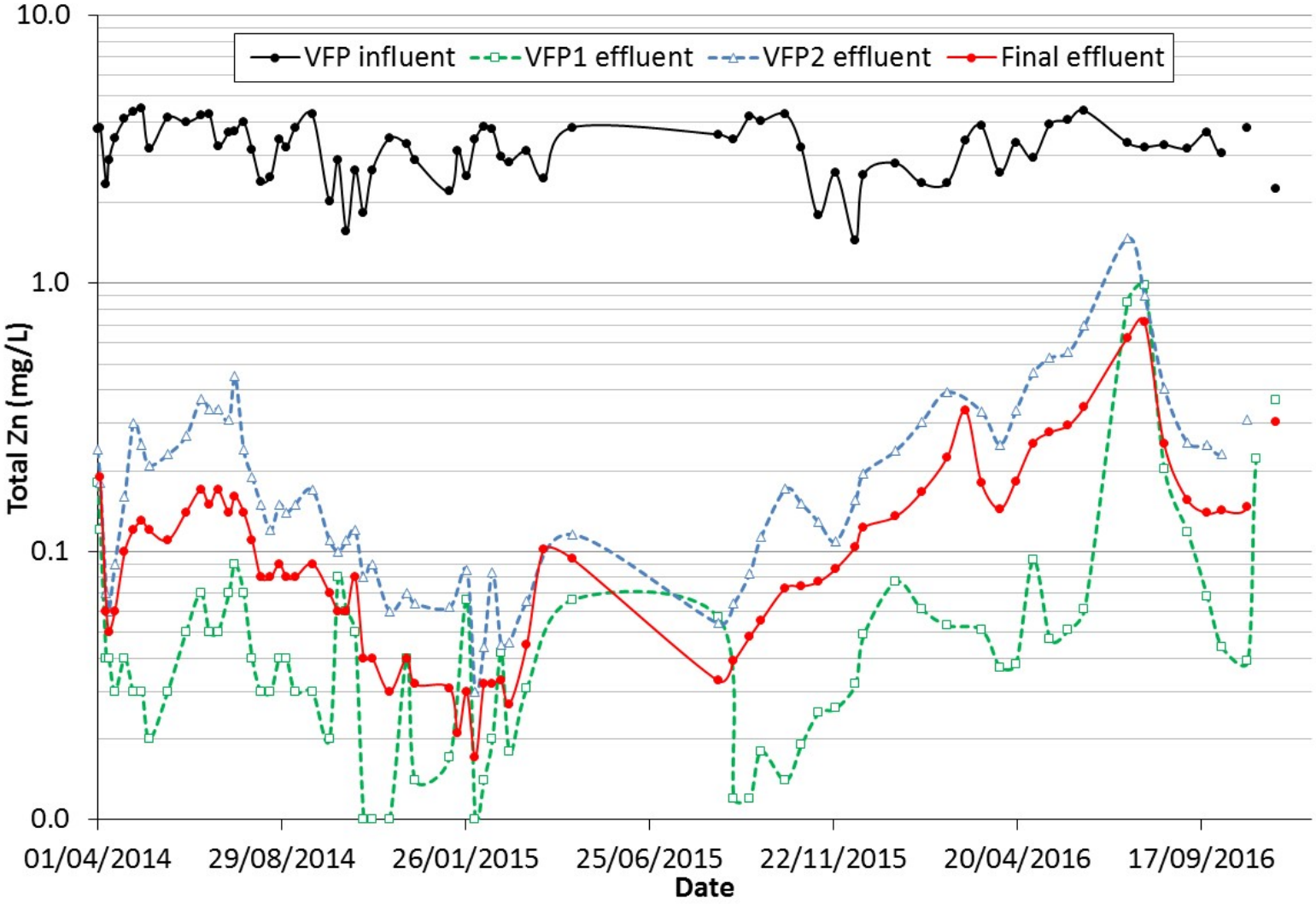


- Very acidic water (seasonally)
- Substantial generation of alkalinity, although evidence of slight deterioration in effluent quality with respect to acidity / alkalinity

From: Matthies, R., Aplin, A.C. and Jarvis, A.P. (2010) Performance of a passive treatment systems for net-acidic coal mine drainage over five years of operation. *Science of the Total Environment*, **408**, 4877-4885

VFP Treatment system performance

Force Crag

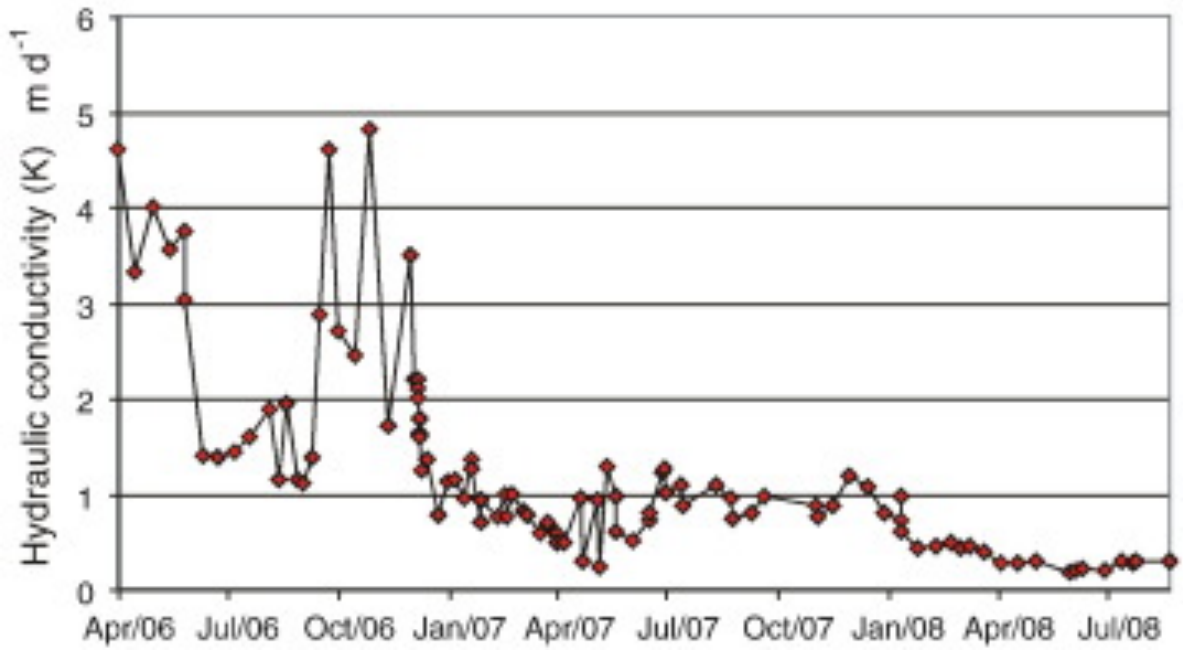


Maintenance challenges: Permeability

- Depth and characteristics of compost a compromise:
  - For both RAPS and VFPs: Require compost fine grained enough to facilitate reducing conditions, but coarse enough to maintain permeability.
  - For VFPs: Thicker layer of compost effectively reduces area of treatment unit, but decreasing permeability over time a risk

Maintenance challenges: Permeability

- At Tan-y-Garn: 700 mm compost in total
- Decreasing bulk permeability due to compaction / accumulation of iron solids
- Possibly results in short-circuiting and poorer performance



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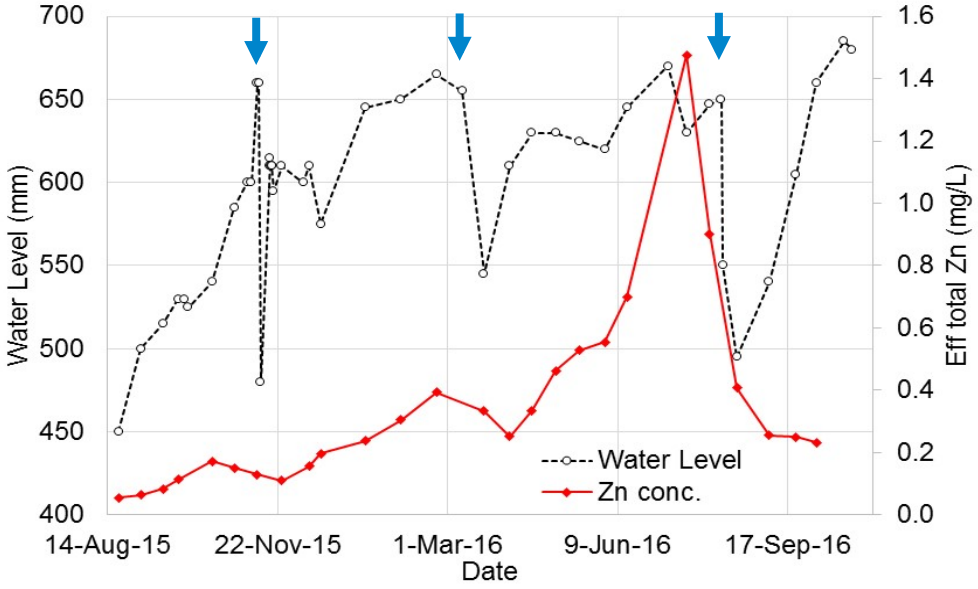
Maintenance challenges: Permeability

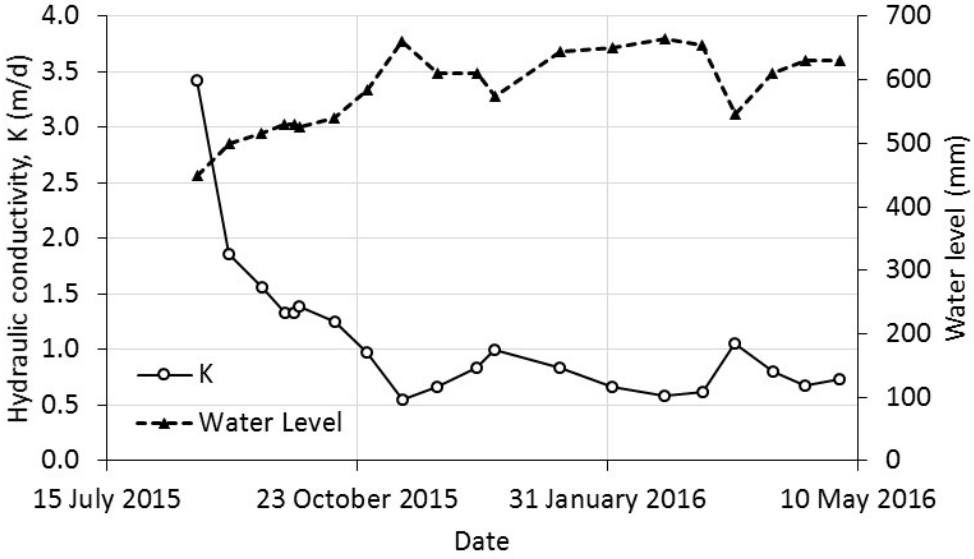
- At Force Crag: 400 mm compost in total
- Rising water levels in both VFPs imply decreasing permeability
- But not an issue of bulk permeability

Development of cyanobacterial mat (*Oscillatoria*) on compost surface impedes water passage

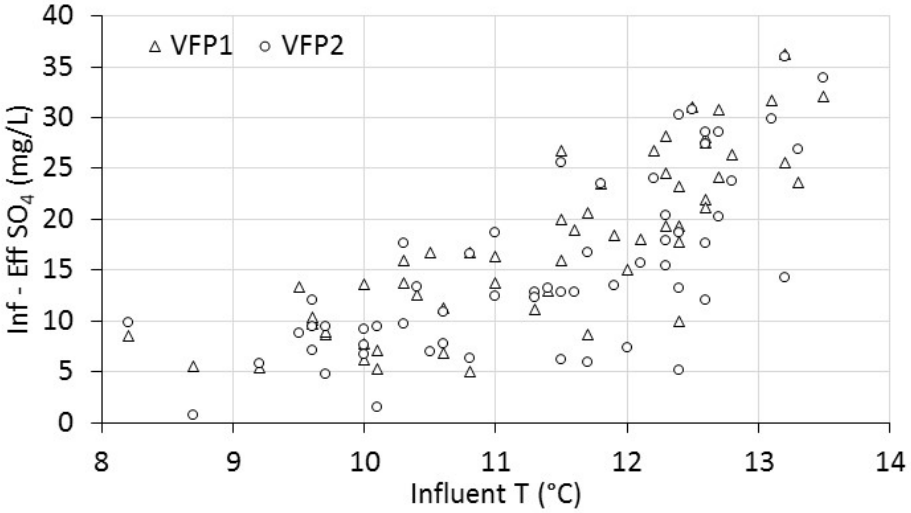
Maintenance challenges: Permeability

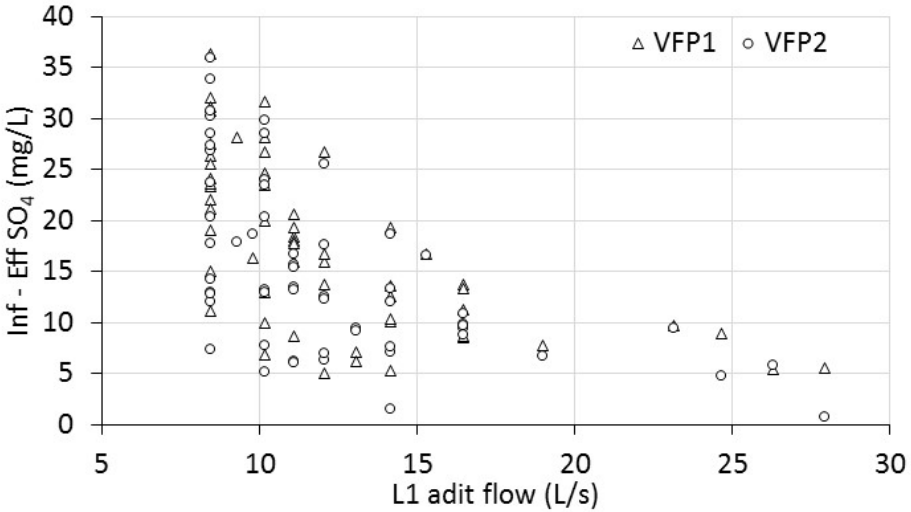


- Rising water level results in poorer performance (hydraulic short-circuiting)
- Hydraulic conductivity decreases as mat develops
- Necessitates regular manual clearance of mat



Maintenance challenges: Cold weather

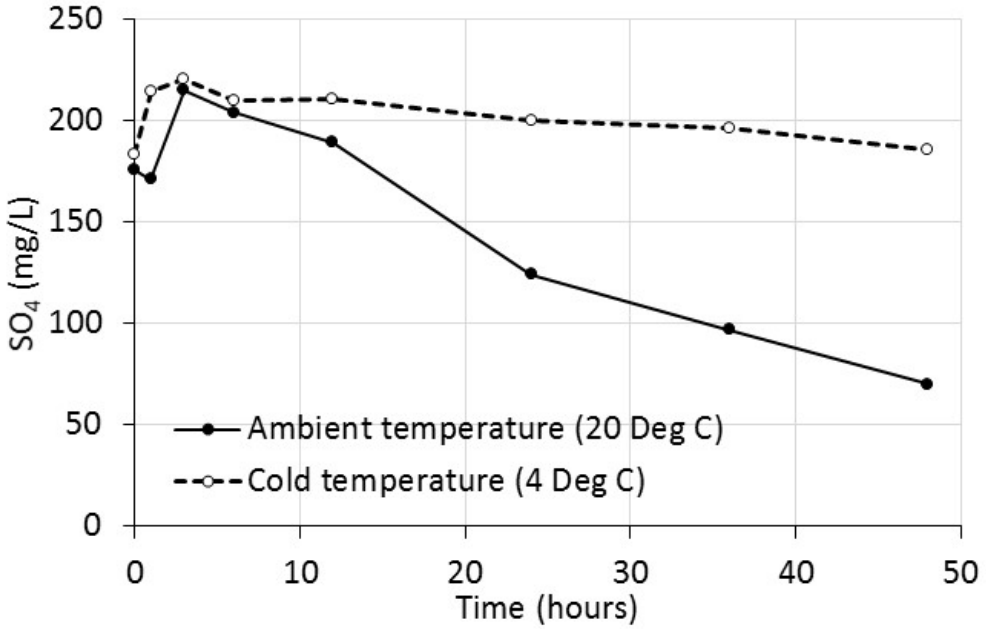




- At Force Crag, apparently greater SO_4 reduction during warmer weather ….
- … but this may just be covariance, because higher flows, and lower influent SO_4, during the winter months

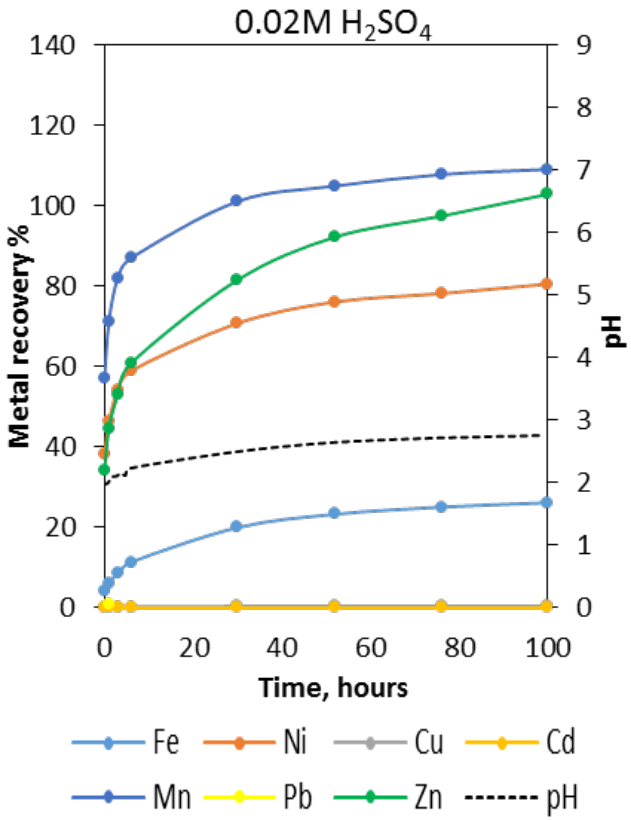
Maintenance challenges: Cold weather

- Sub-zero ambient temperatures common during winter at Force Crag
- Some evidence of lower rates of SO_4 reduction in colder weather at this site and others, and also from lab
- But not reflected in reduced performance with respect to Zn removal (depending on Zn concentration)



Maintenance challenges: Compost disposal

- Undoubtedly a key issue, especially with regard to (a) full life cycle costs and (b) sustainability
- Metals are recoverable e.g. acid leaching, but practicalities / costs may be prohibitive
- Worst case scenario: disposal to hazardous landfill.
- Predictions suggest costs would still be less than an equivalent active treatment system



From Bailey, M.T. (2016) *Recovering resources from abandoned metal mine waters: An assessment of the potential options at passive treatment sites.* Unpublished PhD thesis, Newcastle University, UK

Conclusions

- In the UK at least, RAPS tend to be favoured passive treatment option for net-acidic coal mine discharges, and VFPs currently main passive option for base metal mine discharges
- Design is empirical, but be useful to move towards process-based design
- System longevity uncertain but critical to overall life cycle costs
- Permeability of compost may be key factor in determining longevity
- Metal-rich substrate disposal, recovery / re-use of metals also major influence on overall life cycle costs
- Although rates of sulfate reduction may decrease, cold weather does not appear to prevent systems operating effectively


THANK YOU!
MERCURY