Engineering of Nature-based Treatment Technologies: Lessons from Mine Water Treatment

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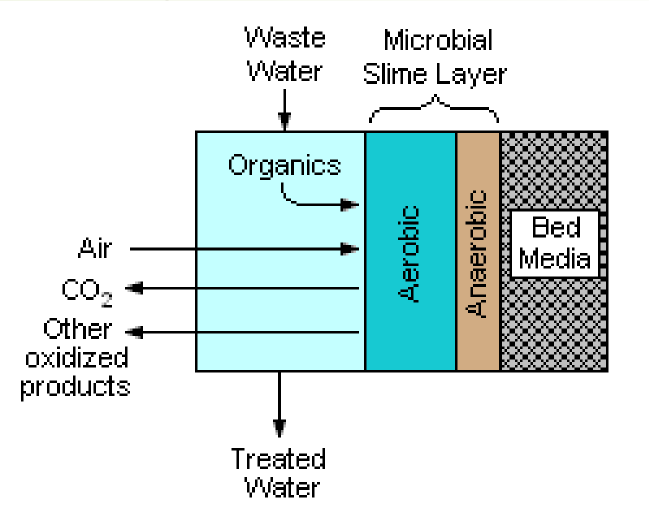
Nature-based Solutions (NbS) for Water Quality…not just managing Quantity

- Leveraging nature for the improvement of water quality not just quantity
- Leveraging nature includes utilising biology (especially microbiology); environmental energy/exergy gradients; minimal/no addition of refined treatment chemicals and little to no non-renewable power.
- Ostensibly NbS for sustainability but often an underlying cost driver in mine water treatment

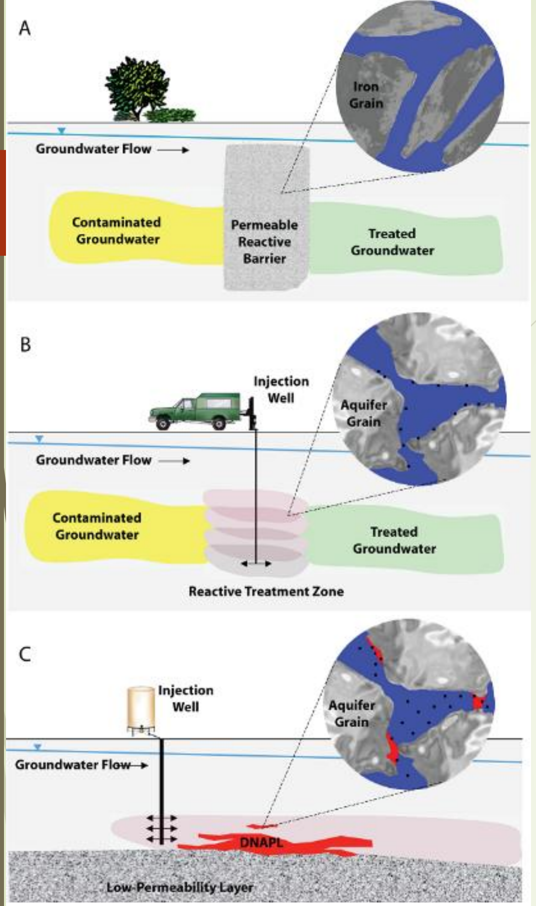
SuDS at Greener Grangetown in Cardiff Summer 2018
(Courtesyu susdrain/CIRIA)

NbS for water quality improvement are not new!

Respiration		
$^1/_4CH_2O + {^1/_4}O_2$	$\rightarrow$	$^1/_4CO_2 + {^1/_4}H_2O$
Denitrification		
$^1/_4CH_2O + {^1/_5}NO_3^- + {^1/_5}H^+$	$\rightarrow$	$^1/_4CO_2 + {^1/_{10}}N_2 + {^1/_2}H_2O$



e.g. Trickling Filters



- Constructed Wetlands (WWTW/landfill leachate etc)
- Permeable Reactive Barriers
- WTW Sand Filters
- Biobeds for pesticides
- Bioswales for road runoff

Biogeochemical Engineering

Physicochemical Mechanisms
Microbial mediated oxidation/reduction
Biodegradation
Sorption, precipitation and complexation
Uptake by biota
Filtration
Photolysis and volatilisation

Hydraulic Retention Time
Rates of Mass Transfer (e.g. O_2, CO_2)
Flow behaviour in porous media (unsaturated or saturated)
Hydraulic conductivity v time
Temperature

Global Problem of Acid Mine Drainage /Mine Water


NbS for treatment of mining-influenced water (MIW)

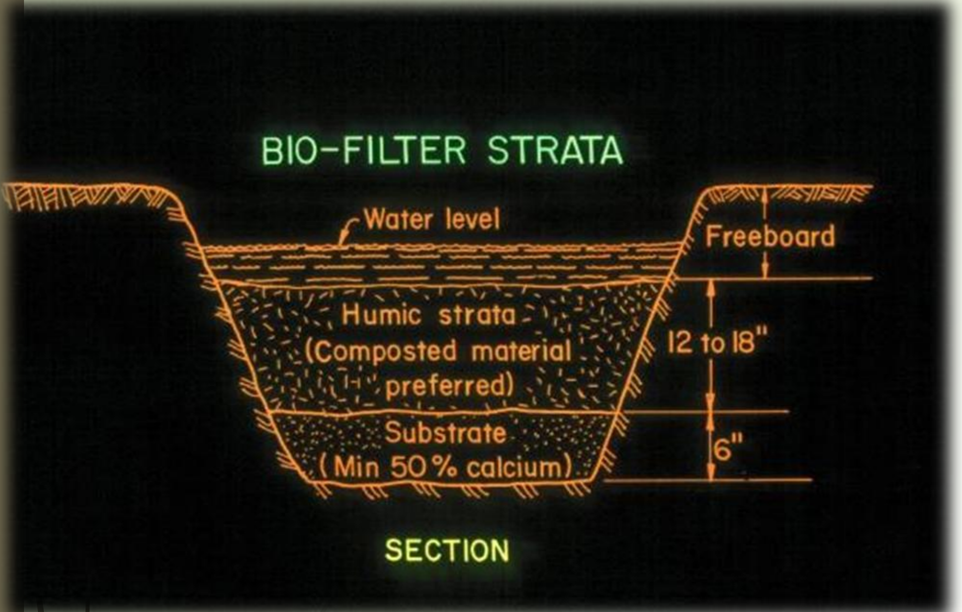
"The goal of a passive MIW treatment system is to enhance natural ameliorative processes, so that they occur within the treatment system, not in the receiving water body."

Kleinmann et al., 2021*

- Note: same principle as wastewater treatment…..
- Note: Acidity can be neutralized but metals don't biodegrade and thus stay in the treatment system.
- Inexpensive treatment systems needed as polluter pays legislation was not in place

*Kleinmann, B., Skousen, J., Wildeman, T., Hedin, B., Nairn, B. and Gusek, J., 2021. The early development of passive treatment systems for mining-influenced water: A North American perspective. *Mine Water and the Environment*, *40*(4), pp.818-830.

Development of “Passive” in North America for AMD from coal mines



> A separate but parallel development path from treatment wetlands for wastewater

>1970s Sphagnum moss treatment*

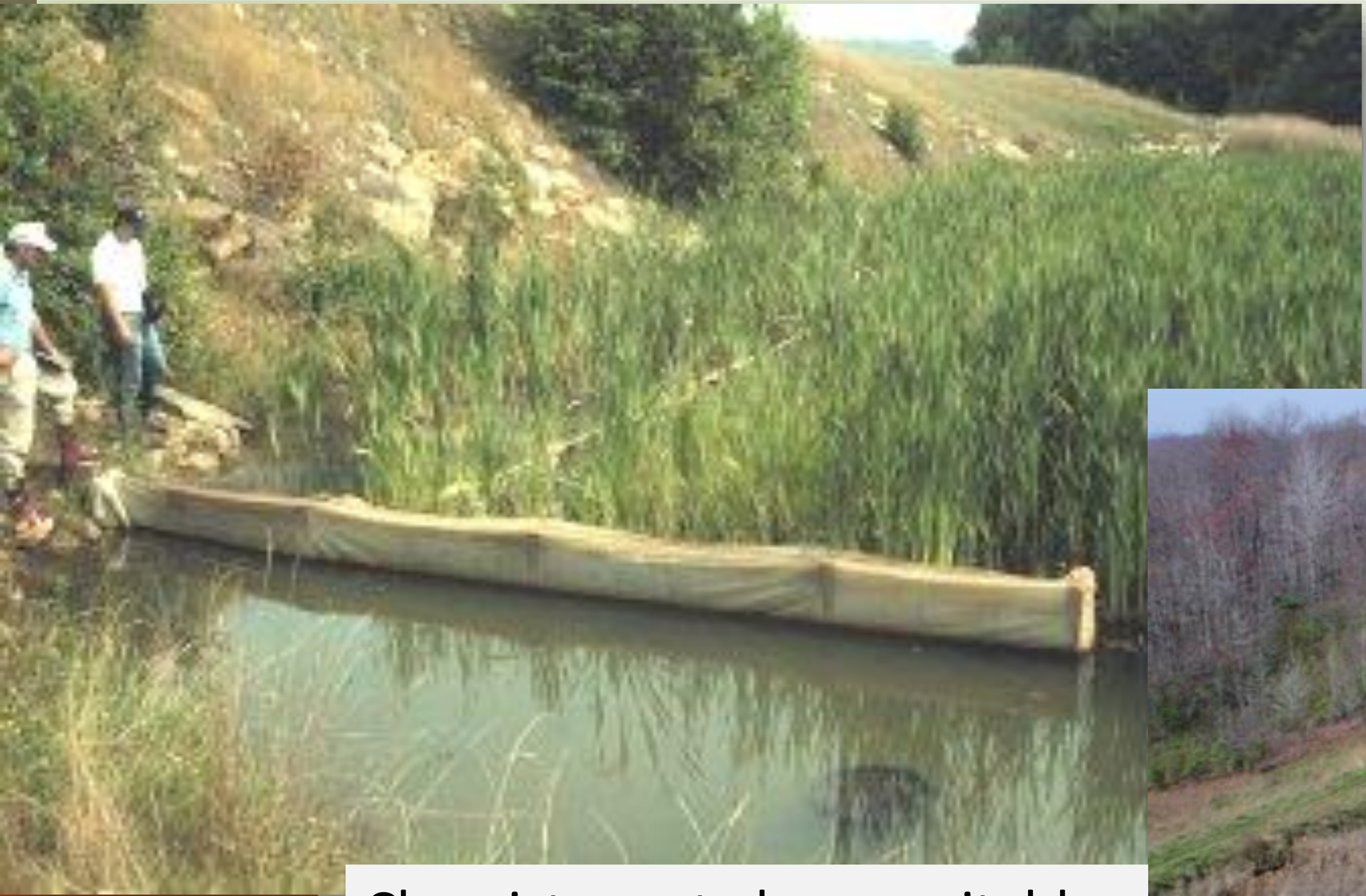
>1980s Typa/cattails Wetlands*


Photos courtesy of Dr Jeff Skousen, West Virginia University

*Kleinmann, B., Skousen, J., Wildeman, T., Hedin, B., Nairn, B. and Gusek, J., 2021. The early development of passive treatment systems for mining-influenced water: A North American perspective. *Mine Water and the Environment*, *40*(4), pp.818-830.

Open Limestone Drains (OLDs) These blocked so Anoxic Limestone Drains (ALDs) devised

West Virginia has >1000 built



Chemistry not always suitable for ALDs
so SAPS/RAPS developed →

Photos courtesy of Dr Jeff Skousen, West Virginia University

Chemistry not always suitable for ALDs
so SAPS/RAPS developed →

Photo courtesy of Dr Jeff Skousen, West Virginia University

Wetlands picked up in UK and now a standard treatment for net-alkaline coal mine drainage

Mining Remediation Authority has constructed ~ 70 schemes of aerobic wetlands

Site of Taff Merthyr colliery - Then and Now


Image taken from google Earth
R3
R2
R1
L1
L2
1
2
3
4
5
6
7
8
20m
Image taken from google Earth
L2
L1
R1
R2
R3
1
2
3
4
5
6
20m

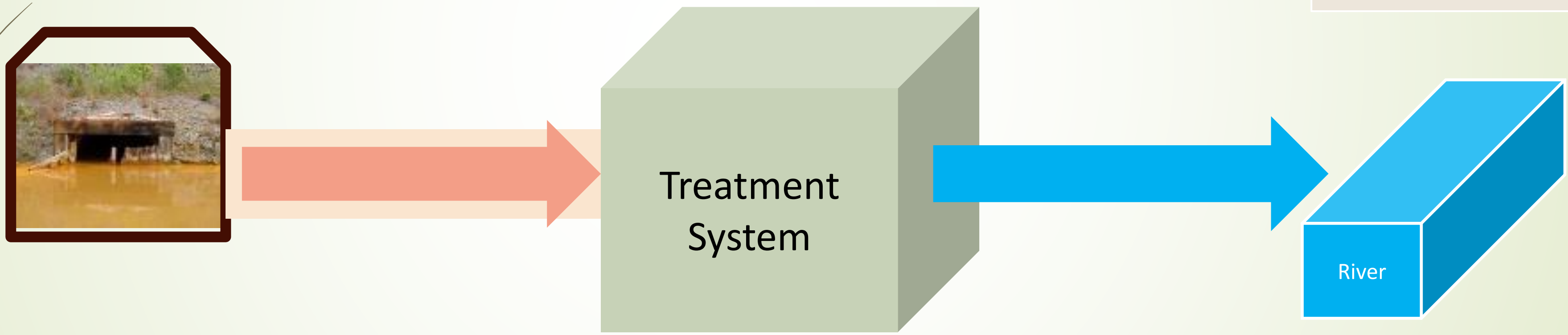
Current UK Challenge: build metal mine water treatment systems

Design must be optimized for:

- Effectiveness to target concentrations
- Whole life cost (£) including land and waste
- Sustainability & Carbon
- Biodiversity net gain
- Public acceptability

Note: both flow (Q) and metal concentrations can vary considerably with time!

Zn, Cd, Cu,
Ni, Pb, As, Fe
Acidity



- How big is the flow?
- What do we have to remove?
- To what target concentration?

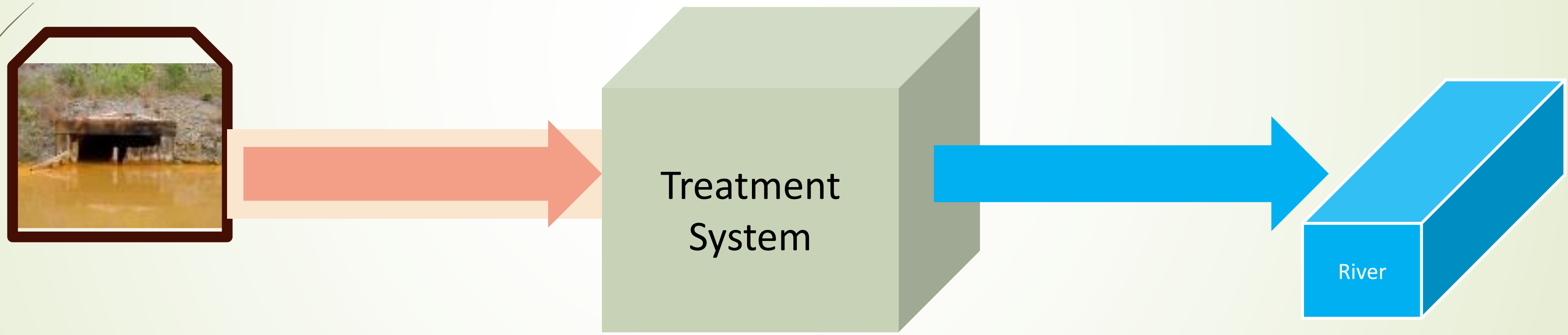
Major Constraints

- Available or suitable land

...how to remove the contaminants?

...Biogeochemical Engineering

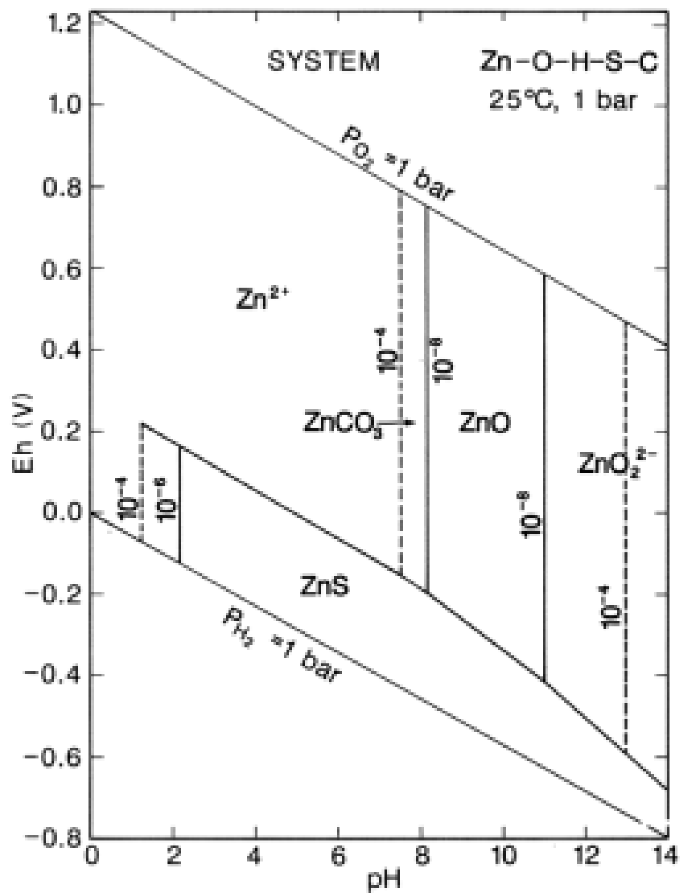
Zn, Cd, Cu,
Ni, Pb, As, Fe
Acidity



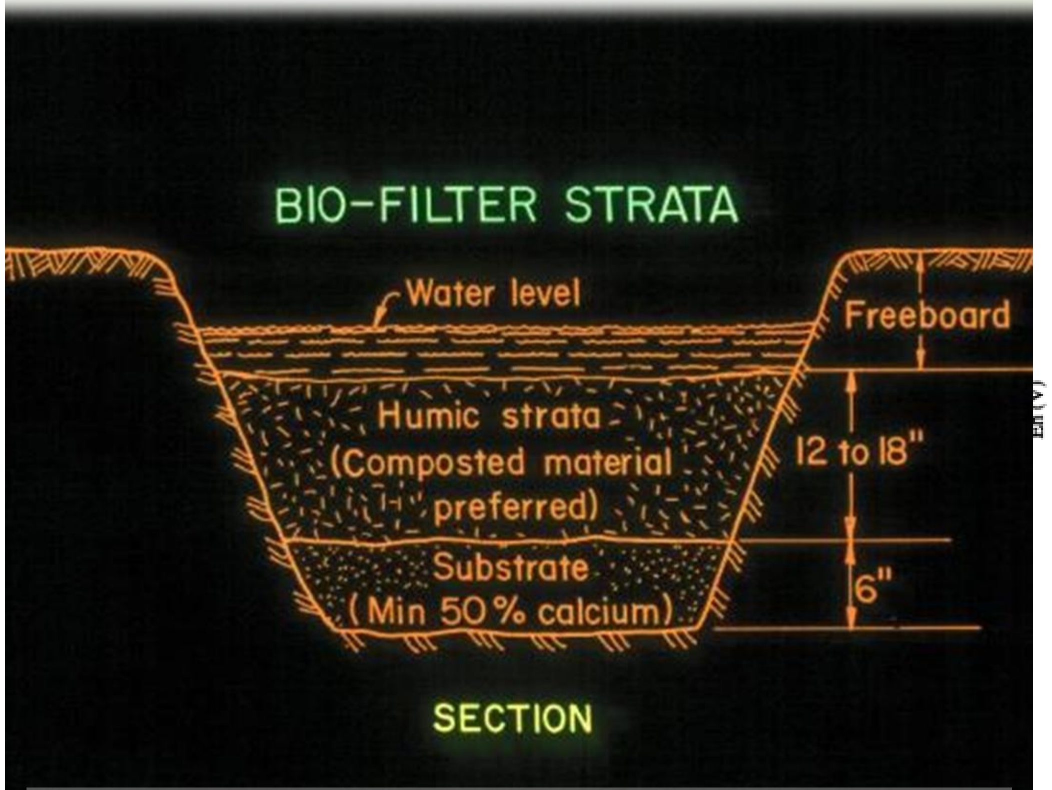
Mechanisms

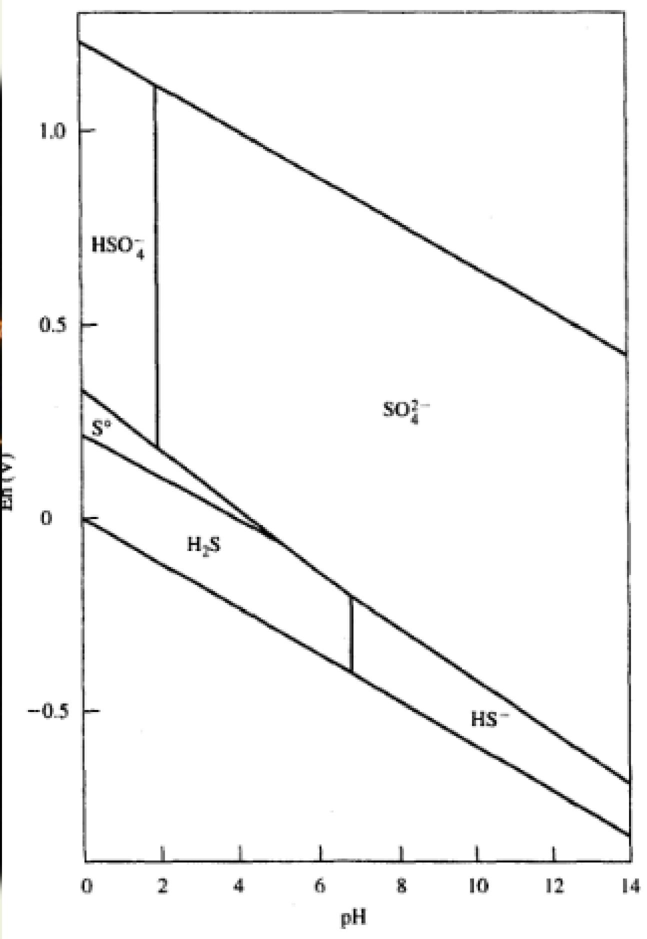
- If particulate: settle/ filter
- If dissolved:
  - Change chemical environment to induce precipitation and then liquid/solid separation
  - Sorption (adsorption, absorption, ion exchange etc)
  - Uptake by biota? All about the microbiology

Removal of Zn as ZnS



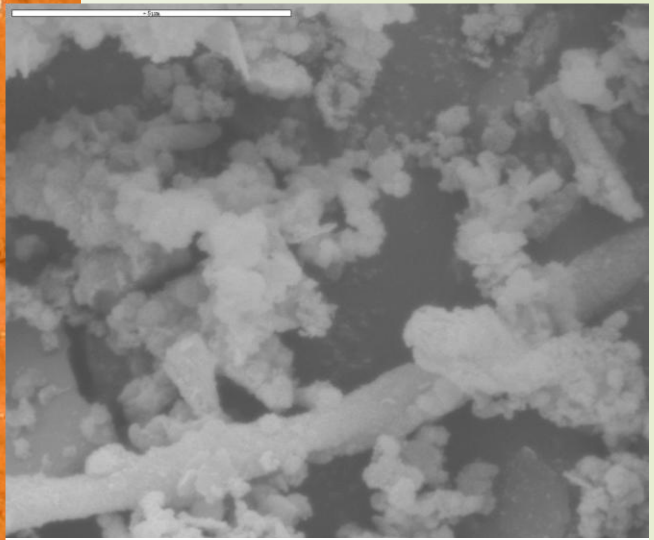
Brookins, D.G. 1988. Eh-pH diagrams for geochemistry, Berlin, Springer.





Sulphate Reducing Bacteria

$Zn^{2+}_{(aq)} + SO_4^{--}{}_{(aq)} + CH_2O_{(s)} \rightarrow ZnS_{(s)} + HCO_3^-{}_{(aq)}$



Iron encrusted *Gallionella ferruginea* stalk

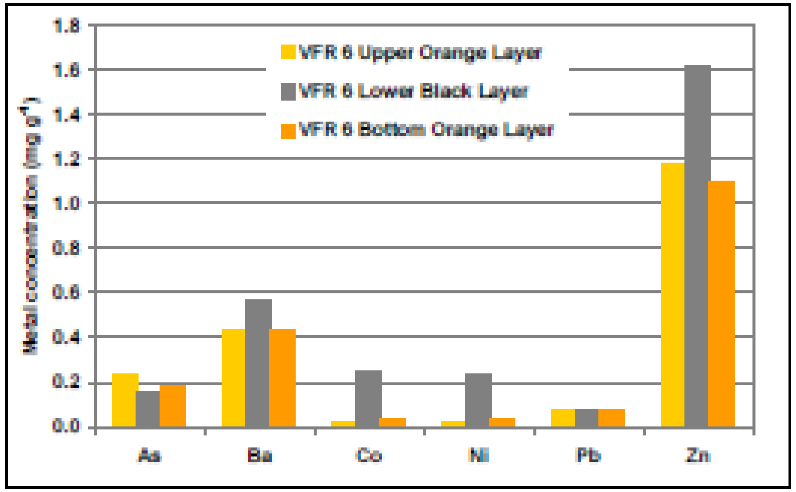


Figure 7-21: Al, As, Ba, Co, Ni, Pb and Zn concentrations in ochre bed layers

Autocatalysis and microbial oxidation

Outcome from the METAL-SoLVER Project* 2021/22

Original VFR trials undertaken with WSP for Coal Authority in 2017

Granite Media VFR | **Limestone Media VFR**

Day zero

After about three months

dark coating indicates Mn removal.

*Welsh European Funding Office Smart Expertise under the METAL-SoLVER project (#82347) NRW, Coal Authority and Geochemic Ltd

Removal Mechanisms in METAL-SoLVER VFR trial

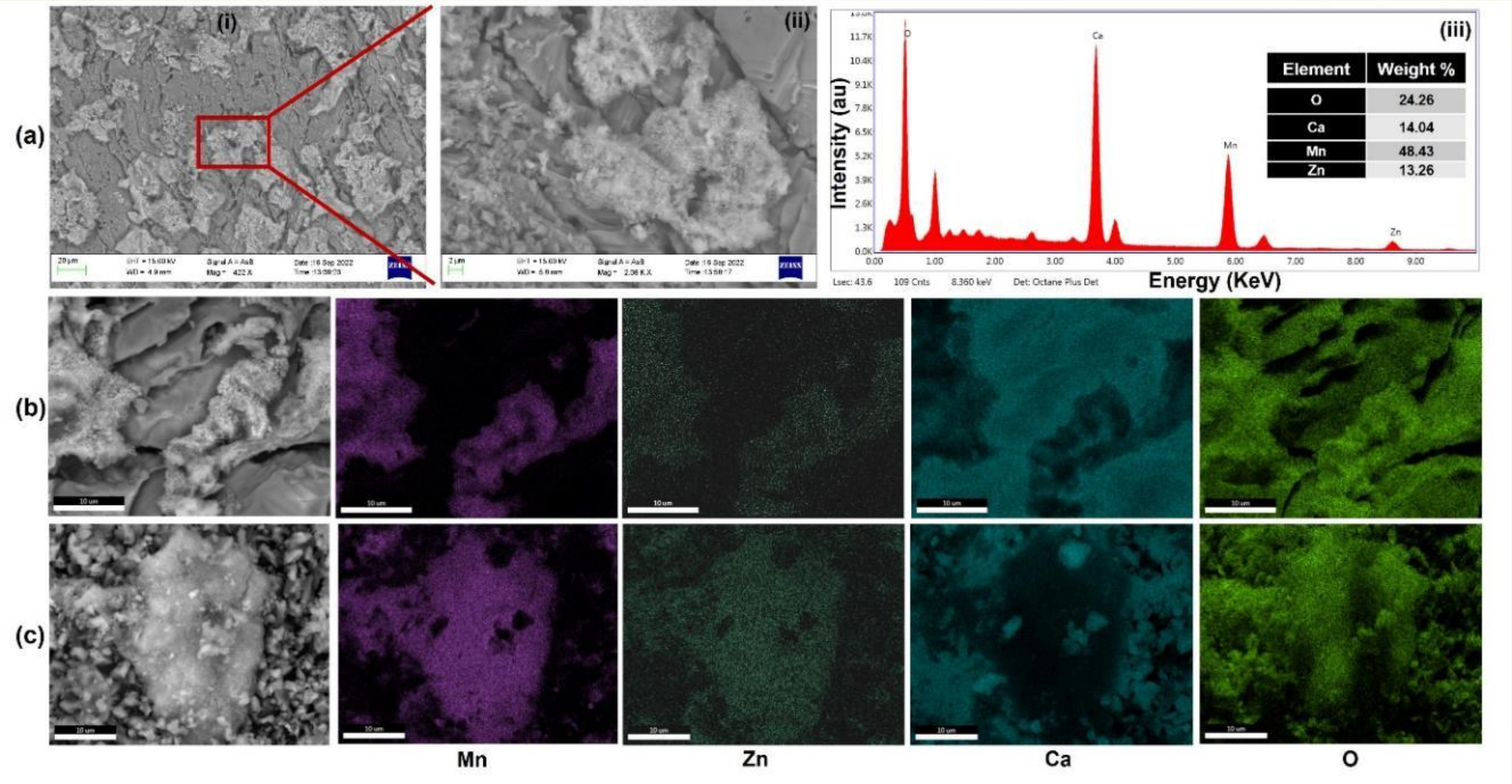


Figure 2 (a) SEM micrographs ((i)& (ii)) of the dark sponge like precipitate on the limestone chips from the limestone reactors alongside the associated EDS spectrum and composition with characteristic emission peaks (iii); (b) & (c) Backscattered electron micrographs (grey) and the corresponding elemental map of the dark sponge like precipitate on the surface of the limestone chip (b) and scrapings (c) showing the distribution of Mn, Zn, Ca, & O. *Extract from Okeme, I.C., Srivastava, P. and Sapsford, D.J., 2025. Highly efficient co-removal of zinc and manganese during passive treatment of mine drainage: Mechanisms, microbiology and application. Ecological Engineering, 219, p.107681.*

DEFRA WAMM Programme

VFR Mine Water Treatment Trial

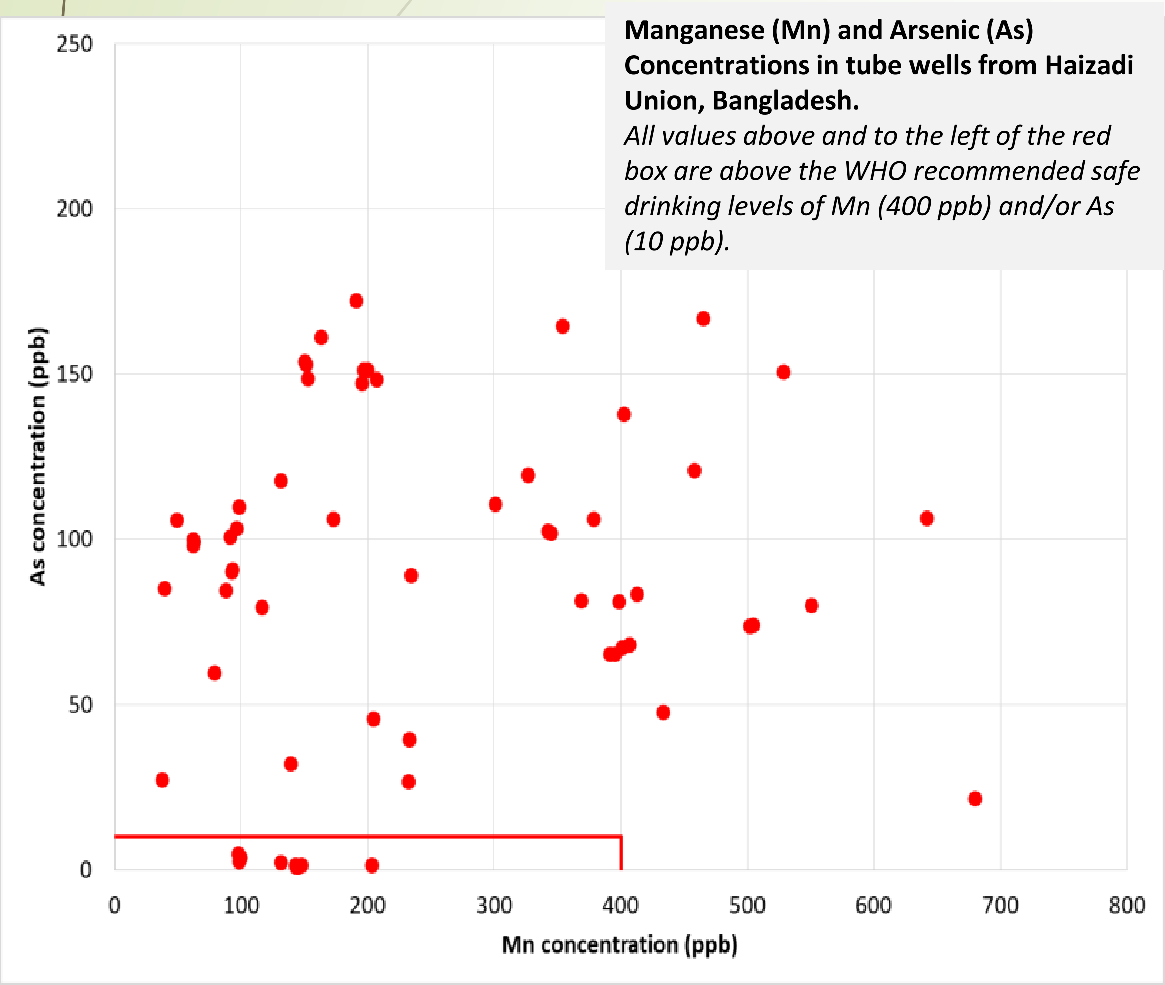
- Coombe Adit is an abandoned mine water drainage tunnel that pollutes about 14km of the Coombe Stream, Gwindra Stream and River Fal with zinc, copper and/or cadmium.
- https://www.gov.uk/government/collections/coombe-mine-water-treatment-scheme

Drinking Water Treatment in Zambia

Degassing CO_2 is important

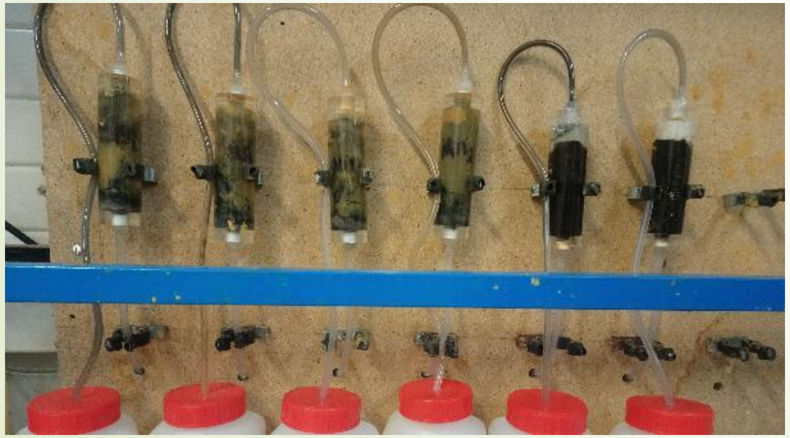
Biogeochemical Engineering of As removal

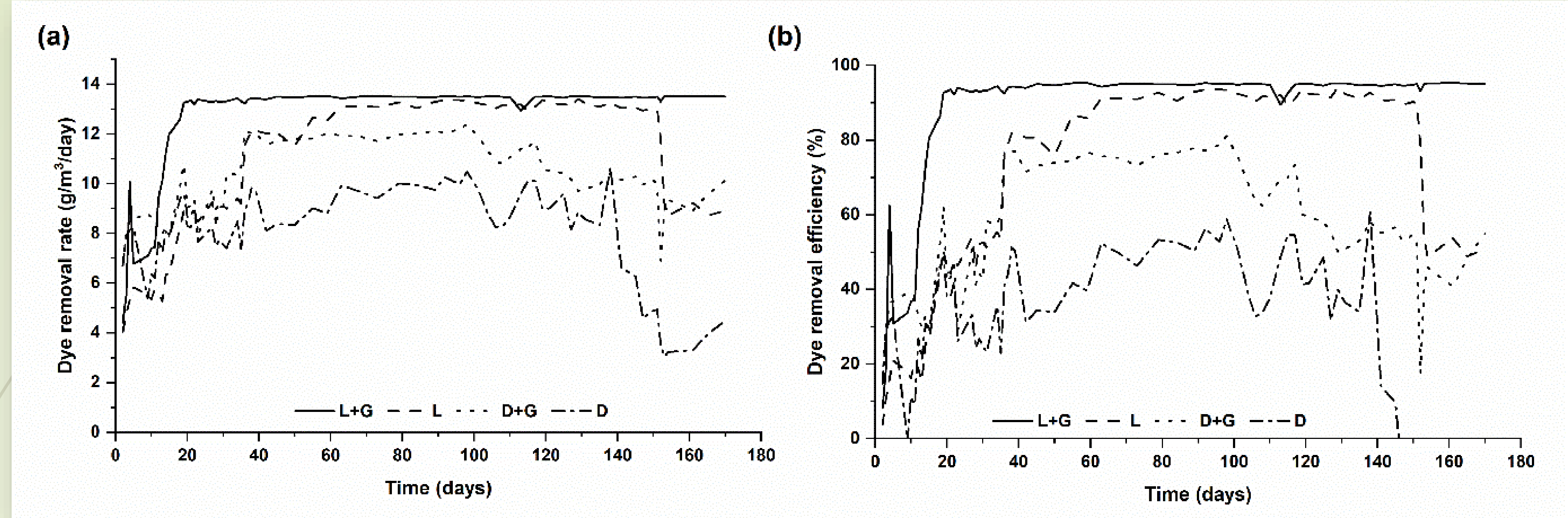
Data (2017) collected by us on RAEng grant

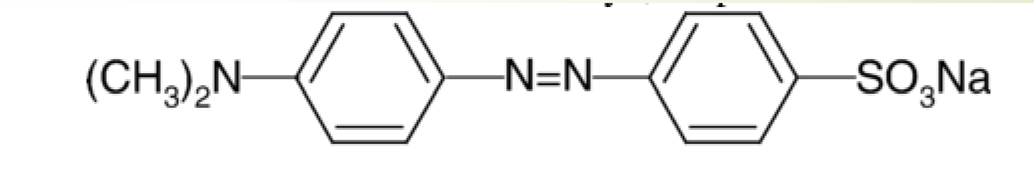


Cardiff University based treatment system in New Zealand (Oceana Gold Globe Progress)

Iron-rich sludges for treatment of dye-bearing textile effluent and BTEX







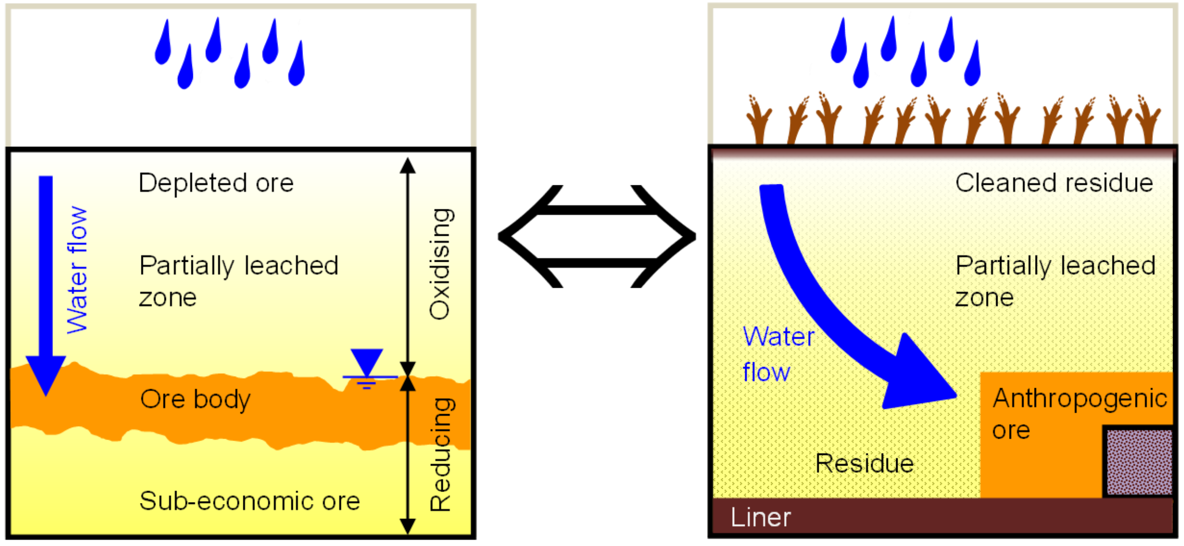
Phase I – Methyl Orange (MO)and MO + glycerol

Phase II – Methyl Orange (MO) in synthetic effluent

Phase III – Real mixed dye/textile effluent

All about the microbiology!

Use the prolonged time in storage to apply green low-intensity and low-cost processes



(a) Supergene ore forming processes

(b) ASPIRE repository

Now no longer leaching threat and perhaps can be reused (e.g. aggregate)

Now at concentrations economically viable to process

ASPIRE

Accelerated Supergene Processes in Repository E

"Developing self-cleaning, temporary storage lar Economy"

Sapsford, D.J., Stewart, D.I., Sinnett, D.E., Burke, I.T., Cleall, P.J., Harbottle, M.J., Maye landfills for temporary storage and treatment of mineral-rich wastes. In *Proceedings of th* No. 2, pp. 77-93). Thomas Telford Ltd.

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Waste and Resource Management

Circular economy landfills for temporary storage and treatment of mineral-rich wastes

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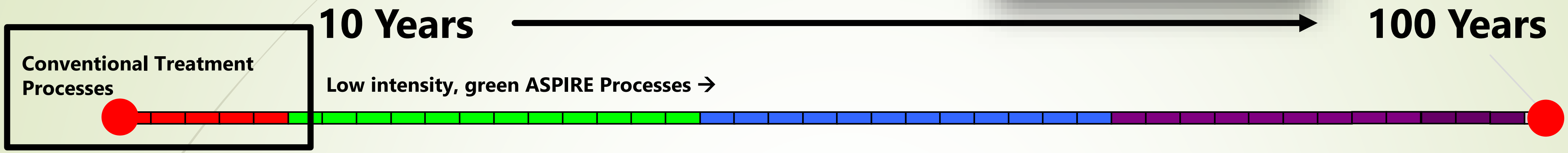
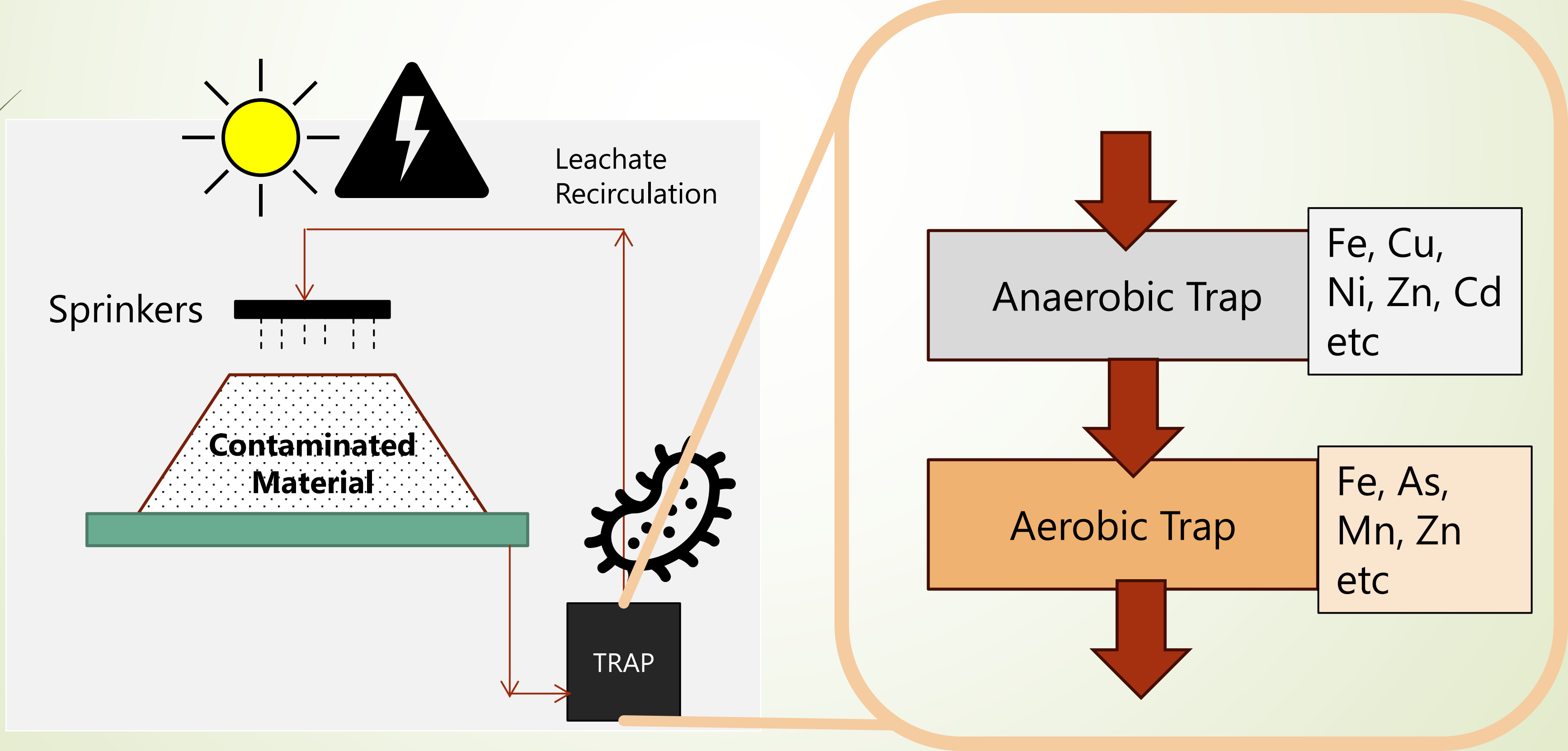
ASPIRE Concept

Carbon storage may become an important consideration





Summary

- NbS for water quality improvement is becoming more common.
- Biogeochemical engineering is key; more research needed on the art of the possible for a range of pollutants/water types.
- Potential for not reinventing the wheel by looking at lesson learnt from other NbS
- Where recalcitrant organic or inorganic contaminants build up – they will eventually have to be removed.
- Maintenance key (especially of hydraulic conductivity) and plan for cleaning/ disposal/renovation etc.
- Plants and organic matter are great, but they do complicate things…especially re: management of final residues.
- LCA studies and MCDA are needed for optioneering to make sure NbS are the appropriate and sustainable solution – don't just assume they are.
- Further research looking at various other NbS treatment systems with colleagues across Cardiff University and externally is underway…

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