Catchment-scale approaches to managing metal pollution

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Outline

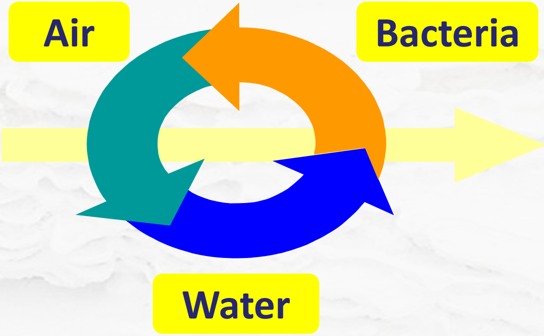
- Metal mine pollution in the UK
  - National extent of issue
  - Management initiatives
- Developing passive treatment systems
- Force Crag system, Cumbria
- Small scale initiatives in Yorkshire

Mine water pollution

- Exposure of metal-rich minerals to air, bacteria and water
- Weathering and release of ecotoxic metals e.g. lead, zinc, cadmium, arsenic, copper, nickel
- Pyrite oxidation: $FeS_2(s) + {}^{7}/_{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$

Metal-rich minerals

Metal-laden acidic water



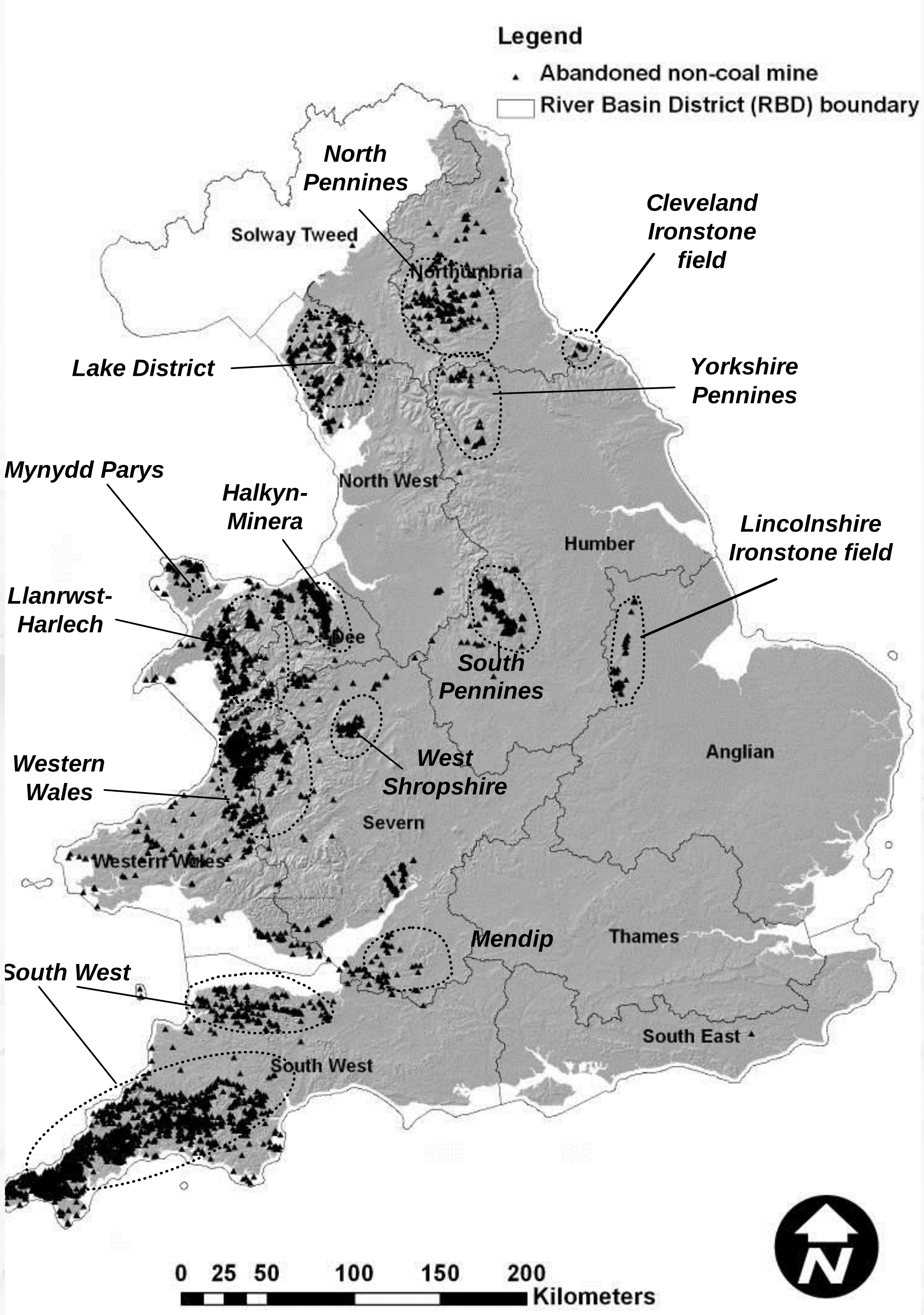
Mine water pollution - problems

Ecological issues

- Physical smothering by Fe-oxides of detriment to macroinvertebrate communities
- Zn and Cu of particular importance to salmonids

Metal mine pollution: UK context

- Limiting factor to legislative compliance in large parts of UK
- 'Orphaned' sites: unclear or absent liabilities for clean-up
- Defra / EA metal mines initiative since 2005
- GIS-based approach using environmental archives and local expert knowledge
- Basis for national remedial strategy



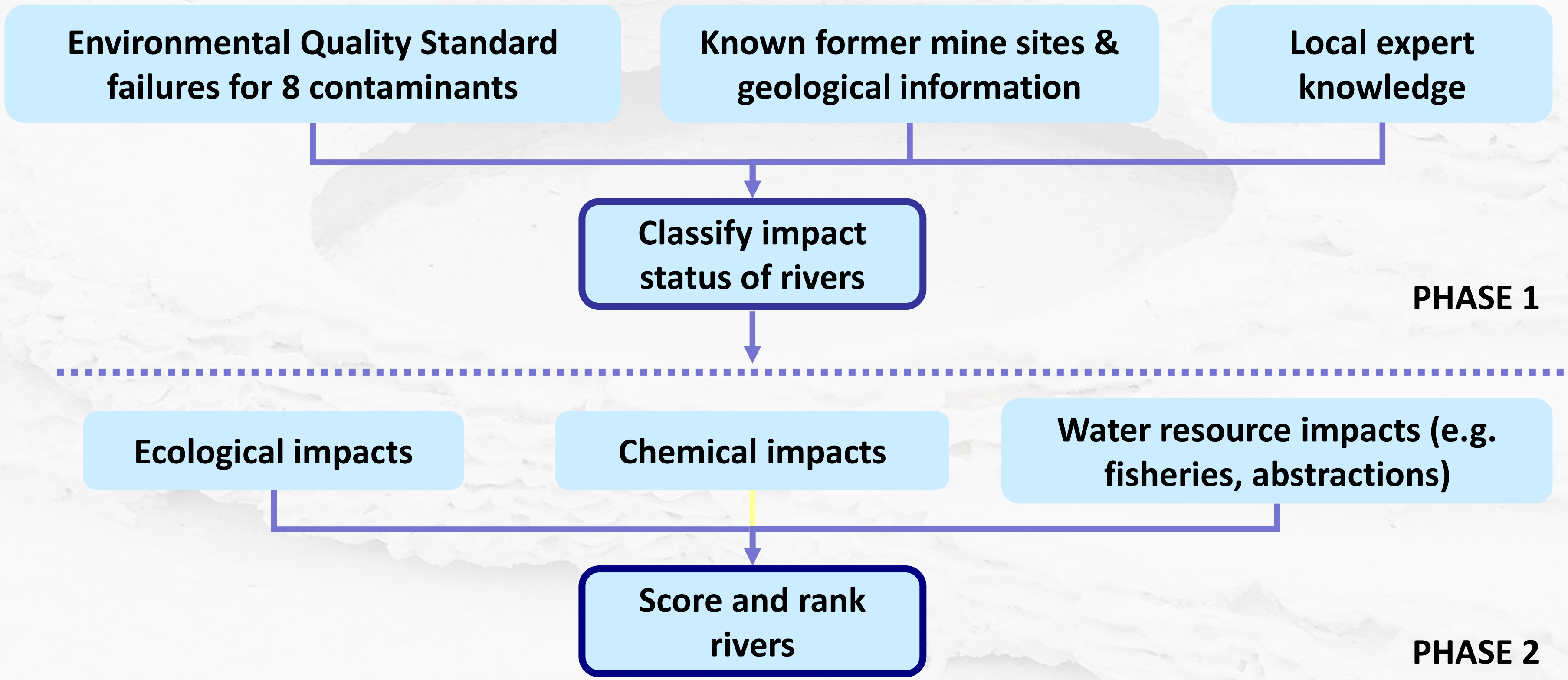
Management process

- Prioritise catchments for action
- Identify key sources at catchment scale
- Treat key sources
- Challenges:
  - Funding
  - Technology gap
  - Longevity
  - Terrain
  - Converging stakeholder interests

Sir Francis Level – the principal reason for EQS failure in Gunnerside Gill (Swaledale)

Metal mine management: national assessment

- Establish link between current pollution (>55000 data points) and historical mining (4900 mines + mineral veins)
- Weighting impact in catchments by severity of chemical quality failures, ecological impact, water resource impacts

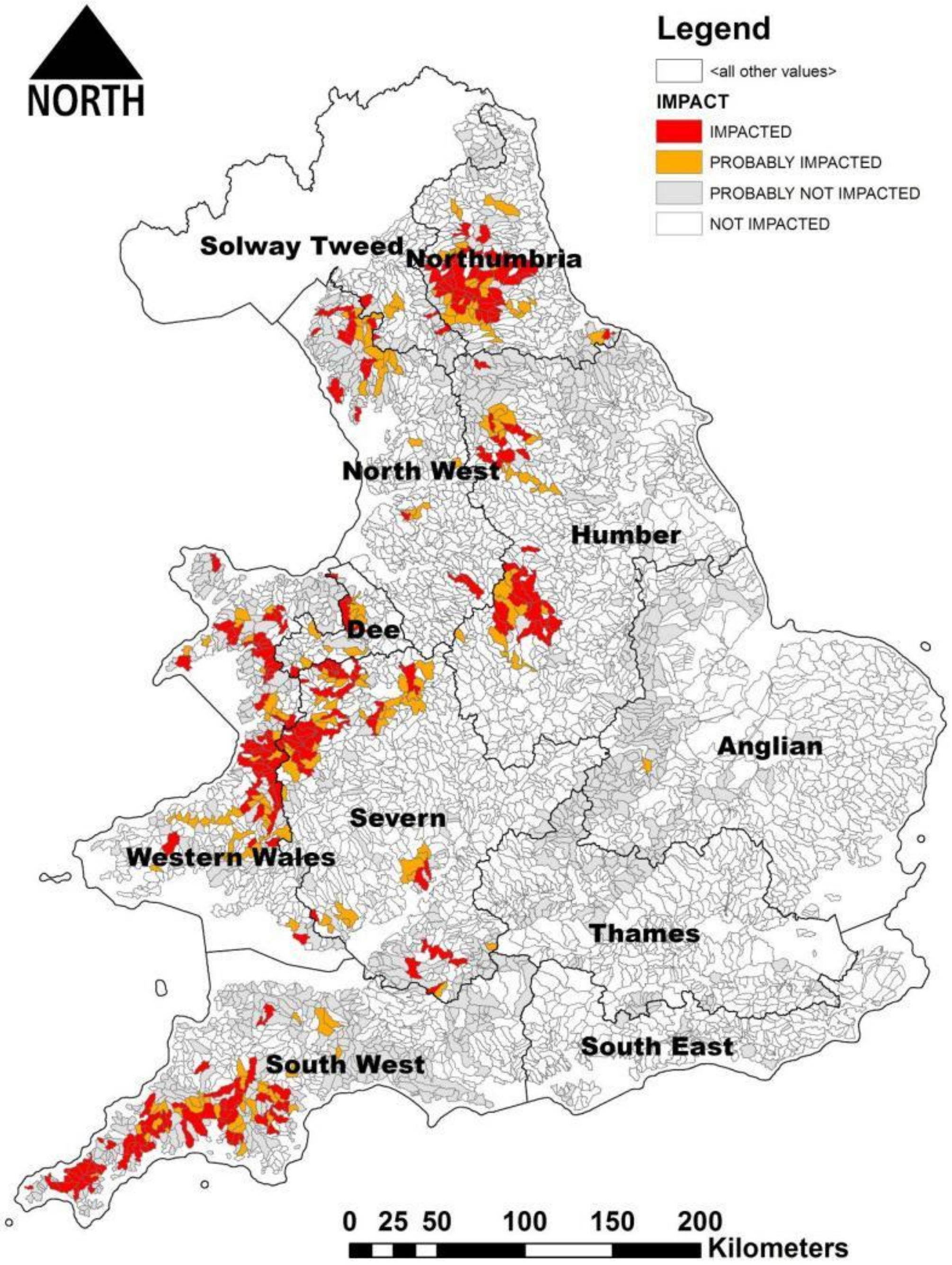


National prioritisation

- Mining a significant pressure: >300km streams affected
- 'Orphaned' status of mine sites abandoned pre-1999
- National management plan 2007-
- ~5% streams in England and Wales
- >250 discharges
- Key EQS failures:

Zn> Pb> Cd> Cu> Ni> Fe

Water bodies where metal concentrations exceed EQS due to metal mining



Point sources and diffuse sources

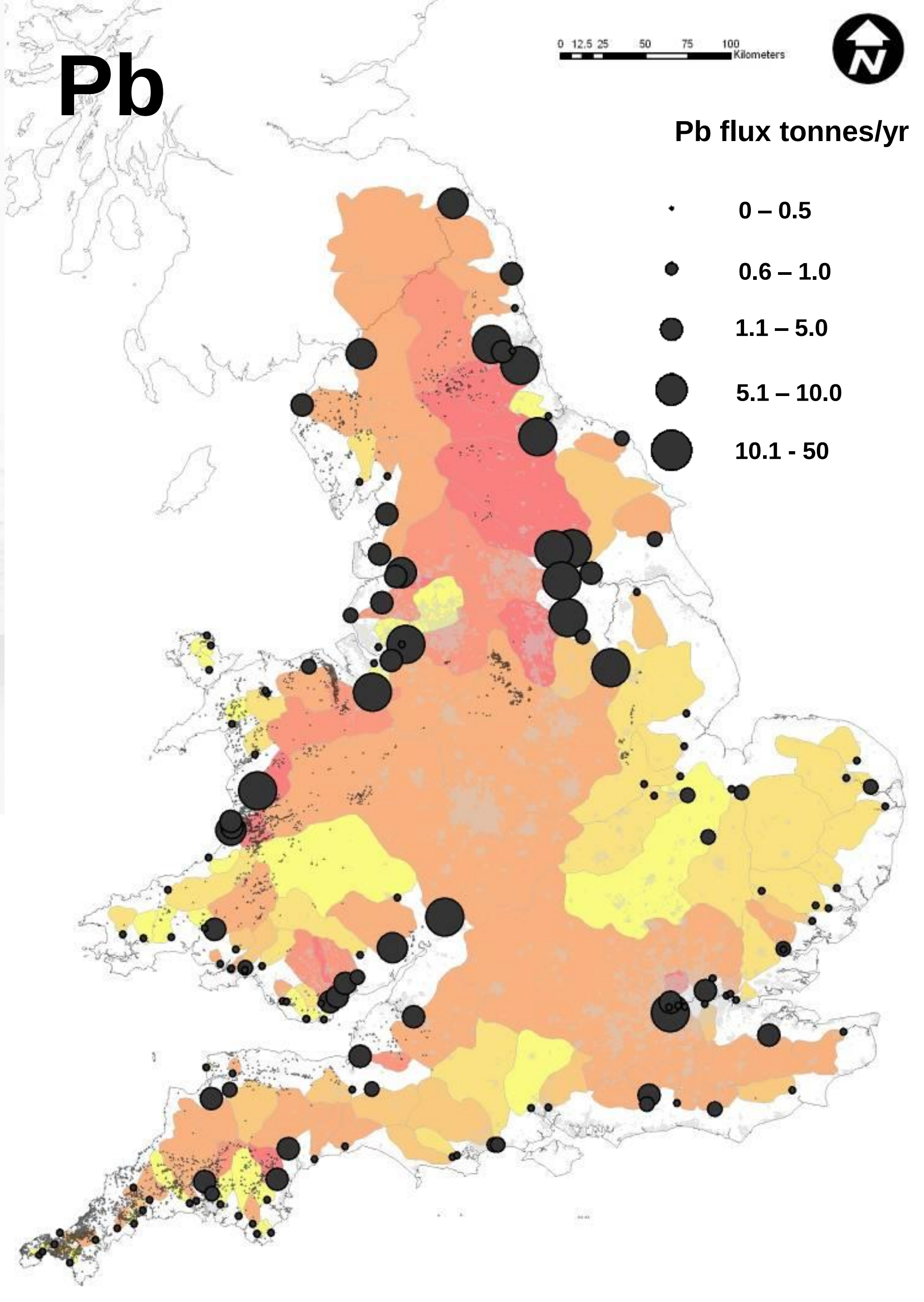
- Point discharges from adits and drainage levels – obvious focus for management efforts (>270 identified)
- Diffuse sources – spoil heaps and tailings: a more challenging management issue (total area of 91km^2)

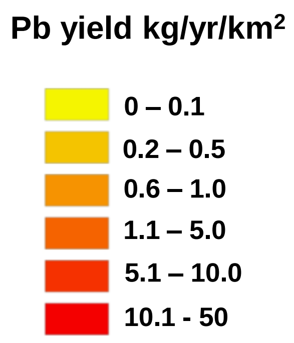
Scale of pollution problem – initial estimates

	As	Cd	Cu	Fe	Mn	Ni	Pb	Zn
n (concentration)	*47*	*142*	*114*	*125*	*117*	*82*	*155*	*189*
n (flux)	*43*	*95*	*95*	*99*	*88*	*25*	*115*	*130*
Measured flux (t/yr)	**8.8**	**0.83**	**32.3**	**853.1**	**68.2**	**2.63**	**22.9**	**253.6**
Consented discharges *n*	*130*	*177*	*140*	-	-	*276*	*194*	*161*
Consented discharges flux	**6.0**	**1.0**	**78.1**	**-**	**-**	**46.7**	**18.3**	**197.8**

Spatial patterns

- OSPAR data – flux of contaminants at tidal limit
- Number of former mines = single best predictor of tidal limit flux



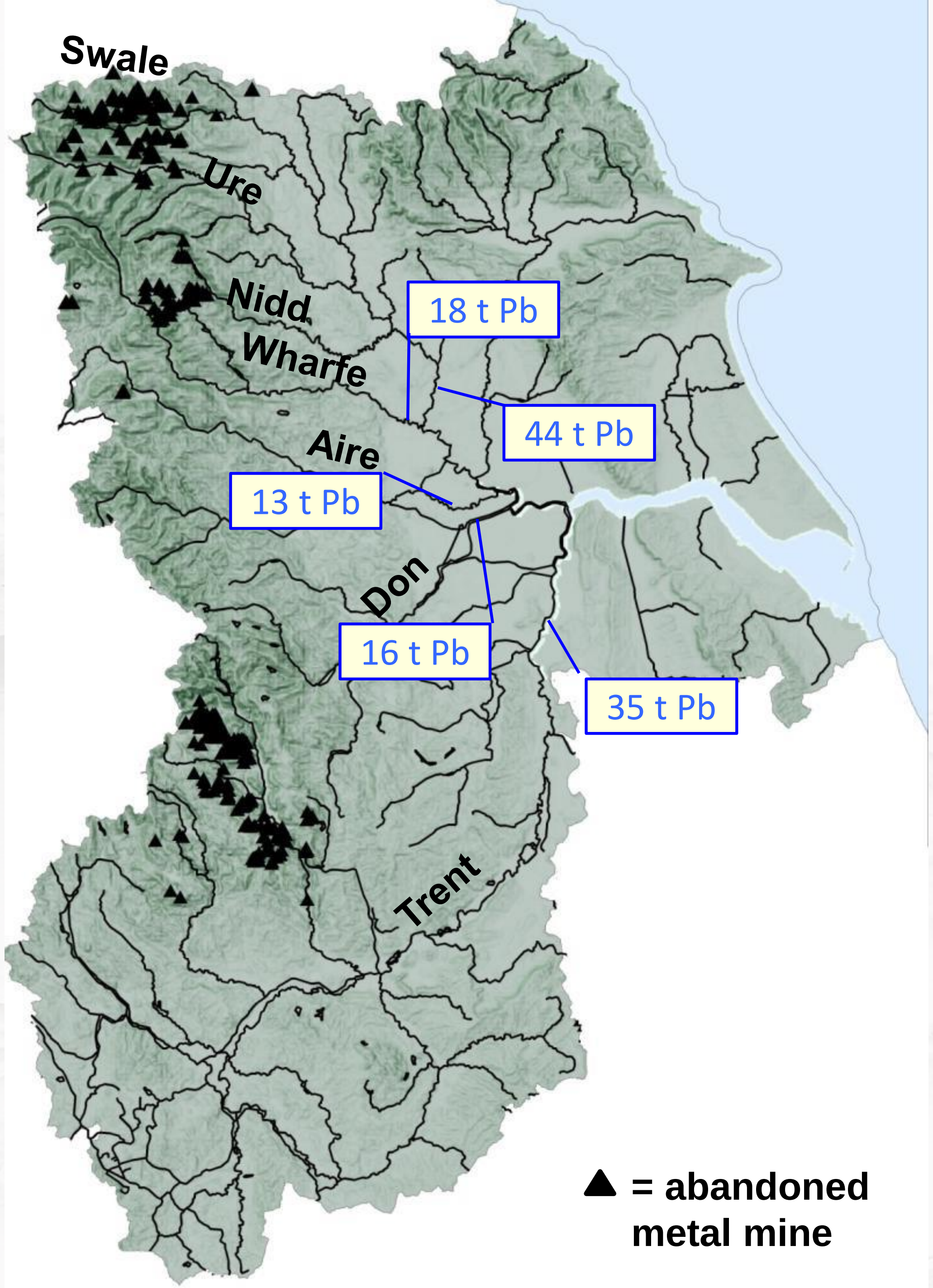


Humber perspective

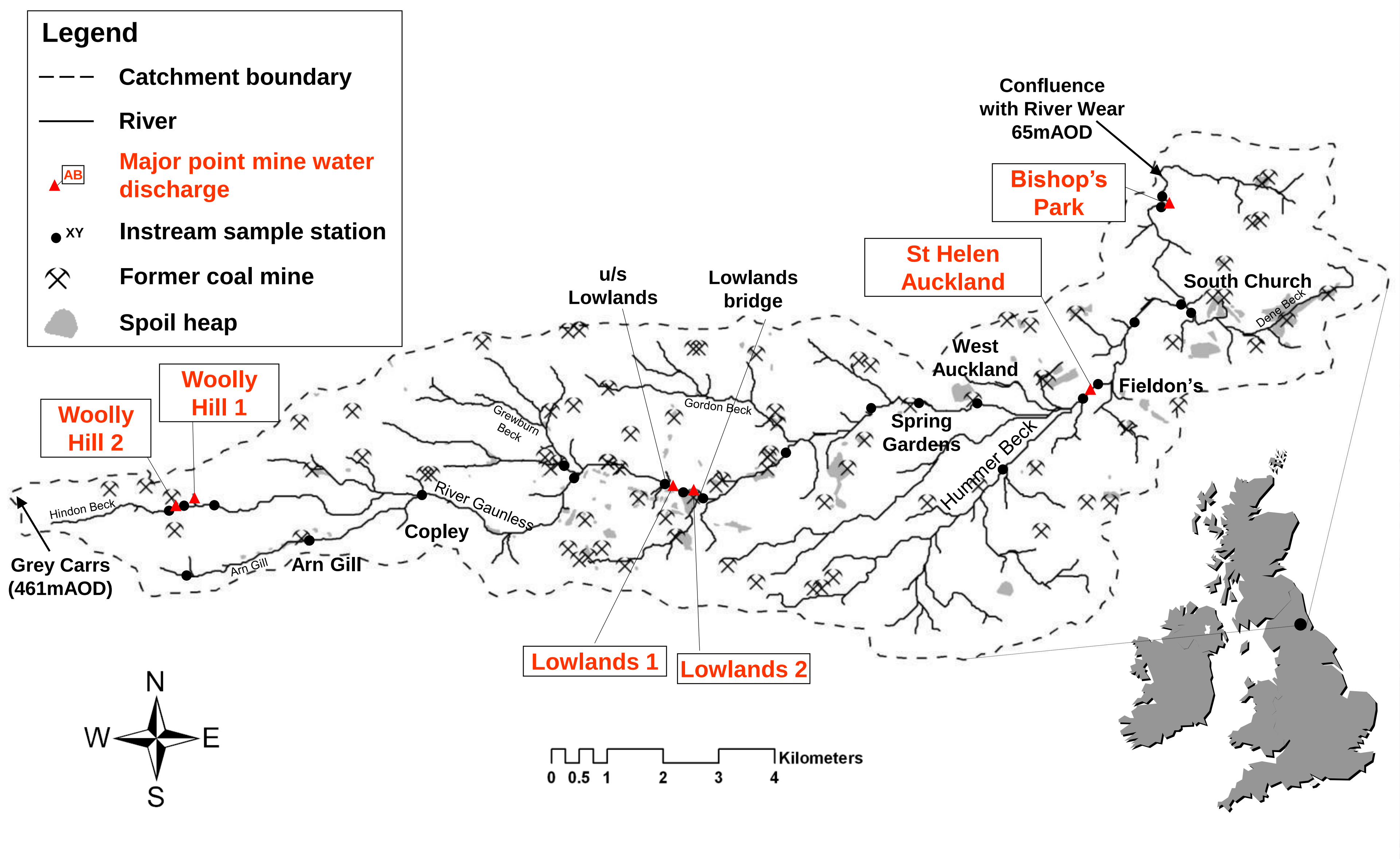
- Historically major Pb mining areas: Dales and Peak District; Fe mining: NYM, N. Lincs.
- Major centre for car making

	Cd	Cu	Pb	Zn
UK total (tonnes/year)	5.3	293.0	365.3	1570.5
Humber total (tonnes/year)	1.8	59.2	128.1	293.2
Humber %	**34.4**	**20.2**	**35.1**	**18.7**

- Contaminated sediments in Humber
  - Zn: 130-330mg/kg (PEL: 171)
  - Pb: 90-200mg/kg (PEL: 112)



Management – identifying key sources



Management – treatment

- Requirements:
  - small land footprint,
  - low-cost (capex and opex ideally),
  - sustainable (and sustained) treatment technologies
  - Zn removal key in many cases

- Conventional treatment
  - Lime dosing and high density sludge plants

- Passive treatment
  - Make use of naturally available energy gradients

Old Gang Beck, Yorkshire Dales: a typical mine-affected catchment: remote, steep-sided, minimal flat land area

Remedial approaches tested

e.g. Mayes et al. (2009); Warrender et al (2011); Gandy and Jarvis (2014); Sapsford et al. (2015)

BIOREACTORS

- Mixtures of compost, woodchip, limestone
- Encourage bacterially-mediated sulphate reduction
- Well tested at range of scales
- Issues of H_2S
- Organic supplements required?
- Mixed waste substrate

SORBENTS

- Various media tested under lab and field conditions
- Steel slags, waste shells, recovered hydrous ferric oxide from coal mine treatment sites
- Short residence time
- Saturable process – maintenance burden

Force Crag, Cumbria: the first passive metal mine treatment system in the UK

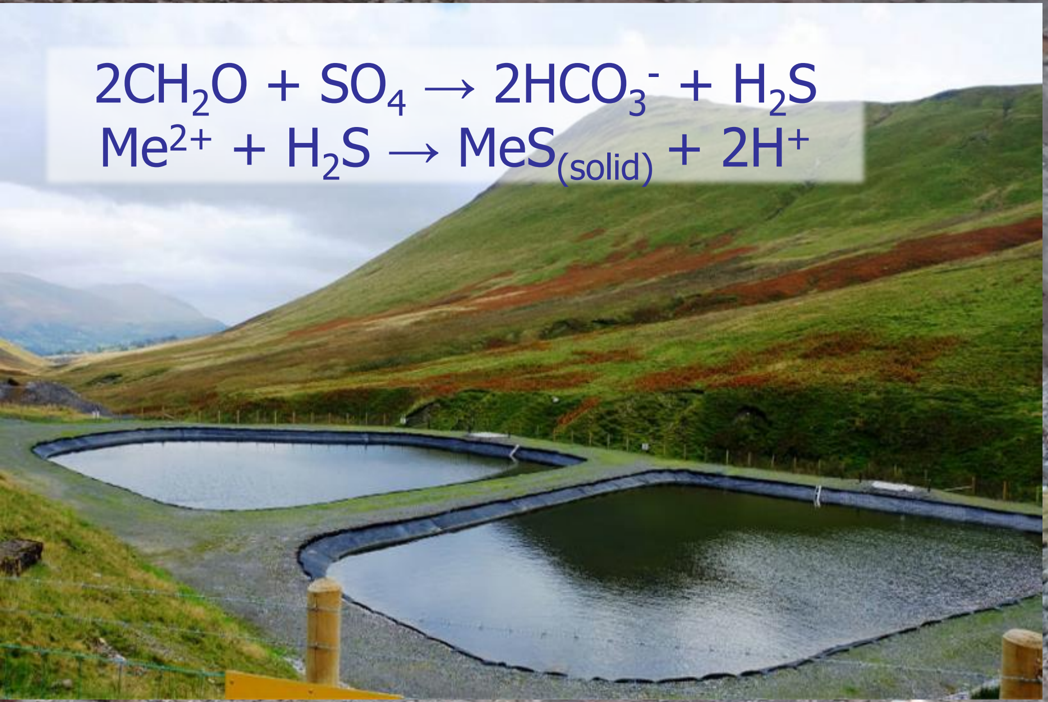
- Former Pb-Ba-Zn mine operating 1839-1991
- SPA, SAC, National Park, Scheduled Ancient Monument, SSSI
- Single biggest source of Zn to Newlands Beck
- £1 million capex
- Partnership between Defra, EA, Coal Authority, National Trust

Photo: John Malley

Force Crag, Cumbria: bioreactors in vertical flow ponds

- Two vertical flow ponds receiving Level 1 discharge
- pH ~7, Zn ~ 3mg/L, flow ~15L/s
- ~£30k opex

$$2CH_2O + SO_4 \rightarrow 2HCO_3^- + H_2S$$
$$Me^{2+} + H_2S \rightarrow MeS_{(solid)} + 2H^+$$



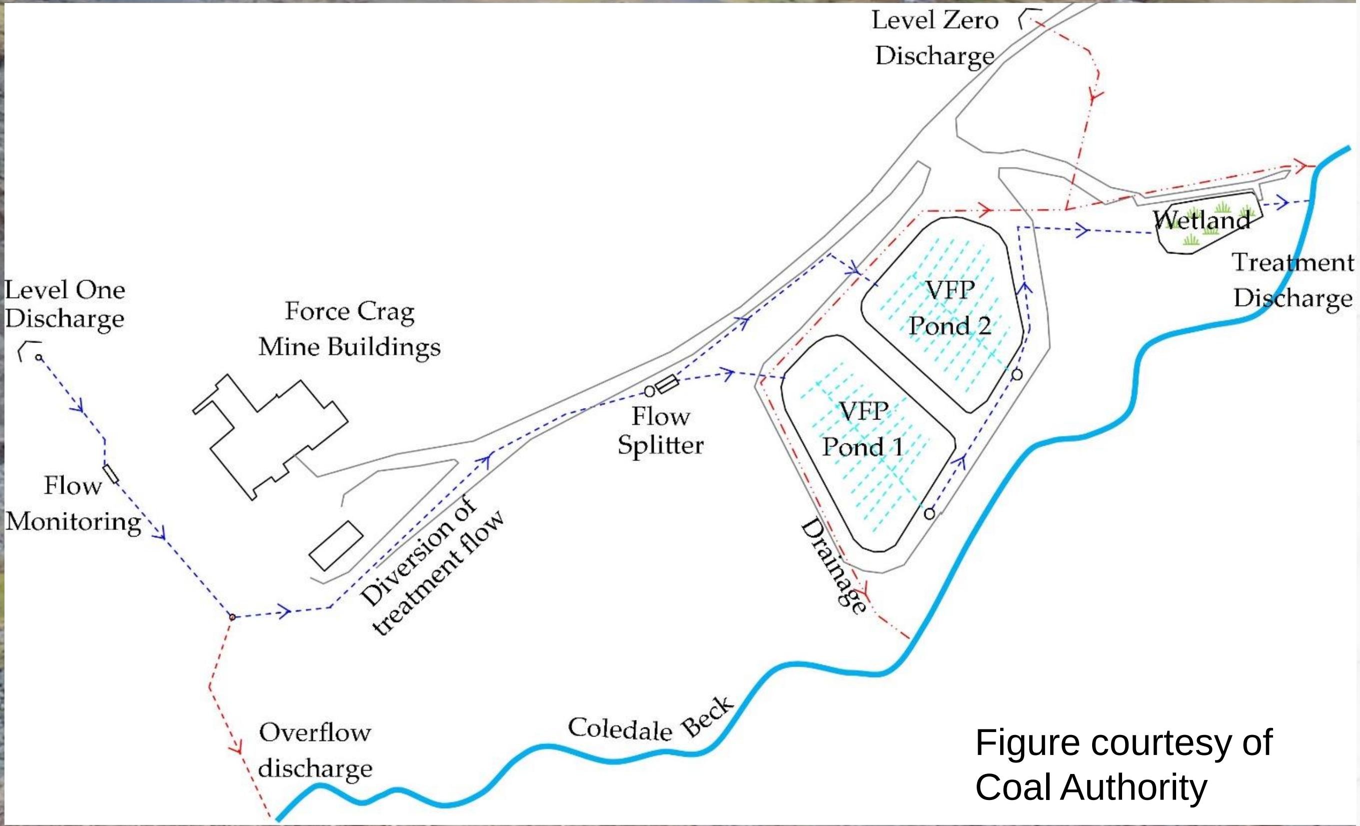
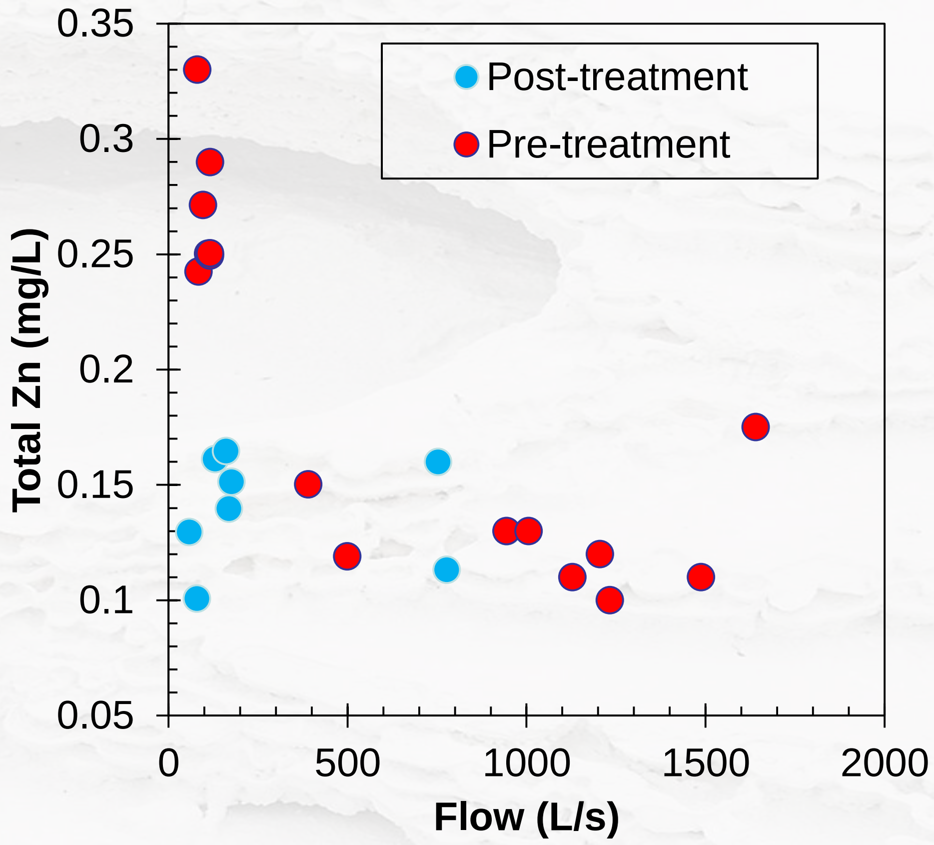


Figure courtesy of Coal Authority

Results - effectiveness of remediation

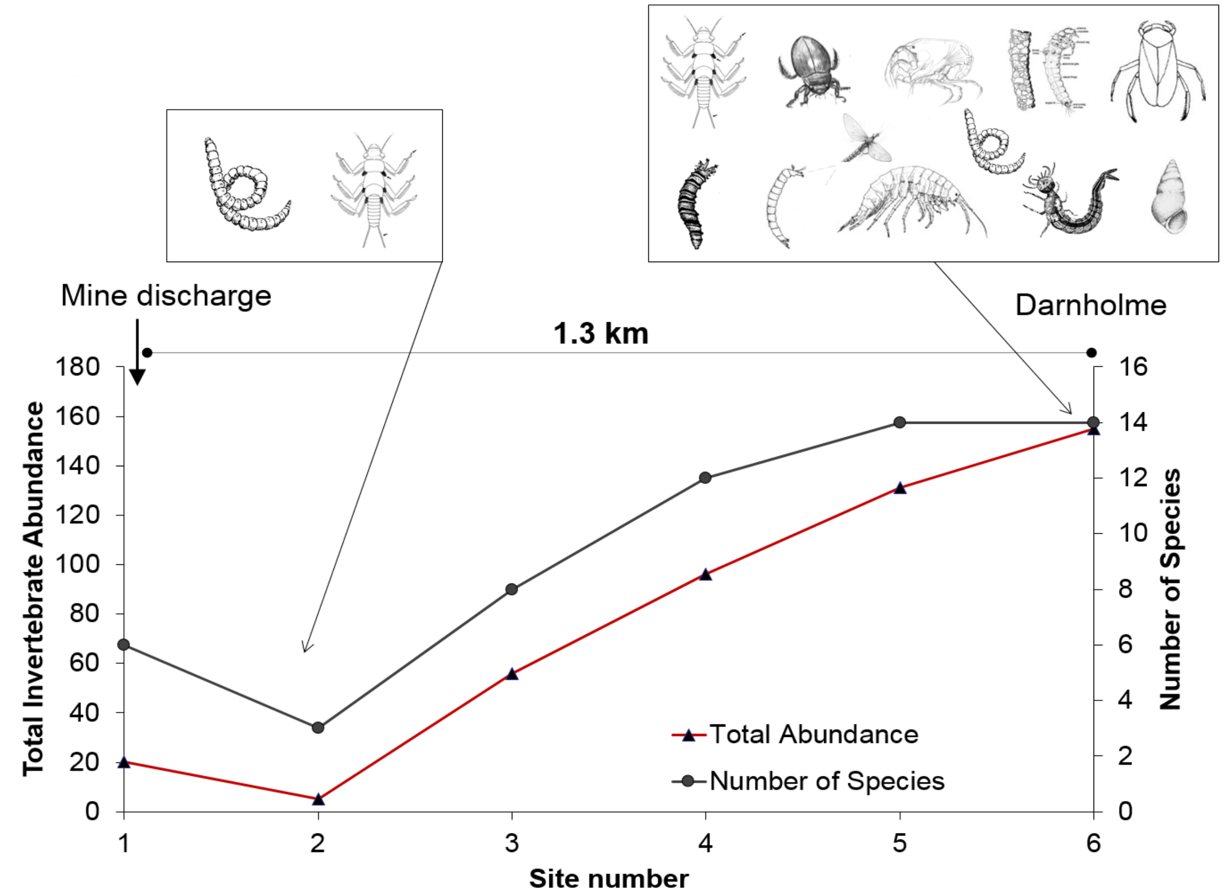
- 97% Zn removed in first 2 years of operation
- Demonstrable baseflow reduction in Zn concentration
- Load reduced from ~2.5kg/d to <1kg/d at Braithwaite



Total Zn concentration at Braithwaite (~5km downstream of Force Crag mine) against flow

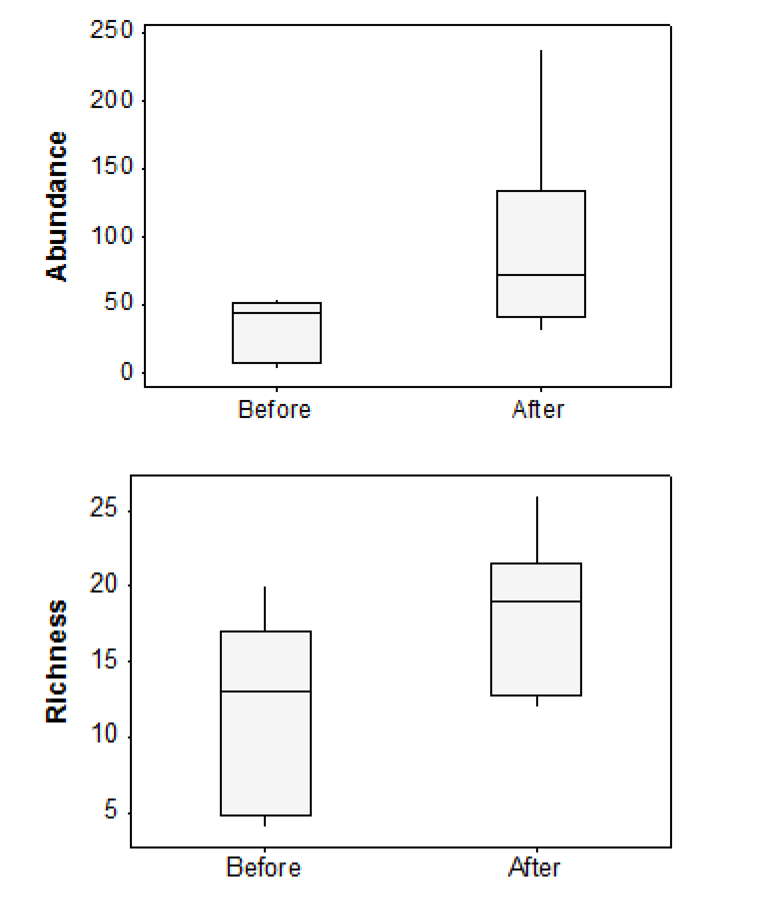
Closer to home – smaller scale partnerships

- Ironstone in the North York Moors: Fe pollution
- Too small to be on Defra / Coal Authority priority lists
- Locally important given modest dilution capacity and sensitive area



Closer to home – smaller scale partnerships

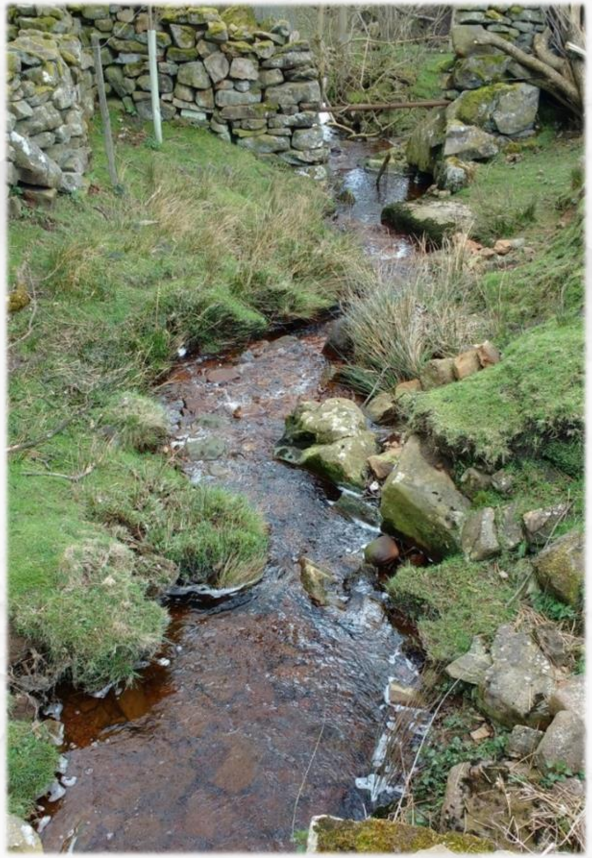
- Partnership approach with EA, NYMNPA, NE, land owners
- Detention ponds / wetlands in former mining features
- Slow flow and encourage Fe settlement



***Left**: Demonstrable improvements in instream macroinvertebrate diversity and abundance downstream of Silhowe mine after settlement ponds / wetland constructed (n = 18 for each)*

Closer to home – smaller scale partnerships

- Two systems in last 3 years (Silhowe and Clitherbeck) cost <£30k
- Evidence to date says potential improvements in status at WB scale
- Maintenance via National Park volunteers network
- Monitoring in part by student projects



*Clitherbeck (nr. Danby) before (Mar 16: **left**) and after (April 16: **right**) construction of wetland ponds at Rose Cottage*

Summary

- Despite the long time since closure, metal mines are a persistent source of aquatic pollution in UK
- Treatment is challenging given liability issues, funding gaps and technical barriers
- Programme of national scale → catchment scale → site remediation
- Large and small scale approaches can be effective depending on catchment-specifics
- Diffuse sources still need addressing

Photo: John Malley

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