The influence and implications of hydrological conditions on metal flux from long-abandoned mining districts of the North of England

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Introduction

- Previous investigations have shown diffuse pollution in abandoned mine watersheds to be a significant source of metals pollution

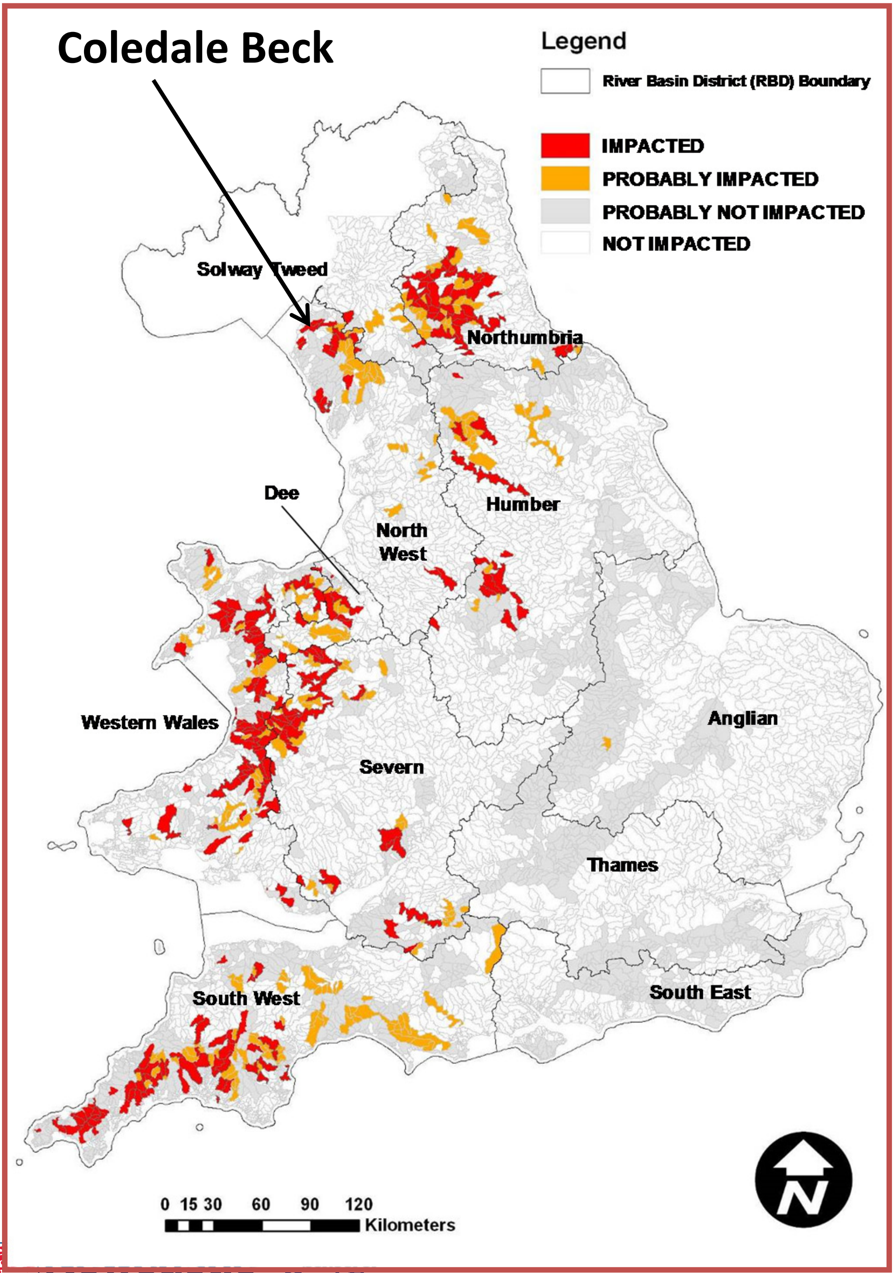
- Quantitatively discerning importance of diffuse pollution necessitates measurements of metal flux of both point sources and in-stream monitoring locations

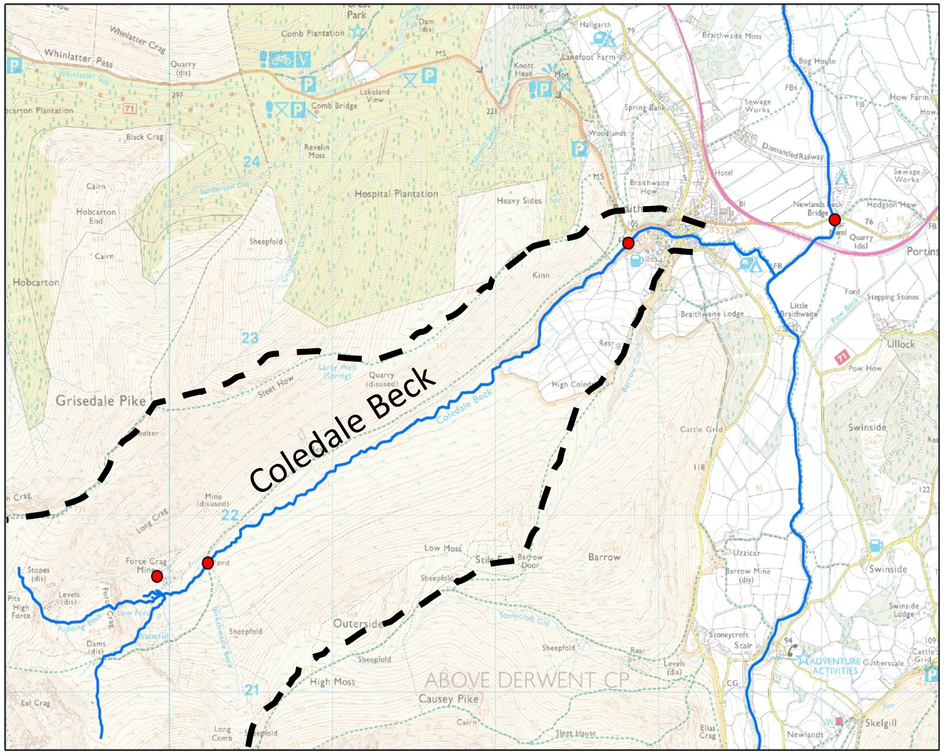
- Necessary to monitor conditions over a range of hydrological conditions to properly understand metal dynamics in abandoned mine watersheds

- Here we discuss such issues for two contrasting watersheds:

  10 km^2 watershed of the Coledale Beck, Cumbria, and the
  3 000 km^2 watershed of the River Tyne, north east England

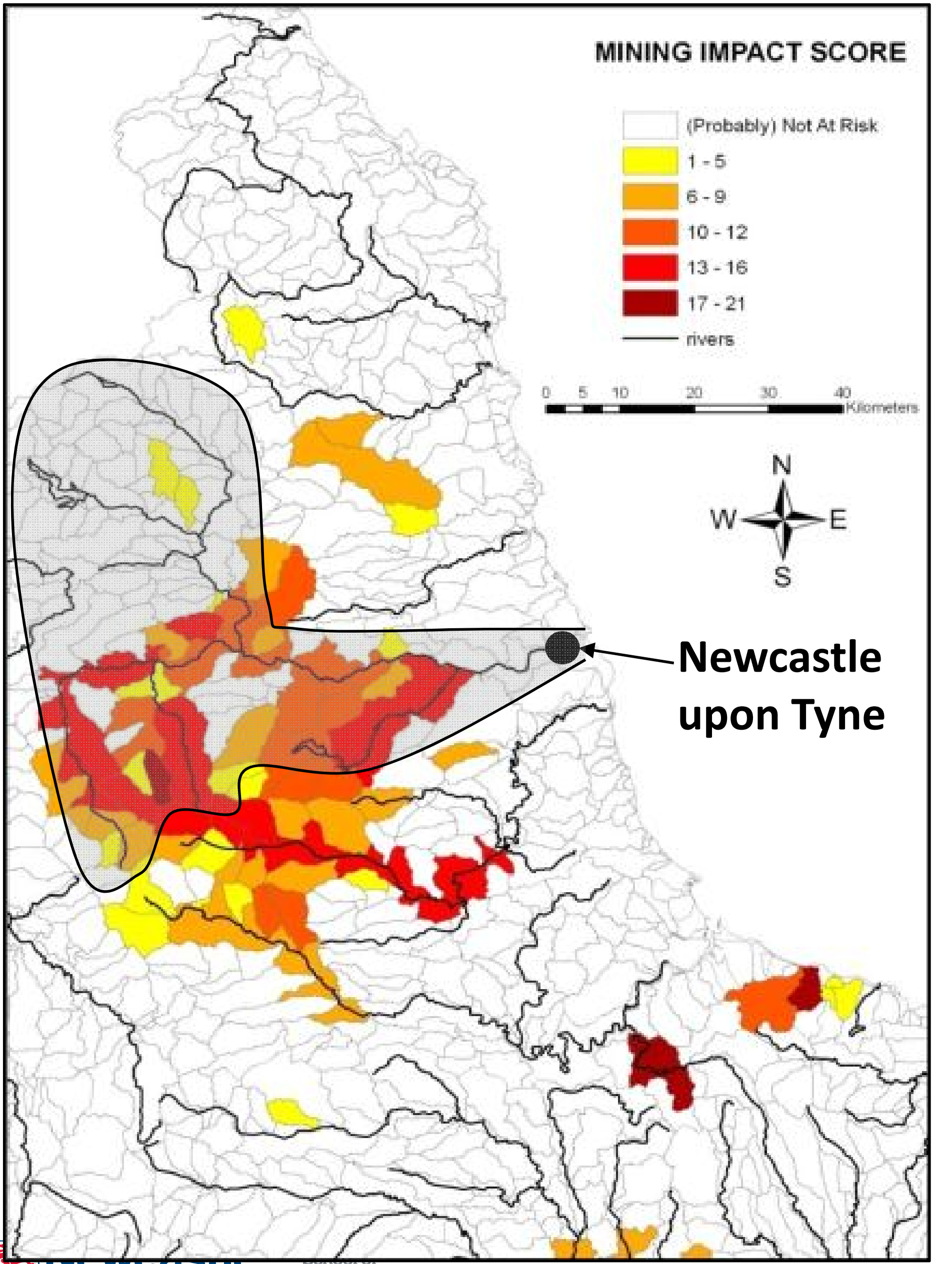
Introduction

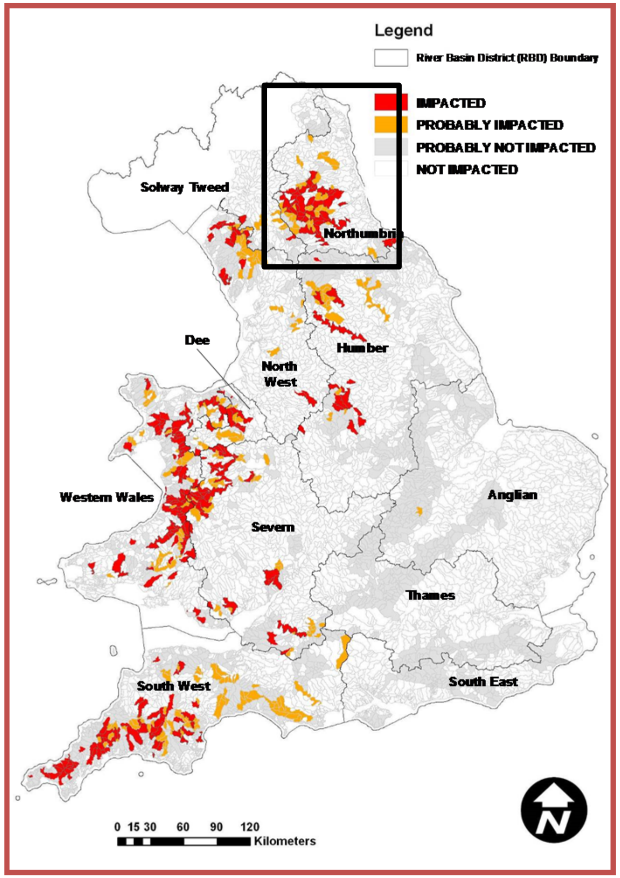




- $10\ \text{km}^2$ upland watershed
- Dynamic stream (550 m asl to 100 m asl in 4 km)
- Single abandoned mine at head of watershed

Introduction



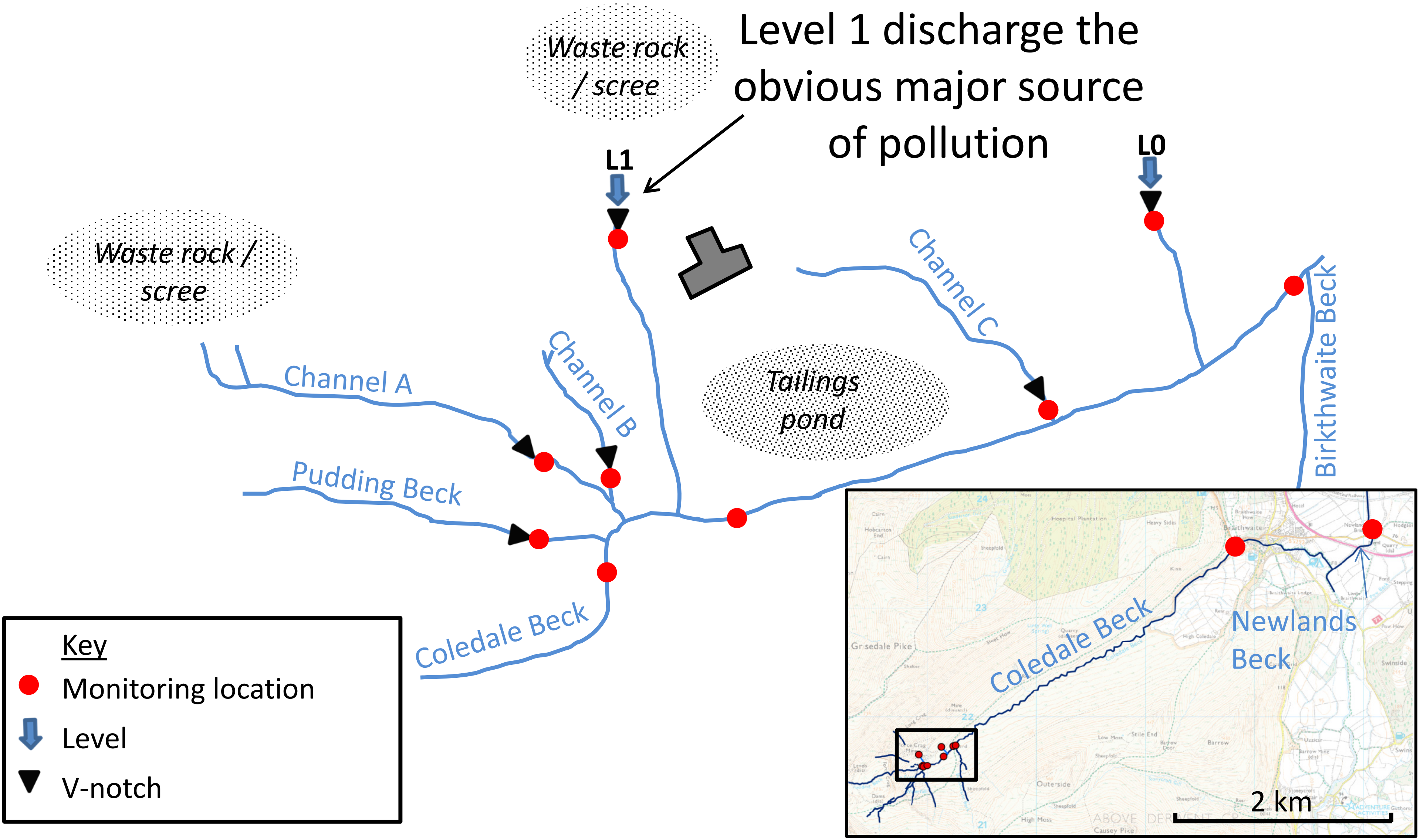


- •3000 km^2 watershed; upland headwaters to estuary ~ 80 km
- •Southern half of watershed heavily mined (Pb, Zn)

Methods

- Synchronous flow and water quality monitoring, at up to 12 locations in any one day, and repeated over a range of hydrological conditions (~ Q5 to Q95)
- Flow measurement:
  - Sharp-crested V-notch weirs in smaller channels
  - Flat V weirs
  - Salt gulp injection (using NaCl) at ungauged locations
  - Environment Agency gauging stations
- Standard methods for field and lab water quality analyses

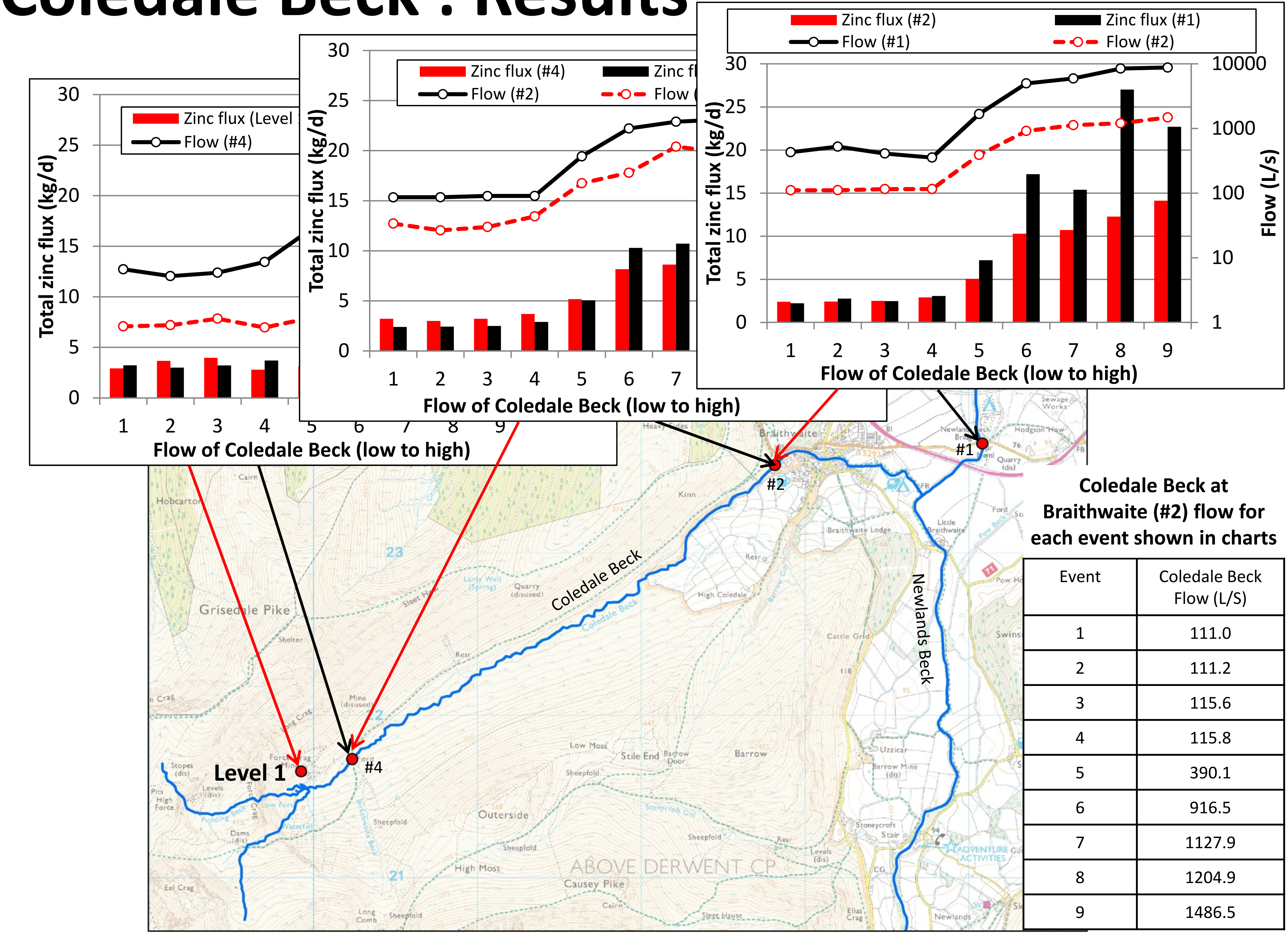
Coledale Beck: Monitoring locations



Level 1 discharge the obvious major source of pollution

Key
- ● Monitoring location
- ⇩ Level
- ▼ V-notch

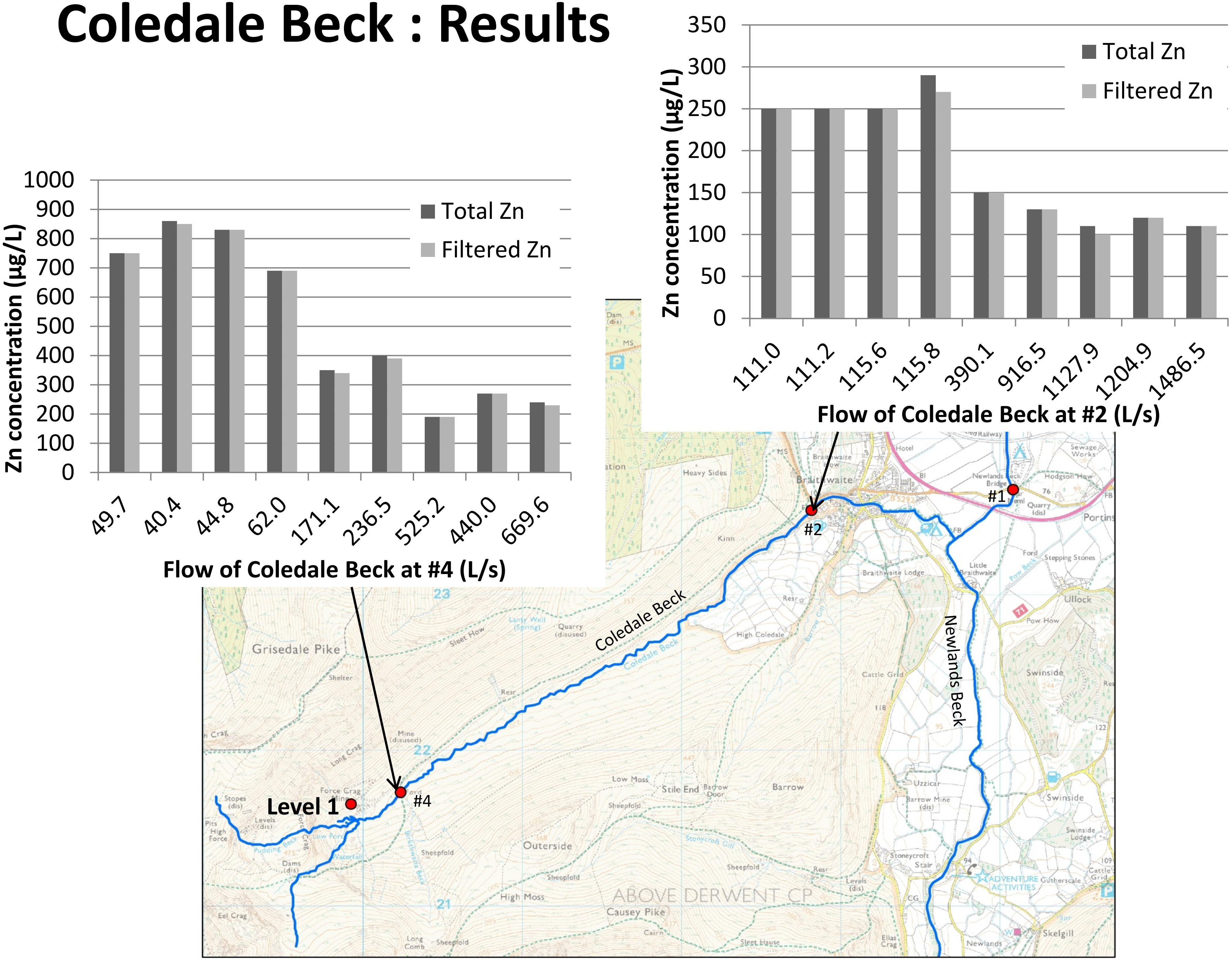
Coledale Beck : Results



Coledale Beck at Braithwaite (#2) flow for each event shown in charts

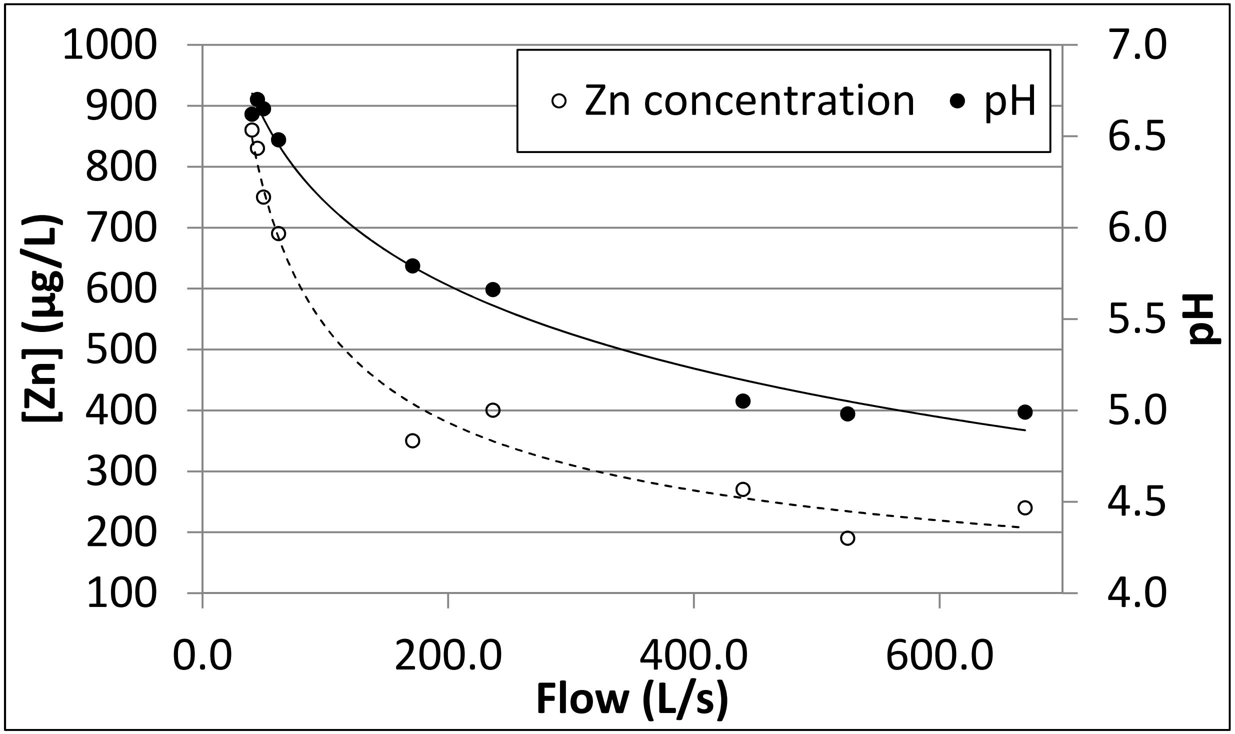
Event	Coledale Beck Flow (L/S)
1	111.0
2	111.2
3	115.6
4	115.8
5	390.1
6	916.5
7	1127.9
8	1204.9
9	1486.5

Coledale Beck : Results



Coledale Beck : Results

- Level 1 discharge by far the most important source of zinc pollution to the Coledale Beck under low flow conditions
- At higher flow conditions diffuse sources become more important
- Candidate diffuse sources include mobilisation of zinc in runoff from waste rock and inflows of Zn-contaminated groundwater
- Remobilisation of zinc associated with stream bed sediment also a possibility



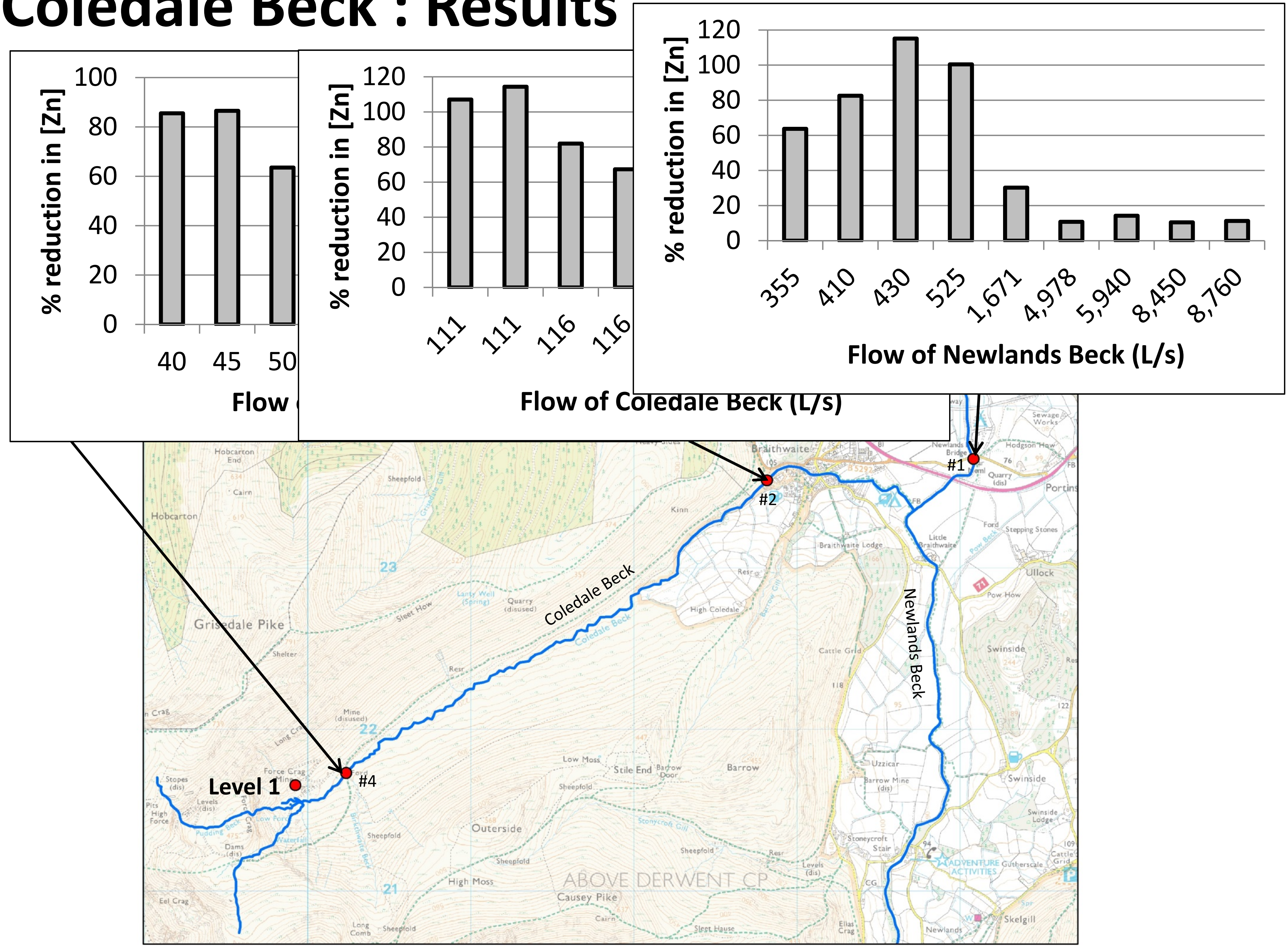
Coledale Beck: Improvements from treatment

- Level 1 discharge is the obvious target for remediation, but clear from Zn flux data that diffuse sources important, especially at higher flows

- Mass balance calculations enable quantitative predictions to be made about reductions in Zn concentration at different locations under different hydrological conditions

- Calculations here assume treatment removes 70% of the zinc (from results of pilot-scale passive treatment investigations)

Coledale Beck : Results



Coledale Beck: Improvements from treatment

- Under low flow conditions treatment is predicted to lower downstream zinc concentration by > 90% in the Coledale Beck

- Under higher flow conditions improvements are much less; approximately 20% reduction in zinc concentration under the highest flow conditions

- Improvements are also less with distance downstream, especially in Newlands Beck, as other sources of zinc contribute to total flux

- Under some circumstances > 100% lowering of zinc concentration is predicted, which is because mass balance calculations use data that indicate attenuation of zinc is occurring under low flow conditions (e.g. sorption to stream bed sediment) i.e. downstream zinc flux < upstream zinc flux

Coledale Beck: Conclusions

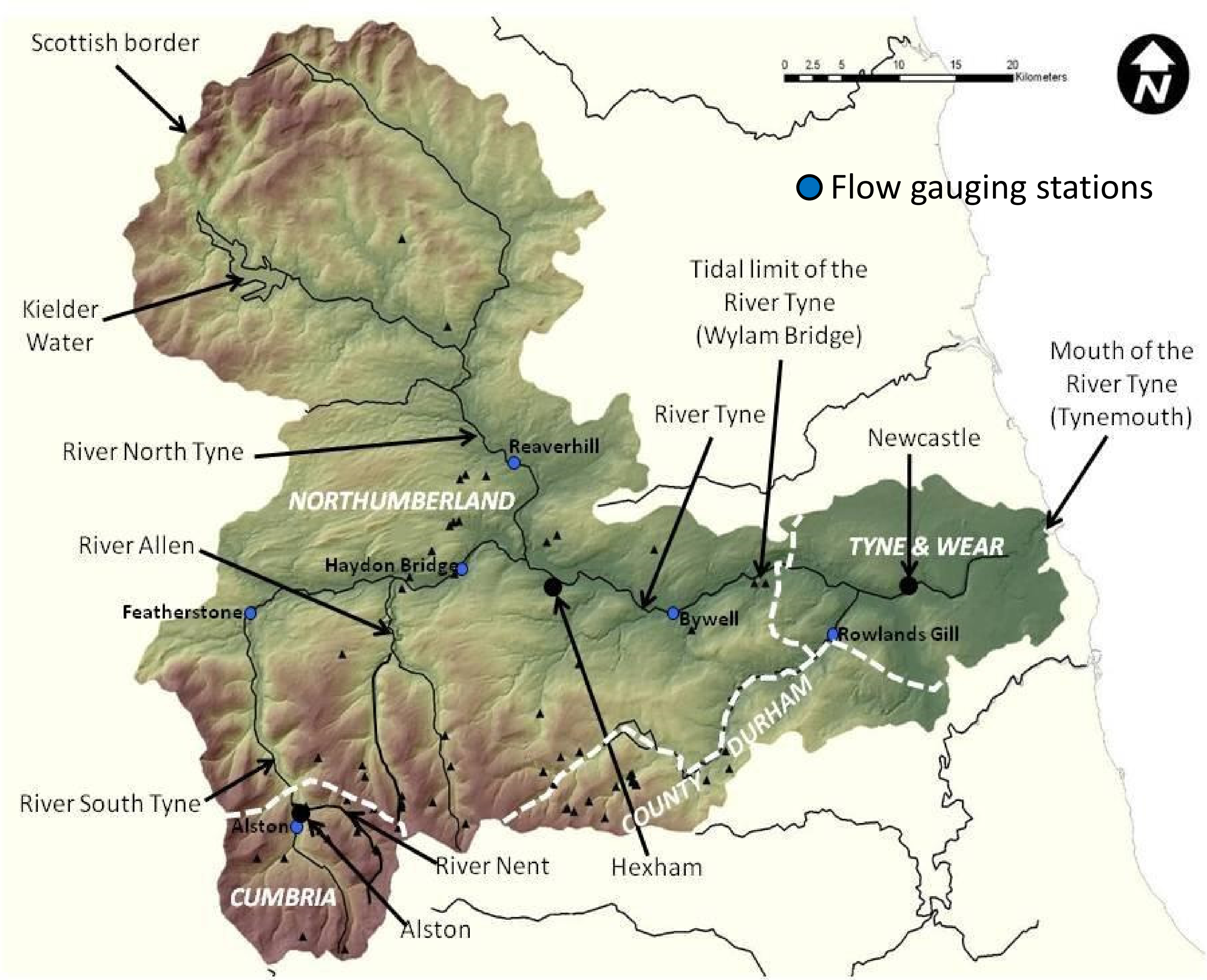
- Diffuse sources of mining pollution are important, especially at higher flows, and may limit benefits of point source treatment

- Quantification of point and diffuse sources requires synchronous monitoring of flow and quality across varying hydrological conditions within a watershed

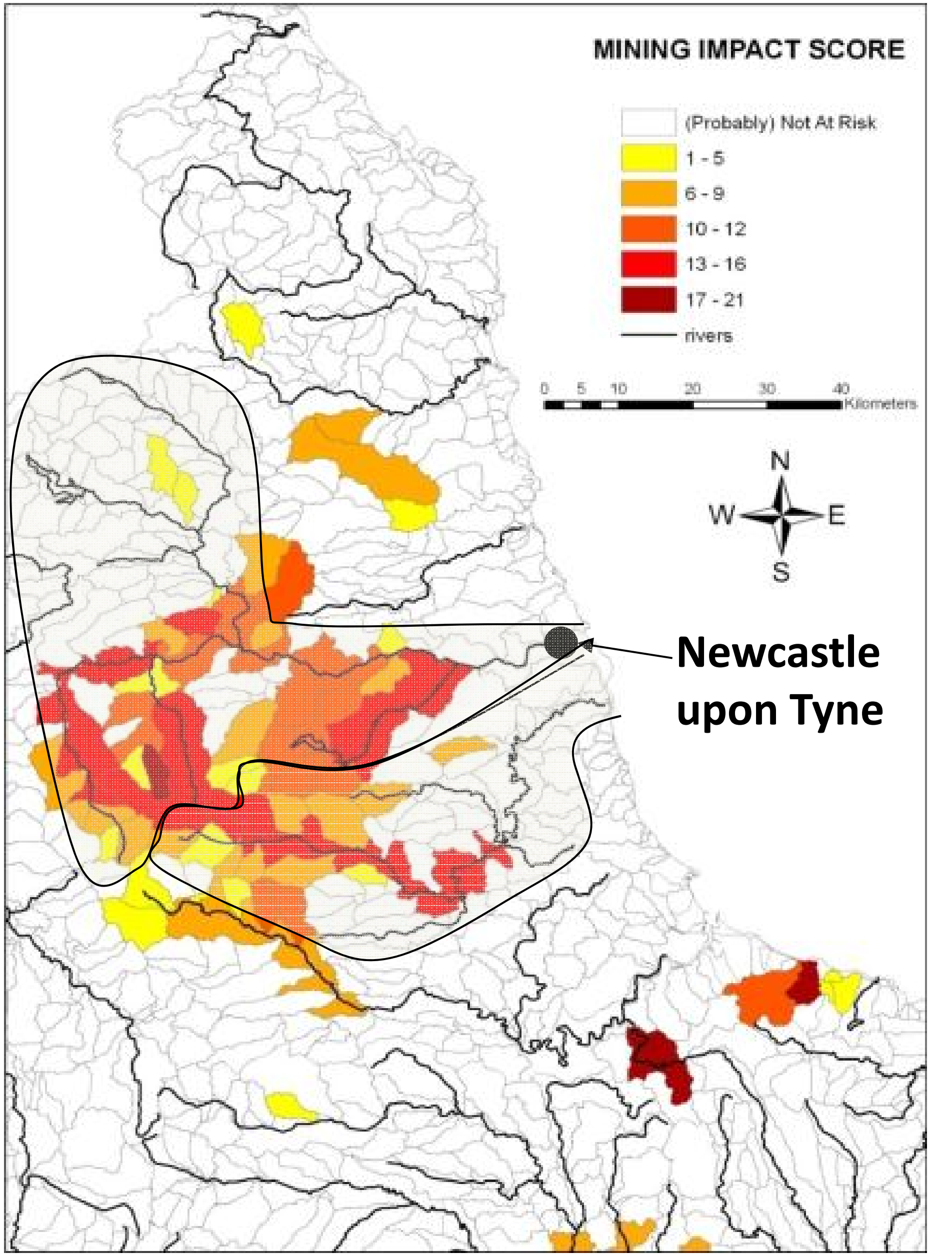
- In the case of the Coledale Beck, using flow-duration curve data it is estimated that treatment of the Level 1 discharge will result in substantial reductions (>50%) in zinc concentration 75% of the time in an average year

- Predictions of improvements accruing from treatment are important for regulator / treatment system constructors, as enables more accurate cost-benefit analysis

River Tyne watershed



Scale of metal mine pollution



Newcastle upon Tyne

- Rivers in North east England at risk due to pollution from abandoned metal mines.

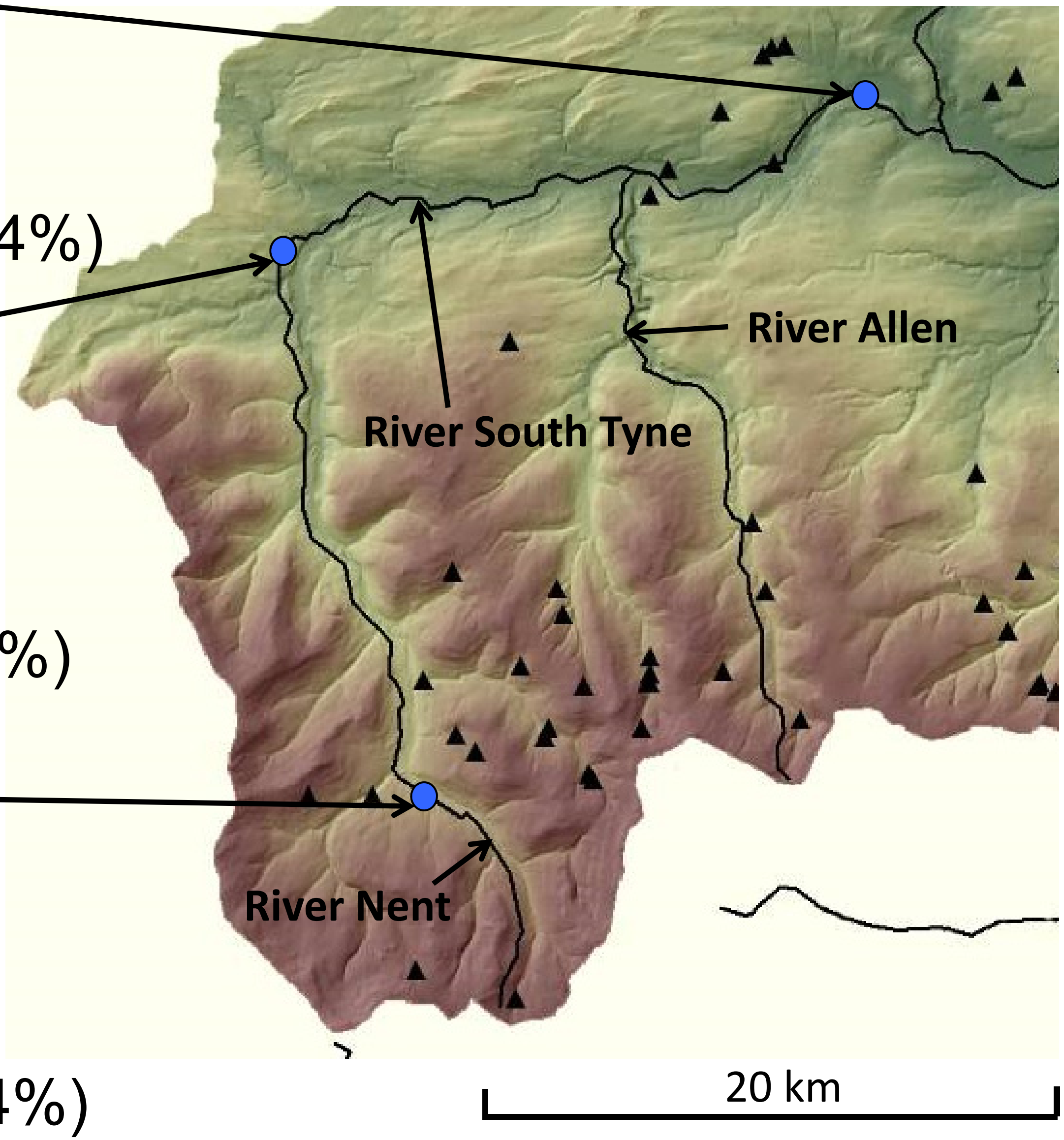
- Entire sub-watersheds and watersheds are impacted

- Pollution predominantly arises from the heavily mined southern portion of the watershed

Diffuse sources

Point sources

Metal flux in River Tyne: *LOW FLOW CONDITIONS*



Haydon Bridge

Flow: 2.45 m^3/s

Total Zn: 8.06 kg/d

Filt. Zn: 6.17 kg/d

Part. Zn: 1.89 kg/d (23.4%)

Featherstone

Flow: 1.10 m^3/s

Total Zn: 10.86 kg/d

Filt. Zn: 10.12 kg/d

Part. Zn: 0.74 kg/d (6.8%)

River Nent

Flow: 0.11 m^3/s

Total Zn: 24.55 kg/d

Filt. Zn: 23.70 kg/d

Part. Zn: 2.05 kg/d (8.4%)

Metal flux in River Tyne: ***LOW FLOW CONDITIONS***

- Point sources of pollution on Rivers Nent and Allen account for majority of Zn pollution
- Substantial attenuation of Zn (sorption to bed sediment?) in River South Tyne
- Majority of Zn present in filterable fraction (though particulate zinc becomes increasingly important with distance downstream)

Metal flux in River Tyne: *HIGH FLOW CONDITIONS*

Haydon Bridge

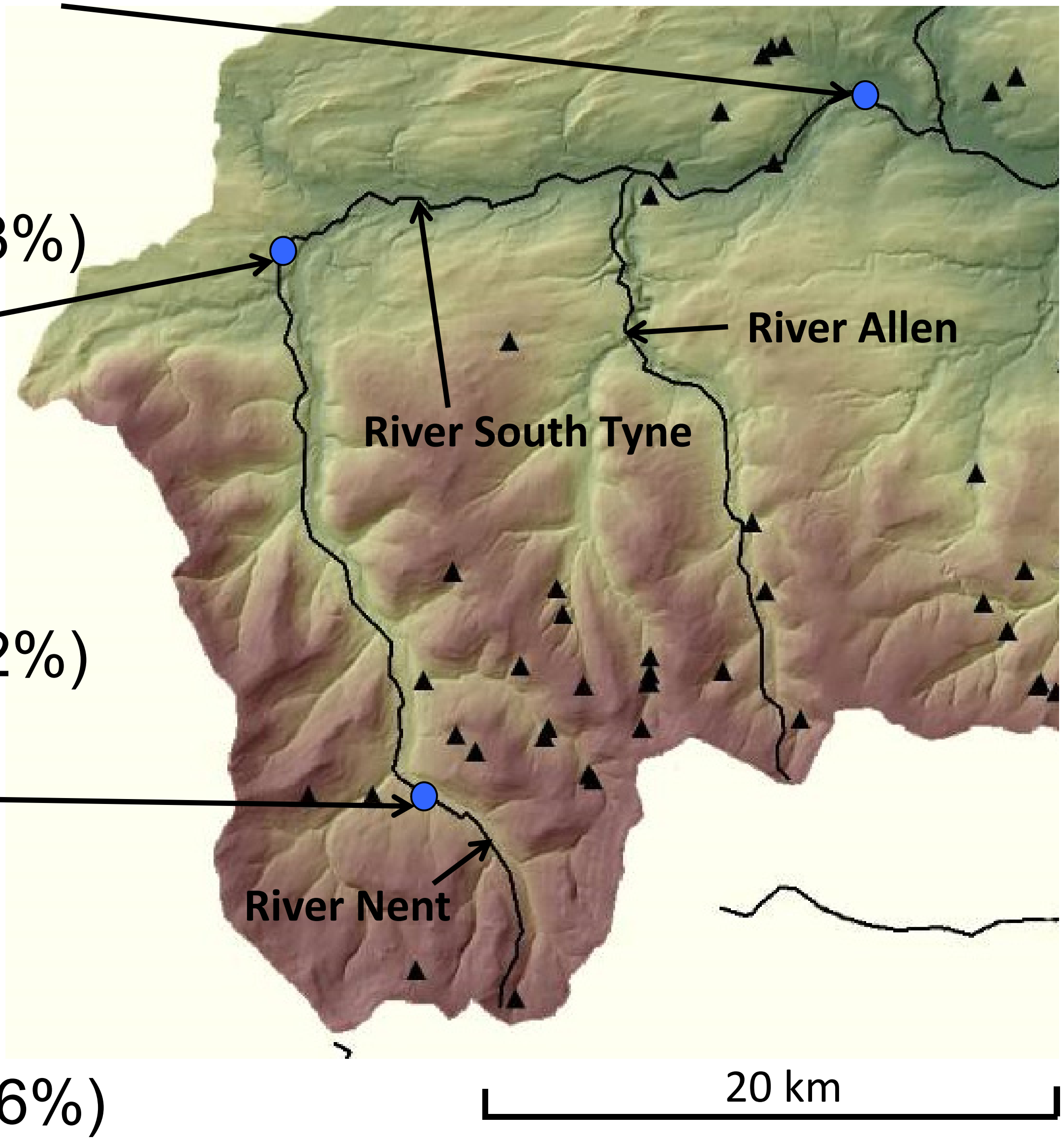
Flow: 53.34 m^3/s
Total Zn: 508 kg/d
Filt. Zn: 364 kg/d
Part. Zn: 144 kg/d (28.3%)

Featherstone

Flow: 29.57 m^3/s
Total Zn: 308 kg/d
Filt. Zn: 252 kg/d
Part. Zn: 56 kg/d (18.2%)

River Nent

Flow: 4.05 m^3/s
Total Zn: 265 kg/d
Filt. Zn: 229 kg/d
Part. Zn: 36 kg/d (13.6%)



Metal flux in River Tyne: ***HIGH FLOW CONDITIONS***

- Zinc flux from River Nent increases 10-fold
- Flux from point sources relatively constant and therefore additional zinc due to diffuse sources
- Substantial increases in zinc flux moving down River South Tyne, due to mobilisation of diffuse sources (contaminated bed and bank sediments)
- Particulate zinc becomes more important with increasing flow and with distance downstream

River Tyne: Conclusions

- Just like Coledale Beck, diffuse sources of mining pollution are important, especially at higher flows

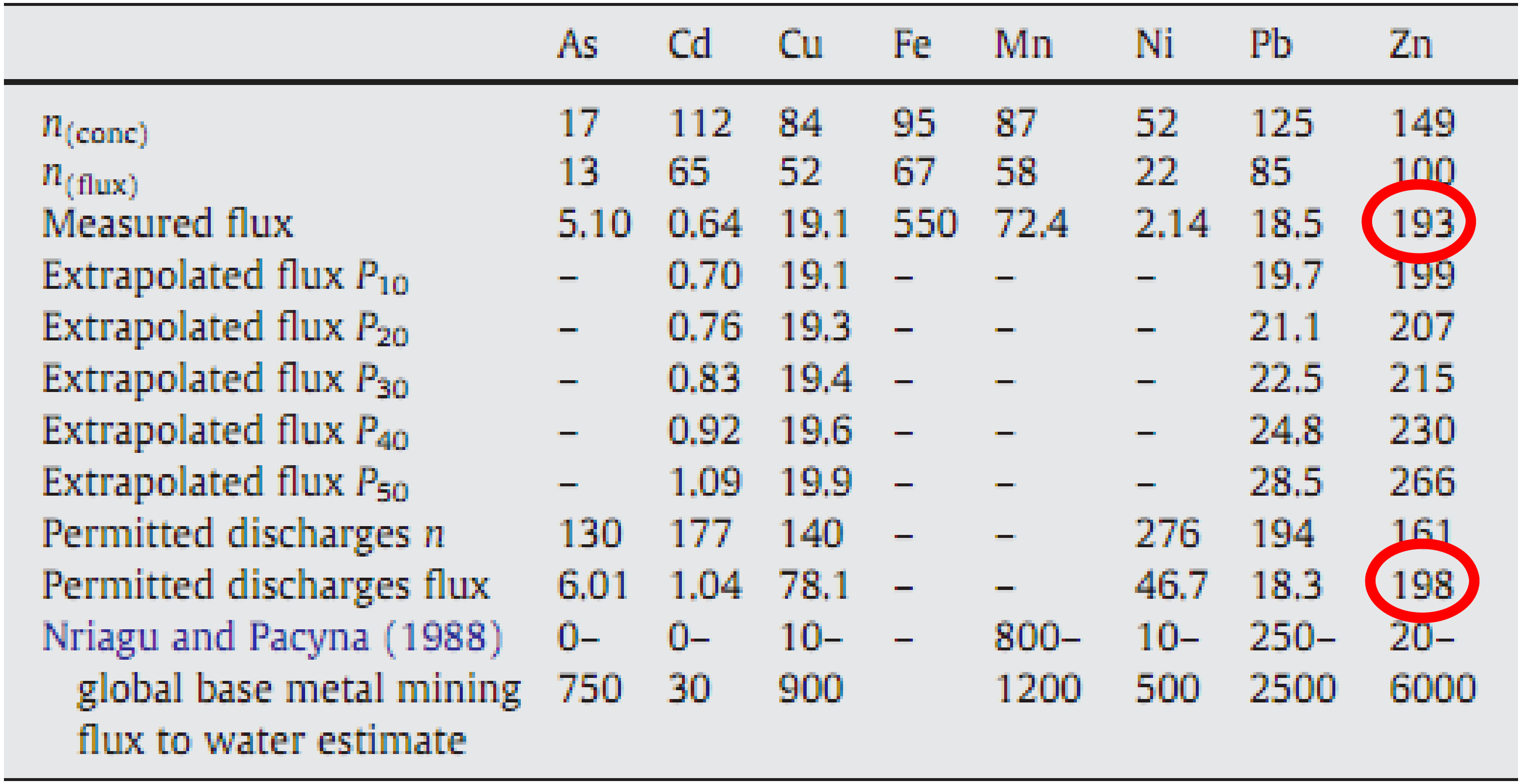
- Unlike upland Coledale Beck, particulate Zn an important component of overall zinc flux – reflects both high flow sources of pollution (fine-grained bed and bank sediments) and geomorphological characteristics (sand and silt bed material)

- Very high zinc flux may put pressure on downstream water uses and river management (exacerbated by future hydrological extremes?)

- Treatment of point sources of zinc pollution on upstream treatment may help reduce overall zinc flux, but will not resolve all issues

- Diffuse source pollution remediation very challenging

Finally – national / international context

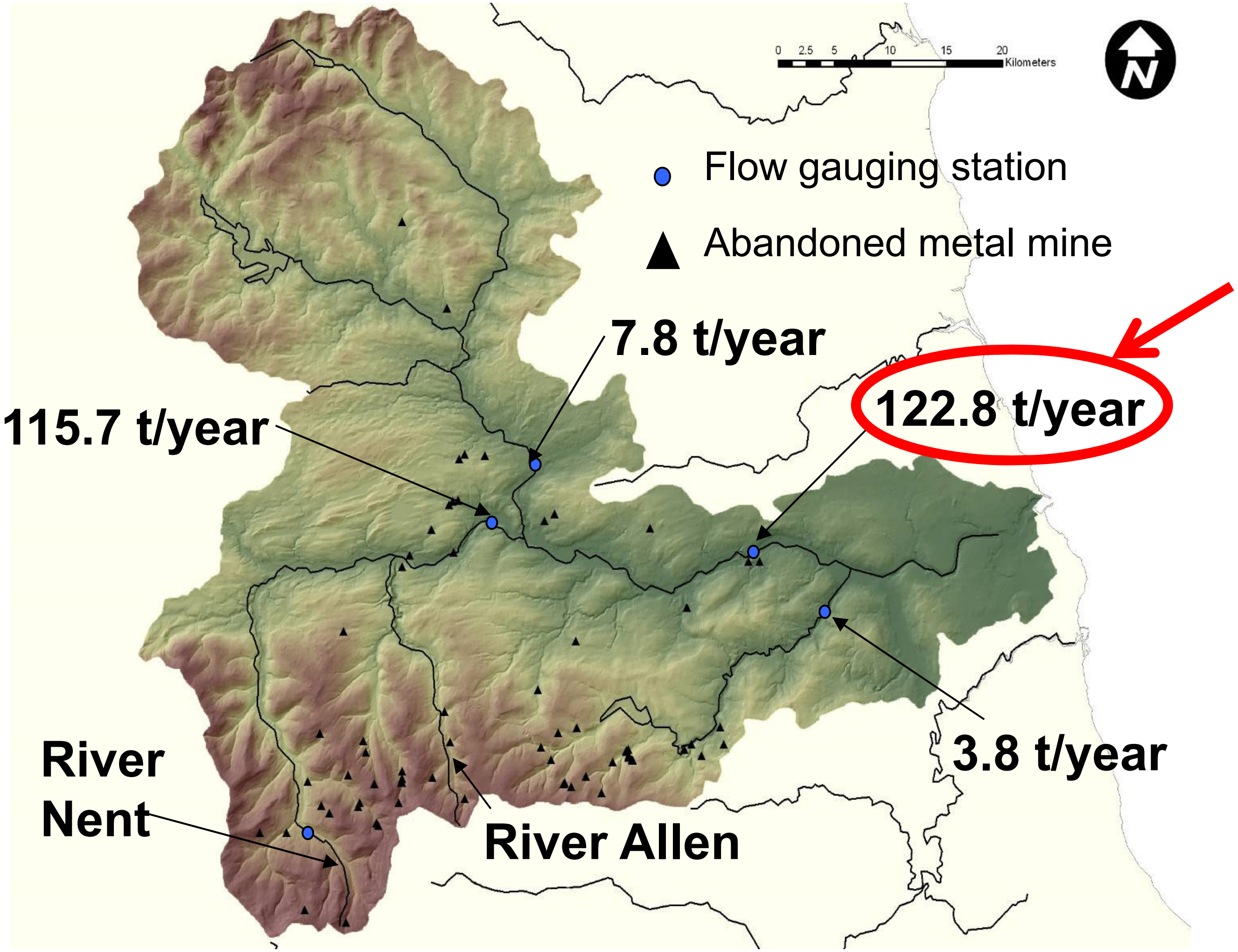


	As	Cd	Cu	Fe	Mn	Ni	Pb	Zn
$n_{(conc)}$	17	112	84	95	87	52	125	149
$n_{(flux)}$	13	65	52	67	58	22	85	100
Measured flux	5.10	0.64	19.1	550	72.4	2.14	18.5	193
Extrapolated flux P_{10}	–	0.70	19.1	–	–	–	19.7	199
Extrapolated flux P_{20}	–	0.76	19.3	–	–	–	21.1	207
Extrapolated flux P_{30}	–	0.83	19.4	–	–	–	22.5	215
Extrapolated flux P_{40}	–	0.92	19.6	–	–	–	24.8	230
Extrapolated flux P_{50}	–	1.09	19.9	–	–	–	28.5	266
Permitted discharges n	130	177	140	–	–	276	194	161
Permitted discharges flux	6.01	1.04	78.1	–	–	46.7	18.3	198
Nriagu and Pacyna (1988) global base metal mining flux to water estimate	0–750	0–30	10–900	–	800–1200	10–500	250–2500	20–6000

Abandoned metal mines are responsible for at least 50% of the total metal flux (tonnes/year) to rivers and streams across England and Wales i.e. at least as much as **<u>all</u>** other permitted discharges put together

Mayes WM, Potter, H.A.B and Jarvis, A.P. (2010) Inventory of aquatic contaminant flux arising from historical metal mining in England and Wales, *Science of the Total Environment*, 408(17),3576-3583

Finally – national / international context



Measured flux from all point source discharges of 193 t/yr, but absolute metal flux from terrestrial to marine environments likely **much** higher

cf. Nriagu and Pacyna (1999) estimate of *global* flux of zinc from base metal mining of 20 – 6000 t/yr??