PROSPECTS FOR EFFECTIVE NATIONAL MANAGEMENT OF ABANDONED METAL MINE WATER POLLUTION IN THE UK

Adam Jarvis[1], Adrian Fox[2], Emma Gozzard[1], Steve Hill[3] Will Mayes[1] and Hugh Potter[4]*
[1]Hydrogeochemical Engineering Research & Outreach (HERO) group, 3rd Floor Devonshire Building, Newcastle University, Newcastle upon Tyne, UK, NE1 7RU
[2]Atkins Ltd, 10 Holliday Street, Birmingham, B1 1TF
[3]The Coal Authority, 200 Lichfield Lane, Berry Hill, Mansfield, Nottinghamshire, UK, NG18 4RG
[4]Environment Agency, address as HERO Group
**Corresponding author: tel: 0044 (0)191 246 4871; e-mail: a.p.jarvis@ncl.ac.uk*

Abstract
This article briefly outlines the estimated scale of water pollution arising from abandoned non-coal mines (particularly metal mines) in the UK (in the order of 200 km of streams and rivers affected), and provides examples of the chemical characteristics of such waters, which are principally polluted with metals such as zinc, copper and iron. Although there is a substantial body of water quality data for some of the worst abandoned mine sites, the overall national picture is piecemeal in terms of our understanding of the impacts of metal mine waters on the UK's watercourses. This is in part because of a limited understanding of the significance of diffuse mine water pollution in river catchments affected by mine water pollution. The advent of the EU Water Framework Directive has re-focused attention on pollution from abandoned non-coal mines, and the UK government has therefore recently commissioned a research project that has the aim of identifying and prioritising non-coal mine sites which have a significant impact on the environment. The methodology that is currently being developed will identify sites that are a priority for remediation or a priority for further data collection, and will take account not only of the chemical and ecological impacts of mine water discharges on receiving watercourses, but also of stakeholder interests, such as conservation and heritage concerns, which experience shows can both impede or compliment efforts to remediate mine sites. It is hoped that the outcomes of the project will be the foundation of a Water Framework Directive programme of measures for effective management of non-coal mine water pollution in the UK.

Introduction
The UK has a very effective national programme of coal mine water management and remediation, spearheaded by the UK Coal Authority, in liaison with the environment regulators in England, Wales and Scotland (the Environment Agency and Scottish Environmental Protection Agency respectively). Johnston et al. (2007) have briefly reviewed the success of this programme. A notable statistic identified by Johnston et al. (2007) is that of the 51 fully operational mine water treatment schemes in the UK all but 2 address discharges from abandoned coal mines. This reflects the fact that whilst the Coal Authority has taken on national responsibility for management of environmental issues associated with abandoned coal mines, no such equivalent body exists for the management of abandoned non-coal mines (principally abandoned metal mines). As the UK moves towards meeting the objectives of the EU Water Framework Directive (WFD), and the Coal Authority continues its rolling programme of remediation initiatives, degradation of water courses due to discharges from abandoned non-coal mines may increasingly become the limiting factor to meeting the objectives of the WFD. This paper therefore examines prospects for effective national management of discharges from abandoned non-coal mines, focusing on some of the particular challenges faced, and on new initiatives aimed at overcoming these problems.

Scale and nature of metal mine water pollution in the UK
Accurate figures for the national extent of pollution arising from abandoned non-coal mines in the UK do not actually exist (and, in any case, such a figure may well vary with season). Early estimates made by the Environment Agency's predecessor, the National Rivers Authority (NRA), suggested that some 200 km of the streams and rivers of England and Wales were impacted by discharges from abandoned metal mines (NRA, 1994), but more recent assessments by the Environment Agency suggest that well over 100 km of streams are affected in Wales alone, and therefore the national figure may be significantly higher than that estimated by the NRA (1994). In terms of absolute number of abandoned mining facilities (e.g. known mine entrances and shafts) Kitts and Smith (1996), in compiling an early database of such features for the National Rivers Authority, identified over 1,300 non-ferrous metal mine sites in Wales alone. Thus, we may conservatively estimate, when the other districts of the UK where extensive metal mining was undertaken are accounted for (in particular Cornwall and the north Pennines), that the total number of abandoned metal mine sites in the UK is likely to

exceed 3,000. Since many of these facilities have been abandoned for hundreds of years (indeed mining on the island of Anglesey, north Wales, dates back to the Bronze Age), records are often incomplete or totally absent.
To our knowledge the metal mine discharges resulting in the severest environmental impact (typically measured in terms of the magnitude and extent of elevated metals concentrations in receiving watercourses) have all been identified, and in some cases have been the subject of detailed study. However in many cases our understanding of the water quality and volume of metal mine discharges, their impact, and how they vary seasonally, is poor. In short, there has not been a concerted, nationally coordinated, programme of sampling and analysis to identify and prioritise non-coal mine water discharges. Such an exercise is now commencing, and this is the subject of further discussion below.
For the sites which are known about, both the water quality and volume of individual discharges vary between sites, but in general terms the key pollutants are zinc, copper and in some cases iron (typically where pyrite is associated with the mineral veins exploited). Some of the worst discharges are also strongly acidic (again, due to oxidative dissolution of pyrite), although low pH discharges are in the minority. Table 1 summarises water quality data for a selection of discharges in England and Wales. The Wheal Jane discharge (now treated using a High Density Sludge plant) was the most severe mine water outbreak ever recorded in the UK. Beyond Wheal Jane, water quality of discharges from the Parys mountain mine complex is probably the poorest in the UK (and these discharges are a major source of zinc to the Irish Sea, despite the modest flow-rate). There are a number of metal mine discharges in mid Wales which are responsible for imparting very significant zinc loads to local rivers, of which the Cwm Ystwyth discharge in Table 1 is one example. Although most of the UK's metal mines are long abandoned, and we may therefore expect 'steady-state' conditions, the discharge at Rookhope, County Durham, is a new discharge, which is believed to have commenced flowing in December 2006 following the collapse of a crown hole into shallow workings below. The remote Cashwell mine, in Cumbria, is an example of a discharge which to our knowledge had not previously been subject to sampling and analysis. The discharge emerges from a distinct mining feature (an old water drift), and therefore might be expected at first glance to be contaminated. However, the data in Table 1 illustrate that in fact the water drift appears simply to be a conduit for the rapid drainage of rain water from the surrounding upland area.

Table 1. Examples of discharge water chemistry for a selection of metal mine sites in the UK.

	Site name				
	Dyffryn Adda adit, Parys Mountain, Anglesey, Wales	Cwm Ystwyth, mid-Wales	Wheal Jane, Cornwall[1]	Rookhope, County Durham[2]	Cashwell mine, Cumbria
Principal metal(s) extracted during working	Copper	Lead / Zinc	Tin	Lead / iron carbonate	Lead / Silver
Indicative flow (L/s)	2 – 15	8	300	80	50
pH	3.00		4.39	6.56	7.28
Conductivity (µS/cm)				837	130
Alkalinity (mg/L as $CaCO_3$)	0		0	119	50
Ca (mg/L)		22.3	105	124	19.3
Mg (mg/L)		7.0	17.7	23	2.3
Na (mg/L)		5.8	88.5	10.3	2.4
K (mg/L)		< 1.0	14.1	10.3	1.3
Fe (mg/L)	600	0.8	173.5	4.98	< 0.1
Zn (mg/L)	57.5	20.2	42.0	3.53	0.1
Pb (mg/L)	0.2	0.4	0.08	< 0.2	< 0.2
Cu (mg/L)	37.5		0.14		
SO_4 (mg/L)	2480	91	1123	304	6
Cl (mg/L)		7	262	14.8	5

[1]Data from Neal et al. (2005)
[2]Source of this new outburst not certain, but thought to be the former Rispey lead mine, which was latterly worked extensively for iron carbonate

Whilst some discharges, such as Wheal Jane and Parys Mountain, are well characterised (principally due to their severity and visual impact), important questions remain about the source and nature of many other discharges, and it is for this reason that some of the examples above have been chosen:

- the Rookhope example is a case where we are currently unclear as to the source of the water, which is important information if remediation is to be considered.

- although the discharge at the Cwm Ystwyth mine shown in Table 1 is well characterised in terms of water quality, wider investigations have revealed that the total zinc load in the river to which this mine water discharges is nearly double that which can be apportioned to this point source of contamination, which poses questions about the source(s) of additional zinc.

Diffuse mine water pollution appears to be important (though not yet proven) at Cwm Ystwyth. In other heavily mined catchments of the UK diffuse sources of mine water pollution have been identified as being quantifiably significant. These authors have conducted long-running investigations of the River West Allen, in Northumberland, demonstrating that diffuse sources of pollution may account for 50 – 95% of the total zinc load to the river depending on flow conditions, as illustrated in Table 2 (see Mayes et al., 2006 for further details). Diffuse mine water pollution may therefore be an important contributor to the overall contaminant loads of mining-impacted river catchments, confounding efforts to quantify the overall scale of the problem.

Although collectively there is a fairly substantial body of data on UK metal mine water characteristics (largely due to the efforts of the Environment Agency and research institutions), what these examples illustrate is that on a national scale our understanding of the nature and impacts of non-coal mine water discharges is nevertheless rather piecemeal at present. Individual studies have facilitated characterisation of particular discharges or river catchments, but major gaps remain, and where data are available it has not been collected within the framework of a national programme, and therefore the results of individual investigations are not necessarily comparable (for example in terms of objectively assessing comparative impacts on receiving watercourses). The WFD necessitates EU member states to implement 'programmes of measures' for addressing water quality problems such as those arising from abandoned mine facilities. However, in order to prepare an effective, scientifically-based, programme of measures for addressing non-coal mine water management it is necessary to understand the issues at a national scale, such that future remediation initiatives can be appropriately, and cost-effectively, targeted. The following section of this paper outlines a new initiative which has the aim of accomplishing exactly that.

Table 2. Evidence of diffuse mine water pollution in the River West Allen, Northumberland; the total zinc load in the river cannot be accounted for by the point sources of pollution (adapted from Mayes et al., 2006).

Distance downstream (km)	Zinc concentration (mg/L)	Cumulative zinc load due to point discharges (kg/d)	Total zinc load in the river (kg/d)
0.62	0.14	1.2	1.2
2.25	0.18	1.2	20.6
4.41	0.50	11.4	83.1
7.21	0.50	11.4	129.7
10.89	0.28	11.4	125.7

Identification and prioritisation of non-coal mines

At the beginning of 2007 the UK government's Department for Environment, Food and Rural Affairs (Defra) commissioned a 2 year research project with the aim of identifying and prioritising non-coal mine sites in England and Wales (we already know that the vast majority of these 'non-coal' mines are in fact metal mines). The project is being led by Newcastle University, in partnership with the UK Coal Authority and Atkins Ltd, under the management of Defra and the Environment Agency.

The specific aim of this project will be to develop a methodology that will facilitate the identification and prioritisation (in terms of environmental impact and/or risk of environmental impact) of abandoned non-coal mine sites (and especially discharges to the environment from them). At this stage the methodology is still under development. Such an identification and prioritisation exercise was conducted for abandoned coal mine water discharges in the UK in the early 1990s (see Jarvis and Younger, 2000 for a critical review). However, this necessitated extensive chemical and biological monitoring to quantify impacts, and whilst the new methodology may draw on that approach, it is unlikely to necessitate such a high level of detailed monitoring. Rather, the methodology will largely draw on existing data (where available) to enable a broad categorisation of sites (e.g. high, medium and low priority) in order to guide future detailed monitoring work and remediation planning. Such a categorisation, based on impact and probability (of impact), has served the UK Coal Authority well in its rolling programme of remediation initiatives, and this is recreated as the 2-dimensional model in the foreground of Figure 1. However, it has already been noted above that there is only limited information about many non-coal mine sites in the UK, and therefore the conceptual model for the prioritisation takes on a third dimension, which we refer to as 'confidence' (in data quality / feasibility of remediation). In cases where confidence is low the priority becomes data collection, rather than remediation planning (the former must precede the latter in any case), particularly where local knowledge suggests that the potential of a high impact from these poorly characterised sites is perceived to be high (e.g. in environmentally sensitive areas). Given this, it is already clear that the methodology will need to evolve beyond the 2 year timeframe of the project, and therefore the database that will be developed as part of the methodology will allow insertion of new data as it becomes available, thus allowing amendments to the prioritisation of non-coal mine sites across the UK.

Experience in the UK, and particularly that of the Coal Authority, suggests that other factors, beyond the chemical and ecological impacts arising from mine water discharges, influence which sites should be prioritised for further data collection and/or remediation. Many former mine sites, and particularly abandoned metal mine facilities, are rightly regarded as important features of the UK's industrial heritage. An especially notable example of this is the recent designation of the Cornish mining district as a World Heritage Site. In addition, at some sites the particular chemistry of mine waters has resulted in the development of unique aquatic flora and fauna, which in some cases have consequently received special conservation status. These issues, together with physical constraints such as access and steep topography, may conflict with, or impede, planning for remediation of polluted mine waters. In its assessment of metal mine waters in Wales the Environment Agency (2002) has therefore made a distinction between sites at which there are 'converging' and 'diverging' issues i.e. between sites at which mine water treatment and maintenance of conservation / heritage value are complimentary (converging), and those sites at which mine water treatment might adversely effect a conservation or heritage designation (diverging). These are important issues in the overall analysis of mine water pollution remediation costs and benefits, and therefore will also be accounted for in the methodology currently being developed for prioritisation of non-coal mine waters in the UK.

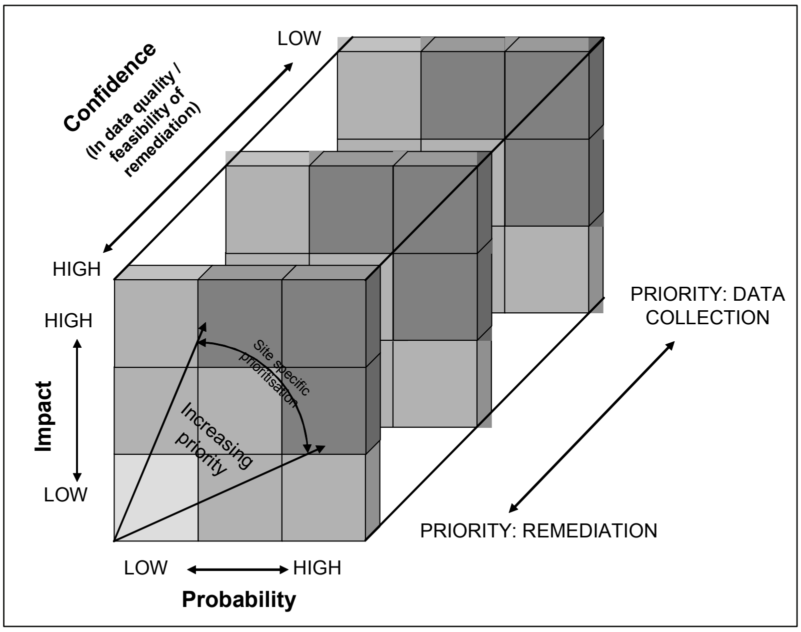

Figure 1. Conceptual model for prioritisation of non-coal mine environmental impacts in the UK.

Conclusions

The UK has a very successful record of mine water management, the most obvious evidence of which is more than 50 full scale mine water treatment plants. However, to date non-coal mine sites, in particular abandoned metal mines, have received only limited attention in terms of remediation. The introduction of the EU Water Framework Directive has necessitated a new focus on non-coal mine sites, which may increasingly become the limiting factor to meeting the objectives of the WFD. The exact scale of pollution arising from non-coal mines is poorly quantified, albeit there is a substantial body of data for some sites. There is also strong evidence to suggest that a significant proportion of pollution from metal mine sites may in fact be from diffuse sources, compounding the difficulties of management of river catchments in which mining was formerly an important industry.

In order to address non-coal mine water pollution in a more concerted manner, at a national scale, the UK government's Department for Environment, Food and Rural Affairs (Defra) has recently commissioned a research project to develop a methodology for identification and prioritisation of such sites. Although still in development, the methodology is likely to utilise existing data to prioritise non-coal mine sites for remediation where possible, but also to identify sites where further data collection is a priority. An important aspect of this exercise will be to account not only for the water quality and ecological impacts of mine water pollution, but also to evaluate priorities in terms of other stakeholder concerns (e.g. conservation designations, industrial heritage), which may conflict with, or compliment, plans for water quality improvements. It is hoped that the new methodology will be a significant aid to the development of a WFD programme of measures for addressing mine water pollution in the UK.

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Disclaimer

The views expressed in this article are those of the authors alone, and do not necessarily represent those of the Defra, Environment Agency, Coal Authority, or any other organisation mentioned herein.

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