Mine water outbreak and stability risks: examples and challenges from England and Wales

William M. Mayes[1], Adam P. Jarvis[2]

[1] *Centre for Environmental and Marine Sciences, University of Hull, UK, w.mayes@hull.ac.uk*
[2] *School of Civil Engineering and Geosciences, Newcastle University, UK. Adam.jarvis@ncl.ac.uk*

Abstract

Although their frequency of occurrence is rare, the sudden outbreak of mine water from abandoned mines, or collapse of waste rock stores can be environmentally significant and represent significant post-closure legacies. This paper reports on a national survey of abandoned non-coal mine sites where concerns over mine water outbreak or stability are apparent across England and Wales. A range of respondents across environmental regulators and local authorities were consulted to populate a geodatabase. Outbreak risk was highlighted as a documented or suspected concern at 19 mine sites. Typical issues were related to adit blockages and associated perched mine water alongside issues of sudden ingress of surface waters into mines under high flow conditions. The majority of the responses concerning stability issues (72 sites in total) were related to fluvial erosion of riparian waste rock heaps. While successful management of such issues is highlighted in some cases, these are generally isolated examples. In both cases, the fact that stability or outbreak issues are often caused or exacerbated by extreme rainfall events highlights a potential future management issue with the predicted effects of climate change in north west Europe.

Key words: Mine water, outbreak, hazards, hydrology, climate change

Introduction

Hazards associated with the sudden, abrupt release of mine water and stability concerns associated with waste rock heaps are common at many abandoned mine sites. Some of the most notorious mine-related pollution events are those where sudden, catastrophic failure of mine structures or waste storage facilities have occurred (e.g. Aznalcóllar, Spain; Wheal Jane, UK: Hudson-Edwards 2016; Younger 2002) and released contaminants into surrounding water systems. Such events often prompt great media attention and require significant, ongoing management, as was typified in the case with the Wheal Jane mine water outburst in southwest England in 1996 (Younger 2002). Given both mine water outbreak and collapse of waste rock heaps can be caused, or exacerbated by multi-day rainfall events (Rico et al. 2008), their frequency of occurrence may be anticipated to increase with the predicted effects of climate change in north west Europe (Hannaford 2015). As such, information on the nature of such potential hazards and the conditions surrounding previous episodes are important for forumulating robust management strategies that can minimise future risks. Inventories of mining wastes have been collected across Europe in recent years as part of reporting requirements of the Mining Waste Directive (European Commission 2006) which should help in that regard. This paper provides a review of occurences of mine water outbreak and stability issues at abandoned non-coal mines in England and Wales.

Methods

This paper reports on part of a national non-coal mine water management initiative in England and Wales (see Mayes et al. 2009 and Jarvis and Mayes 2012 for further details). A national database of catchments affected by non-coal mine pollution, discharge composition and hazards associated with abandoned non-coal mines was collated via an online data response platform. This database was populated by regional experts in the regulatory bodies (Environment Agency, Natural Resources Wales) and local government contaminated land management teams. A total of 99 local authorities responded alongside regulators in the seven River Basin Districts of England and Wales affected by former non-

coal mining (Figure 1). The responses requested from local authorities and regulators concerned two key questions: (a) were they aware of any previous or potential mine water outbreak risks in their area / region?, and (b) were they aware of previous or potential stability issues associated with abandoned non-coal mines in their area / region? Respondents were asked to populate responses for the outbreak and stability risk category for individual mine sites. A Yes-Suspected-No dropdown menu provided a simple means for data sorting (null responses are deemed to be unknown), while an adjacent open text field for each question which permitted end-users to provide technical details, case studies and / or data sources.

Results and Discussion

General response and limitations

Specific details about mine water outbreak risk were highlighted at 19 mine sites scross England and Wales while stability concerns associated with waste rock heaps and tailings were documented at over 72 sites (Figure 1). However, as with any survey exercise relying on data return from multiple respondents, the data must be viewed with a degree of caution in terms of completeness and accuracy. For example, of the 387 local authorities approached, responses were received from 99 County, District and Borough Councils, with 26 noting the presence of abandoned non-coal mines within their boundary. Additionally, some of the data show clearly erroneous patterns. For example, the Environment Agency data return for the Severn River Basin District (Welsh-England border) included a number of "Suspected" or "Yes" responses to outbreak risk, which on closer reflection appear to reflect only sites where there currently is a mine water discharge – as opposed to sites where there is a risk of a sudden outbreak. As such, all data returns were reviewed as the database developed with erroneous responses removed.

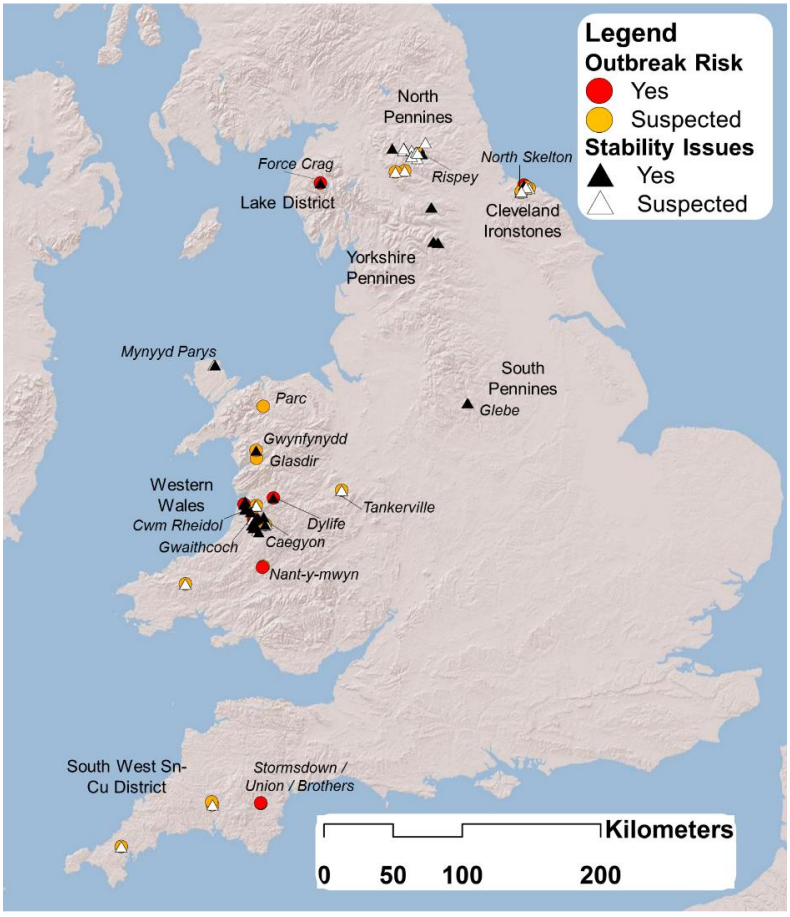

Figure 1. *Non-coal mine sites with reported risk of mine water outbreak and stability issues across England and Wales.*

Mine water outbreak risk

Table 1 summarises some of the outbreak risks identified by the respondents. Typical issues highlighted include flooded shafts with water at higher elevations than recipient water courses and drainage adits (e.g. Force Crag, Cumbria; Cwm Rheidol, Dylife, Nant y Mwyn, all Western Wales), underground blockages (e.g. Glasdir, Gwaithcoch, Parc all in Western Wales), previous history of outbreak in the area and other evidence of instability in shallow workings which could create conditions conducive to breakout. At two sites (Nant y Mwyn and Caegynon, both in Western Wales) issues of upwelling under high flow are explicitly mentioned. At sites with history of outbreak in the south-west of England, the Stormsdown, Union and Brothers mines can be viewed together as they all drain into a tributary of the River Lemon and were subject to a sudden outbreak in 2004 after a suspected mine collapse.

The Rispey site in the Rookhope Burn (northern England) is also mentioned as a site with history of outbreak. The metal mines of the North Pennines have experienced several incidences of recent mine water outbreak which usually follow extreme rainfall events. The Rispey outbreak occurred in December 2006 and was considered to be due to obstruction of the adjacent (and hitherto flowing) Tailrace Level discharge. This forced the collapse of a nearby crown hole from which the discharge newly emerged to the Rookhope Burn. Another comparable incident occurred nearby at Rookhope in April 2005. Following 98.5mm of rainfall in 48 hours (which equates roughly to a 1 in 5 year recurrence interval in that region) and subsequent increase in river flows, former mine workings under the Rookhope Burn collapsed. Large volumes of water subsequently leaked through the workings and emerged from another entry point to the mine on the Boltsburn Old West Level. Diversionary river works were necessary to limit the flow of water into the workings. These incidences are fairly typical in karstified (fissured) and heavily mined terrain such as that found in the Carboniferous limestones of the North Pennines, where workings are susceptible to rapid ingress of waters in high flow which can contribute to conditions conducive to breakout (Gozzard et al. 2011). The former include flooded shafts with water perched at higher elevations than recipient water courses and drainage adits, underground blockages, previous history of outbreak in the area and other evidence of instability in shallow workings which could create conditions conducive to breakout.

The hazards and risks associated with potential outbreak from abandoned non-coal mines depend on numerous factors including:

1. the presence of any infrastructure in the immediate vicinity of the outbreak (e.g. roads, paths, buildings)
2. the time the outbreak occurs (in terms of human activity: e.g. on roads / footpaths)
3. the volume and quality of mine water released
4. the size of the recipient water course(s) and flow rate at time of outbreak (dilution capacity)
5. the presence of potentially sensitive ecological communities in downstream surface waters.

In terms of the risk of occurrence of outbreaks in the future, it is not possible to rule out the possibility of such events occurring, particularly at those sites identified in Table 1. Those sites at which there is an observed head of water above a potential discharge point (e.g. Force Crag, Dylife) probably present the highest risk, and should therefore be priorities for intervention. Indeed, in the case of Force Crag, recent investigative works suggested relieving the mine water build-up via temporary pumping of water from the lowest mine level via a new borehole, to then allow drilling of a new replacement adit entrance which would permit long term gravity-driven drainage of the mine.

In general terms, it is however worth noting numerous factors that are likely to minimise the potential impacts of mine water outbreak at non-coal mines in England and Wales. In most cases, the mines are located in sparsely populated upland areas away from centres of population and major trunk infrastructure. In many of the upland mining settings (e.g. North Pennines, Western Wales) previous outbreaks have occurred following intense rainfall events (e.g. Rispey, Boltsburn Level in Rookhope Burn), or conditions conducive to breakout have been reported under high flow (e.g. Nant-y-Mwyn, Caegynon). As such, outbreaks have tended to occur at times when the dilution capacity of recipient streams is very high due to high flow rates, therefore limiting the measurable short-term water quality impacts. However, the long term residual pollution can be worse than pre-existing states (due to new

drainage paths in hitherto dry levels flushing out contaminants) and therefore a cause for concern (e.g. Younger et al. 2002).

***Table 1**: Examples of mine water outbreak risk identified across England and Wales*

Issue	Example sites
Flooded workings / perched mine water	Force Crag, Cwm Rheidol, Dylife, Nant y Mwyn
Underground blockages	Force Crag, Glasdir, Gwaithcoch, Parc
History of sudden outburst	Rispey, Belmont, Longacres/North Skelton, Stromsdown/Union/Brothers
Instability in shallow workings	Longacres/North Skelton, Boltsburn Level

Stability risks

A total of 72 mine sites returned an affirmative ('Yes' or 'Suspected') response for stability concerns. Over half of the 'suspected' responses did not provide any details on the nature of the stability concern. In some cases the stability concerns are repeated in the safety and even outbreak risk categories. 42% of the documented Yes responses were associated with areas of riparian spoil which are being scoured by rivers (Table 2). This is a common feature of many former metal mining areas and poses a significant risk also for diffuse contaminant input into surface waters under high flow conditions (e.g. Gozzard et al. 2011; Mighanetera et al. 2009; Byrne et al. 2012). Other stability issues are associated with instability in shallow workings (and associated surface subsidence), ingress of surface drainage channels into workings (see Outbreak Risk) and stability of spoil heaps due to steep slopes (in the absence of fluvial erosion).

The bulk of the mine sites where stability issues have been highlighted fall within the Western Wales and North Pennine orefields (Figure 1), which may be in part a feature of completeness of records in these areas. Stability issues were also noted in the South West (Wheal Andrew, Mount Wellington), Northumbria (Saltburn Gill in the Cleveland ironstone Field), Western Wales (Parys Mountain, Gwynfynydd), Severn (Tankerville) and the Lake District (Force Crag). Some issues relate to historic collapses, such as at the Glebe lead-fluorspar mine in the Southern Pennines where a bund for mine tailings was overtopped after heavy rainfall in 2007. At some of the sites significant geotechnical stabilsation works have taken place to manage the stability issues. One such example is at Nenthead in Cumbria (North Pennine Pb-Zn orefield) where rock-filled gabions and additional rock armour have been used to stabilise the river banks, and the waste heaps immediately adjacent to the river have been capped and vegetated (Figure 2). Artificial rock weirs have also been constructed, in an effort to prevent downstream transport of any contaminated sediments that do enter the river (Figure 2(A)). These works, which extend for a distance of approximately 1 – 2 km, had a reported capital cost of approximately £3 million. Although, unfortunately, no information is available about the resulting improvements in water quality, visual inspection by the authors indicate the intervention has been effective in minimising bank erosion.

***Figure 2.** Use of gabions to stabilise banks of the River Nent, Cumbria (A) and re-grading, capping and vegetation of spoil material along the same stretch of river (B)*

These documented sites represent a snapshot of known issues at a much larger number of mine sites. A recent inventory of non-coal mine-related waste rock heaps across England and Wales found a total of 91 km^2 of material based on archive map analysis (Mayes et al., 2015). Within this inventory 46% were located within 50 m of a major (i.e. first order or above) water course. The documented impacts of diffuse metal-mining pollution have long been recognised in impacting floodplain sediment quality (Lewin et al 1977; Hudson-Edwards et al. 2006) as well as water quality (e.g. Gozzard et al. 2011). There remains some uncertainty over the potential long term impacts of extreme events on waste mining rock at a catchment scale. While extreme high flows can increase delivery of metal-rich material, the balance between input of these potential contaminants and input of freshly eroded uncontaminated material however remains uncertain (NERC, 2016) and requires further attention.

***Table 2**: The number and nature of stability concerns at abandoned non-coal mine sites in England and Wales*

Response	Yes	Suspected
Total number of mine sites	26	46
No details given	1	25
Spoil heaps / tailings being scoured by river	11	9
Shaft collapse / general instability in workings / fill material	6	6
River flowing into workings	4	0
Concern over stability of tailings dams / spoil heaps	4	5
Steep terrain	0	1

Conclusions

There are a range of documented issues at abandoned non-coal mine sites in the UK surrounding potential risk of sudden mine water outbreak or risk of stability concerns. The latter are primarily related to waste rock heaps in riparian areas. However, the national survey here highlights the uncertainty and incompleteness in the records and future efforts should aim to consolidate records systematically for non-coal mines. Given the forecasted increase in incidence of extreme high flow events in many of the upland catchments of the UK where metal mining activity took place (Hannaford 2015), information about locations and types of hazard are crucial for informing management strategies. Previous outbreak events have been preceded by extreme rainfall events, while anecdotal evidence has suggested stability issues at waste rock heaps are exacerbated by high flows. The initial database collated here provides a basis for future site specific risk assessments, and where necessary, remedial works. Successful management of outbreak risk and stability concerns has occurred at a number of mine sites in the UK provides a good model for future site specific management.

Acknowledgements

The project was funded by the UK Government Department for Environment Food and Rural Affairs (Defra), the Environment Agency (England & Wales), and the Department for Communities and Local Government (Defra Project Ref: WQ0601; Environment Agency Project Ref: SC030136/14) alongside the Natural Environment Research Council under grant NE/P000053/1. We also express our gratitude to project collaborators at The Coal Authority and Atkins as well as to the many staff at local Environment Agency offices, and also Local Authorities, who have spent time populating the internet-hosted questionnaire that was essential to this work. The views expressed in the paper of those of the authors and not necessarily those of the funding agencies.

References

Byrne P, Reid I, Wood P. (2012) Stormflow hydrochemistry of a river draining an abandoned metal mine: the Afon Twymyn, central Wales. Environmental Monitoring and Assessment. 45: 211-222.

European Commission. Directive (2006) 2006/21/EC The management of waste from extractive industries. ["The Mining Waste Directive"]

Gozzard E., Mayes WM, Potter HAB & Jarvis AP (2011) Seasonal and spatial variation of diffuse (non-point) source zinc pollution in a historically metal mined river catchment. Environmental Pollution. 159: 3113-3122.

Hannaford J. (2015) Climate-driven changes in UK river flows: a review of the evidence. Progress in Physical Geography, 39:28-28. 2015.

Hudson-Edwards K. (2016) Tackling mine wastes. Science, 352: 288-290.

Jarvis AP; Mayes WM (2012) Prioritisation of abandoned non coal mine impacts on the environment: the national picture. Environment Agency report SC030136/R2.

Lewin J, Davies BE & Wolfenden PJ. (1977) Interactions between channel change and historic mining sediments. In: Gregory KJ. (editor) *River channel changes.* John Wiley and Sons, Chichester, pp. 353-367.

Mayes WM, Anton AD, Thomas C, Potter HAB, Rudall S, Amezaga J, Gandy CJ, Jarvis AP. (2015) National assessment of sediment-related diffuse mining pollution in England and Wales. Proceedings of the 10th International Conference on Acid Rock Drainage (ICARD) and the International Mine Water Association (IMWA), Santiago, Chile, April, 2015.

Mayes WM, Johnston D, Potter HAB & Jarvis AP (2009) A national strategy for identification, prioritisation and management of pollution from abandoned non-coal mine sites in England and Wales. I. Methodology development and initial results. Science of the Total Environment. 407: 5435-5447.

Mighanetara K, Braungardt CB, Rieuwerts JS, Azizi F. (2009) Contaminant fluxes from point and diffuse sources from abandoned mines in the River Tamar catchment, UK. Journal of Geochemical Exploration, 100: 116-124.

NERC (2016) Impact of an extreme rainfall event on solute and sediment dynamics in a mineralised river system. www.gotw.nerc.ac.uk/list_full.asp?pcode=NE%FP000053%2F1 [last accessed: 05/05/16]

Rico N, Benito G, Salgueiro AR, Díez-Herrero A, Pereira HG (2008) Reported tailings dam failures. A review of European incidents in a worldwide context. Journal of Hazardous Materials 152**:** 846-852.

Younger PL (2002) Mine water pollution from Kernow to Kwazulu-Natal: geochemical remedial options and their selection in practice (Scott Simpson Lecture 2002*).* Geosci Southwest England (Proc Ussher Soc) 10, 255–66. 2002.

Younger PL, Banwart SA and Hedin RS. (2002) Mine Water: Hydrology, Pollution, Remediation. Kluwer Academic Publishers, Netherlands. 442 pp.