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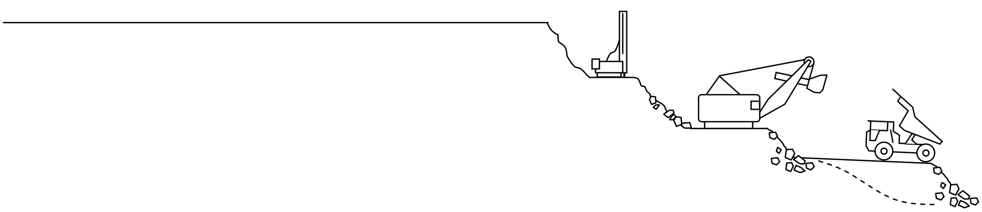
A review of the impact of the EC Mining Waste and Water Directives on the management of abandoned mines in the UK- with emphasis on Welsh metal mines

Maria Thornhill [1]

[1] Dept. of Geology and Mineral Resources Engineering., NTNU, Sem Sælandsvei 1, 7491 Trondheim (maria.thornhill@ntnu.no)

ABSTRACT

This article provides a brief review of management strategy conducted by the relevant United Kingdom (UK) authorities in response to the European Mining Waste Directive and in particular, the Water Directive which has been a strong stimulus to the supervision and management of abandoned mine sites. Stability concerns, safety, water and airborne pollution, human and animal health risks have been assessed. This may be of interest in light of the differences and similarities with the management of abandoned mines in Norway. Metal pollution loading to aquatic recipients from abandoned metal mines must be addressed in order to achieve the requirements regarding water quality by the Water Directive. In addition, alternative solutions for the use or disposal of ferric hydroxide sludge from remediation operations are required, while the true cost of 'perpetual' water treatment systems should be considered.



1. INTRODUCTION

The UK possesses approximately 175 500 abandoned mines and mine entries which represent a considerable environmental challenge. At the current time they are the direct cause of 9% of English and Welsh rivers and 2% of Scottish rivers risking failure to achieve the Water Framework Directive targets for good chemical and ecological status due to excessive discharges of cadmium, iron, copper, zinc and other metals. 72% of failures to achieve cadmium quality standards for freshwater occur in mined areas while plumes of sulphate and chloride are of high concern with regard to portable water supply aquifers in some mining impacted areas (Johnston et al. 2008). Additional impacts other than acidic or metal containing effluents are waste tip instability or other structural hazards and airborne dust transport

Prior to the adoption of the Mining Waste Directive (2006/21/EC) and the Water Directive (2000/60/EC) the remediation of abandoned mines in the United Kingdom (UK) and in particular, the environmental challenges posed by abandoned metal mines, did not receive the attention which it merited.

In order to comply with the Mining Waste Directive a comprehensive survey of waste facilities was required and this has recently been completed. The 2015 deadline for restoration of water quality to a 'good' standard as proscribed by the Water Directive has become a driver towards the establishing of a national strategy for the management of abandoned metal mines, which have not been prioritised due to the focus on the remediation of areas impacted by coal mining. This has primarily been due to the recent closure of many coal mines and the establishment of a single responsible authority for their management.

Many of the issues regarding the management of abandoned mines in the UK are shared by Norway, some examples being the challenges posed by mining waste treatment in remote locations; uniting industrial heritage preservation with environmental quality requirements; solutions to the placement of ferric hydroxide generated by many treatment systems etc. This paper will provide a brief overview of remediation strategy for abandoned mines in the UK as well as information regarding changes that have occurred as a result of the greater attention focused on pollution arising from non-ferrous metal mines. A brief comparison to Norwegian remediation strategy will be given.

2. BRIEF HISTORICAL BACKGROUND

The United Kingdom (UK) has an extensive legacy of mining and mineral production dating from the Bronze Age. Extraction of lead, gold and silver expanded during the Roman occupation but it was the industrial revolution that led to peak mineral output during the Eighteenth and Nineteenth Centuries. For example, until the 1870's Wales was one of the World's leading lead producers. However, non-ferrous metal production virtually ceased after the early years of the Twentieth Century, while coal and industrial mineral production continued. Many coal mines were closed during the 1980s to early 1990s but some remain in production. The abandoned metal mines of Wales are illustrated in figure 1.

Following the 1966 coal tip disaster at Aberfan which resulted in the loss of 144 lives, of whom 116 were children (Davies et al. 1967), the first legislation regarding the management of mineral waste facilities was enacted in the Mines and Quarries (Tips) Act 1969. Local authorities were then forced to inspect all waste facilities and initiate enforced remedial action where necessary. This resulted in a programme of land reclamation from the 1970s-1990s which addressed tips that were unstable or posed other health and safety hazards.

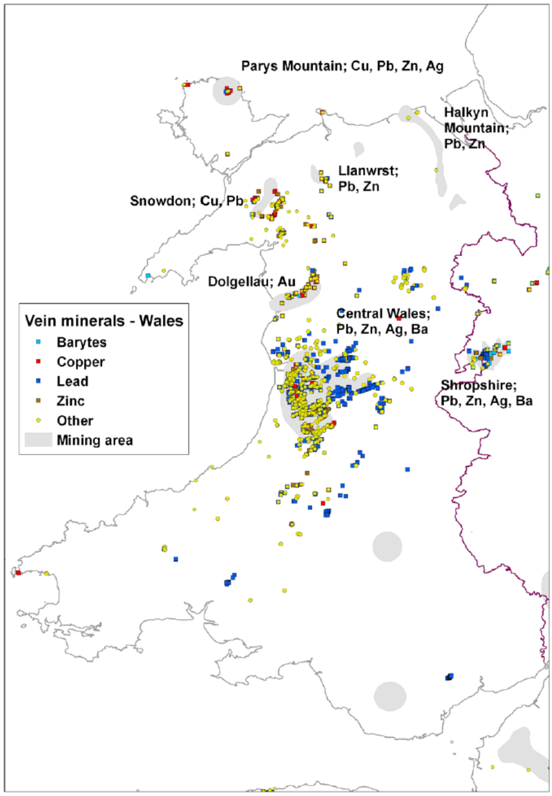


Figure 1. Abandoned metal mines in Wales and Shropshire (Palumbo et al. 2010).

Additional legislation, regarding the Inventory of closed mining waste facilities under the auspices of the Health and Safety Executive (Mines Inspectorate) on abandonment, together with the Mineral Planning Guidance regulations have secured waste facilities which have been abandoned since 1969.

Due to the historical nature of many abandoned mines in the UK, particularly the fact that metal mines were often abandoned nearly 100 or often more years previously it is not possible to recover the costs of any remediation action from site owners. This is taken into account by the requisite legislation, so that no mine owner or operator is responsible for pollution arising from mines which were closed prior to 1999 and therefore any such schemes must be publically funded.

3. ENVIRONMENTAL IMPACT

Concern with regard to pollution stemming from the poor disposal of mining wastes is not solely a modern phenomenon. In 1868 the River Pollution Commission expressed frequent concerns regarding metal mining related pollution in Britain, particularly in regard to the impact on aquatic recipients but also detailing severe soil pollution in surrounding agricultural areas which not infrequently resulted in the death of livestock and ill health amongst humans, due to a combination of windblown fines contaminated water and inefficient smelting practices.

In order to comply with the EU Directive on management of waste from the extractive industries (2006/21/EC) the UK Environment Agency (EA), has produced an inventory of closed mining waste facilities which identified more than 170 000 coal mine entries and 5 500 non-ferrous metal mines (Mayes et al. 2012).

Figure 2. Part of the Cwmystwyth mine site, illustrating the steep nature of the local topography. (Countryside Council for Wales 2008).

However, it is believed that these figures represent an underestimate of the true figures since many mines were abandoned prior to the Twentieth Century as details regarding records of mining waste facilities, processing plants and other infrastructure are frequently poor, or unavailable. In particular, the registration of waste not deemed to be of economic importance was not common practice, so it is difficult to ascertain true values. In addition, historical industry practices in Britain have produced a huge number of small, frequently interconnected mines as opposed to a small number of distinct large sites. A single mine frequently contains numerous individual waste facilities together with many mine water inputs and discharges which may increase pollution over a large area, thus making it difficult to track all sources of pollution at a site. (Mayes et al. 2012). A typical example is given in figure 2 which illustrates a part of the Cwmystwyth mine site, which is composed of a suite of small mines located in steep terrain.

The results from the Environment Agency's inventory of waste facilities (Jarvis et al. 2012a) show that England and Wales possess at least 226 water bodies which are impacted by non-coal (mainly metal) mine water pollution, together with some 243 water bodies which are probably impacted. At least 425 mine sites are linked to definite concerns regarding airborne pollution, stability, safety and public and animal health; while a further 275 sites are suspected of such impacts. Additional issues included 257 sites with confirmed mine water discharges, and a further 81 at which this is suspected. There is confirmation of diffuse mine water pollution at 112 sites but this must be regarded as an underestimate since investigations in this area are complex owing to the ad hoc method of working historical metal mines in the UK. Evidence of outbreak risk has also been established at 19 sites.

Waste produced by non-coal and non-metalliferous mines and quarries has been defined as inert (Palumbo et al. 2010).

4. REMEDIATION STRATEGIES

Considerable work has been done with regard to the development of passive and occasionally, active solutions to mine water pollution from Britain's abandoned coalmines. The UK currently has some 54 full-scale passive treatment systems for coal mine drainage remediation, the majority of which have been installed by the UK Coal Authority (Jarvis et al. 2012b). It should be noted that the main issues regarding passive remediation of coal impacted water are iron content and acidity (which is related to the sulphur content of the coal). For metal mines the addition of a variety of more soluble metals to the water requiring remediation requires larger treatment areas and more complex passive solutions.

It is clear that the strategy and implementation of remediation operations at abandoned coal mine sites has benefited from the 1994 establishment of the Coal Authority, a single government authority for coal mine control, which now owns the majority of the abandoned coal mines. Unfortunately, there is no true equivalent to the Norwegian Mining Directorate with the additional responsibility for abandoned metal and non-coal mines

Therefore, action with regard to metal mines has been slow, since multiple agencies, local government and other stakeholders must be involved in decisions and implementation of management practices for abandoned metal mines. This has made the production of an overall strategy for the management of abandoned metal mines very difficult. However, the impetus provided by the Waste Management Directive and in particular the Water Directive has led to the start of development of an overall strategy for the management of abandoned metal mines.

Many issues remain to be solved. Engagement and agreement between the multiple stakeholders responsible and involved with abandoned metal mine issues is still a problem. The frequently highly diverse interests of these groups is an issue with regard to the implementation of remediation actions at abandoned metal mines.

The Metal Mines Strategy for Wales (Welsh Assembly Government and Environment Agency Wales, 2002) identified 50 of the approximately 200 metal mines deemed to be the most polluting for the purpose of remediation. However, during the consultation process discussion with stakeholders (which included other government agencies), the EA found that at only a single site was there no divergence between all stakeholders, at 30 sites it was felt that agreement could eventually be produced as a result of further consultation processes. However, at 7 sites stakeholder disagreement was reported to be so diverse that the EA found it impossible to consider any form of remediation operation. This situation raises questions with regard to current precedence of authority to 'act' at such sites.

A strong interest in industrial heritage, as well as specialised flora and fauna means that agencies such as the Countryside Council for Wales (CCW) have adopted the promotion of passive treatment systems wherever possible, since these are believed to result in less visual impact and alteration of the sites.

In addition, some Welsh metal mines, such as Frongoch (SN723745) have received the protective status of Site of Special Scientific Interest (SSSI) solely due to 'one special feature: mineral-bearing spoil tips.' (Countryside Council for Wales 2008). This complicates any remediation operations at such sites.

The successful implementation of many passive treatment systems by the Coal Authority at abandoned coal mines (albeit with some additional active treatment) naturally focuses attention on passive solutions. However, passive remediation of metal mines is more complex, and while the method may be appropriate and perform successfully at some sites, wetland systems require larger areas of land to cope with metals remediation, which may not be available, or the topography of the location may be too steep.

Cwmystwyth (SN803746) another Mid Wales SSSI, consists of a series of interconnected mines with a considerable number of diffuse minewater sources. In addition, as figure 2 shows, as is frequently the case with Welsh mines, the site itself is situated in steep terrain. Here the EA in Wales has estimated that for a single source in this complex (Pugh's adit) a passive wetland system would require an area of over 3 ha for the removal of zinc (Jarvis et al. 2012b), making this an inappropriate solution.

There is also the question of disposal of the ferric hydroxide sludge which is deposited in the treatment cells. Approximately 20 000 tonnes of ferric hydroxide sludge are in fact produced annually by the Coal Authority's coal mine remediation operations in the UK (Jarvis et al. 2012b). This figure includes both passive wetlands together with active operations. Jarvis et al. (2012b) state that the sludge is currently disposed to landfill as inert waste with an estimated cost for 2011-12 of around £1.2M. Assuming that passive remediation systems, or enhanced passive systems were found to be appropriate, a conservative estimate of the annual landfill costs for the disposal of ferric hydroxide sludge from the 20 English and Welsh mine waters classified as belonging to the *impacted* priority category by the EA and for which flow data are available, was given as £152 000. However, this assumes that the sludge would contain metal contents falling within the 'inert' category, should it be classified as 'hazardous' disposal costs would be considerably higher.

It is perhaps interesting to note that the Welsh Assembly Government is currently pursuing a 'towards zero waste strategy' (Welsh Assembly Government 2010) which includes attempts to address the low capacity of Wales' landfill system, with few facilities suitable for depositing hazardous waste. The Government has in fact stated that 'Landfill is no longer an option. The amount of landfill space left in Wales is running out fast and landfill taxes mean that we cannot afford to keep sending waste to landfill' (Welsh Assembly Government 2012).

The possible use of ferric hydroxide sludge has been discussed by numerous authors. However, the issue of sludge product quality (as well the cost of transport and overall economy) is critical. Currently, all ferric hydroxide generated by Coal Authority projects is sent to landfill disposal, although research projects have been undertaken to examine applications for the ferric hydroxide sludge. Sludge generated from non-ferrous metal mines would be likely to include levels of precipitated metals such as lead, zinc and cadmium that would preclude its use as a pigment.

The Environment Agency (Jarvis et al. 2012b) has stated that direct reuse of metal mine waste would be a desirable solution, or should this prove impossible, economically and environmentally acceptable direct recovery of metal from aqueous solutions, or recovery from waste sludge would be preferable solutions for managing polluted effluent from metal mines. Reprocessing of the wastes in order to extract the metal content has also been briefly considered. However, these options are currently regarded as being economically unviable as a result of: lack of processing facilities, small quantities of refined metals, difficulty of site access and conflicts of stakeholder interest. Jarvis (Jarvis et al. 2012b) states that more emphasis should be placed on the potential for the use stabilisation technologies of metal in order to reduce leaching potential together with landfilling costs, and with the possible production of a saleable product for use as a building material (provided that any metal content can be demonstrated to be sufficiently immobile).

This last point is interesting with regard to one of the criticisms frequently made regarding reprocessing - that the reduction in metal content of remaining tailings may be insufficient to pass environmental quality standards. Since such standards are often based on total metal content, they take no account of how mobile metals are. A sufficiently immobile metal content might permit natural attenuation at levels insufficient to impact the overall quality of aqueous recipients and such information could be assessed by utilising mineralogical characterisation in conjunction with appropriate leaching tests.

Indeed, Jarvis (Jarvis et al. 2012b) notes that with all reuse options the barriers to implementation may relate as much to regulatory issues as to the development required of technology. In addition, the evaluation of such methods should be made considering the financial value of environmental benefits gained by *not* disposing treatment sludge to landfill sites as well as focusing on the total flux of metals from the affected catchments rather than point sources, with the inclusion of metals in temporary storage in stream bed sediments which may be greater than the sum of point sources, thus improving viability of metal recovery strategies.

5. COMPARISON WITH NORWAY

Both Norway and the UK have a legacy of pollution resulting from historical mining and mineral production, with the major difference being the greater extent of coal mining in the UK and earlier period of industrialisation.

Many Norwegian mines were closed more recently, as a result of which more consideration was given to mine closure and environmental control. This is similar to the situation for many UK coal mines. In contrast, the majority of British metal mines were abandoned at an early time when statutory control was weak with regard to the environment and mining closure.

Both nations possess mines and areas of mineral production which are categorised as being of importance with regard to industrial heritage i.e. the UNESCO World heritage sites at Røros and the 10 areas which comprise the Cornwall and West Devon Mining World heritage site.

In addition, as in Norway, many British abandoned mine sites have received official protected status (Site of Special Scientific Interest for the UK (SSSI)) due to industrial heritage, metal tolerant fauna and flora, or mineral assemblages. Thus both nations experience restrictions with regard to environmental remediation options.

The strong emotional attachment with regard to mining waste which is sometimes seen in Norwegian communities e.g. Løkken, Folldal, Røros is more frequently mirrored in the UK with respect to historic abandoned non-ferrous metal mines, and some non-coal mines. The impact of the 1966 Aberfan coal tip disaster has presumably played a role in facilitating public acceptance of remediation operations concerning coal waste facilities, in addition, many Welsh coal tips were located in steep terrain where potential instability was frequently of concern.

Despite the extreme temperature differences between the Wales and Norway some similarities exist with regard to the upland topography and the location of mines in areas of thin soil cover with low human population density. Thus many of the challenges facing remediation of such abandoned mines are common ones.

A general comparison of remediation strategies in Norway with those utilised in the UK indicates that a far greater use of passive treatment solutions has been adopted in the UK where the majority of these systems are operating at coal mine sites. Norway has made limited use of passive treatment systems (e.g. Folldal and Kongens Gruve at Røros) at abandoned metal mines, while the covering operations remain the major form of remedial treatment to date.

6. CONCLUSIONS

The European Mining Waste Directive and in particular, the Water Directive have introduced a strong stimulus to the supervision and management of abandoned mine sites in the United Kingdom (UK). A national strategy for the remediation of metal mines in the UK would be a positive step in solving the complex issue of remediation and conflicting stakeholder interests. Establishing a single authority for metal mines, such as is the case with the Coal Authority might be of some benefit.

Metal pollution loading to aquatic recipients from abandoned metal mines must be addressed in order to achieve the requirements regarding water quality by the Water Directive.

Solutions other than landfill to the disposal of ferric hydroxide sludge from remediation operations should be addressed, in particular, with regard to the treatment of abandoned metal mines.

The true cost of water treatment systems requiring extreme long term operation may be higher than that of one-stop process based remediation options combined with geotechnical measures and these should therefore be reconsidered.

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