MANAGEMENT OF ABANDONED MINEWATER POLLUTION IN THE UNITED KINGDOM

Dave Johnston[1], Keith Parker[2] and Jim Pritchard[3]
[1] Environment Agency, Ty Cambria, 29 Newport Rd, Cardiff, UK, CF24 0TP. Dave.johnston@environment-agency.gov.uk
[2] Coal Authority, 200 Lichfield Lane, Mansfield, Nottingham, UK, NG18 4RG. Keithparker@coal.gov.uk
[3] Scottish Environment Protection Agency, Clearwater House, Heriot Watt Research Park, Avenue North, Riccarton, Edinburgh, UK, EH14 4AP. Jim.pritchard@sepa.org.uk

Abstract
The UK has a long and distinguished history of mining, and has now developed an unparalleled record of minewater remediation. 3000 years of mineral exploitation has left us with a legacy of pollution in our rivers, estuaries and groundwater. It is only since the creation of the Coal Authority in 1994 that there has been a strategic approach to managing any of those impacts and providing treatment facilities, at least for coal mines. In the UK we have built 52 abandoned mine treatment plants to date, all bar two for abandoned coal mines. Between them they treat over 155,000 m^3 per day of minewater and remove more than 2000 tonnes of iron and other metals from the environment every year. These plants have greatly improved the quality of over 100 km of rivers and have prevented a similar length from becoming contaminated. Aquifers, including water supplies serving many thousands of people, have been protected. Despite these successes there are still significant challenges not the least of which is devising a strategic approach to the management of our legacy of non-coal mining pollution. This paper provides an overview of the successes of our strategies, some of the challenges we overcame and some of those that still face us.

Introduction
Mining for minerals has been a feature of the British landscape since the Bronze Age, as has the pollution that comes with it. Across many of our coalfields, abandoned mines have flooded and the pollution problems are evident where adits and shafts provide a ready conduit for the minewater to discharge into our rivers. Groundwater in more recently closed coalfields was managed on a very large scale through interconnected workings. Since the cessation of pumping, the groundwater is rebounding and poses a future threat to surface waters and sensitive groundwater bodies. Spoil heaps continue to leach metals and sulphates into ground and surface water as well as posing health and safety risks if they are not managed.

After the boom times of the 17th and 18th centuries the majority of our metal ore mines had closed by the early 20th Century, with the final few Cornish tin mines closing in the 1990s. These mines present a long-term pollution problem. Direct discharges from shafts and adits enter our rivers but diffuse pollution arising from the large scale land disturbance associated with the mining activity has been shown to contribute between 45% and 95% of the total polluting load (Mullinger, 2004; Mayes et al., 2006).

The impacts from abandoned mines are recognised as a significant risk of us not achieving good chemical or ecological status in many rivers, as required by the European Water Framework Directive (WFD). All of our strategies for dealing with abandoned mines will now be aligned with its objectives. We have to achieve good chemical and ecological status in our ground and surface water bodies over a succession of river basin planning cycles. Our initial risk assessment for this directive identified that 7% of our rivers (by length) and 14% of our groundwater (by area) in England and Wales, 2% and 6% respectively in Scotland, were at risk of failing to meet its requirements due to the polluting impacts of mining. This exercise has recently been reviewed in England and Wales by the first author to inform the forthcoming river basin plans. This used nationally available datasets to identify water bodies where water quality did not achieve its targets, and that failure could be attributed to a mining source. Of the 7816 surface water bodies, 141 could be shown to be at risk of failing to achieve good status, and a further 314 were probably at risk but further information is needed to confirm that assessment.

Until 1994 there was no strategic approach to dealing with mining pollution in the UK. Action was taken, or at least attempts were made to take action, where the pollution problems were particularly acute and where sources of public funding could be found. Successful examples include the treatment plant for the Wheal Jane Tin Mine in Cornwall (Environment Agency) and the Pelenna Wetlands in South Wales (Neath Port Talbot County Borough Council). The legislative regime at the time was also a barrier to remediation as mine owners could not be found guilty of an offence merely by permitting a discharge from an abandoned mine (Section 89 Water Resources Act 1991).

The mass closure of coal mines in the early 1990's and the privatisation of the remainder of the industry led to concerns being voiced by local authorities in the coalfield communities that action was necessary if an environmental disaster was to be avoided. These groups also called for legislative changes to ensure a clear line of responsibility for discharges from abandoned mines. Although the law was not changed in terms of historic pollution, the loophole allowing operators to walk away from a closed mine was closed in 1999. In 1994 the creation of a new government body, the Coal Authority, opened the way for a strategic approach to coal minewater remediation. There are now a total of 52 abandoned mine treatment plants in the UK, 50 for abandoned coal mines.

While there is still no national strategic approach, or clear mechanism, for the remediation of the pollution from non-coal mines, we have been successful in starting a project to identify and prioritise their impacts across England and Wales (Jarvis et al., 2007). This builds upon the successful Metal Mine Strategy for Wales, which has been previously reported (Johnston, 2004; Mullinger, 2004).

Managing Abandoned Coal Mines

The Coal Authority have built 44 of the 50 coal minewater treatment schemes, by far the majority of all those in the UK. In the early years following their creation in 1994 they had no statutory remit for such works but were given the responsibility by Government. This position was strengthened in 2003 with the granting of statutory powers whereby "*The Authority may take such action as it considers appropriate (if any) for the purpose of preventing, or mitigating the effect of, the discharge of water from a coal mine into or on to any land or into any controlled waters*." (S85 Water Act 2003).

The Coal Authority have memoranda of understanding with both the Environment Agency (for England and Wales) and the Scottish Environment Protection Agency which facilitate the works and set out our common objectives. The backbone of the memoranda is the priority list of minewater discharges which was devised to assess sites based on their environmental impact, not only on water quality but also on the aesthetic impact to local communities. That list now includes 172 sites, 85 of which are for existing discharges and the remainder are monitoring sites for rebounding minewater, not all of which will require treatment.

In managing their 44 treatment schemes and a number of groundwater pumping stations the Coal Authority is responsible for over 140,000 m^3 per day of minewater being discharged to our surface waters. The quality of those waters before treatment varies enormously: from very low levels of iron in some of the untreated pumped discharges to 620 mg L^{-1} Fe at Blenkinsopp in Northumberland. The treatment plants collectively remove over 1200 tonnes of iron per year which would otherwise enter the environment. The relative performance of these plants is summarised in Table 1.

The majority of the treatment plants are a semi-passive system of aeration, settlement lagoons and aerobic wetlands, which have proved to work well with the ferruginous net alkaline minewaters which prevail in the UK. For net acidic or particularly iron rich minewaters then chemical addition has been built into the otherwise passive schemes. This is typically alkali dosing to raise the pH (e.g. Monktonhall in Scotland) or hydrogen peroxide to rapidly oxidise ferrous iron to the less soluble ferric (e.g. Six Bells in South Wales). Some recent schemes have been developed with more innovative treatment methods:

- **Tanygarn** in South Wales is piloting a Reducing and Alkalinity Producing system (RAPS) to treat a low volume, net acidic minewater, so improving the quality of a valuable sea trout spawning tributary;
- The **Lamesley Wetlands** in County Durham co-treat minewater and secondary treated sewage effluent in a 5 hectare aerobic wetland. The combined treatment has additional advantages for both effluents, the ochre in the minewater adsorbs phosphate from the sewage and the sewage provides a nutrient source for the wetlands so making the minewater treatment more efficient.

The success of the minewater treatment schemes is not only measured in terms of the volume and percentage of iron removed. The chemical improvements are matched by ecological and community benefits. The biodiversity in the rivers improves and the treatment methods themselves bring their own biodiversity. Wetlands are often a scarce habitat and the minewater treatment plants provide this habitat for many species of birds, including little ringed plover, skylarks and reed buntings. The Lamesley wetlands in the north east of England are a valuable wetland habitat in an otherwise industrial area and the scheme has been incorporated into the wider Team Valley Regeneration project. The Mousewater scheme in Scotland is planted with native species specifically to encourage wildlife, and has been rewarded with sightings of many birds and butterflies. Local communities also benefit with many schemes being open for public enjoyment, providing a catalyst for regeneration which would not otherwise have happened. The Taff Merthyr Scheme in South Wales is incorporated into a public park with canoeing and fishing lakes which would not have been possible without the water quality improvements. All of these schemes include footpaths and bridleways and are extensively used for leisure by the local community.

We have recently reviewed the future strategy for the priority coal mine remediation programme to ensure that it fits with the objectives of the Water Framework Directive and to form the basis for applications for funding from central government over the coming years. Value for money and affordability are considered in line with recent guidelines issued by the Department of the Environment Food and Rural Affairs.

Table 1. Coal Authority Abandoned Mine Treatment Plants Monthly Performance September 2006.

Mine	Discharge Rate Ls^{-1}	Mean Influent Iron mgL^{-1}	Mean Effluent Iron mgL^{-1}	Efficiency	Total Iron Removal Tonne $month^{-1}$
Scotland					
Dalquharran*	2.5		146		
Polkemmet	76	63	0.15	99.76	11.18
Frances	71	43.2	3.35	92.25	5.95
Minto	43	5.88	0.49	91.67	0.61
Monktonhall	75	45.6	0.96	97.89	3.01
Kames	18.8	15.2	1.95	87.17	0.65
Mousewater	39	13.1	0.22	98.32	1.32
Mains	4.3	11.4	0.12	98.95	0.13
PoolFarm	56.5	9.84	0.14	98.58	1.44
Cuthill	4.58	*28.1*	0.05	99.82	0.44
Lathallan	8.8	*13.9*	*0.23*	98.35	0.32
England					
Bates	124	30.4	9.66	68.22	6.23
Chester Moor*	172		2.45		
Horden	55.27	149.5	1.3	99.13	19.82
Kibblesworth*	347.26		6.72		
Kimblesworth*	192		4.27		
Lumley*	11		8.6		
Page Bank*	*50*		1.05		
Vinovium*	0		2.19		
Edmondsley	*4.7*	41.8	0.15	99.64	0.04
Acomb	12.65	36.7	5.5	85.01	1.06
Whittle	19.86	32.2	0.22	99.32	1.54
Blenkinsopp	10	620.67	0.1	99.98	14.20
Ewanrigg	6	*30*	*2*	93.33	0.44
Caphouse	*35*	*35*	*4*	88.57	2.85
Wooley	73.15	6.95	0.1	98.56	1.52
Bullhouse	40.14	46.8	0.47	99.00	5.62
Silkstone	*10*	15.7	3.45	78.03	0.32
Bridgewater	21.84	13.6	0.252	98.15	0.88
Old meadows	39.64	25.8	0.97	96.24	2.37
Aspull	10.09	30.1	0.23	99.23	0.91
Deerplay	9.09	28.15	2.42	91.40	0.71
Hockery Brook	12.41	26.2	0.01	99.96	0.98
Mid Cannock	38.58	5.45	3.2	41.28	0.22
Fender	44.58	7.29	0.1	98.63	0.97
Silverdale	27.38	27.4	4.36	94.09	1.91
Wales					
Ynysarwed	*30*	*78.3*	*0.68*	99.13	6.12
Gwynfi	8	13.5	0.1	99.26	0.28
Vivian	70	27.3	1.58	94.21	3.27
Lindsay	13.8	17.3	2.88	83.35	0.63
Taff Merthyr	16	8.96	0.254	97.17	0.36
Morlais	20	29.9	0.466	98.44	1.55
Blaenavon	6.9	9.22	0.147	98.41	0.16
Glyncorrwg	18.4	16.8	0.777	95.38	0.77
Glyncastle	4.2	24.1	1.06	95.60	0.25
Tanygarn	0.3	45.6	0.13	99.71	0.04
Total	**187.6**				**101.08**

*denotes a pumping station with no treatment, figures in italics are estimates.

Remediation and preventive schemes have been reassessed and included in a programme designed to fit the first three rounds of river basin planning. Remediation schemes are spread across those three plan periods based on their environmental impact, with flexibility built in to bring forward lower priority schemes if budgets or timescales allow. Preventive schemes, those done to ensure environmental impact from rising minewaters do not occur, are ranked on a matrix of expected impact against probability and timescale of occurrence, see Figure 1. Those with the highest probability of occurring soon and the highest expected impact, the darkest portion of Figure 1, are targeted for completion in the first round of river basin planning from 2009 until 2015. Those not predicted to occur for some years are ranked medium or low and will be phased for construction in subsequent rounds until 2027.

In the next two years only one major scheme will be constructed in the UK, at Dawdon in County Durham. This will protect an aquifer providing 35 million litres of potable water per day, serving many thousands of people.

The scheme is complementary to the existing plant at Horden, which was built as a temporary measure when the imminent nature of the threat was recognised. Two pumping stations will control the level of groundwater so it does not threaten the sensitive Magnesian Limestone aquifer. The works will employ the high density lime sludge technology used at Horden and treat up to 12,000 m^3 of minewater per day, before discharging to the North Sea via a long outfall. The total cost of this project, predicted at £6.5m, is the highest of any scheme built to date and has required the approval of central government.

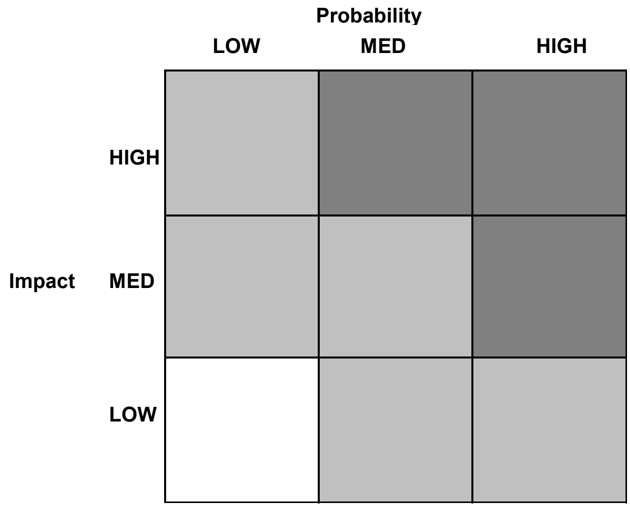

Figure 1. Coal Authority Preventive Programme Risk Matrix.

Dealing with non-coal mines

The situation with non-coal mines is less advanced. In part this is because of the more historic nature of the mines themselves. Many of the metal mines causing significant pollution closed over 100 years ago and the oil shale and fireclay mines of Scotland's central belt closed in the 1960's. Furthermore, unlike the nationalised coal industry, metal mines were owned by disparate private interests. The impacts of non-coal mines are often less visible, with fewer having the orange ochre staining so distinctive of coal mine discharges.

Diffuse pollution is extensive due to the large-scale land disturbance associated with the winning of metal ores. Opencasting, hushing and direct discharges of tailings to rivers has resulted in contaminated floodplain sediments many kilometres from the sources. It is estimated that 55% of the floodplain of the River Swale in Yorkshire is contaminated with lead at concentrations up to 1000 times the background (Macklin et al., 2006). Analysis of data collected at the tidal limit of UK rivers entering the North Atlantic shows that certain mining areas contribute very large loadings of metals, particularly copper and zinc (Potter and Jarvis, 2006). In 2003, Parys Mountain Copper Mine (Anglesey, Wales) discharged 10 tonnes of copper and 24 tonnes of zinc into the Irish Sea. And Restronguet Creek discharged 12 tonnes of copper and 52 tonnes of zinc into Falmouth Bay, mostly from the County Adit, a 60 km network of drainage channels started in 1748 to drain the orefield across a large area of the county of Cornwall.

At the former Wheal Jane tin mine, the high-density sludge plant treats over 13000 m^3 of minewater per day. In 2006, 670 tonnes of iron, 150 tonnes of zinc and 0.5 tonnes of copper were removed, which would otherwise have added to the pollution in the Restronguet Creek (S. Morcom, United Utilities, personal correspondence 2007). In North Cornwall a pilot plant is treating copper rich water from the appropriately named Red River in admixture with ferruginous minewater from South Crofty Tin Mine, the last large scale metal mine to be closed in the UK. The plant was built by the Cycleau (EU INTERREG IIIB, www.cycleau.org) project and consists of a sequential anoxic limestone drain and aerobic wetland. The Environment Agency is working with Newcastle University (HERO Group) to investigate whether copper can be treated by co-precipitation with iron hydroxide.

The Metal Mines Strategy for Wales (Johnston, 2004) continues to investigate the feasibility of remediation at the highest priority metal mines in the Principality. The project has successfully drawn in funds from diverse sources including EU structure funds and the Welsh Assembly Government's Contaminated Land Capital Fund to continue to investigate sites. A significant monitoring exercise is underway at three of the largest and most polluting lead/zinc mines in the central Wales orefield. To quantify the contribution from point and diffuse sources so that remediation strategies can be devised. Minewater from Cwmrheidol Lead mine has undergone laboratory trials at Newcastle University to inform the construction of a pilot RAPS plant and works have been undertaken to stop clean surface water entering the mine (Edwards and Potter, 2007). At Parys Mountain Copper

Mine Unipure Europe Ltd are to trial a high density sludge plant similar to that successfully used to design the works at Wheal Jane in Cornwall.

Remediation or treatment at many metal mines is made more complex by the inherent ecological or archaeological value of the sites. Many spoil tips have rare assemblages of plants and animals because of the harsh conditions. The sites are often considered to be locally and internationally important as examples of our industrial heritage. The tin and copper mining areas of Cornwall and West Devon have recently been declared a World Heritage Site (www.cornish-mining.org.uk) because of the important role they played in developing the techniques of hard rock mining which were exported around the world.

The needs for a strategic approach to non-coal mining pollution in England and Wales has been recognised by the UK Government Department of the Environment Food and Rural Affairs (Defra) with the start of a project to identify and prioritise the water bodies most impacted by non-coal mining and the sources of the pollution. The project will approach the problem on a water body basis, in line with the Water Framework Directive, and is the first step in developing a national strategy for its management. (Jarvis et al., 2007). This water body approach will allow us to develop management plans on a catchment scale, including diffuse sources and individual sites. The Environment Agency and SEPA are both working on strategies to encompass all aspects of mining, so allowing us to focus our resources on achieving significant environmental gains.

Conclusions

The pollution from abandoned mines in the UK is a barrier to achieving good ecological and chemical status in our water bodies. Whilst progress with the discharges from abandoned coal mines is good there is still a considerable amount of work to do. This is reliant on a clear strategy, a secure funding stream and the political will to complete the task. The problems of non-coal mines are more complex and require a similar strategic approach across the country to deliver a sustainable solution which does not compromise the ecological and heritage value of the abandoned mine sites themselves.

There is still a significant need for research to help us overcome some of the challenges presented to us. Sustainable passive treatment methods for minewaters containing heavy metals such as zinc and copper are in their infancy. The reuse of the by-products of minewater treatment is still under-utilised. Almost all of the ochre produced in our treatment plants ends up in landfills, despite its potential as a phosphate adsorbent, a raw material or as a source of metals.

Acknowledgements

Thanks are due to the staff of the Coal Authority, the Environment Agency and the Scottish Environment Protection Agency whose work over the last twelve years has resulted in the successes reported in this paper and who continue to ensure that our legacy of abandoned mine pollution is appropriately managed.

References

Edwards P.J., Potter H.A.B. (2007). The Cwm Rheidol Metal Mines Remediation Project – Phase 1. IMWA Symposium 2007.

Jarvis A.P., Gozzard E., Mayes W.M., Potter H.A.B. (2007). Prospects for effective national management of abandoned metal mine water pollution in the UK. IMWA symposium 2007.

Johnston D. (2004). A metal mines strategy for Wales. Proceedings of IMWA conference, Newcastle upon Tyne, September 2004. University of Newcastle upon Tyne. Vol. 1, 17-23.

Macklin M.G., Brewer P.A., Hudson-Edwards K.A., Bird G., Coulthard T.J., Dennis I.A., Lechler P.J., Miller J.R., Turner J.N. (2006). A geomorphological approach to river basin management in mining-affected rivers. Geomorphology 79(3-4), 423-447.

Mayes W.M., Gozzard E., Potter H.A.B., Jarvis A.P. (2006). Identifying diffuse sources of inorganic pollutants in post-industrial catchments. 4th Annual CIWEM conference, Newcastle upon Tyne. September 2006.

Mullinger N. (2004). Assessing the Impacts of metal mines in Wales. Proceedings of IMWA conference, Newcastle upon Tyne, September 2004. University of Newcastle upon Tyne, Vol. 1, 209-217.

Potter H.A.B, Jarvis A.P. (2006). Managing Mining Pollution to Deliver the Water Framework Directive. 4th Annual CIWEM conference, Newcastle Upon Tyne, September 2006.