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Treatment of Acid Mine Drainage

The problem of acid mine drainage (AMD) has been present since mining activity began thousands of years ago. Mining activity has disrupted the hydrology of mining areas so badly that it is extremely difficult to predict where water would eventually re-emerge. Individual mine closures have not resulted in massive AMD events as pumping continued so as to allow mining at nearby operational mines. It is now, when whole coalfields will finally close, that AMD will become the problem it has promised to be. AMD will be a chronic problem and one that will degrade local streams, rivers and other watercourses.

Whilst, in some cases, drainage occurs that is not acidic, all mine drainage events pose the problem of introducing iron, and potentially other metals, to local watercourses. With the advent of major AMD events, as evidenced by Wheal Jane in Cornwall, it will become necessary to identify methods that will be used to treat AMD when coal fields close and the source of money to pay for them. The alternative is to prevent drainage occurring by continued pumping.

Stephen McGinness

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Summary of main points

Mining has an ancient history within the UK. As this industry now contracts there will be environmental impacts associated with that contraction, and further impacts to follow in the future. Minewater treatment is often necessary to prevent the pollution of nearby watercourses with iron precipitates (ochre) and acidity.

The standard treatment is to pump the water and add lime to precipitate the iron before it enters rivers and streams. The residual solids are voluminous and present a disposal problem. This solution is not sustainable in economic or environmental terms.

Each discharge tends to be highly variable and requires tailored treatment. In virtually all cases however the discharge will have highly polluting effects on rivers and streams.

It is difficult to predict where discharges will occur once a mine is abandoned and pumping stops.

There is no national strategy within which dedicated staff co-ordinate responses to the growing problem of minewater discharges. There is no recognised central fund with which such treatment can be funded.

Current legislation does not identify responsibility for costs and may act to deter volunteer groups from attempting to solve local problems.

CONTENTS

I Acid Mine Drainage

The generation of acid mine drainage (AMD) and its discharge into the environment surrounding abandoned mines is likely to cause serious environmental pollution. AMD is a problem now because of the increasing numbers of closed mines and the eventual closure of whole coalfields. The pumps, which currently keep these mines dry, are being switched off and groundwater is returning to its pre-mining industry levels leading to AMD. This has been discussed in a previous Library paper.[1] The treatment, or the prevention, of such pollution will be costly and the requirement to treat is likely to be a chronic situation. AMD originating from abandoned mines to date has carried no, or extremely limited, liability and so has had to be funded from the public purse.

The problem with treatment is that there is no recognised, environmentally friendly, way to deal with AMD. The standard treatment has been to treat with lime. This produces a ferruginous (iron bearing) waste material (ochre) which is often of too variable a quality to represent a resource. Such waste must be disposed of in a nearby tailings dam if possible or in landfill. The many technologies proposed for treatment of mine drainage, are usually as expensive and always more complex than liming. Liming is not sustainable due to the requirement for lime and the need for disposal space. This paper will discuss the problem of acid mine drainage and the methods which have so far been proposed for its treatment.

A. What is Acid Mine Drainage?

Acid mine drainage is a natural consequence of mining activity where the excavation of mineral deposits (metal bearing or coal), below the natural groundwater level, exposes sulphur containing compounds to oxygen and water. Since the introduction of steam powered engines it has been possible to mine ores substantially below the groundwater level. There is also a problem where surface waters run over exposed ore seams and elicit similar chemical mechanisms and acid formation.

There have been several stages of mining. When mining first began it was only possible to mine those ores that were above the level of the ground water. As mining engineering improved it was possible to build adits (horizontal shafts leading to outside the mine) to drain groundwater into local low lying river valleys and provide access to lower levels. With the advent of steam powered engines it was possible to pump water from ever increasing depths, artificially lowering the groundwater level in the vicinity of the mine. Obviously there were costs associated with the pumping of the groundwater but they were offset by the value of the minerals extracted.

The environmental problem occurs because, when the pumping stops, the groundwater begins to flood the mine, slowly approaching the original groundwater level. As the

[1] P Hughes, *Water Pollution from Abandoned Coal Mines*, Library Research Paper 94/43, 11 March 1994

water rises it eventually reaches the level where adits were built to drain the mine into river valleys and begins to drain once again, sometimes over one hundred years after it last did so. This water is not clean after running through the mine.

Oxidation reactions take place (often biologically mediated) which affect the sulphur compounds that often accompany coal seams. Whilst the mine remains dry these sulphur compounds normally generate sulphate salts in a solid, but more available form. The metals within accompanying minerals are often incorporated into these salts. When the water flows through the mine these salts dissolve and this acidic, metal-containing mixture comprises the initial AMD discharge. The activity of chemolithotrophic bacteria[2] continues to oxidise the available sulphur compounds in the mine and therefore maintain the flow of the AMD, often over decades after the initial flush.

pH – A Physico-Chemical Measurement

A useful measure to make of any water sample is its pH. This measures the relative concentrations of hydrogen ions and hydroxide ions. pH varies between 0 and 14 where lower numbers indicate more acidity and higher numbers more alkalinity. pH 7 indicates neutrality.

Most kinds of life are adapted to live in environments that are neutral or slightly acidic in nature (pH between 5.5-7.5). When environments become severely acidic the result is usually a drastic decline in biodiversity.

AMD is a problem because the vast majority of natural life is designed to live and survive at, or near, pH 7 (neutral). The drainage acidifies the local watercourses and so either kills or limits the growth of the river ecology. Effects are even more pronounced on vertebrate life such as fish than on the plant and uni-cellular life. There is also a problem because of the metals contained in the drainage. As most mines in the UK extract coal rather then metalliferous minerals the main metal of concern is iron. Its presence in the water is a problem more due to its physical properties than its poisonous effects. Iron may be found in two forms, ferrous and ferric. When the AMD is generated it will generally be in the form of ferrous (the more soluble form) but later changes in the presence of oxygen (*oxidises*) to ferric iron (Fe^{3+}) when it forms solid particles (*precipitates*) which are a bright orange colour. The ferric iron forms a very low-density solid. Very small concentrations in the water are capable of producing large volumes of precipitate which cover the surfaces of land and streams close to the point of drainage. This iron coating effectively smothers the environment and prevents life from flourishing. This precipitation coats the gills of vertebrate lifeforms (such as fish) and causes fatalities but the metal is not inherently poisonous.

Water pumps are not always immediately switched off when a mine is closed as the groundwater level is kept low to protect other, nearby mines which are still in operation.

2 Chemolithotrophic bacteria are those which obtain their energy from inorganic compounds such as iron and sulphur. "*chemo*" means chemical "*litho*" means rock and "*trophic*" means loving, therefore bacteria which prefer chemical, rock based energy sources

Now, as the last mines in certain coal fields close, it is likely pumping will cease completely. Mines will begin to fill up and minewater will eventually discharge into the environment. If the water is not treated then it will cause severe damage to the environment, both visually and to wildlife. Many salmonid rivers will be at risk from AMD. The affected rivers will be unsuitable for habitation by these fish and form barriers for migration to other watercourses. This will harm the angling community and impose financial costs to remediate the situation. If the water is treated then there are other problems that have to be addressed. Money will have to be spent, subsequently, either on maintaining the water level below the discharge level, or disposing of the metal-rich sludges remaining after treatment.

B. Is Mine Drainage always Acidic?

Not all mine drainage is acidic. It is possible in areas where the geology is rich in carbonates or lime that the effluent will become closer to neutral. Often these neutral waters are also saline. Whilst this tends to suggest that the drainage will be less of a problem (after all, the acid is responsible for at least some of the environmental degradation) this drainage too requires treatment.

The reason for this is the presence of ferric iron. The iron, as it is already in a more neutral environment, will be more likely to precipitate and cause the environmental problems outlined above. The neutral pH makes the treatment options far easier, i.e., it is not necessary to encourage iron precipitation through, for example, addition of lime. The problems of capital costs and disposal of iron containing waste material remain. It must be ensured that iron-bearing waters are treated before discharge to the environment. Whilst the rest of this paper concentrates upon acid mine drainage it should not be forgotten that not all drainage is acidic.

C. Who is Responsible?

The responsibility for treating acid mine drainage is the crucial issue. As it was not foreseen, when the pumping of mines began, that there would be a problem of acid mine drainage there was nothing set aside to deal with the financial implications. There was also little concern in the early 19th century about potential environmental problems which might result from industrial activity. Often the companies responsible for the sinking of shafts into the ground are no longer in operation and the problem has not materialised because of the continued pumping by other mine operators in the near vicinity.

The question is whether the last operator to stop mining and switch off the pumps should be held responsible for the drainage. It is only then that the problem is noticed though the activity responsible for the drainage will have been carried out by all of the mine operators within the same catchment area. It was argued in a court case in 1993[3] that

3 "Failure of test case on abandoned mines", *ENDS Report 227*, December 1993, p 44

Section 89(3) of the Water Resources Act (WRA) 1991 allows that pollution events which are caused only through "permitting" water from an abandoned mine to enter controlled water are not considered an offence under section 85 of the same Act. The subsequent judgement highlighted a loophole in the law which allowed pollution to occur and no-one to be held responsible. The loophole will be removed as of the 31st of December 1999 (through section 60 of the Environment Act 1995), but this foreknowledge may be responsible for mines closing in advance of liability being taken on by mine operators.[4]

It is possible that section 89(3) of the WRA 1991 contravenes EC law which has considered drainage from mines to be unlawful since 1978. Those suffering damage as a result of such pollution may already be entitled to claim damages.[5] Section 60 of the Environment Act 1995 will remove this defence from former owner and operators of the mine though landowners who find mine discharges emanating from streams on their land may still be able to use the defence.

Directives 80/68/EEC (*protection of groundwater against pollution caused by certain dangerous substances*), 76/464/EEC (*pollution caused by certain dangerous substances discharged into the aquatic environment of the Community*), 79/923/EEC (*quality required of shellfish waters*) and 78/659/EEC (*quality of fresh waters needing protection or improvement in order to support fish life*) all relate to the pollution of water or the aquatic environment.

The basic issue at stake is whether the failure to continue pumping and thereby allowing acidic drainage to enter watercourses can be defined as discharge, whether direct or indirect, by man. It is on this definition that any action in European courts, as well as UK courts may rest. If the action of permitting minewater to be causing a discharge of pollution is established as unlawful then the way is open for prosecution within the courts.

D. How is treatment funded?

When the Wheal Jane metal mine flooded in 1992, the news impact made it necessary to take some kind of action. The Department of the Environment made money available for the Environment Agency (then the National Rivers Authority) to make interim arrangements. This has been an unsatisfactory arrangement as the Agency has to regulate itself, policing its own actions. Knights Piesold, consulting environmental engineers, were employed to carry out the treatment at the plant and to act as advisors. The Agency would like to be able to remove themselves from the immediate work and concentrate on enforcing the regulations.[6] The work has been completely funded by the Department of

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4 R Williams, "Are overflows from abandoned mines unlawful?", *Water Law*, Vol 9 No 1, 1998, p 28

5 ibid

6 Phone conversation with Agency representative

the Environment, Transport and the Regions but this is not the general case for such incidents.

Three case studies are presented later in the paper: Pelenna in Wales, Wheal Jane and Bullhouse. Each of these cases were funded in different fashion. Due to the variable nature of the problem it is unlikely that a universal solution to the problem could be found but it would be helpful to those active in the treatment of these incidents if there was a universal funding solution, or at least a consistent approach.

The Government through the Environment Agency and the Coal Authority have provided the means to treat a number of mine drainage problems. In 1998/9 the Coal Authority spent £3 million tackling the problem of water pollution from abandoned mines and this is projected to rise to £3.9 million in 1999/2000. Estimates on the spend on Wheal Jane so far range between £9.5 million and £14 million.[7]

A recent announcement by the DETR[8] made provision for ring-fenced funding specifically for the treatment of acid mine drainage and channelled through the Coal Authority. The announcement of the funding, however, did not include any estimate of what future costs may be, or make any commitment to treat, or fund treatment of, all minewater incidents.

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[7] *Minewater Treatment Using Wetlands,* Conference of Chartered Institute of Water and Environmental Management, Newcastle 1997

[8] Department of Environment, Transport and the Regions Press Release ENV/972, *Minewater Pollution – Government Prescribes prevention as well as cure,* 1 December 1998

II Previous Parliamentary Discussion of the Problem

The issue of minewater was not ignored in the discussion of the Environment Act 1995 which closed the legal loophole in responsibility, nor was it missed that a temporal gap existed between implementation of the legislation and the closure of the loophole.

> **Mr. Chris Mullin (Sunderland, South):** Why does the Bill exempt coal mines from any consequence of polluted minewater until 1999? Why does it apply only to pits that are still open after 1999, and not to the large number of pits which have closed? Does that not speak more about the interests of the Government in creating a sustainable environment than all the lofty sentiments expressed at international conferences?
>
> **Mr. Gummer:** The hon. Gentleman cannot have read what my noble Friend said in the House of Lords. He made clear the responsibility that the Coal Authority would take on its shoulders until 1999. When the hon. Gentleman looks at the facts, he will see that we have protected people. I hope that he will not spread a misreading of what the situation will be.
>
> A proper balance has been introduced. It has been discussed in great detail in their Lordships' House, and it will undoubtedly be discussed here, too. We are clearly protecting the environment in a sensible way and making sure that people have proper notice of the responsibility which will lie on their shoulders after 1999. Up to that time, clear responsibilities will lie on the Coal Authority. The Coal Authority has accepted those responsibilities.[9]

The debate in the Lords was reported in the Library research paper on the Environment Bill.[10] The problem of minewater leaking from abandoned mines when pumping stops, the subsequent pollution of water courses and the statutory defence for this have been sources of widespread concern, heightened by the privatisation of British Coal. The situation in the Durham coalfield has been particularly pressing.

To summarise the problem, s85 of the *Water Resources Act (1991)* provides for the prosecution of river polluters, and allows the NRA to recover from the polluter the cost of cleaning up. A working mine is the responsibility of the owners, and if pollution is taking place then the NRA can make the owner deal with the pollution. But abandoned mines are specifically exempted by section 89(3):

"A person shall not be guilty of an offence under section 85 above by reason only of his permitting water from an abandoned mine to enter controlled water".

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9 HC Deb 4 April 1995 c 35

10 P Hughes & J Vernon, The Environment Bill [HL Bill 85 1994/95], Library Research Paper 95/50, 12 April 1995

To prosecute, one would need to prove that switching off mine pumps had *caused* pollution, which is extremely difficult to do. The Coal Authority assumed its full range of functions on 31 October 1994. Announcing this, the DTI noted that its functions would include "dealing with events such as landslips, water discharges or gas emissions which are its responsibility as owner of the coal reserves".[11]

In its response to the Coal Authority draft model licensing documents,[12] the NRA judged in April 1994 that there was nothing to suggest that the Coal Authority would have any more responsibility to prevent pollution than did British Coal, and stated "Clarification is needed about who, and in what circumstances, will have responsibility for water discharges from abandoned mines ... Neither the Bill nor the consultation document address any of the legal deficiencies ... ". The NRA was reported to be still unhappy with the Coal Industry Bill after its passage through both Houses.[13]

The *Coal Industry Act 1994* (CAP 21) contained no specific provisions relating to water from abandoned mines however, despite the fact that amendments to that effect were being tabled throughout the Bill's passage. Indeed, Mr Eggar said that the Bill's final stage in the Commons was a "re-run of a re-run of a re-run of previous debates". Lords and Government amendments dealing with liabilities and the financial wherewithal of operators to meet these were however added to the Bill,[14] and Lord Strathclyde gave the most far-reaching assurances during the Bill's passage:[15]

> "I should like there to be no doubt that so far as water pollution or potential water pollution is concerned the Government will not be content for the [Coal] Authority to rest on the present effect of the exemptions. On the contrary, we will expect it to go beyond the minimum standards of environmental responsibility which are set by its legal duties and to seek the best environmental result that can be secured from the use of the resources available to it for these purposes".

Lord Crickhowell went on to say that the Coal Authority (CA) would have to set priorities with the help of the NRA. He was certain this would include a commitment to keep pumping in the Durham coalfield. The CA's resources would "necessarily be limited" but he could assure the Committee that it would in due course have an earmarked budget for these purposes. Mr Atkins has since confirmed that the CA will have "a specific budget...which will enable it to carry forward in full the role and activities of British Coal in this area".[16] However, Mr Stuart Bell pointed out that Government

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11 DTI Press Release P/94/557, 19 September 1994

12 The Coal Authority - National Rivers Authority Response to Consultation on the Explanatory Note and draft model licensing documents plus PQ from Chris Mullin (Sunderland South) dated 20 April 1994, DTI, 20 April 1994, DEP 10699

13 *Water Bulletin* 8 July 1994 p 3

14 HC Deb 28 June 1994 cc 688 onwards

15 HL Deb 26 April 1994 c 541

16 HC Deb 4 May 1994 cc 534-535W

assurances amounted to "nothing in writing, nothing in the Bill and nothing in the statute book".[17]

There was a recent adjournment debate introduced by Alan Beith MP on the subject of minewater, in particular Whittle Colliery. Whittle is not, as yet, discharging minewater but it is accepted that it will begin to discharge in the year 2000:

> In March 1997, the pumps were stopped because the electricity bill had not been paid. They had been pumping 1 million cu m a year to keep the water level down. When the mine was working, they pumped 3 million cubic metres a year. The Environment Agency identified the seriousness of the problem in its local Environment Agency plan for the area in July 1997, and immediately public concern grew. Water levels are rising by 9 centimetres a day, and it was accepted that the mine was likely to overflow on a very large scale early in 2000.[18]

This demonstrates the likely time lag between closing a mine, switching off the pumps and the appearance of minewater discharge. Mr Beith went on to address the question of who would pay for the treatment of minewater discharges:

> On 16 July this year, the Minister for the Environment, the right hon. Member for Oldham, West and Royton (Mr. Meacher), was interviewed about the issue on Radio 4. I was delighted to hear him say:
>
> > "There's no question, action is going to be taken--no question whatsoever."
>
> He referred to the Strathclyde principle, under which the Coal Authority has moral obligations beyond its legal duties in cases of severe breakout of water. But it was still not clear who would be paying.
>
> The Minister for Trade, who is to reply to tonight's debate, issued a press release on 2 October in which he announced:
>
> > "the Coal Authority will take the lead role in preventing pollution and . . . funding will be provided to ensure a scheme is in place in good time."
>
> That sounds fine, but there is a rather worrying line in the press release which refers to the Coal Authority, the Environment Agency, Northumbrian Water and other local groups, and says:
>
> > "these organisations will now decide the best way of making provision."

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[17] HC Deb 28 June 1994 c 688

[18] HC Deb 19 October 1998 cc 1054-60

> Is it clear that the Coal Authority will foot the bill? If not, who else? What if it does not agree that it should contribute? Are the Government guaranteeing, as the Minister implied on the radio, that the money will be produced on time without any doubt or delay? Delay, of course, would be utterly disastrous, but we are entitled to some reassurance. I want to know whose name will be on the cheque.

The Minister (Mr John Battle MP) replied to the question of funding for this instance of minewater:

> I shall now turn to a point on which the right hon. Gentleman sought specific reassurance. On 2 October, I was able to confirm that the Coal Authority would oversee implementation and that the Department of Trade and Industry would ensure that the necessary funds would be available to allow it to do so. The first estimates are that the capital costs of the treatment will be around £450,000, with annual running costs of between £30,000 and £80,000. That spend will not adversely affect the authority's existing minewater programme. As a result of that action, any pollution of the River Coquet will be avoided.

This answer however does not guarantee that such money would be available for all such instances of minewater discharge. He went on however to issue a statement of principle about the issue:

> We take pollution from abandoned mines seriously, but it is important to keep the problem in clear perspective. Coal mining has been carried out in this country since Roman times, and more or less intensively for the past 400 years. Although overflows occur throughout the coalfields, the number of serious pollution incidents is amazingly low given the scale of former coal mining. The priority list agreed between the Coal Authority, the Environment Agency and the Scottish Environmental Protection Agency includes about 50 sites with serious discharges. Other pollution incidents do not figure on that list, but they are relatively minor in scale and impact.

This statement may be challenged by some academics.[19] It may be claimed that whilst it is true that the number of pollution incidents has been low, mining below the natural level of groundwater has only taken place since the development of the steam engine. Since then pumps have operated almost continuously. It is only now that the pumps are being switched off that the risk of pollution has significantly increased.

One suggested solution to the problem has been that the pumping of the mines be continued, thereby circumventing later discharge problems:

19 Personal Communication, *Minewater Treatment Using Wetlands*, Chartered Institute of Water and Environmental Management, Newcastle 1997

> **Lord Mason of Barnsley** asked Her Majesty's Government: Whether the Environment Agency has been liaising with the Clean Rivers Trust and the Anglers Conservation Association to examine the problems of environmental damage to lakes, rivers and streams caused by polluted minewater from closed coal mines; and what financial steps the agency intends to take to assist in keeping the pumps working.
>
> **Baroness Hayman:** The Environment Agency has discussed this issue with many organisations, including the Clean Rivers Trust and the Anglers Conservation Association.
>
> Under the "polluter pays" principle, the issue of whether or not pumps should be kept working to avoid a potential pollution incident when a mine is abandoned is a matter for the operator or former operator of a mine to consider alongside other options to prevent or treat any resulting water pollution. The Environment Agency is able to help operators to decide if this is the most appropriate environmental outcome for a particular mine, but would not expect to assist financially in keeping the pumps working…..[20]

Without financial input from the government it is unlikely such pumping would continue in all cases. The Clean Rivers Trust has been researching the possibility of using such water as potential sources of water for industrial or even potable water supplies.[21] That option would circumvent the requirement for Government money but interim support for such activity may be necessary as, once the pumps are switched off, it is often very expensive to reinstall and recommence pumping operations.

A recent report by the House of Commons Trade and Industry Select Committee[22] considered the issue of discharges from disused mines

> **Disused mines**
>
> **104.** We received evidence from a number of organisations, primarily from the Coal Authority and the Clean Rivers Trust, on the environmental effects of discharges from disused mines.[23] Water is pumped continually from many working deep-mines, in order to keep them in operation. If the pumps at a mine are switched off then that mine, and any connected workings, will gradually fill with water.[24] This can cause a number of problems, including the discharge of polluted minewater into the water table; flammable or noxious mine gases to be forced into the water table or to the surface; or the erosion of building

20 HL Deb 14 May 1998 c 136W

21 Clean Rivers Trust, The Wharf, Trent lane, Collingham, Newark, Nottinghamshire. NG23 7LZ

22 Trade and Industry Committee; *Energy Policy*, 2 June 1998, HC 471-I

23 Trade and Industry Committee; *Energy Policy* 2 June 1998, HC 471 App, pp 212-5; Coal Evidence pp 235-9

24 Trade and Industry Committee; *Energy Policy*, 2 June 1998, HC 471 App, pp 212-5; Coal Evidence pp 235-9

foundations.[25] The issue of emissions from disused mines is most serious with former coal mines. The Clean Rivers Trust said that "in most parts of the country where coal has been won and the coalfields abandoned these pollutions can be found."[26]

105. The responsibility for ensuring that mineworkings do not cause pollution rests with mineowners.[27] In the case of abandoned coal mines, the Coal Authority has assumed ownership and has undertaken a range of measures to monitor and deal with minewater and other emissions, including;[28]

Maintaining water pumping at 11 sites, mostly in County Durham.[29]

Working in cooperation with the Environment Agency and others to initiate surface water treatment projects, including those at the former Woolley Colliery, Yorkshire; and on the River Pelenna, south Wales. Four new treatment works were due to open during 1997/98, including at the former Bullhouse Colliery, Yorkshire.[30] A report commissioned by the Welsh Office in 1994 noted that "collection and treatment of contaminated water is usually the 'control of last resort' as it requires long term operation and maintenance, implying long term management, costs and liability.[31]

Monitoring water levels in a number of mines.

Monitoring coal bed methane levels and venting off the gas in several areas. There has been some commercial interest shown in using the gas currently vented at the Authority's sites.[32]

Researching the effects of turning off the pumps at various mines, and other research projects.[33]

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25 Ibid, and HL Deb, 5 November 1997, cc 1490-10. Also HC Deb 23 January 1992, c 486, HC Deb 28 January 1992 cc 479-80W concerning the water pollution incident associated with the Wheal Jane tin mine

26 Ibid. For an assessment of the scale of the problem see HC Deb 30 April 1996 c 427W

27 HC Deb 14 May 1996 cc 436-7W; HL Deb 27 June 1995, cc 599-601

28 Coal Authority, Report and Accounts 1996/97, pp 13-15. Also Coal Evidence, pp 236-9, sections 1 and 5; HL Deb 22 February 1994 c 517; 27 June 1995 c 600. Owners of existing abandoned mines have a statutory defence against prosecution for permitting minewater to flow into controlled waters, which, following the passing of the Environment Act 1995, expires after 31 December 1999. The Coal Authority have not made use of this protection

29 HC Deb 16 April 1996 cc 374-5W

30 Ibid; HC Deb 26 January 1994 c 242W; Daily Telegraph 25 March 1997

31 Study of ferruginous minewater impacts in Wales: phase 2a, determination of remedial options, Volume 1 - main report, Steffen, Robertson and Kirsten (UK) Ltd., for the National Rivers Authority and the Welsh Office, September 1994, p 26. Also pp 50-58

32 The Times 8 November 1997 p 23; The Observer, 1 February 1998 p 16. Also, App. p 224. HC Deb 25 February 1998 c 249W

33 Trade and Industry Committee; *Energy Policy*. 2 June 1998 HC 471. App, p 214; HC Deb, 16 April 1996, c 376W

The Authority spent approximately £2 million on these operations in 1996/97.[34]

106. Three areas of concern were brought to our attention regarding the current regime for dealing with minewater emissions:

Where mineworkings are linked, the cessation of water pumping from one mine can affect activity at neighbouring mines. For example, water pumped from RJB Mining's Calverton colliery in Nottinghamshire currently relieves pressure on the coal measures to the west of Annesley Colliery, owned by Midlands Mining.[35] Were Calverton to close, then Midlands Mining would be required to assume some of RJB Mining's water pumping responsibilities in order to keep Annesley operational. Midlands Mining argue that the costs of taking over the pumps could raise the overhead costs of mining at Annesley to such an extent that they would be forced to close the pit. Midlands Mining have requested that the Government pay the costs of water pumping in cases such as this.[36]

Although the ownership of coal reserves is vested by law in the Coal Authority, no corresponding body exists to own, and thereby be responsible for any damage resulting from, the UK's other mineral reserves. The Environment Agency has assumed responsibility for pumping water from the abandoned Wheal Jane tin mine, at a cost of approximately £2 million per annum.[37] The Coal Authority has stated that "perhaps it is now time to consider legislative change to allocate responsibilities for minewater discharges from all types of mining activities and not just coal".[38]

The position with regard to responsibility for the emissions of gases from abandoned mines is uncertain. The report commissioned by the Department of Environment on the discharge of gases from disused mines concluded that "there would be an obvious advantage if there was an appropriate consultation authority for coal mine gases", with whom local authorities could deal when emission events occur.[39] The Coal Authority concurred, arguing that there should be "further analysis of responsibility for gas emissions from all types of mining activities and not just coal".

We believe that it is time for the Government to look again at the legislation which deals with the UK's historic mining legacy, particularly with regard to the merits of establishing one body to which ownership of all the UK's onshore mineral reserves can be attributed.

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34 HC Deb 16 April 1996 c 375W
35 Trade and Industry Committee; *Energy Policy,* 2 June 1998 HC 471 App p 213
36 Coal Evidence p 194 paragraph 10; Sunday Telegraph 30 November 1997 p B1
37 HC Deb 16 April 1996 c 375W; 26 January 1994 c 242W; 15 February 1996 c 661W; App, p 213
38 Coal Evidence p 238 Section 5
39 Methane and other gases from disused coal mines: the planning response, Wardell Armstrong for the Department of the Environment, November 1996, p 61, 67, 85

III Treatment of Acid Mine Drainage

A. What are the treatment options?

AMD events are more pernicious than incidents involving nitrate and oil because the pollutant will not be broken down in the environment. Whilst nitrates may be utilised by aquatic organisms and oil may eventually be broken down to carbon dioxide and water, the metal pollutants will remain in the environment in one form or another. The iron will be present; the copper will be present. Under certain conditions metals may be concentrated in the environment, under others they may be dispersed. Without treatment there will be no controls as to where these concentrated, or dispersed, metals will deposit. In the meantime there will be an extended period of time in which the local environment will suffer the effects of the pollution.

AMD is not however a new problem. There have been several AMD incidents in the past and they have been treated by an assortment of technologies. In Canada there has been a long-term programme (MEND) involving government, academic and industrial partners which has investigated a range of minewater treatments. There is still no real consensus on what is the ideal solution, and it may be that each and every AMD incident will have to have its own unique treatment solution.

In the UK there has also been some experience with acid mine drainage. One of the major incidents was the Wheal Jane AMD pollution incident. In this case the mine produced metals (rather than coal) and the drainage contained high levels of zinc and cadmium as well as the ubiquitous iron. It was the presence of the iron that made the headlines as this metal turns a bright orange and the plume of orange pollution was highly visible to onlookers. The metals impacted on the local Fal Estuary which has received similar waters from the local mining industry over much of the last two centuries. It was likely the result of the visual impact, rather than the threat of zinc and cadmium contamination, which stimulated the public outcry and encouraged swift Government intervention. The Wheal Jane site has become a test site for AMD treatment in the UK. There have been several active technologies tested at the site and the largest passive treatment pilot plant in Europe built to test the potential of this technology.

B. Who will carry out the treatment?

The issue of funding and liability is fundamental to who will carry out the task of treating acid mine drainage. As the law stands no-one has a statutory responsibility or duty to treat the minewater problem. Although there are academics with proposals for treatment technologies there are liability problems with carrying out these programmes. If a treatment plant is put in place and there is a subsequent breach of discharge consent then the operators of the plant may be liable for the costs of cleaning up the problem. This is despite the fact that the situation is unlikely to be worse than it would have been had the treatment not been attempted.

One option that has been investigated is the use of the minewater as a water source. In many instances this will be impractical as the source will be too far away from potential users to make it worthwhile treating the water and pumping it. In others the cost of treatment and liability make the project too risky for a water company to contemplate.

Water companies would be well equipped to carry out this work as they possess the multidisciplinary teams necessary for the analysis and engineering required. The treatment of mine drainage is specialised. The acidity and the metals content of the water make it very different to most other waste streams. The existence of so many small incidents may make it necessary to award a national contract for the treatment of all the mine drainage incidents rather than award contracts piecemeal. A unified approach would be of immense value in clarifying what action might be undertaken and who would fund it. It may be that only through a national programme might all the environmental issues of the problem be satisfactorily addressed.

The treatment of AMD by most, if not all, of the current active and passive technologies produces a metal-containing residue which requires disposal. Due to the metal content this often means special waste conditions which can become very expensive over the long period over which such discharges are likely to continue.

Water companies, especially those with waste disposal subsidiaries, are well placed to carry out such a role but have argued for a co-ordinated framework in which they might operate and a limited liability against which they might make sensible business plans.[40]

Currently the legislation makes it unlikely that anyone will volunteer to take up any remediation due to the reluctance to accept the liability and there is no organised fund to which academics might apply to conduct research into the problem.[41]

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40 Personal Communication, *Metals Minerals and the Environment II*, IMM conference, Prague, 1994

41 Personal Communication, *Minewater Treatment Using Wetlands,* Chartered Institute of Water and Environmental Management, Newcastle 1997

IV Treatment Options

Treatment of mine drainage can take two basic forms. There are active treatment systems and passive treatment systems. The main difference between these is that active treatment systems, as the name suggests, requires a constant maintenance of the system, supplying, e.g., lime for neutralisation and transport of wastes away from the site. Passive treatment systems by comparison are designed to allow for low, or no, maintenance and should be self contained with regards to treatment and waste.

The use of lime to neutralise mine drainage and precipitate metals (an active treatment system) is considered, within this paper, as the standard against which other methods are compared as it has been the automatic treatment choice for many years. Lime treatment is simple and robust, and the benefits and drawbacks of the treatment well known due to long usage. It does, however, present several environmental problems. The material produced after treatment with the lime is metal rich and usually contains a significant amount of water. The metals mean that it will often require special waste disposal facilities which add to the costs of disposal. The water content increases the volume and weight of the waste which means that money is being spent to dispose of water (both in transport and landfill fees) which might otherwise be avoided. The general methods to reduce the water content are often labour or energy intensive which also increase costs and are often unable to keep up with the flow of material from the treatment system. The requirement for lime also has direct environmental consequences for the regions where the limestone is quarried. Derbyshire is a major source of limestone (which cannot be recycled and reused) and this will subsequently be transported to wherever it is required. Both the quarrying and the transport degrade the environment and cast doubts on whether this option is sustainable in the long term, especially as the problem of mine drainage becomes more widespread.

Alternatives must provide some advantage over the lime treatment either in the use of materials, the disposal of waste, or the production of usable materials. These questions will be addressed in the remainder of this section. A more detailed look at the technologies is available in Appendix A.

A. Greater waste stability

The generation of ochre is a problem because of its inherent instability. In an environment such as that represented by most natural watercourses then ochre exists as a low density solid material. The ochre can be packed by pressing but under running water the ochre will erode and deposit elsewhere. It may also be re-dissolved if exposed to acidic water, precipitating later in other watercourses. The low density of the material means that very small amounts are capable of coating large surface areas. This gives it a very high environmental impact for the relative amounts present.

Some technologies have been developed to improve the density, or other physical characteristics of the waste material. Some treatment technologies involve using materials (natural or manufactured) which have been shown to adsorb the metal contaminants (*adsorption technology*), or manipulate the environment to make precipitates more dense (*physical process technology*). Increased density will encourage a more rapid precipitation of the waste material as will adsorbing the metals onto material which can be readily retrieved from solution (such as that used as an adsorbent).

In both of these solutions there exists a waste disposal problem, though it may be reduced due to the reduced volume of the dense particles, or because the adsorbent may be burned or recycled leaving a more concentrated waste. In both situations there may be an increased resistance to metals re-dissolving when exposed to acidic solutions.

B. Recovery of metals and other valuable products

It is possible using some of the technologies available to extract and retain valuable metals from the mine drainage and use these to offset the costs of treatment. In some cases this recovery is the only reason to convert to the technology. *Ion exchange* and *membrane-based separation* treatments both offer this option. In these cases the metals can be taken out of solution and selectively concentrated until they effect a commercial product.

With the use of these technologies it is also possible that a potable water supply may be produced, though this is likely to be more expensive than the revenue such a product would generate. A more likely option is the production of 'grey' water which may have industrial uses.

Some lime-using processes produce gypsum as a waste product. This gypsum may have a market to which the waste (or product) can be disposed. There is one system on the market[42] which currently claims that all the products of the mine drainage would be converted to saleable products. This does of course rest on the fact that a market exists near the treatment facility as all products will tend to be of low value and transport costs could outweigh any market value.

Most of the ion exchange and membrane based technologies will also require some pH modification, usually in the form of adding lime. This is a far lesser use of lime however as only small amounts are required to modify the drainage to neutral as opposed to the amounts required to make the solution alkaline enough to precipitate metals as in standard lime treatment scenarios.

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42 http://www.info-mine.com/rgroup/rtc/gypsix.html

C. Alternative waste products

Another possibility is utilising technologies that do not produce ochre. One option is to precipitate the metals in another form entirely, such as achieved by *biologically based technology*. These systems are predicated upon the ability of sulphate reducing bacteria to produce hydrogen sulphide which can precipitate the metals as metal sulphides. These sulphides are far more dense than ochre and, when kept out of an oxidising environment, extremely stable in acid solutions. Other technologies, such as offered by Keeco,[43] utilise proprietary *pH modifiers* and claim to produce a more stable precipitate that is not only more dense and contains less water than ochre but also is far more environmentally stable.

D. Passive Treatment Technology

This category of treatment is generally restricted to the use of wetlands to remediate the mine drainage. There are many instances of mine water running into volunteer (naturally occurring) wetlands where the water emanating from the wetland is improved with regard to both metal content and acidity.

The nature of AMD is that it persists for long periods of time, often requiring constant low level treatment. The maintenance of equipment is often more expensive than the reagents used for treatment and the development of a treatment method which did not require the active participation of managers. When wetlands technology was proposed after some promising results in the United States it seemed to be the answer to the AMD problem. It was a natural answer to the problem removing both metals from the water and acidity. Unfortunately the technology has not lived up to the promise suugested by early research. It is unlikely that wetlands will prove a walkaway solution to the problem.

The attraction of the wetland is that the bacteria that occur naturally in the sediments are capable of reducing the sulphate in the acid to hydrogen sulphide which can react with the metals to form the metal sulphide minerals which originally caused the acid mine drainage. The main problems with the wetlands solution are the time it may take for a natural system to react to the, sometimes extreme, changes in water flow and the fact that whilst the water flows all year round the bacteria are most active when the weather is warm. There is also an engineering problem: getting the water to contact, most efficiently, the anaerobic (oxygen-free) parts of the wetland where the remedial process is most efficient.

There have been several modifications to the original wetland solution, with each adding more and more active elements to the passive solution. It is now recognised that there is unlikely to be a completely passive system, but there are hopes that a low maintenance solution may be found.

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[43] http://www.keeco.com

The construction of a wetland treatment system for AMD will generally require water being treated to comply to the same discharge consents as would have been granted to active treatment plants. There may be some arguments made as to the positive environmental benefits of constructing the wetland rather than an active treatment system but this is usually considered to be balanced by the much higher construction costs of wetland systems.

Consideration must also be given to the design of the wetland system. To aid the treatment of mine drainage the wetland is often highly engineered, sometimes to the extent that the system is a wetland only in name. Such wetlands are often referred to by consultant engineers simply as passive treatment systems rather than engender expectations by calling them wetland systems. The problem here is that such highly engineered systems are likely to require much higher maintenance costs and are unlikely to develop into self sustaining ecosystems over time.[44]

It has been proposed[45] that wetland systems should be engineered only to enhance the efficiency of natural systems and allow the wetland to develop into something approaching a natural state. If left to develop then the metals contained within the wetland would be maintained in a form that would be unavailable and non-polluting to the environment until the wetland was disturbed. The technology for such an approach is not yet available but would provide a solution for both the treatment and waste disposal problems posed by acid mine drainage.

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[44] S McGinness et al, *Constructed Wetlands – A flawed Concept?*, Metals Minerals and the Environment II, Institute of Mining and Metallurgy, Prague 1994

[45] S McGinness et al *Care and Feeding of Constructed Wetlands*, Minewater Treatment Using Wetlands, Chartered Institute of Water and Environmental Management, Newcastle 1997

V Case Studies and Research Programmes

A. MEND[46]

The first action by the Canadian Government on acid mine drainage was through the establishment of a group known as the National Uranium Tailings Program in 1982. This group focused on the isolation of low levels of radiation from uranium tailings but the research showed that acid being generated from residual sulphur in general mine tailings was a far more serious problem. From these concerns a task force was established which issued a report in 1988 setting out a research programme. This programme was planned to continue over 5 years and cost $12.5 million.

The program was to be known as MEND (Mine Environment Neutral Drainage) or in French as NEDEM (Neutralisation des Eaux de Drainage dans l'Environnement Minier). The objectives of the programme were:

- to provide a comprehensive, scientific, technical and economic basis for the mining industry and government agencies to predict with confidence the long term management requirements for reactive tailings and waste rock, and

- to establish techniques that will enable the operation and closure of acid generating tailings and waste rock disposal areas in a predictable, affordable, timely and environmentally acceptable manner.

The following arguments were used against the programme, some of which still are:

- Acid drainage was a temporary, short term issue at mine sites;
- If wastes or mine walls are not now acid generating, they never will be;
- Natural processes will treat or compensate for acid generation as had been the case for hundreds of years; and
- Consultants have all the answers already.

After some research the programme estimated the liability from acid mine drainage in Canada to be between $1.9 billion and $5.3 billion.

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[46] DG Feasby, GA Tremblay and CJ Weatherell, A Decade of Technology Improvement to the Challenge of Acid Drainage - A Canadian Perspective, Fourth International Conference on Acid Rock Drainage, Vancouver, BC, 31 May - 6 June 1997

1. What has been achieved?

Over 200 projects have been conducted or are under way across Canada. The major elements of the research have been:

- development of chemical prediction methods;
- development and application of predictive models;
- demonstration of water covers and underwater disposal as a prevention technique;
- adaptation of dry covers as oxygen and infiltration barriers;
- passive treatment evaluation and lime sludge stabilization; and
- sampling manuals, standards.

These achievements do not represent new technology that will solve the programme but a study conducted in 1996 on five mine sites showed that a reduction of $340 million had been achieved through application of these results. The same study showed:

- there has been much greater common understanding of issues and solutions;
- the research has led to less environmental impact;
- there is increased diligence by regulators, industry and public;
- MEND has been recognised as a model for industry-government cooperation;
- the work should continue with strong international connections; and
- future work should include expert practitioners.

2. What can the UK learn from MEND?

From the MEND program useful lessons have emerged on the legislative side as well as on technical aspects. Those involved with the program believe that it shows co-operation between industry and various levels of Government not only works but is absolutely necessary for any progress to be achieved.[47] Solutions can be developed if there is a national focus for the research. It has also been found that the best results have been achieved using good common sense, approaching problems by enhancing natural processes rather than trying to engineer solutions that work against or around the natural environment.

MEND has provided a central focus absent in the UK. In the UK the problem seems to require solving as each individual minewater event becomes apparent.[48] The Government has taken the first steps toward solving the problem by placing the Coal Authority in the front line. This, however, only addresses the Governmental part of the problem, it does not really integrate Government, industry and academia in the way achieved by the MEND programme.

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[47] DG Feasby, GA Tremblay and CJ Weatherell. *A Decade of Technology Improvement to the Challenge of Acid Drainage - A Canadian Perspective*, MEND Secretariat, CANMET, Natural Resources Canada

[48] Discussion, *Minewater Treatment Using Wetlands,* Conference of Chartered Institute of Water and Environmental Management, Newcastle 1997

B. UK Research

There is, of course, UK based research into both the cause of AMD and potential remediation technologies. There are many aspects to the treatment of acid mine drainage and is divided between the active (those which require reactive water to be pumped and treated) and passive technologies. Some of the major sites for acid mine drainage research are

University of Exeter (Camborne School of Mines)
University of Newcastle
University of Wales, Bangor
Imperial College, London
University of Leeds
University of Nottingham.

The research cannot be easily separated into chemical, biological, engineering and modelling. There is often a substantial overlap in the requirements from each discipline. It is often difficult to see how it all fits together to provide the answer to the problem of AMD. Many of these research efforts have been fed into Environment Agency (EA) managed research at sites of acid mine drainage. The EA is keen to encourage research at the sites where such treatment is taking place. At Wheal Jane there are currently moves to co-ordinate a large scale research programme to study passive treatment systems. It is hoped that such information might help make the process more efficient and possibly become a real alternative to active treatment systems.

There is, however, no programme such as MEND within the UK. Whilst water companies are interested in the issue and the application of developing technologies, there is little industrial interest in funding the basic research required in the treatment of AMD. This lack of strategic planning within AMD treatment research may have severe and expensive consequences when it becomes necessary to treat the mine drainage expected at many sites as mines inevitably close.[49]

C. Wheal Jane

Wheal Jane and the local vicinity has been mined for copper, zinc, tin and lead since at least the 18th Century. Wheal Jane and South Crofty were the last two mines in the area though they did not have any interconnecting workings. When Wheal Jane closed the mine was allowed to flood and, despite some last minute efforts by the Environment Agency, the water burst out of the mine and into the local waterways.

The quality of Wheal Jane AMD, as would be expected, has improved with time, although treatment is still necessary. The water quality of the initial flux of minewater,

[49] Discussion, Minewater Research Seminar, Newcastle Mining Institute, August 1998

when the Nangiles adit plug failed in January 1992, and in 1995, are shown in Table 1. The rapid decline in metal content is due to the intial flush of water carrying all of the sulphate salts that had accumulated when the mine was working and dry.

Table 1 Chemical quality of Wheal Jane minewater
All units parts per million dissolved (except pH**)**

	Jan 1992[a]	**1995[b]**
pH	2.6-3.1	3.5
Aluminium	170-197	30
Arsenic	26-29	9
Cadmium	1.4-1.9	1
Copper	14-18	1.5
Iron	1720-1900	300
Manganese	11-25	12
Zinc	1260-1700	120

[a] Hamilton *et al.* 1994; **[b]** Dodds-Smith *et al.* 1995

Despite this dramatic fall in metal concentrations this water is still far higher than can be allowed to discharge into the natural environment. Three hundred parts per million iron would create huge discolouration of the river once it had precipitated onto the river bottom. The zinc provides a potential revenue but it is difficult to remove from the iron economically. All minewater incidents if monitored would show an exponential decline in metal content. Whilst this is encouraging (the high levels of contamination are transitory) it is also discouraging (low levels of iron contamination are likely to persist for long periods of time).

1. Active Treatment System

The quantity of water requiring treatment is seasonally dependent. Water is currently pumped from the main shaft, with a maximum pumping capacity of 315 litres per second. In times of high precipitation, when this pumping capacity is insufficient to maintain water below adit level, excess minewater flows from the Nangiles adit.

The current treatment method for AMD at Wheal Jane involves addition of lime and flocculant[50] to precipitate out the metals. This treatment results in a relatively low-density sludge (generally less than 2% solids) which is deposited in the tailings dam. However, the tailings dam has a finite capacity - probably sufficient for only a further 5 to 10 years deposition of sludge at the current rate.

50 *flocculant* – a substance that encourages fine particulates to clump together and drop to the bottom of the container

The cost of the lime addition treatment is taken as the 'baseline' with which to compare the alternative technologies. These costings are taken from the NRA report (1996) on the environmental appraisal and treatment strategy for Wheal Jane.

Annual operating costs of Wheal Jane lime treatment plant

	Consumption	Unit price	Annual cost (thousands)
Installed capacity			300 l/s
Treatment rate			155 l/s
Electricity	0.38 kWh/m^3	1.8 p/m^3	£88
Lime	0.87 kg/m^3	5.8 p/m^3	£285
Flocculant	3 g/m^3	0.6 p/m^3	£27
Water & sundries		1.8 p/m^3	£90
Maintenance		1.2 p/m^3	£60
Sludge disposal		£43.75/tonne dry solid	£198
TOTAL		**15.2 p/ m^3**	**£748**

kWh/m^3 – *kilowatts hours per cubic metre*
kg/m^3 – *kilograms per cubic metre*
p/m^3 – *pence per cubic metre*
l/s – *litres per second*

No capital costs are included in this assessment since the plant is already installed and operative. However, it is estimated that capital costs in the region of **£1.5 million** would be necessary to install a lime treatment facility at Wheal Jane.[51]

Whilst the lime treatment has proven effective in treating the effluent and stopping the pollution reaching the local watercourses it cannot be seen as an ideal long term solution. Quarrying lime in Derbyshire and transporting that to Cornwall, or wherever else required, then generating waste that may also have to be transported to landfill is not sustainable environmentally. There must be a cheaper solution, in economic and environmental terms.

[51] Based on pilot study carried out by the NRA with regard to lime treatment of coal mine discharge in Yorkshire, Bird 1994

2. Passive Treatment Pilot Plant

> **Wetlands Technology**
>
> This paper uses the phrase wetlands technology throughout. This technology is based around utilising the natural processes that take place within the oxygen-free, carbon-rich areas of the wetland. These processes result in the production of hydrogen sulphide gas and the natural precipitation of metals within the wetland sediments.

The Wheal Jane incident provided an opportunity to test the passive treatment option represented by wetlands technology being utilised in the United States to treat AMD. The idea of the pilot plant was to assess whether the technology would prove sufficient to treat the drainage from the mine.[52] This would avoid the need for active treatment of the minewater for the next forty or fifty years (a not unrealistic estimate of how long the discharge might continue). Despite spending approximately £2 million on the pilot plant it was concluded that the technology would not be as efficient as the active treatment system and would require too much of the local land area to even approach the same level of treatment efficiency. Much data was gathered during the pilot scheme which could be applied to future AMD events where passive treatment may be applicable.

D. River Pelenna Minewater Treatment Project

This is a major treatment initiative in the south of Wales. The project is neatly summarised in a paper presented at a conference in Newcastle[53] the abstract of which is reproduced below:

> River Pelenna, in the Tonmawr area of the western valleys of South Wales, is stained a vivid orange for approximately 7km of its length, due to elevated concentrations of iron which is flushed from the numerous abandoned coal mines in the area. The River Pelenna Minewater Treatment Project has been established to restore the river using passive methods to remove metals from the minewater before it reaches the river. The project is being implemented by a partnership between Neath Port Talbot County Borough Council and the Environment Agency with financial support from the Welsh Development Agency and the European Union LIFE Programme. Funding for additional work is being provided by the BOC Foundation for the Environment. To date, the first of five wetland treatment systems has been constructed and achieved 80% iron removal on average during the first eighteen months of operation. Treatment systems for the other four main discharges in the valley will be constructed in 1997 and 1998.

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52 Knights Piesold and Environment Agency launch of the pilot treatment plant, Stithians Church Hall, 1994

53 PJ Edwards, CP Bolton, CM Ranson, & AC Smith, *The River Pelenna Minewater Treatment Project* Wetlands for Minewater Treatment, CIWEM, 1997

As stated this project utilises a passive treatment system where reed beds have been constructed to remove the iron from the water. Due to the reduced toxicity as compared with Wheal Jane there is not the same need for active systems such as are present there. The major problem remains the same however, what to do with the sludge generated in the treatment.

The reed beds at Pelenna do not utilise the anaerobic chemistry that transforms the solubilised iron to iron sulphides but merely to enhance the oxidation processes required to precipitate the iron as hydroxyferrous sulphates and generate ochre. The ochre will accumulate and may eventually overwhelm the wetland unless it is removed. The project does however represent one of the first examples of treatment of a major AMD related problem solely through the use of constructed wetlands. There exist a number of smaller projects, such as the Quaking Houses Project in Tyneside which also utilises wetland principles but on a much smaller scale. Dr Paul Younger, the Newcastle University academic behind this project, wrote the following about the Quaking Houses:

> The pilot wetland at Quaking Houses was constructed with the vigorous assistance of the local community. This comprised four cells in series, the first two occupied by saturated horse manure and soil, the third with open water and a limestone berm to provide pH adjustment, and the fourth an aerobic overland flow system established on in situ soil. During 18 months of operation, the wetland performed favourably, reducing acidity at an average rate of 9.6 g/d/m2. The third cell of the wetland was extensively colonised by aquatic invertebrates (which are absent in the polluted stream).
>
> A scheme for full-scale passive treatment at Quaking Houses has now been devised, based upon the successful outcome of the NRA(EA)-funded project. This scheme has now received financial support from the Northumbrian Water Kick-Start Fund, Shell Better Britain and other funding agencies, and construction is due to commence in Spring 1997. Funding so far received will cover the capital costs of the scheme (around £55K), with long-term maintenance being undertaken by local volunteers at minimal cost.

1. The need for good forward planning[54]

The Pelenna Project centred around three discharges of AMD. Two of these discharges were large and one much smaller. The two larger discharges were allocated more attention and without a complete hydrogeological survey it was decided that the small discharge would not require similar treatment resources as its larger counterparts.

[54] Phone discussion with Environment Agency and Dr Paul Younger

During the heavy rains over the Winter of 1998/9 it was discovered that one of larger discharges was no longer producing significant volumes of acid mine drainage and that the small discharge had increased its flow significantly. Subsequent investigation showed that the heavy rains had washed away a roof-fall within the workings which had been diverting water. Once the blockage was gone, the water followed a predictable course to what had been the site of the small discharge which now requires far greater treatment than was provided. Had the initial study, or the treatment provision over the three sites, been more comprehensive then it is unlikely there would now be a problem.

This highlights the need for good planning with less focus on costs. With the variable nature of the AMD problem and the possibility of changes underground, it makes sense to ensure that treatment plans are as flexible and comprehensive as possible.

E. Bullhouse Colliery[55]

The Coal Authority is a major partner in a £1 million scheme to clean up polluted water along a six kilometre stretch of the River Don near Penistone in South Yorkshire. Ochreous discharge, caused by water building up inside the old Bullhouse colliery workings, is ranked the sixth worst in England and Wales.

Although the River Don is a good fishery, supporting brown trout upstream, Fish cannot breed in the area affected by the Bullhouse mine, which closed in 1918. The condition of the river has caused concern for many years. This scheme is designed to achieve a natural clean-up of the river with fish and other wildlife recognising the affected stretch of water within a couple of years.

The project is regarded as a pilot scheme in Europe as other countries, such as Germany, Spain and Greece, face similar minewater pollution problems. It has been funded by £470,000 from the European Union, £225,000 from The Coal Authority, £115,000 from the Environment Agency, £100,000 from Hepworth Building Projects and £5,000 from Barnsley Council.

In recent years, the Bullhouse colliery has been quarried from the surface by Hepworth's for the valuable clays which lay beneath the coal. The quarry is now worked out and around 30 acres have been restored but five acres of the quarry void has been set aside for a lagoon system capable of cleaning up the minewater discharge.

Water from the mine workings is diverted to the treatment facility and then discharged into the river lagoons being built in the quarry will contain up to 40,000 tonnes of minewater. The minewater then passes over cascades to allow reaction with air prior to entering the lagoon, encouraging the ochre to drop out more quickly.

[55] http://www.coal.gov.uk/

After treatment in the lagoons, the water passes through a reedbed which acts as a further treatment level by trapping any remaining fine particles suspended in the water This will ensure that the minewater which is released into the river will be treated and free from sediment.

It is proposed that ochre from the bottom of the lagoons could be collected and utilised, thereby offering a potential resource for local companies in processes such as brick and cement manufacturing. There are still problems however ensuring that the quality of the ochre produced in treatment plants will be as high and as reproducible as supplied from mined sources.

The Environment Agency when tendering for consultant engineers for this project have been highlighting the requirement for forward planning in tenders and the inclusion of innovative ideas and research within the main treatment remit. It is difficult however to innovate when failure may result in financial penalties that would not be risked by playing safe.

F. Other Current Minewater Activities

1. Coal Authority[56]

Further wetland schemes to improve the quality of minewater discharges from former mineworkings are planned throughout the coalfield areas.

The Coal Authority has welcomed the announcement of the Environment Agency list (below) of more serious minewater discharges from abandoned coal mines, and is working in partnership with interested bodies to establish the next priorities.

Priority Abandoned Minewater Sites in England and Wales

1	Sheephouse Wood	18	Abersychan	35	Dunvant
2	Lambley	19	Aspden Valley	36	Craig y Aber
3	Allerdeanmill	20	Stoney Heap	37	Bullhouse
4	Deerplay	21	Bradley Brook	38	Blaenavon/Llwyd
5	Blackwood	22	Craggs Moor	39	Old Meadows
6	Clough Foot	23	Tawe trib (Llechart)	40	Aspull Sough
7	Silkstone	24	Hapton Valley	41	North Celynen
8	Pontilanfraith	25	Corryg Fechan	42	Acomb
9	Taff Merthyr	26	Edmonsley	43	Tir y Berth
10	Jackson Bridge	27	Shepley Dyke	44	Summerley No.1
11	Corrwg	28	Chirm	45	Tanygarn
12	Summersales	29	Hagwood	46	Unstone No.1
13	Claywheels Lane	30	Llyfni	47	Haydock Sough
14	Six Bells	31	N. Gwynfi	48	Lowlands
15	Loxley Bottom	32	Ynysarwed	49	Byrons Drift
16	A. Morlais	33	Harecastle Canal	50	Ynysbwl
17	Fender	34	Bridgewater Canal		

This is the latest available list. Obviously the list is subject to change as site conditions change either through more recent analyses or remediation work.

[56] The Coal Authority, 200 Lichfield Lane, Berry Hill, Mansfield, Nottinghamshire. NG18 4RG

Work is planned to start on schemes at selected priority sites in Scotland, England and Wales this year, where negotiations are currently taking place to acquire the necessary land.

Continuing to develop understanding of the environmental effects and treatment of minewater is one of eight objectives set by the Authority Code of Environmental Practice.

The Coal Authority is working closely with the Environment Agency and the Scottish Environment Protection Agency, local authorities and other external agencies to introduce a phased programme of treatment schemes at the next priority sites.

Appendix A - Active Treatment Technologies

For classification purposes, the available technologies considered in this report are grouped according to the type of treatment, although there is sometimes overlap if a particular technology applies more than one treatment principle. However, technologies can be broadly subdivided into:

- pH modification;
- ion exchange;
- biology-based technology;
- other adsorption technology;
- electrochemical technology; and
- physical process technology.

A. pH Modification

The basis of such treatment is to raise the pH of the AMD causing first the iron, and then other metals, to precipitate out of solution. The lime treatment currently used at Wheal Jane uses this chemical process. Liming has the following advantages:

- It is a tried and tested technology;
- It is effective for the treatment of highly acidic waters;
- Treatment is largely unaffected by seasonal temperature fluctuations;
- It requires relatively straightforward plant and operation;
- Decant water from the settling dam is of sufficient quality to be discharged into the river;
- The process can accommodate changes in water quality or quantity by relatively easy adjustments of the operating parameters.

However, there are also numerous drawbacks to liming:

- Equipment maintenance is relatively high due to scaling;
- The high pH that is needed to remove metals such as manganese may cause remobilisation of other metal hydroxides (e.g. aluminium);
- The sludge is chemically complex and unstable, making long-term disposal problematic;
- Sludges are low density and gelatinous so there are large volumes which are difficult and expensive to handle and dispose of;
- The sludges generally have no commercial value - reclamation of metals is uneconomic due to the complexity of the mixture and the large excess of lime that is generally used to ensure complete precipitation.

Subsequent pH modifying technologies have been developed to attempt to address some of these problems. Refinements made to the conventional lime-dosing treatment have included:

- use of waste products rather than lime, making the technology cheaper because the material is cheaper than lime;
- use of alternative reagents to produce a sludge with a lower water content, or a more stable sludge, or both;
- use of processing techniques, rather than alternative reagents, to achieve these results.

It is possible that alternatives to lime, e.g., KB-1,[57] may be found where the mixing technology already familiar to workers in the field may continue to be used but the resulting sludges would be more dense and less likely to subsequent movement back into the environment.

There are a huge number of treatments which have been discussed in the literature and demonstrated to be capable of treating AMD. There are few, however, that have been demonstrated on a large scale or are proven to work efficiently or quickly enough. There must also be some concern raised over the use of waste products to treat any AMD as there will inevitably be variability in the availability and content of such reagents.

However, some companies have developed their technology to a level where it may be seriously considered as an alternative to lime. Their approaches to AMD treatment are outlined below.

B. Ion Exchange

The presence of base metals such as zinc and copper in acid mine drainage holds out the promise that costs may be offset against the value of metal recovered. The concentrations of the metals in sludge produced by simple liming are not sufficient for smelter operators to pay for it. An obvious choice was to utilise ion exchange technology to strip valuable metals from the minewater before it was limed and subsequently eluting the metal from the ion-exchange material in a far more concentrated form. Laboratory studies proved it was possible to do so and the metal concentrates easily good enough to sell to smelting operations. The problem was that the ion exchange materials were often too expensive and the flows too great for the technology to handle economically. The cost of producing the metal was greater than the potential value, or the profit so small that initial costs in providing the technology to produce the metal would not be repaid for periods of fifteen years or more. Furthermore the yield of the minewater, and therefore economic gains, would continually decrease over the life of the plant due to the gradual improvement of minewater quality that often occurs post-closure.

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57 http://www.keeco.com/

C. Biology-Based Treatments

The use of wetlands was proposed as a method of treating minewaters in a passive way. This method, though suitable for some low contamination, low flow examples of AMD has not yet been proved as a universal solution to the problem of acid mine drainage. Some companies have however taken one of the active components of wetlands (the sulphate reducing bacteria) and used this to produce a biologically-based active treatment system. The bacteria require a good carbon-based substrate for metabolism but use sulphate instead of oxygen, and therefore do not require the air sparging that is so often a high cost of biological-based systems. The biological system is usually not good enough, on its own, to remove the complete acidity of the minewater, and so in many instances there are means of applying lime to the waters that have been cleaned of metals. The resultant products from the biogenic systems however are not stable in oxic environments and so there must also be some consideration made for the disposal of products. Another example of biologically-based treatments is the use of biologically-produced adsorbents for the concentration of metals from the waste stream.

D. Other Adsorption Treatments

The use of non-biological adsorbents is another technology option that has been investigated and proposed as a solution to the treatment of acid mine drainage. The aim of this process is to utilise particles of known size and density to adsorb the metals from solution and to exploit knowledge of physical processes in the separation of the solids later in the treatment.

E. Electrochemical Treatment Technologies

As the behaviour of metals in solution is often controlled by their electrochemistry, the use of electrical technologies in the treatment of AMD has received some attention. The problems that may be associated with the use of such technology are the requirement for nearby technical support and a constant electrical supply.

F. Physical Process Technology

There have been efforts to utilise physical process technology to remove the metals from AMD as salt crystals rather than as sludges or precipitates.