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THE CONTROL OF ACID MINE DRAINAGE WITH WETLANDS

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ABSTRACT

The recent increases in environmental legislation, especially in the USA have meant that there is a need on behalf of the mining companies for more judicious operational planning and more thorough restoration techniques in order to reduce costs and prevent violation of the strictly enforced regulations. Water pollution is probably the greatest problem and many less enlightened operators, especially for example, in surface coal milling in Pennsylvania, have been forced into liquidation after having been unable to meet the severe restrictions on Acid Mine Drainage (AMD).

The problems of AMD are also inherent in most forms of metalliferous and coal mining and also in some types of aggregate quarrying. As excavations go deeper in search of ever diminishing reserves then they are more likely to encounter groundwater which can become polluted if insufficient care is not taken.

It is to be expected that the laws will also become more severe than they are at present in Europe and methods of treatment of AMD will need to be developed that are more efficient than the costly chemical methods currently used. Research by the author and others into the source of AMD pollution and its treatment with engineered wetlands and other operational methods are discussed in the paper. The methods have the distinct benefit that they are cheap to install, are cost effective over a long period with the minimum of supervision and are environmentally acceptable to the planning and regulatory authorities.

INTRODUCTION

As the environmentalists are continually reminding us more and more wetlands are being lost to development along with the important environmental niche for wildlife that they provide. The construction of new wetlands as a means to control pollution from mines and quarries is therefore very desirable.

There are now several hundred engineered wetlands controlling pollution on mine sites in North America and the method is slowly becoming accepted in Europe and to a lesser degree in the United Kingdom. A wetland is being considered for the treatment of

potential groundwater rebound pollution after the closure of the Wheal Jane Mine in Cornwall.

Mining companies find that not only are wetlands successful in dealing with acid mine drainage but also that they are much more cost effective than simple treatment with chemicals and lagoon facilities.

The Environmental and Legislative Background

The environmental constraints recently brought about by EC Directives and the Water Act 1989 in the United Kingdom mean that the Consents to Discharge water into receiving downstream watercourses are very severe and being rigorously monitored and enforced by the newly created National Rivers Authority (Norton 1990).

The forthcoming "water quality objectives" and classification of the quality of controlled waters that will come into being within the next two years will mean even tighter restrictions on future mine developments. List 1 Metals (Cadmium and Mercury) will have mandatory restrictions of 0.005 ppm and 0.0005 ppm respectively and the List 2 Metals (Arsenic, Chromium, Copper, Lead, Nickel and Zinc) will be restricted to values between 0.001 ppm and 3.0 depending on the type of environment within the receiving stream or river estuary etc.

In many parts of the world there is a legacy of environmental pollution as the result of many centuries of almost unchecked mining and it would be unfair to place the responsibility for cleaning up the mess upon the last operators in the area. Such areas as the Iberian Pyrite Belt (Rio Tinto Mines), the tin mining areas of Cornwall and the coal mining areas of Appalachia in the USA have such gross river pollution that could only be cured by full government assistance. It would be too costly for the present mining companies to undertake without going into receivership, which has been the case or the less enlightened operators in the more intensely regulated States in the USA.

There is therefore a definite need for water treatment methods which are cost effective to replace the crippling costs of chemical treatment with lime, caustic soda and alum etc. Recent research with biotechnical methods have proved very encouraging, especially with wet restoration techniques and the use of engineered wetlands. Examples from the author's experience in the USA, Portugal and the UK will be used to illustrate the paper.

The Cause of Acid Mine Drainage

In order to explain the complex chemistry involved in wetland treatment it is necessary to briefly describe the cause of AMD in the first place.

Many types of mine workings, whether they be coal or metalliferous mining voids, backfilled surface mines and quarries, tailling dams or overburden dumps all contain the oxidised remnants of sulphide minerals especially the ubiquitous iron pyrites (FeS₂).

The production of AMD from these sulphides is complex and involves the interaction of water, oxygen and bacteria in various amounts. The most important point to remember is that taking away any one of these elements will slow down or even prevent the following reactions occurring:

- (1) $2\text{FeS}_2 + 2\text{H}_2\text{O} + 7\text{O}_2 = 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4$ (Exothermic)
- (2) $4\text{FeSO}_4 + \text{H}_2\text{SO}_4 + \text{O}_2 = 2\text{Fe}_2(\text{SO}_4)_3 + 2\text{H}_2\text{O}$
- (3) $\text{Fe}_2(\text{SO}_4)_3 + 6\text{H}_2\text{O} = 2\text{Fe}(\text{OH})_3 + 3\text{H}_2\text{SO}_4$

The overall result of these reactions is that 1 gramme of sulphur produces 3,125 grammes of acidity, expressed as CaCO_3 (Henderson and Norton 1984).

The breakdown of the sulphide minerals is accelerated in the presence of certain aerobic bacteria and there is no doubt that oxygen is needed for most AMD production. However, if the acidity falls below pH 4.5 it is now widely accepted (Kleinmann et al 1983) that oxidation of the ferrous ions by bacteria and a reduction of the ferrous ions by pyrite will further combine to create more acidity and of course further leaching of other metals from the mine environment.

Elimination of the bacteria (some of which are anaerobic) will therefore greatly reduce AMD production. There is no doubt that the rate of pyrite oxidation increases with falling grain size, increasing acidity and oxidation potential (Eh). This latter analysis of mine water gives a very good indication as to the activity in the water which will produce further pollution with toxic metals if the process is not checked.

Under normal groundwater equilibrium conditions these soluble metal salt products will be contained in the water issuing from the mine or quarry and cause pollution of downstream watercourses. However, during periods of rapid groundwater rise in flood conditions they will be flushed out in greater volumes from the mine voids. Fortunately, during flood conditions there is also a greater volume of water in the receiving stream and because of dilution the pollution effect is reduced.

WETLAND CHEMISTRY

The research into wetland chemistry has shown it to be a very complex environment indeed with several physical, chemical and biological processes acting together to contribute to the improvement in the water quality as it flows through the system.

Physical Processes

The most simple of the physical processes is probably the filtering mechanism of the dense plant root system in the substrate which catches any of the suspended solids and flocculated particles as they pass through the wetland.

As wetlands are usually built at the lowest part of the mineland then there is a certain dilution factor by mixing with clean rainwater falling over the large surface area of the system and possibly groundwater inflow from unpolluted sources other than the mine.

In warmer climates the evapotranspiration factor in the overall water balance can be high and can increase the metal removal. This factor should also be taken into account when calculations are made for the volume of flow expected through the system.

Aeration of the water to induce a greater oxygen content is a useful addition to be provided before the water enters the wetland environment or between each of the wetland units and can be achieved by the construction of cascades with limestone boulder beds if there is a sufficient slope to the proposed site. The use of pumps to gain height or fountain the water is not advised as the essence of the method is to be cost effective and the deleterious effect of AMD on pumps can be very expensive.

Oxidation and Hydrolysis

The main process of toxic metal removal is by oxidation and hydrolysis. In some cases up to 90% of the available iron can be accumulated in the form of iron hydroxides on the bed of the wetland. This is caused by the presence of iron oxidising bacteria (*Thiobacillus ferrooxidans*) and the oxidised water around the plant roots.

It should be noted that the iron concentration in the water is a good indicator of the wetlands performance in dealing with the more toxic List 1 and 2 metals such as Lead, Arsenic, Copper and Zinc as they are known to absorb onto the surface of the iron oxides (Johnson 1984).

Manganese concentrations in the water are a specific area of control in the USA where in some states, notably Pennsylvania the effluent limits are set at a maximum of 4 ppm. Much research has been undertaken into the use of algae, notably the blue-green *Oscillatoria* which has been observed to contain upto 56,000 micro grammes/gramme of Manganese by dry weight.

Vegetation Chemistry

Some of the plants can accumulate metals to quite a high degree, for example *Sphagnum* has a capability to absorb iron until it reaches a toxic level. Many of the early wetland failures were due to the fact that they were planted almost wholly with *Sphagnum* and the plants died when the toxic levels were reached within one year in very polluted environments.

Typha (Bulrushes) are much more tolerant to AMD than *Sphagnum* as they do not accumulate metals to such high levels. Originally it was thought that the *Typha* rhizomes and root mass accumulated the metals but research has shown that this only accounts for 0.3% of the of the iron loading in the mine drainage (Sencindiver and Bhumbra 1988).

Other plants which can be introduced to the wetland are *Equisetum* (Horsetails), *Scirpus* (Rushes) and *Carex* (Sedges). These may well introduce themselves naturally over the life of the wetland.

Notable species of algae such as *Microspora* and *Oedogonium* have encrustations of Manganese and the visible signs of algal blooms on the surface of the water in wetlands are evidence of this process which is little understood. However, these algal performance only account for a minute proportion of the total pollution reduction. The recent research into the use of microbial cultures, e.g. the "Bio-carb" product (Davison et al 1990) which can be added to the wetland environment to enhance these processes seems to have met with some success.

Sulphate Reduction

Perhaps the most important metal removing mechanism in wetlands is bacterial sulphate reduction in the anaerobic environment of the organic substrate. The activity of such bacteria as *Desulphovibrio* are well documented by early research workers (Caruccio et al 1968). It is therefore very important to make sure that there is enough decomposing organic material provided by rotting vegetation or by the original addition of organic-rich material in the construction of the system.

The creation of this reducing environment is similar to the geological conditions in which sedimentary metallic sulphide ores were created in the first place. The metallic sulphates in solution in the AMD are reduced to sulphides which form an insoluble precipitate that remains buried in the organic substrate of the wetland. This reaction also raises the pH and excess sulphur is given off as the familiar rotten egg smell of marsh gas (H_2S).

WETLAND CONSTRUCTION

As a result of the recent research into the chemistry of wetlands it is now possible to engineer the system to individual AMD requirements and each wetland should be

"tailor-made". As can be seen it is typical of a natural environment and a very complicated balance of varying processes needs to be maintained if the system is to be successful.

The degree of failure in some of the original wetlands has often proved to be proportional to the lack of engineering in their construction and lack of patience in allowing the natural scheme of things to take over with time. Many of the early wetlands failed because they were simply disturbed and tampered with by over-enthusiastic operators.

This has a particularly bad effect on the sulphide precipitates in the reducing black, organic mud substrate as iron, for instance, is in the form of FeS (monosulphide) which can revert back to sulphate if there is a drastic change in the environment and oxidising conditions are allowed.

A schematic drawing of a wetland incorporating the latest research is shown in Figure 1. It should be noted, however that it is much more acceptable to local government planning authorities and environmental groups to design the wetland in a more aesthetically pleasing shape that includes woodland and islands for the wildlife that they inevitably attract.

Pretreatment Facilities

If the AMD has more than one source then the various seepages must be collected and piped to a common holding pond or lagoon. This is desirable even if there is only one source such as an abandoned mine entrance as, in the author's experience, some form of constant head control is needed to maintain a constant steady state flow into the downstream wetland. This collection pond is vital to prevent storm surges and reference to the Flood Studies Report is a necessary prerequisite in UK construction.

Such a pond should be relatively deep to retain water during dry seasons and to minimize evaporation. It will also serve to precipitate any suspended solids in the AMD. In order to maintain a constant flow into the first wetland area then a piped discharge with a sufficient diameter to create the desired steady flow from the holding pond is preferable. Aeration before the water enters the pond is recommended.

Wetland Treatment Area

The wetland area should be prepared as for a typical lagoon treatment facility with embankments of a minimum 2 metres in height and 1 in 2 gradient to allow for the wetland substrate and freeboard in wet conditions. The floor should either be horizontal or have a slight gradient of up to 3% from the inflow to the outflow end.

A 0.15 metre layer of alkaline material such as crushed limestone or preferably phosphate should be laid on top of the compacted base in order to provide an initial raising of the pH to initiate the process.

Some researchers prefer the introduction of deeper zones of up to 1 or even 2 metres in depth in the centre of the wetland to give a refuge for fish and other wildlife and also to create a sink for the rapid accumulation of iron oxides during the initial stages after construction.

An organic substrate of minimum 0.50 metres thick is placed uncompacted on top of the limestone and can be made of spent mushroom compost, well digested sewage sludge, peat, chicken manure or any well composted material. Where relatively unpolluted AMD is concerned a sandy loam or even sandy mine backfill has been used with success by the TVA in the USA.

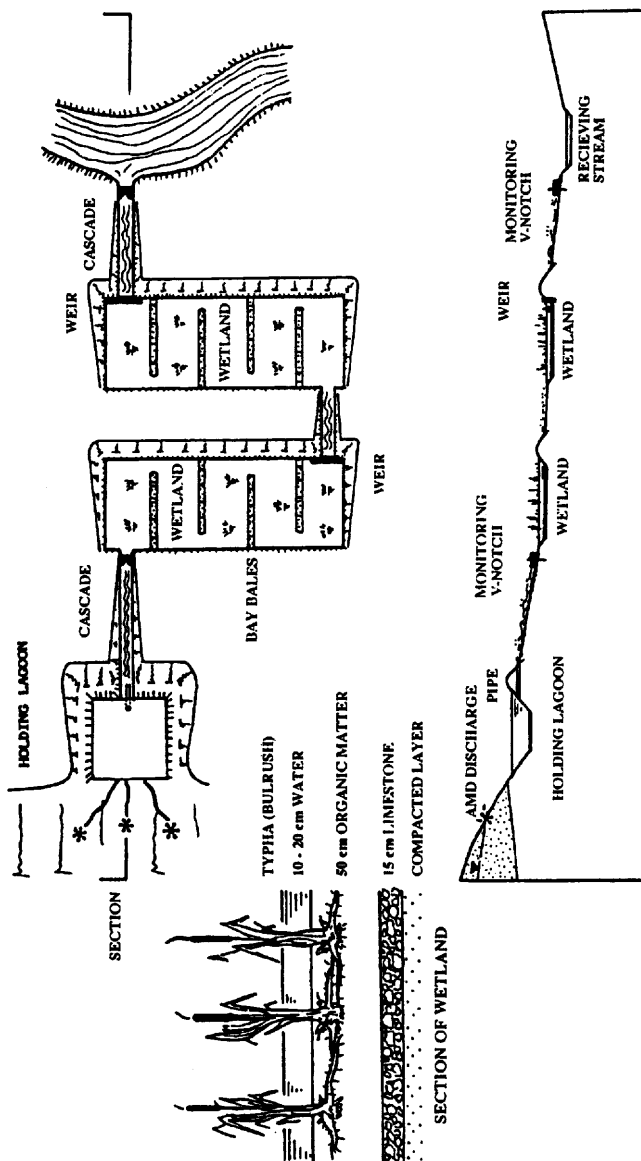


Figure 1. Schematic of a typical engineered wetland

Peat or compost can be spread at a rate of about 3 square metres/tonne. In order to induce further flow through this organic layer it has been found beneficial to create islands of organic material to increase the reduction process.

The bullrush rhizomes are planted at a density of one per square foot and well into the substrate prior to flooding.

It is extremely important that there is as much attenuation as possible of the water in the wetland and this is achieved by making the area as large as possible and also inducing a serpentine flow. The latter can be achieved by placing hay bales as finger dykes from the embankments, or by creating them, of mine waste or organic material. The wetland areas should have a low length to width ratio to prevent channelisation and erosion of the all important organic layer.

If it is intended to have more than one wetland area then it has been shown in recent research by the US Bureau of Mines that the aerobic treatment process should proceed the anaerobic one. To this end the initial areas in the flow path should have shallower water (say, less than 0.15 metres) than the final areas (upto 0.50 metres deep).

The final discharge into the receiving stream should be constructed in a way that will prevent any backwash in flood conditions and preferably the whole wetland area should be placed well above the flood plain of the stream.

Wetland Performance

The bigger the wetland the better, as exemplified by the 980 hectare site at Peabody Coal's Will Scarlet Mine in the USA (Mining Journal 1991). However, it is expected that this will replace the expenditure of \$750,000/annum on chemical treatment.

Most wetlands are much smaller and usually around 1 hectare in size. the best guide to sizing is the recently published (Kleinmann 1990) information from the survey of over 200 wetlands by the US Bureau of Mines:

If the pH of the AND is 6 or above then the wetland area required in square metres is equivalent to the iron loading in grammes/day divided by ten.

If the pH is between 4 and 5 then the area needed is the iron loading divided by 5.

Where the pH is below 4 then the iron load should be divided by 2 to estimate the area required.

For example, in a typical case with an AND inflow of 26 litres/sec, with a pH of 5 and iron content of 5ppm (a loading of 11,232 grammes /day) then a wetland area of 2246 square metres is needed.

In practise, and if there is space available, then it is best to double the area to allow for contingency, potential damage and future changes in flow or quality of the water. The cost of wetlands is so low in the long term in comparison to chemical treatment that the cost effectiveness is not impaired. Most wetlands are expected to have a life of at least 30 years and the equipment needed is usually readily available at most mine sites.

CONCLUSION

As a result of thorough research, mostly in the USA, the use of engineered wetlands to treat acid mine water is gaining popularity with both the mining industry and environmentalists alike. Although there is still some scepticism in the UK and Europe the author considers that their use will increase with the benefit of the hindsight from the work in the USA.

It is important that all installations are properly monitored for performance so that meaningful data can be shown to the regulatory authorities in order to convince them of the effectiveness of this natural solution to a major mining problem.

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