RECLAMATION AND DECONTAMINATION OF METALLIFEROUS MINING TAILINGS

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ABSTRACT

Parts of Britain have large accumulations of metalliferous tailings derived from mining in the 18th, 19th and 20th centuries. These tailings were never subject to land reclamation schemes at the time of mining and are situated very close to water courses. They cause considerable environmental damage in terms of contamination of soils, dust blow and pollution of water courses and groundwater. In some parts of the country mine drainage is a major part of river pollution. In recent years, particularly in Wales, efforts have been made to "clean up" these sites. This has involved using techniques to isolate and contain the spoil, diversion of water courses, and the installation of water treatment facilities and drainage and the establishment of a vegetation cover. Research is also being initiated to investigate ways of decontaminating these metalliferous spoils as an alternative to using covering systems to reclaim them.

INTRODUCTION

Water use has been an integral part of metalliferous mining operations since such activities began. In modern mines water is principally used to separate ore from tailings but in past activities it was a major source of power for the mine also. It is therefore unsurprising that in many of the metalliferous mining areas, mines and their processing plants were either situated adjacent to water courses or were linked to these water courses by constructed channels. In

Britain the peak period of metalliferous mining was in the nineteenth century and the legacy of that mining is of derelict mining sites, land contaminated by air and waterborne pollution and water courses which are devoid of life solely because of pollution from these abandoned mines. In recent years there have been attempts to clear up the dereliction left by these mining operations. This is particularly so in Wales where initiatives by Welsh Development Agency have led to a number of reclamation schemes for metalliferous mines having been completed.

TAILINGS CHARACTERISTICS

The processes of ore separation, although more sophisticated today, have changed little in their methodology since ancient times and are certainly very similar to those of the nineteenth century in Britain. Fig. 1 shows a flow chart of an ore dressing plant in mid-Wales in 1848 and it can be seen that principles of ore crushing and separating fractions out on the basis of their size and density led to products of coarse jig tailings, fine tailings and waterlogged slimes. Many mines were worked intermittently for centuries leading to sporadic deposition of spoil and the accumulation of spoil of different characteristics in the same heap. In some instances old spoil heaps were reworked when techniques made metal recovery better. At other sites spoil was removed for use as construction materials.

Mineralogically the spoils were derived primarily from the acid rocks of Silurian/Ordovician age in mid Wales and Snowdonia and the Carboniferous limestone of North East Wales. Spoils from workings in limestone areas do not pose acid problems but are still responsible for land and water pollution even though the pH of the spoils are between 7 and 8. Silurian and Ordovician spoils range from being mildly acid to very acid depending on the amount of pyrite associated with them. The range of spoil characteristics is shown in Table 1.

WATER COURSE POLLUTION BY METALLIFEROUS TAILINGS

Many rivers in Wales are polluted to a greater or lesser extent due to metal mining. The ways pollution occurs are as follows:

1. Erosion of tailings into water courses due to surface run off
2. Seepage of metal rich water through tips
3. Polluted drainage from mine adits, this can be intermittent or continuous.

An example of the way seepage can affect water quality is shown in Table 2.

Figure 1 A flowsheet of processes at the Goginan Mine Mill 1848 (from Hughes 1988)

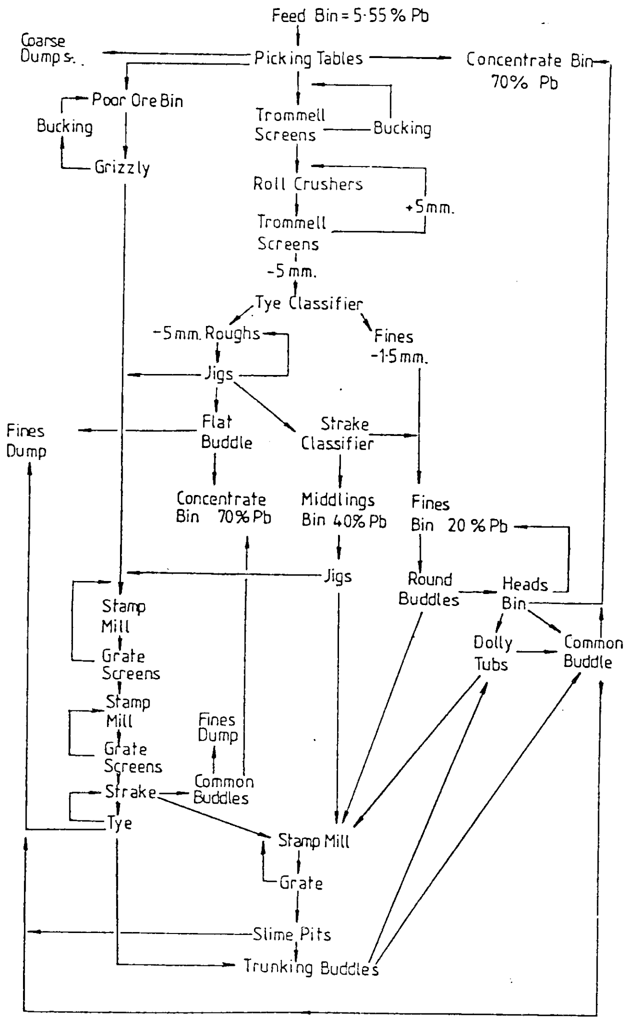

Table 1 Total Concentrations of some metals in mine tailings in Wales (ug g^{-1})

Site (metals mined)	Geology	pH	Pb	Zn	Cd	Cu
Minera (Pb/Zn)	Carboniferous limestone	7-8	14000	34000	435	625
Halkyn (Pb/Zn)	Carboniferous limestone	5-8	22882	65187	380	174
Y Fan (Pb/Zn)	Silurian shales mudstone	4-5	42400	6700	268	376
Parys Mountain (Cu)	Ordovician	3-6	63	88	-	1390
Goginan (Pb)	Silurian shales	3-6.5	175000*	9600	16	-
Drws-y-Coed (Cu)	Ordovician	3-5.5	800	600	-	37000*

* Maximum levels

RECLAMATION TECHNIQUES

The aims of the reclamation of metalliferous mines in Wales are as follows:

1. To reduce the risk to public health through contamination of air, water and soil.
2. To clean-up rivers which are polluted from mining activities
3. To make the sites safe.
4. To remove landscape scars.

Although these are broadly in order of importance there are schemes where the principal aim is to remove landscape scars and where there is the danger that reclamation activities will cause pollution of water courses.

Table 2 Analysis of river water samples in an area of abandoned lead/zinc mining in Wales (mg/l)

Sample No*	Cu	Pb	Zn	Cd	Dissolved Pb	Dissolved Zn	Hardness as $CaCO_3$
1	<0.01	0.08	0.11	<0.005	0.03	0.08	36
2	<0.01	0.02	0.09	<0.005	<0.01	0.05	32
3	<0.01	0.14	<0.01	<0.005	0.06	<0.01	51
4	<0.01	0.06	0.10	<0.005	0.02	0.06	35
5	<0.01	0.11	0.13	<0.005	0.05	0.10	32
6	<0.01	0.12	0.12	<0.005	0.04	0.09	32
7	<0.01	0.10	0.14	<0.005	0.03	0.10	31
8	<0.01	<0.01	<0.01	<0.005	<0.01	<0.01	77
9	<0.01	0.08	0.15	<0.005	0.03	0.13	32
10	<0.01	0.06	0.11	<0.005	0.02	0.06	27
11	<0.01	0.09	0.12	<0.005	0.02	0.09	27
12	<0.01	0.05	0.10	<0.005	0.02	0.07	27
13	<0.01	0.02	0.11	<0.005	<0.01	0.05	26
14	<0.01	0.06	0.29	<0.005	0.04	0.16	28
15	<0.01	<0.01	<0.01	<0.005	<0.01	<0.01	26
16	<0.01	0.04	0.27	<0.005	0.03	0.14	32
17	<0.01	0.01	0.01	<0.005	<0.01	0.01	26
18	<0.01	0.08	0.32	<0.005	<0.01	0.13	28
19	<0.01	0.10	0.41	<0.005	0.03	0.24	28
20	<0.01	0.15	0.57	<0.005	0.05	0.41	26
21	<0.01	0.24	0.70	<0.005	<0.01	0.39	26
22	<0.01	0.21	0.61	<0.005	0.03	0.22	27
23	<0.01	0.04	0.39	<0.005	<0.01	0.20	21
24	<0.01	<0.01	0.02	<0.005	<0.01	0.01	18
25	<0.01	<0.01	0.01	<0.005	<0.01	0.01	20
26	<0.01	<0.01	<0.01	<0.005	<0.01	<0.01	16
27	<0.01	0.01	<0.01	<0.005	<0.01	<0.01	13
28	<0.01	<0.01	<0.01	<0.005	<0.01	<0.01	23
EEC Standards							
Protection of salmonid fish	0.001			0.005	0.004	0.01	
Protection of coarse fish	0.001			0.005	0.05	0.075	
Protection of other freshwater life	0.001			0.005	0.005	0.1	
Watering of livestock	0.2	0.1	2.5	0.005			

* Samples 24 - 28 are upstream of seepage from abandoned tailings. Samples 1 - 23 are downstream except for 3, 8 and 15 which are tributaries.

At abandoned mine sites industrial archaeological and wildlife conservation considerations have to be taken into account and these have been discussed by Richards (1989).

The possible ways by which spoil contaminated by heavy metals can be reclaimed are:

1. By covering the waste in situ with uncontaminated material.
2. By concentrating the spoil in one place prior to capping.
3. By amelioration of the wastes and vegetating them with metal tolerant plants.
4. By excavation of the spoil and removal off-site.
5. By on-site reprocessing of spoil to remove metals as a commercial exercise and incorporating restoration of the site.

Covering waste in situ

This is by far the most common technique for the reclaiming of metalliferous tailings and has been the subject of an appreciable amount of research. This research has included field and laboratory experiments to investigate different capping materials and the use of different types of break layers to prevent the upward migration of metal ions (Jones et al 1982, Cairney 1987, Richards, Moorehead & Laing Ltd 1988). The conclusions from this work indicate the following:

1. Coarse grained materials provide the best capillary break and are effective in preventing the upward migration of ions.
2. Very coarse material alone is not suitable as a capping material because although it is effective as a capillary break it is not suitable as a medium for establishing vegetation.
3. Materials such as colliery spoil which contain some fines and which are infertile at depth have, after 12 years, of trials been shown to encourage little upward migration of metals.

It is worth noting however that these trials have been carried out in a moist temperate climate and in warmer and drier climates the potential for upward migration of metals is much greater over longer periods.

Break layers and the use of coarse grained capping materials do however only address the problem of upward movement of metals. Of as much concern is the downward and lateral movement of metal-laden water through spoil heaps after reclamation. Coarse capping materials encourage the percolation of water into the underlying material and the likelihood of metal rich water finding its way into watercourses or into uncontaminated soils may therefore be increased. There is one instance of a reclamation scheme in which a coarse capping material was used where an adjacent watercourse is more heavily polluted with metals after a reclamation scheme than before although the scheme has done much to reduce wind borne pollution in the area.

The principle of reducing the ingress of water into metalliferous spoil after reclamation is an important one and this is particularly the case where the material is pyritic because of the likelihood of increased oxidation of the pyrites, acid water seepage and resultant toxicity problems in receiving waters. For this reason in the UK and in Wales in particular there has been a move towards covering of spoil materials with a polyethylene membrane prior to covering with a capping material This has the following implications for design of the scheme:

* Care has to be taken that final slopes are shallow enough to prevent the capping material slipping off the membrane.

* The capping has to be deep enough to support vegetation in dry conditions. 500 mm is the most common depth used.

* If tree planting is desired deeper layers of capping material are needed.

* Particular attention has to be paid to surface drainage.

* Afteruse of the site has to be carefully considered so that the membrane does not become damaged.

Concentration of the spoil in one place

At many sites spoil is found over a large area often in thin layers or in sensitive locations such as river banks. Here it is desirable to remove the spoil from these locations and concentrate it into one place prior to capping thus releasing land for beneficial use and making significant contributions to the reduction of the pollution of watercourses. In such situations the contamination status of the underlying ground has to be ascertained so that contaminated original ground can also be removed. This is usually done by boreholes prior to the commencement of reclamation works followed by sampling and analysis during the reclamation scheme. Disposal of the waste removed is usually within the reclamation site either on existing spoil heaps or in specially constructed cells followed by capping.

Revegetation with metal tolerant plants

There has been much research into plant material tolerant of heavy metals both from an ecological perspective and from that of the use of such material to revegetate sites (Johnson et al 1977, Smith & Bradshaw 1972, Humphries & Bradshaw 1976). There are grasses commercially available in the UK which are tolerant of lead, zinc and copper in both acidic and calcareous conditions. One of the consequences of the use of metal tolerant species on spoil is that the spoil material remains at the surface and the runoff from that site will still contain heavy metals. Additionally if establishment is slow after remodelling of the spoil, as it can be with some of the grasses used, then erosion of spoil can occur prior to grass establishment. For these reasons tolerant plants have not been much used on spoil material. They have however been used on mildly contaminated original soils remaining after the removal of spoil such as described above.

Metal tolerant plant material has also been used in the revegetation of uncontaminated capping materials where no membrane has been employed in the capping design.

Excavation and removal off-site

This technique although technically feasible is little used in modern times because of the quantities of material involved and the environmental problems caused by transporting and disposing of such material.

Reprocessing of spoil to reduce its metal content

The commercial reprocessing of metalliferous spoil to recover more of its metal content has been considered as an option at some sites in the U.K. but has not recently been carried out successfully. There are sites however where substantial quantities of spoil exist and which might be reprocessed commercially. The benefits of such reprocessing as a means of reducing the 'contamination status' of a waste are not however as clear as might initially appear. The extent to which metals can be removed from spoil is dependent on the mineralogy of the spoil, the particle size of the feed material and the process used. Although much metal can be removed from a metal-rich spoil, the waste from the reprocessing activity may be no less contaminating. This is because its particle size may have been much reduced resulting in a much larger surface area and consequently greater availability of metal.

There has however been renewed interest in the possibility of reprocessing waste in order to reduce its metal content for environmental reasons. It is clear that using established reprocessing techniques greater recovery of metal may be achieved (and hence less metal in the waste) if maximum recovery is the aim than if the best commercial return is the aim. Using non-conventional laboratory-based techniques recoveries of up to 90% have been achieved in the case of lead leaving 0.8% lead in the residue after using feed material of 7.5% lead concentration. (Table 3).

Table 3 Recovery of lead from tailings using different methods

Method	Best Recovery
Gravity separation	50%
Froth flotation	50%
Alkaline leaching unground tailings 20°C	71%
" " unground tailings 60°C	89%
" " ground tailings 60°C	92%

This approach is now being further researched in association with the University of Cardiff under a Welsh Office research contract in order to establish if these techniques can lead to alternative methods of reclaiming metalliferous spoil.

Prevention of water pollution

Reclamation schemes often incorporate combinations of the above techniques but in addition all schemes incorporate measures to reduce pollution of water courses by metal rich waters. The key to the reduction of water pollution is prevention of its pollution in the first place. Treatment should always be a last resort. Too often in the past acid metal rich waters have been found draining from spoil heaps or mine openings and the solution has been to introduce a bed of limestone and sedimentation tanks to treat the water rather than to see if the water could be diverted round polluting spoil heaps in uncontaminated ground or if water could be prevented from entering the mine workings in the first place. Where limestone beds have been used to treat acid waters in the UK they have been notoriously unsuccessful in the long term the limestone becoming coated with reaction products and rendered ineffective very quickly. Limestone beds are a satisfactory means of treating mine drainage during a reclamation scheme but even then should only be used once all attempts have been made to divert water away from pollution sources.

At some abandoned mine sites water is already being treated by natural means due to the build up of peat and wetland vegetation. In these situations consideration should always be given to not disturbing these areas and allowing them to continue functioning or even to extending them. The recognition of the value of wetlands in treating metal rich water may lead to an important new reclamation technique.

Considerations to be taken into account in the design of a reclamation scheme for metalliferous waste can therefore be complex (Table 4) and those governing the pollution of water courses can dominate reclamation design (Figure 2).

Table 4 Some considerations in the investigation for and design of a reclamation scheme for abandoned metalliferous tailings.

Site investigation needs

Hydrological survey
Contamination survey
Engineering survey
Wildlife survey
Industrial archaeological survey

Design considerations

1. Can water be diverted to avoid pollution sources?

2. Are there any areas to be retained because they are of wildlife or archaeological value or are effective at treating polluted water on site?

3. Can metalliferous spoil be cleared from some locations and concentrated in one place?

4. If the answer to 3 is 'yes' how should the underlying ground be treated?

5. Does the spoil need treatment (e.g. liming) prior to capping?

6. Can the spoil be reprocessed?

7. Should a membrane be used as part of the capping design?

8. What capping material should be used?

9. Will water treatment be required through the construction period or even permanently?

10. If permanent water treatment is needed how will this be maintained?

11. What constraints on the end use of the finished scheme are required to maintain the effectiveness of the reclamation technique?

12. What monitoring if any is required?

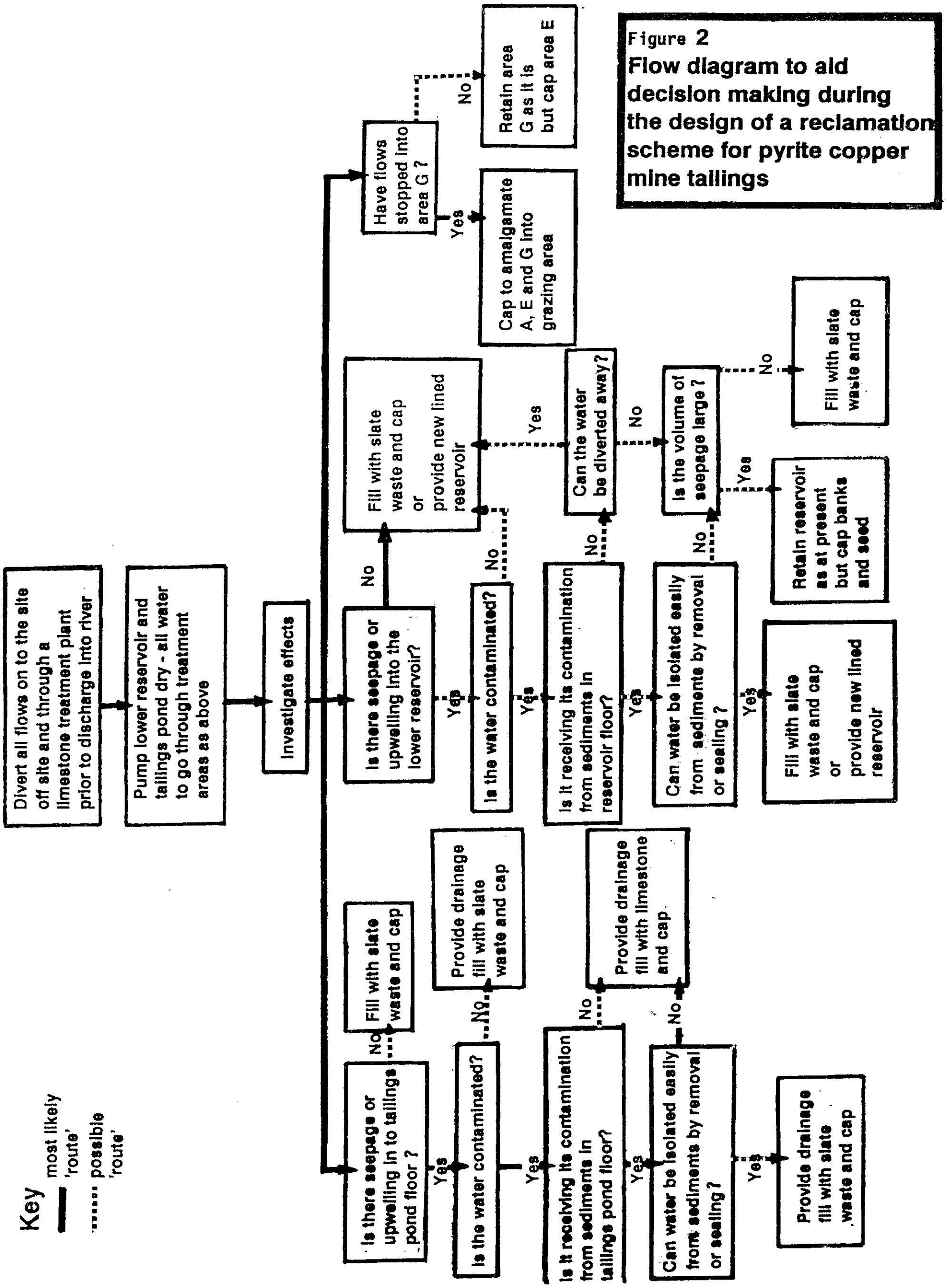

Figure 2
Flow diagram to aid decision making during the design of a reclamation scheme for pyrite copper mine tailings

CONCLUSIONS

1. Water is the primary agent for the movement of metals from abandoned metalliferous mines into surrounding soils, watercourses and groundwater.

2. Current reclamation techniques aim to isolate spoil from water by the use of cut off drainage, and covering systems incorporating break layers and membranes.

3. Treatment of acid and metal rich waters by liming is only effective in the short term.

4. Decontamination of spoil by reprocessing techniques can result in great reductions in the metal content of spoil and research on this topic may lead to new reclamation techniques.

5. Emerging technology on wetland treatment of metal rich mine drainage may be a further method of treatment of metalliferous mine wastes.

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