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Environment Agency

Proceedings of the Conference

National Minewaters

20th – 21st April 1998

Tapton Hall
Sheffield University

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NORTH EAST REGION

CONFERENCE

NATIONAL MINEWATERS

20TH - 21ST APRIL 1998

Tapton Hall

University of Sheffield

CONFERENCE PROCEEDINGS

JANUARY 1999

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Environment Agency, North East Region
National Minewaters
Conference Proceedings January 1999

CONTENTS

INTRODUCTION

David Griffiths
Pollution Prevention Manager

Water pollution arising from long abandoned mineworkings, the rising minewaters associated with recently abandoned mines as well as the problems of contaminated run-off from spoil heaps remain of great concern to the Environment Agency. This was clearly demonstrated through the wide range of problems and indeed solutions discussed at this, the second, Environment Agency sponsored conference on minewaters. I was delighted to be able to chair this conference and pleased to see the progress that had been made since the first conference held in Sheffield in March 1996. Whilst it is heartening to see that work has continued in addressing the issues, it remains the case that minewater pollution is only one amongst a myriad of other environmental problems that the Agency needs to address. It must be recognised that resources to deal with problems associated with mining are unlikely to increase in the face of competing demands made by these other environmental problems and threats.

It is vital therefore that the Agency continues to work with partner organisations such as the Coal Authority, local Authorities, Water Companies and local communities to address the difficult and complex problems associated with minewater pollution. The benefits of such cooperation and persistence are clear to see with the local community project that has resulted in remediation of contaminated run-off from the spoil at Quaking Houses. This community involvement is so often overlooked but it can be fundamental to making change. Indeed it should be seen as one of the primary drivers in bringing about environmental improvement. It can only be hoped that such projects are a feature of the future with good quality research sponsored by various bodies and the active involvement of local residents being a demonstrable way forward.

It is good to see much of the hard work put in by both the Coal Authority and the Agency now coming to fruition. We have progressed a long way from merely identifying the most environmentally damaging discharges in the country to really addressing the problems: The Coal Authority has commissioned over twenty detailed studies and this has led to construction work on four remediation schemes currently being undertaken. Hopefully these, along with the Bullhouse site, will become operational later this year.

It seems very likely that new legislation will come into force this summer in the form of Regulations requiring mine operators to notify the Agency 6 months prior to the abandonment of a mine. It remains to be seen how useful this legislation will be and how the Agency enforces it. The Agency certainly hopes that it will force mine operators to fully address the issue of abandonment and promote better water management, particularly when mining has ceased.

In conclusion I must raise the issue of abandoned metal or mineral mines. This is an exceptionally challenging area for the Agency as there is no body in place to take responsibility for their environmental liabilities and there is no funding mechanism currently available to bring about improvements. Many of these mines were abandoned a long time ago but still have the ability to contaminate rivers and streams, often in high amenity upland areas. It will be interesting to see how the Agency and the UK Government addresses this complex issue.

WHEAL JANE MINEWATER PROJECT

PAPER FOR ENVIRONMENT AGENCY NATIONAL MINEWATERS CONFERENCE TO BE HELD IN SHEFFIELD ON 20-21 APRIL 1998.

SESSION 1 LEGISLATIVE FRAMEWORK AND CURRENT RESEARCH

Wheal Jane - Treatment or what.

History and background to the project

The Wheal Jane Minewater Project was initiated following the uncontrolled release of acidic, metal laden minewater from the Wheal Jane mine, near Truro, Cornwall in January 1992. The release created significantly elevated levels of metals and widespread discolouration in the Carnon River, Restronguet Creek, Carrick Roads, and the Fal Estuary.

The NRA set up a treatment plant in 1992 and the NRA/Agency have been managing the plant since then.

The plant consists of:-

- six borehole pumps suspended in the mineshaft and delivering a total of 330 litres/second
- a header tank which provides measuring and lime dosing facilities
- lime storage silos, lime slurry and dosing equipment
- a pair of large diameter pipelines to convey the treated water to the Clemows Valley Tailings Dam (CVTD) where a flocculant is added and sludge settlement and storage occurs.
- a polishing lagoon to settle out any carry over of suspended solids from the CVTD before discharge to the Carnon River.

Until March 1998, the Wheal Jane mill was in operation and discharging tailings into the CVTD. The minewater mixed with the tailings (grain size of about 0.063mm) and helped the flocculation process by providing a nucleus for the flocs to build around, increasing the density and settleability of the resulting sludge.

The effects of South Crofty mine closure on our operations

Following the closure of South Crofty mine, the mill also ceased operation and the flow of tailings into the CVTD stopped. This has resulted in a lower density sludge which is readily remobilised by wind across the dam leading to a discoloured effluent.

The sludge densities are:-

with tailings 0.23 tonnes /cubic metre
without tailings 0.05 tonnes /cubic metre

A factor of 4.6 less dense.

The polishing lagoon will, under times of moderate flow, resettle some of this discolouration, but at times of high flow there is insufficient residence time in this second lagoon.

In order to maintain the quality of the outflow from the dam, a new regime of pump and dam water level management has been instigated.

The changes may result in more acid generation due to fluctuations in water level in the mine and a worsening of the actual minewater but at least it will be treated and it is only a matter of cost of lime and flocculant.

We can pump the mine down to a lower level as we no longer, for the time being, need to feed the pilot passive plant. It is mothballed pending a final decision on a research facility.

The legislation governing our work

Being such a large scale project, Wheal Jane is subject to a great variety of legislation, covering for example : waste management, water quality, planning applications and mining activities.

Legislation will affect **long term policy** decisions at Wheal Jane (to treat or not to treat and if so, to what standard). We are currently looking at March 2001 as an end date for completion of the long term treatment option. **In the meantime**, we have to ensure that the existing treatment plant is operated effectively to both maximise discharge quality and ensure that any operational changes comply with legislation.

I'm going to use two specific examples, one short term and one long term, to illustrate the potential effect of legislation on the project :

- The effect of the closure of South Crofty on the use of the CVTD
- The potential effect of EC Directives on the selection of the most appropriate long term treatment option.

Closure of South Crofty and Wheal Jane Mill

Whilst the mill was operating, the CVTD (and our use of it as part of the existing treatment plant) was governed by the Mines and Quarries (Tips) Act 1969. This legislation deals with the stability of the dam and has nothing to do with water quality or waste management.

Water quality is governed by an existing consent to discharge for the CVTD. No waste management licence exists. It was originally thought that closure of the Mill would mean that the Agency would need to apply for a Waste Management licence to continue this use of the dam, which created innumerable problems. This meant that, at best a period of several months would exist during which our minewater would be deposited to the CVTD illegally, yet we are the enforcing agency...

Having taken legal advice however, we are assured that the same legal framework exists for us to continue deposition without a waste management licence. This has resulted in a unique legal situation within Cornwall...Since the mill ceased operating the CVTD is now technically a "closed tip" and its operation is controlled under Part Two of the Tips Act. The responsibility for enforcement of this legislation has now passed to Cornwall County Council.

Selection of the Long Term Treatment Option

The project aims to assess the best long term solution at Wheal Jane using a cost-benefit appraisal of treatment options. The cost-benefit being used is a **social** cost benefit rather than just an environmental one - it will address environmental effects **and** conservation, recreation, pleasure boating and port operations, tourism, the fertiliser industry, fisheries and amenity. This takes into account the fact that the area concerned has designations of AONB, SSSI, Sea Bass Nursery Area and is a popular tourist site, particularly for water sports.

To put together this assessment we needed to select several water quality objectives (WQOs). Modelling has been used to determine what treatment is necessary to achieve each WQO and finally to assess the effects of the resulting water quality on all of the areas covered by the social cost benefit assessment. The effects on all areas (including environmental ones) are being quantified economically.

Seven potential water quality objectives for the catchment have been identified in the project. These are both statutory and non-statutory, cover a range of parameters (iron, zinc, copper, arsenic, manganese, cadmium and pH) and use a mix of annual averages and 95 percentiles to assess compliance. The WQOs are:

No treatment
No deterioration
No discolouration
North Sea Declaration commitments
EC Directive - Freshwater
EC Directive - Saltwater
Protection of estuarine biology (based on the Shellfish Waters Directive)

The modelling used had to provide a clear and technically sound basis to assess each of the treatment options being considered.

The modellings key deliverables were predictions of the following:

- the consequences of ceasing all minewater treatment in terms of water quality and the potential for discolouration in the Carnon River, Restronguet Creek and Carrick Roads. The frequency, extent and duration of discolouration events was estimated based on loading and concentration at Devoran Bridge.

- the extent of minewater treatment required to achieve compliance with the WOOS for the Carnon River and Fal estuary. An initial screening of potential treatment methods identified two primary methods for further evaluation - oxidation and chemical neutralisation (OCN), and biochemical sulphurisation (BCS).

- the impact of a range of treatment option s on water quality and the potential extent of discolouration in the Carnon River, Restronguet Creek and Carrick Roads. With OCN and BCS we had actual knowledge of their use at Wheal Jane, which enabled water quality to be predicted for different treatment scenarios with a high degree of confidence.

A suite of linked models were developed which included 7 rainfall runoff models, 6 hydrochemical models, a MIKE 11 Carnon River and Restronguet Creek model and a MIKE 21 Restronguet Creek and Fal estuary model.

This had to take account of factors eg. ongoing decay in minewater metal concentrations and the elimination/treatment of diffuse sources of contamination.

Seven treatment options and sensitivity cases were modelled. The options ranged from "no treatment" worst case to treatment of the entire Carnon River using an Ion Exchange process to achieve a high quality effluent.

Current indications are:

WQO	TREATMENT REQUIRED	RELATIVE COST
No treatment	None	N/A
No deterioration	WJ 6	CURRENT
No discolouration	WJ 6	CURRENT
North Sea commitments	WJ 6	CURRENT
EC Directive - Freshwater	WJ + CA + diffuse sources *	HIGH
EC Directive - Saltwater	WJ + CA + diffuse sources *	HIGH
Protection of estuarine biology	WJ + CA + diffuse sources *	HIGH

It can be seen that very high costs would need to be incurred to meet EC Directive Environmental Quality Standards (EQSs) - this necessitates treating the entire catchment! Modelling indicates that we cannot guarantee achievement of EC Directive EQSs with SRB, although for most parameters, this is expected.

The output from the current study will be the "Selection of Long Term Treatment Option Report", which will identify the treatment option with the highest cost:benefit ratio.

The option selected by cost-benefit may not meet all EC Directive EQSs, although this may not necessarily mean that the requirements of the Directives are not complied with. The ultimate policy will be decided in conjunction with DETR.

Conclusion

The final reports are awaited and based on the recommendations of these reports, decisions will be sought from the Agency Board and DETR on the future courses of action.

It is likely that a continuation at the current treatment intensity and flow rate will be recommended. This being the case, a contract will be let early in 1999 for the construction and operation of an enhanced treatment plant to deal with the minewater with a completion date early in 2001.

ENVIRONMENT AGENCY - MINEWATER CONFERENCE
20th - 21st April 1998

The Coal Authority Minewater Remediation Programme 1997 - 1998

Presented By:- Mr K Parker, Property & Environment Manager, The Coal Authority.

1. Introduction

The year has involved a continued close liaison with the EA, SEPA, DETR, DTI and Local Authorities in order to progress the implementation of Minewater Treatment Projects in England, Scotland and Wales. Work has continued in prioritising sites in consultation with EA and SEPA on a cost/benefit basis to bring high impact sites into the Authoritys programme of ongoing remediation projects as funding becomes available.

In progressing the feasibility study work carried out during 1996/7, the year has targeted the progress of a number of high priority schemes, taking them from initial desk top/ feasibility study to detailed design, planning, contract and construction phase. The target being to progress four projects to construction during 1997/8.

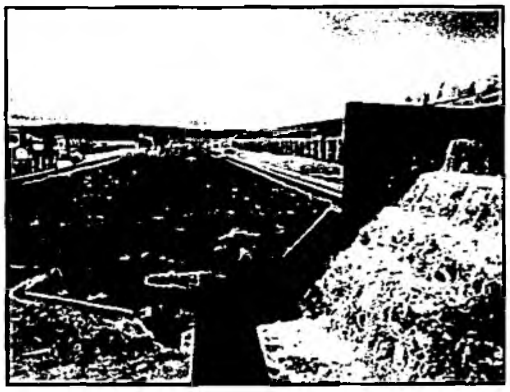
The year has been successful in many ways, in that schemes for Minto and Polkemmet in Scotland, Gwynfi in Wales and Old Meadows in England have all now progressed to construction phase.

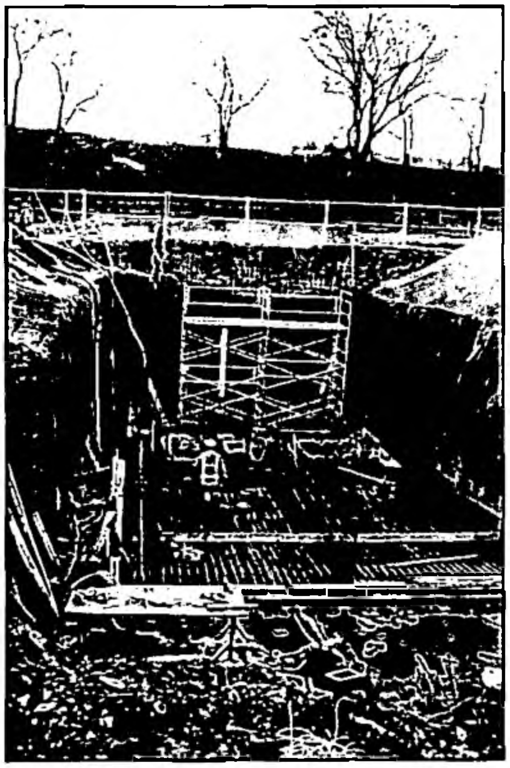
The year has done much to instigate an ongoing minewater remediation programme for the Authority and has set a firm foundation for continued work in 1998/99 subject to funding.

2. Background

MINEWATER REMEDIATION

Background





Top: Aeration of Iron Contaminated Minewater

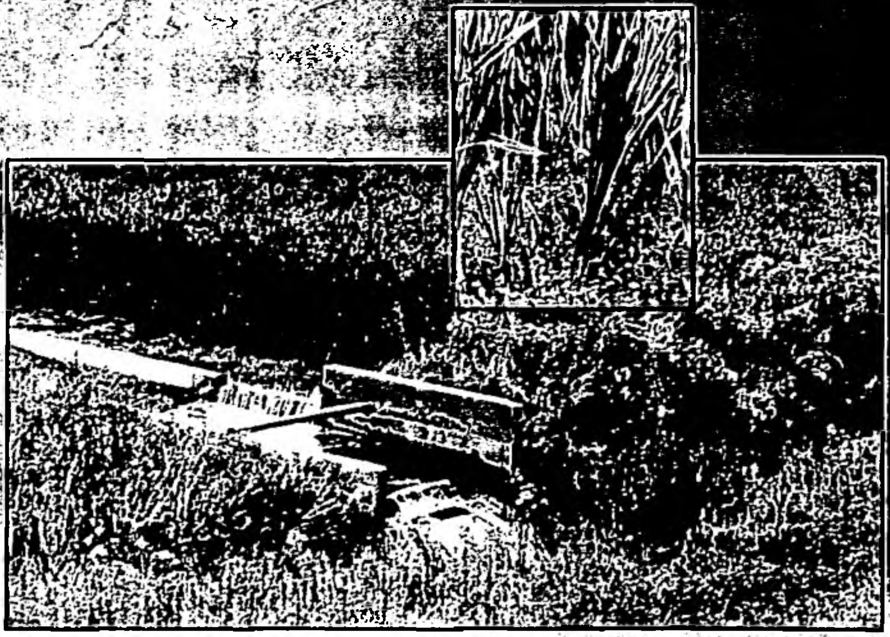
Above: Construction works at Bullhouse

Right: Outfall from Woolley Wetlands

- The Coal Authority, in close liaison with the Environment Agency and the Scottish Environment Protection Agency, have completed a number of detailed feasibility studies relating to priority minewater discharges in the UK.
- In addition to the successful treatment of iron-contaminated minewater, pumped at the former Woolley Colliery in Yorkshire, work has begun on projects at Minto and Polkemmet in Scotland, Old Meadows in England and Gwynfi in South Wales.

Additional schemes are being considered at the former Frances and Michael and Monktonhall Colliery sites in Scotland and at Edmondsley near Durham. Work should commence at Monktonhall and Edmondsley in Autumn 1998.

- The Coal Authority continues to secure land for further minewater treatment schemes and to progress detailed design and planning matters on priority sites, subject to available funding.
- The Authority's partnerships with the Environment Agency, Barnsley Metropolitan Borough Council and Hepworths at Bullhouse in South Yorkshire, and with Neath Port Talbot County Borough Council and the Environment Agency at Ynysarwed in South Wales, are key to progressing the remediation of further high impact discharges.



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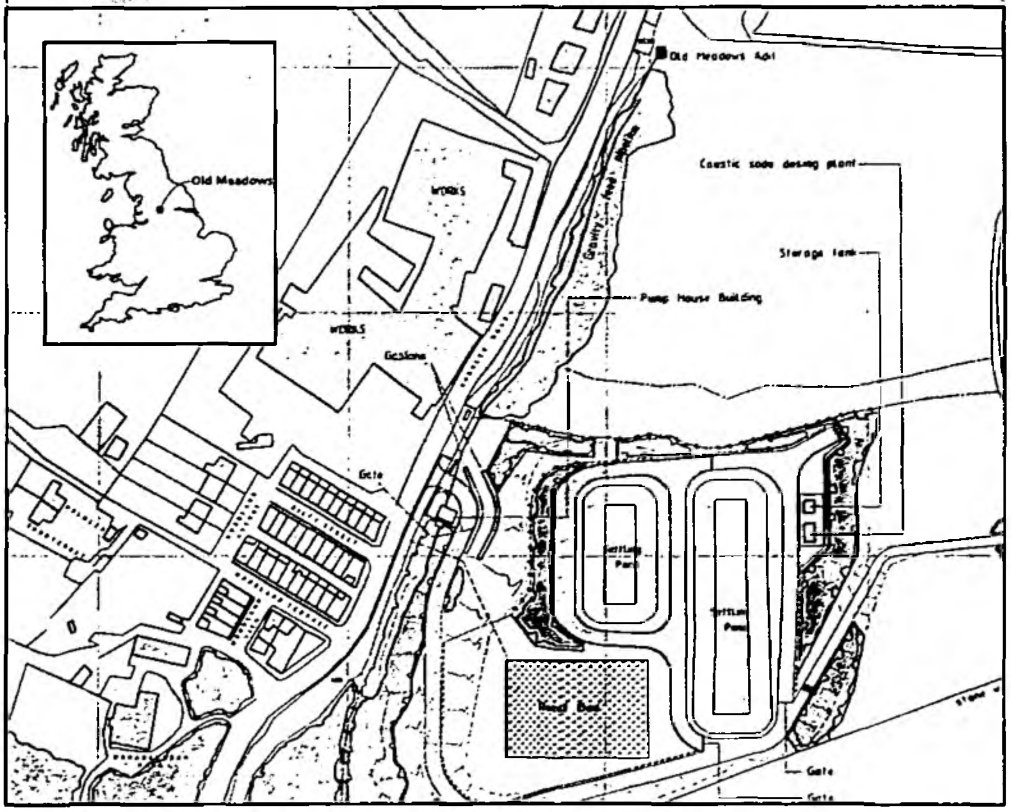
3. Construction Projects (attached case sheets on each project)

MINEWATER REMEDIATION

Old Meadows, Bacup, Lancashire

- Minewater from the former Old Meadows Colliery currently emerges from a single adit, discharging polluted minewater into the River Irwell.
- Visual impact from the current discharge affects some 24km of the river bed and the water quality of the river is impacted for some 5km downstream.
- The only land available to implement the scheme was approximately 3 hectares of privately-owned agricultural land. Topography consists of steep hillside gradients, which are not ideal for construction of a treatment system.
- Current minewater flows are 43 litres per second with a pH of 6.0 and iron loadings of approximately 37mg per litre
- The selected treatment option includes pumping the discharge to a sodium hydroxide dosing plant for pH correction, settlement of iron within a lagoon system and final polishing of the treated minewater in a 2200 square metre reed bed system.
- The aim is to reduce iron in the treated discharge to less than 1mg per litre.
- The implementation of such a scheme involves a high cost of £900,000 due to the characteristics of the effluent and difficult engineering conditions. Further operational management and maintenance costs will require significant future cost provisions.
- Work commenced in March 1998 and is due for completion during late 1998.



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MINEWATER REMEDIATION

Gwynfi, Neath, South Wales

● Minewater flows from the former Glyncorrwg and Corrwg Rhondda Colliery at Blaengwynfi, near Neath discharge from the side of a steep sided valley and enter the Nant Gwynfi River, causing visual impact and water quality deterioration to 2km of the river bed.

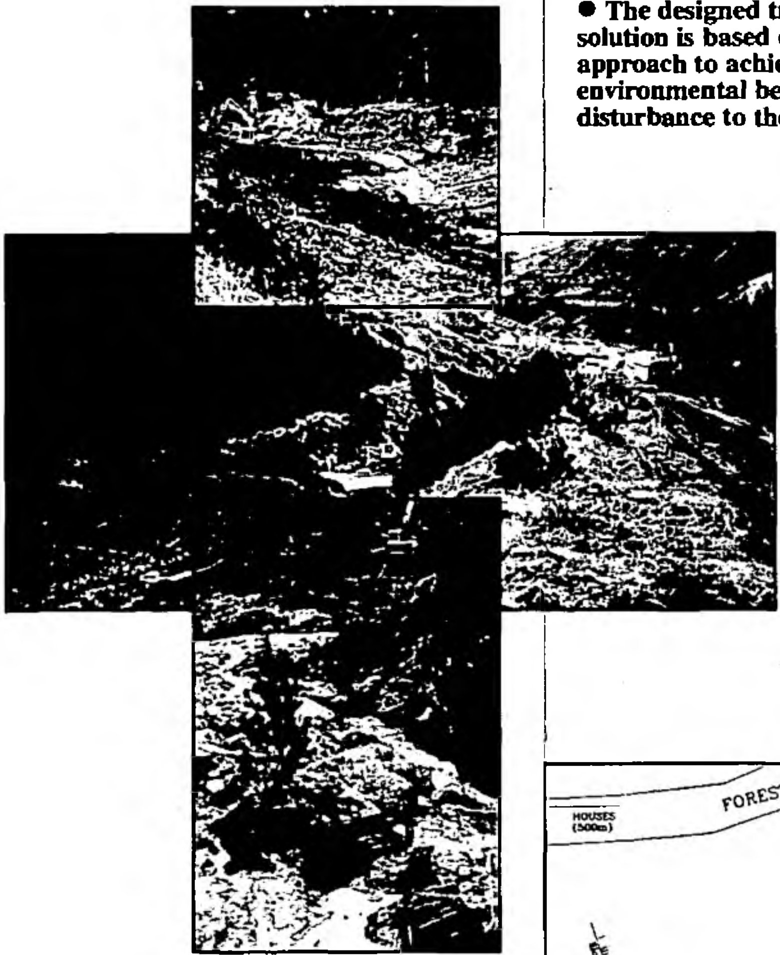
● Topography of the area is difficult and limited land was available to incorporate a comprehensive treatment system.

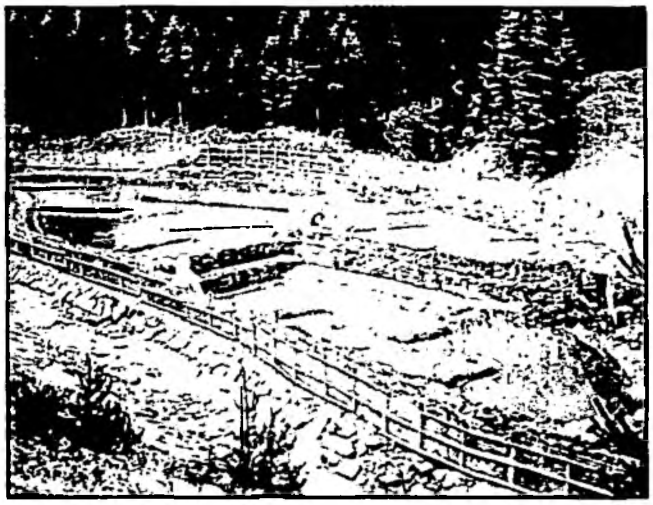
● The discharge of polluted minewater flows at up to 18 litres per second, has a pH of 6-7 and an iron content of 7 mg per litre.

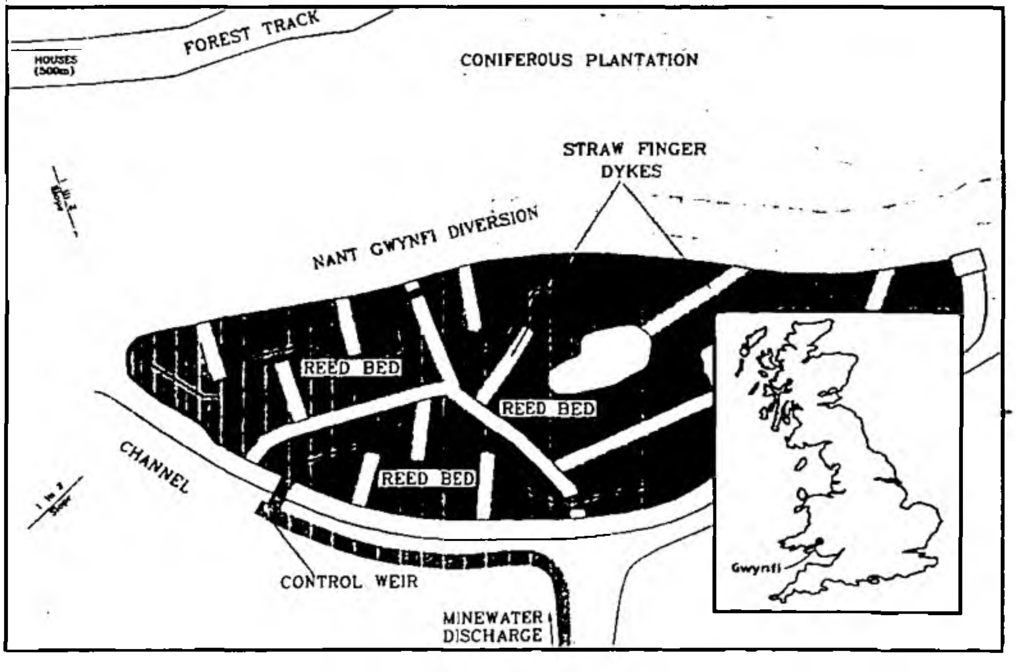
● The designed treatment solution is based on a pragmatic approach to achieve the greatest environmental benefit with least disturbance to the environment.

● 2.5 acres of land is now leased from the Forestry Commission to construct a passive wetland system of about 800 square metres to treat flows of up to 10 litres per second. Works include the realignment of the Nant Gwynfi River.

● The Gwynfi scheme is designed to significantly reduce the iron loadings in the Nant Gwynfi River and involves a simple remediation scheme costing £220,000. Construction started in March 1998 and is due for completion in August 1998.







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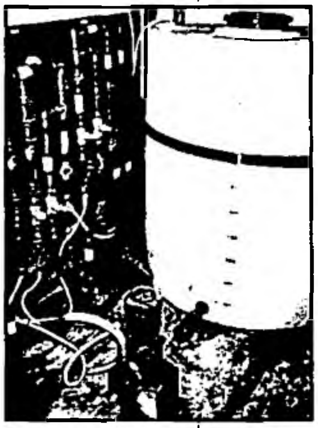
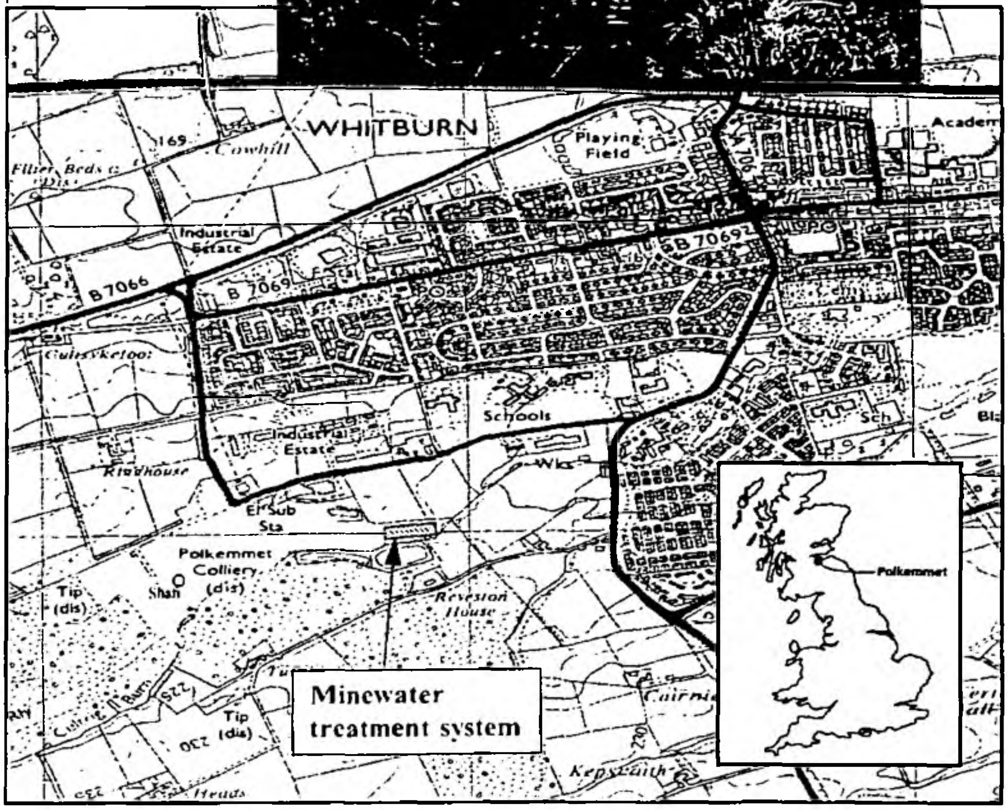
MINEWATER REMEDIATION

Polkemmet, West Lothian, Scotland

- Polkemmet Colliery closed in 1984 and pumping finally ceased at the pit in 1986.
- Monitoring in the area alerted the Scottish Environment Protection Agency (SEPA) and the Coal Authority that rising minewaters were a major cause for concern. SEPA targeted the problem as their priority site for action in Scotland.
- A detailed feasibility study was commissioned by the Authority and the findings suggested that iron-contaminated minewater could break out along coal outcrops during early 1998, causing potential pollution to the River Almond near Bathgate.
- Working in conjunction with West Lothian Council and SEPA, an urgent contingency scheme was designed to pump from Polkemmet shaft, chemically treat the water and discharge approximately 100 litres per second to the Cultrig Burn.
- The construction works commenced in January 1998 and were completed in March 1998.
- Early results are encouraging, in that rising minewaters are currently being controlled by pumping at Polkemmet.
- Work continues to establish a longer term solution to minewater control in the area.





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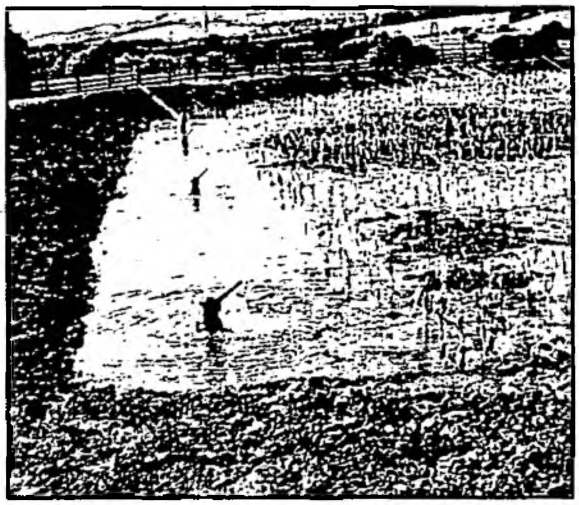
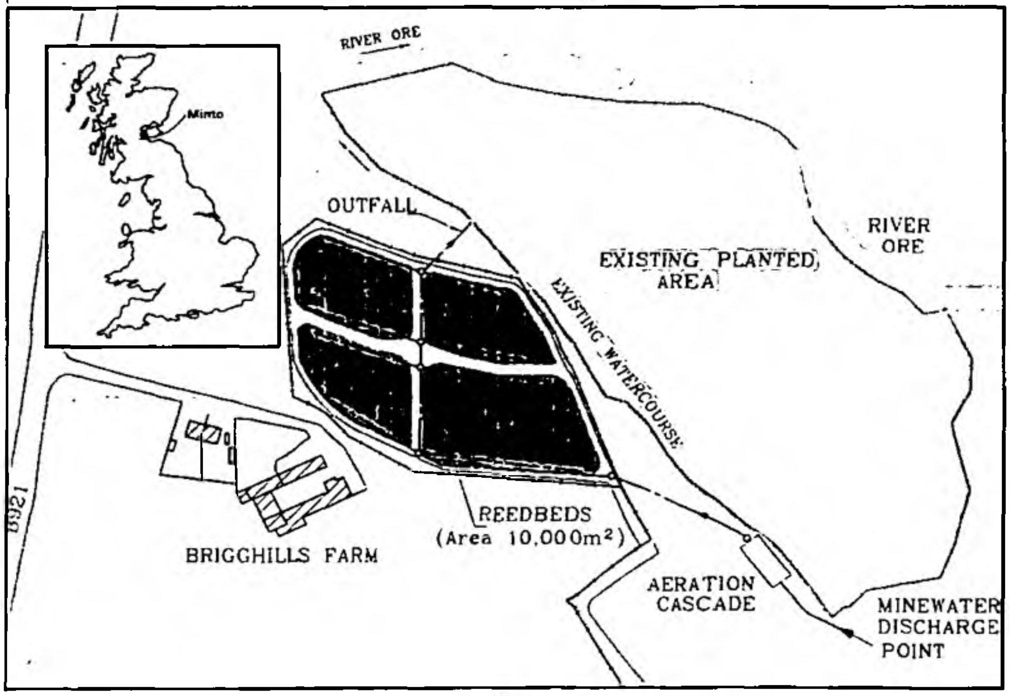
MINEWATER REMEDIATION

Minto, near Lochgelly, Fife, Scotland

- Minewater from abandoned workings at the former Minto Colliery, near Lochgelly in Fife currently discharge into the River Ore with high visual and biological impact.
- A detailed feasibility study concluded that a cost effective remediation scheme could be implemented and 3.5 acres of land was purchased from Fife Council for the project to go ahead.
- Minewater has an iron content of 18mg per litre, a pH of 6.8 and a flow of approximately 60 litres per second.
- The treatment system involves:
  - i) Minewater is diverted to an aeration system.
  - ii) The settlement of iron sediment takes place within a primary and secondary reed bed system covering 10,000 square metres.
  - iii) The discharge of cleaned water into an adjacent stream.
- Typha latifolia reeds have been selected for use in the wetland due to their proven tolerance to high metal concentrations.
- The Minto scheme is a simple passive treatment solution to remediate iron contaminated minewater discharges. The scheme implemented will provide a reasonably low cost solution of around £300,000 to remediate a long standing pollution problem.
- Construction started in October 1997 and was completed in July 1998.
- The improvements in water quality in the River Ore will complement those brought about by the Ore Valley trunk sewer improvement scheme.





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4. New Feasibility Studies Commissioned During the Year

As part of the Authority's ongoing programme of investigating minewater discharges ranked as high priority by EA and SEPA, further detailed feasibility studies have been carried out during the year to investigate potential for future remediation works.

Polkemmet - Scotland

Completion of a detailed feasibility study associated with the contingency scheme for pumping and treatment to prevent an uncontrolled outbreak of contaminated minewater at outcrop during early 1998.

Monktonhall - Scotland

Pumps have been installed and a study completed to investigate treatment options at the site. Plans are well established to implement contingency arrangements to prevent any uncontrolled outbreak of water associated with cessation of pumping at the colliery.

Elginhaugh - Scotland

Silkstone & Jackson Bridge, England

Pontllanfraith - South Wales

Taff Merthyr & Dunvant, South Wales

Feasibility studies for all six of the above sites have been completed and Draft Reports submitted. Findings were be formally presented to the Authority and the Environment Agency during March 1998.

A further feasibility study in relation to the **Bridgewater Canal** is to be commissioned in 1998.

5. Programme for 1998/99

(i) Ongoing Construction Projects:

Work will continue during the year to complete construction on **Minto, Polkemmet, Gwynfi and Old Meadows** sites.

These sites will progress to operation and maintenance phase during the period.

(ii) Anticipated Schemes for 1998/9 build Programme:

Further works at **Polkemmet** to establish a more permanent solution should commence during the year..

Works to establish a contingency system should commence early in the financial year at **Monktonhall.**

Of the schemes progressing towards construction phase, **Edmondley** is the most advanced. Planning permission was granted on 11th March 1998 by Durham County Council.

The discharge is an Environment Agency priority site with mine water currently discharging into the Cong Burn at approx. 13 l\s, pH 6.5 and iron concentrations of 18 - 30 mg\l. The designed scheme involves piping the discharge to a pumping station, where it will be pumped via. a rising main, a height of 45m, to a reed bed treatment area (0.5 ha) for settlement of the iron, prior to gravity discharge back to the watercourse.

Construction should commence during Autumn 1998.

Fender has potential to progress to construction phase during the financial year should funds be available and every effort should be made to tie up all permissions.

Sites such as **Kames, Taff Merthyr, Silkstone and Deerplay** all have potential for advancement in preparation for next year should funds be available, the aim being to set up a substantive construction programme for 1999\2000.

Monitoring at **Frances and Michael** in Fife indicates that construction of a pumping and treatment scheme will be commenced in 1999\2000

6. Conclusions

Building on the past success of the wetland project at Woolley it is very satisfying to be able to report that a substantive minewater remediation programme is now taking shape as projects progress from feasibility study to construction phase. The efforts of all parties involved has enabled significant progress to be made over the past year. Obstacles such as land acquisition, finance, planning issues will differ from site to site but the current staged approach and the level of consultation and liaison will enable further significant progress to be made during the coming year.

"QUAKING IN OUR BOOTS" ANOTHER YEAR OF MINEWATER RESEARCH AT THE UNIVERSITY OF NEWCASTLE

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1. QUAKING IN OUR BOOTS?

Since our earlier paper to the Environment Agency's first national conference on 'Abandoned Mines: Problems and Solutions' (Younger, 1997a), minewater research has been continuing apace at the University of Newcastle. By far the biggest event of the year has been the construction and commissioning of the full-scale treatment wetland at Quaking Houses, County Durham. We have indeed been over our welly-tops in dirt on the Quakies site for much of the year, hence imbuing some meaning to the flippant title of this paper! This event and its various ramifications will be described in some detail in Section 4 below; before continuing on to that, however, it is worth giving a brief update on our other activities in the hope that some of our experiences might be useful to others.

2. PREDICTION AND PREVENTION OF FUTURE MINEWATER POLLUTION

The main developments in this programme area are:

- the finalisation of the PhD thesis which describes the basic development of the GRAM model (Sherwood, 1997).
- successful application of GRAM to the abandoned coalfield areas of South Yorkshire (Burke and Younger, *in review*), Derbyshire (J. Walker, University of Sheffield, *personal communication*), Ynysarwed (South Wales), and Whittle Colliery (Northumberland).
- successful development within the EA-funded IMAC project ('Improved Modelling of Abandoned Coalfields') of a fully-operational 3-D flow code (VSS-NET), in which a pipe network (representing major mine roadways) is routed through a variably-saturated porous medium (representing surrounding strata and goaf) (Adams and Younger, 1997; Younger and Adams, 1997a, 1997b; 1998).
- VSS-NET has now been successfully applied to simulate an area of flooded workings in the Durham Coalfield to the south of the Butterknowle Fault (Parkin and Adams, 1998), and the groundwater rebound in the Blaenant-Ynysarwed system, South Wales (Younger and Adams, 1997b, 1998).
- participation of the University as one of the major partners on the Whittle Steering Group, which is aiming to find a 'partnership-based' solution to prevent the possible destruction of the River Coquet SSSI by acid minewater (see the paper by Butler, *this volume*).
- finalisation of the second Wheal Jane Minewater Study Project, on which I have acted as "Technical Auditor" for some 5 years to date (see the paper by Wright and Proctor, *this volume*, for further details of the outcomes).

- acting as a "Technical Auditor" on the EA's South Crofty project, spanning the period during which the mine finally closed. This has involved very active involvement with the mine operators, EA staff and consultants, trying to understand what risks to water quality are inherent in the process of groundwater rebound at South Crofty. This has entailed underground work in very difficult conditions, working out the route minewater will follow to the surface and assessing the scope for flushing of soluble minerals from the walls of the shallow workings (see Younger, 1998a).

3. CHARACTERISATION AND REMEDIATION OF EXISTING MINEWATER POLLUTION.

The main activities since April 1997 have been:

- establishing a very detailed assessment of the problems of zinc pollution in the Nent catchment (work undertaken primarily by Charlotte Nuttall as a PhD student)
- devising an innovative technique for passive treatment of hard, circum-neutral, zinc-contaminated minewaters. This technique, which is based upon closed-system limestone dissolution and synchronous precipitation of $ZnCO_3$ (smithsonite) has been successfully trialled in the lab, and is now the subject of a field experiment at Caplecleugh Mine, Nenthead
- full-scale construction and commissioning of the Pelenna III minewater treatment wetlands (see Edwards, *this volume*, and also Younger, 1998b, 1998c). The Pelenna III system began to receive minewater in April 1998, and at the time of writing, only one set of influent/effluent samples have been analysed. These have returned extremely encouraging results, with iron removal at rates of up to 99.8%. While it cannot be reasonably expected that such high levels of removal will persist indefinitely (at least some of the iron removal may be due to sorption, and when sorption sites are full, this process will tail off), the results are nevertheless extremely encouraging. The rise in pH in particular vindicates the selection of a limestone-based alkalinity generation process for these discharges.
- completion of four passive treatment systems at an abandoned colliery site in Leicestershire. Details of these systems cannot be released as yet (due to commercial confidentiality), but initial performance is positive in all cases.
- underground hydrochemical characterisation and in-mine passive treatment experiments at Frazer's Grove Fluorspar Mine, Weardale, Co Durham. This work was funded by the EU's BRITE-EURAM programme and undertaken with and on behalf of the mine owners (Durham Industrial Minerals Ltd), with a view to finding innovative solutions to zinc problems which we previously investigated on behalf of the EA (Younger *et al*, 1995a)
- initiation, in collaboration with the University of Sheffield (Dr S A Banwart), of a 3-year research project entitled "Optimising ochre accretion at source: Exploring a new technology for minewater remediation". Funded by the Engineering and Physical Sciences Research Council (EPSRC), with auxiliary funding and major *in kind* assistance from the Coal Authority and International Mining Consultants Ltd, this project is exploring the possibility of harnessing surface-catalysed oxidation of ferrous iron to produce dense hydroxide solids from net-alkaline minewater discharges without the need for extensive settlement ponds or wetlands. A field testing rig is currently under construction at the Coal Authority's Kimblesworth Pumping Station (Co Durham) to facilitate the main experimental work.

- installation and monitoring of a novel, pilot-scale passive treatment system at Foss Mine, Aberfeldy, Scotland, on behalf of the mine owners. This work only commenced in August 1998, so little information can be released yet, save to say that the initial chemical results show very encouraging performance in raising pH from 4 to 7.3, and very high rates of removal for Zn, Fe, Al and Mn.
- execution of a 4-month research project on behalf of Northumbrian Water Ltd's Teesside operations, entitled "Minewater Impacts on Surface-water Sewers (MISS). The study focused on problems encountered by NWL at both Eston and New Marske, two towns situated along the northern scarp of the Cleveland Hills. Drainage from abandoned ironstone mines leads to clogging of surface water sewers under both towns with ochre and other minerals. This in turn cause water to back-up, surcharge inspection covers and gully pots, and in some cases flood domestic properties. As in many of our other projects, our aim has been to find a simple, passive remediation strategy for long-term application.
- finalisation of plans for the Brusselton Farm wetland system, Co Durham, which is due for final construction works at the time of writing.
- evaluation of the pollution threats posed by the mining sector in the Río Das Velhas catchment, Minas Gerais, Brasil. This work was undertaken by myself in collaboration with a local engineering consultancy in Belo Horizonte, as part of a wider World Bank study concerning the initiation of environmental regulation in Brasil.
- construction and initial operation of the Quaking Houses wetland system (Younger, 1998c; Ordoñez et al, 1998), as described in detail below.

4. CASE STUDY: QUAKING HOUSES WETLAND, CO DURHAM

4.1. Pollution of the Stanley Burn

According to residents of the nearby village of Quaking Houses, County Durham, the stream known as the Stanley Burn has been polluted by spoil heap drainage for approximately 17 years. At the head of the Stanley Burn an acidic (pH 4), ferruginous (40 mg/l Fe) and aluminium-rich (35 mg/l Al) discharge enters the Burn, at flow rates varying between 60 and > 500 l/min. The source of this discharge is the 35 hectare spoil heap of the now-abandoned Morrison Busty Colliery. Pollution of the Burn is reported to have begun not at the time of the colliery closure, in 1974, but during the construction of the A693 road in 1980. Disturbance of the spoil, during construction of the road, appears to have fostered infiltration into the spoil, leading to the development of a perched aquifer within the heap, and has also promoted oxidation of pyrite present in the spoil. The resultant acidic groundwater migrates into a road drainage system, eventually discharging into the Burn (Younger *et al.*, 1997). Orange precipitates of iron hydroxides and oxyhydroxides (collectively known as "ochre") coat the bed of the Stanley Burn, and aluminium hydroxide is also evident, in the form of creamy deposits, milky suspensions, and characteristic froths on the water surface.

4.2. Pilot System

The Stanley Burn corridor is the focus of considerable restoration and conservation efforts by a local residents' action group, the Quaking Houses Environmental Trust (QHET). Following sustained pressure from the QHET, the former National Rivers Authority (now succeeded by the Environment Agency) commissioned a study for treatment of the Stanley Burn minewater discharge, in 1995. Undertaken by Nuwater Consulting Services Ltd. (in association with Newcastle University) the study concentrated on the application of constructed wetland technology, since a low cost solution to the problem was considered of tantamount importance. Since the discharge is of net-acidic character (ie. acidity > alkalinity) an anaerobic pilot-scale wetland was constructed. Full details of this investigation are given by Younger *et al* (1995b, 1997). The pilot-scale wetland, which had a surface area of approximately $40m^2$ and treated between 5-10% of the total flow, successfully removed 80 % of the iron and aluminium in the discharge and removed acidity at an average rate of 9.6 $g/m^2/d$ for the 18 months of its operation. This compares favourably with an average removal rate of 7 $g/m^2/d$ for similar wetlands in the USA (Hedin *et al*, 1994).

4.3. Construction of full-scale wetland

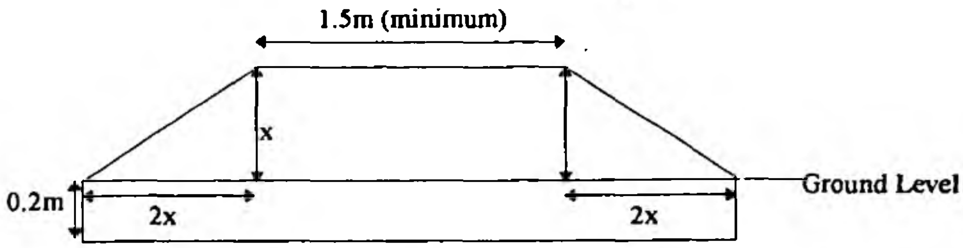
Encouraged by the success of the pilot scheme, the Environment Agency signalled its willingness to accept a passive treatment solution at the site. The pilot plant performance data also proved invaluable in persuading funding agencies to finance a full-scale system, and in 1996 a local philanthropic / environmental organisation (Northumbrian Water Kick Start Fund) committed £54,000 to construct a full-scale wetland at the head of the Stanley Burn. A parcel of land of approximately $500m^2$ was provided by British Coal Property. As soon as the site was available, a thorough site survey was undertaken, revealing two critical design constraints:

(i) only 1.0m of head was available, precluding the construction of a vertical flow system at the site, and

(ii) an investigation of the *in situ* soil revealed that the area of land to be used was formerly the site of an unrecorded finings pond for an old coal washery of the Morrison Busty Colliery. Consequently the soil is heavily laden with iron and aluminium salts. Excavation of the *in situ* soil would result in substantial leaching of previously immobile metals, and therefore any design would have to assume all construction works to be located at and above ground level.

Thus, original intentions to design and construct a vertical-flow Successive Alkalinity Producing System (SAPS; Figure 5), reported to have land requirements 40% less than traditional horizontal-flow compost wetland systems (Kepler and McCleary, 1994), would not be possible at this particular site. Consequently a horizontal-flow anaerobic system, very similar to the original pilot-scale wetland, was designed.

A key objective of the design of the wetland system was to create a remediation solution which would be long lasting. A nominal design life, based upon experiences in the USA (Hedin *et al.*, 1994)), of 15-20 years was therefore considered reasonable. Consequently, a key issue in the design of the wetland was that of the retaining embankments. Figure 1 illustrates the final design of the retaining embankments. A minimum crest width of 1.5m should ensure robustness over time, and slope angles of 2:1 (length:height) will minimise the potential for slippage and erosion. The material used in the wetland embankments is Pulverised Fuel Ash (PFA), which was compacted immediately after the emplacement of each load. Whilst having the essential impermeable property required for a water retaining structure (when compacted), this material costs less than half the price per tonne than the obvious alternative, clay. To prevent toe drainage the embankments have been sunk approximately 0.2m into the *in situ* ground (Figure 1).



where, x = 0.4m - 1.0m

Figure 1: Design of retaining embankments at the Quaking Houses wetland.

A central weir (Figure 2), also constructed from PFA, but with a covering of PVC (to prevent erosion), divides the wetland into two cells, the second 0.4m lower than the first. This was included in the design to keep the absolute height, and thus the width, of the retaining embankments to a minimum, hence saving on materials costs.

A combination of limestone and three types of manure were used as substrate in the wetland. Approximately 30 tonnes of limestone at the far end of the wetland, adjacent to the effluent pipe, facilitate final pH adjustment. Three locally available composts have been used in combination - cattle manure, municipal waste compost and horse manure. The latter was the substrate used in the original pilot-scale wetland. The approximate ratio of these is 40:30:30 respectively. A 100mm diameter influent pipe carries the water from the culvert (the original discharge point into the Stanley Burn) to the influent of the wetland itself. From the end of the second wetland cell a 150mm diameter effluent pipe carries the water into an effluent channel, and hence back into the original Stanley Bum stream channel. Installing a greater diameter effluent pipe it is possible to ensure that, assuming no blockages occur, water will never overtop the wetland embankments. An adjustable 90° bend on the end of the effluent pipe (wetland side) enables control of the water level within the wetland, as and when it becomes necessary.

Figure 2 is an as-built plan of the final constructed wetland. The substrate depth in the wetland varies between 0.3m and 0.5m, and the total area of substrate is approximately 440m^2. Unlike all of its predecessors in the UK, the Quaking Houses wetland has not been designed or built in an angular manner. Beyond the primary objective of treating the minewater one of the key aims of the project was to ensure that, as far as possible, the wetland was in keeping with the local countryside, and to the liking of the local community; hard concrete structures and right-angled geometry were effectively precluded.

4.4. Initial performance of the full-scale wetland

Figure 3 illustrates the effective removal of iron, aluminium and acidity from the spoil drainage as it passes through the wetland. Although the quality of the spoil drainage has not been as severe as usual in these first months of operation (due to dilution effects from the winter rains) these early indications of the wetland's performance are very encouraging. Iron, aluminium, and even manganese concentrations are being lowered through the wetland. Even at this early stage of its operation, when a period of acclimation may be expected, the wetland is removing 65% of the iron, and 75% of the aluminium from the minewater. pH is consistently increasing, although the alkaline nature of the PFA embankments may be having some influence at present. This rise in pH is reflected in decreases in acidity (Figure 3), and increases in alkalinity.

The metal removal processes operating within the wetland appear to be similar to those of the pilot-scale wetland (Younger *et al.*, 1997): iron hydroxide precipitates are developing on the surface of the wetland substrate, and below the surface black deposits of iron monosulphide are increasingly evident. This is consistent with the liberation of hydrogen sulphide gas from the substrate (gas bubbles rise from pock marks in the substrate surface continually, with the identity of the gas being confirmed by occasional faint odours). Aluminium, which will not form a sulphide, appears to be deposited predominantly on the substrate surface, as aluminium hydroxide and hydroxy-sulphate.

4.4. Future Plans.

In April 1998, the Quaking Houses project was awarded the UK Conservation Award 1998. This major award, which is sponsored by the Henry Ford Foundation, attracts several hundred applications annually. We were delighted enough to learn that Quakies had won the "Conservation Engineering" category of the Awards, but completely thrilled to learn we were overall national winners also. We had to travel to London for the award ceremony, and were then dispatched to Istanbul to represent the UK in the European Conservation Awards (which was won by the Turkish entrant). The Award brought with is substantial prize money, which has allowed us to undertake some planting in and around the wetland, and to afford some further activities to ensure the future sustainability of the system.

After reviewing early performance data, we are currently working to provide a small aerobic wetland at the tail-end of the main wetland to "polish" the final effluent for iron. Although iron removal rates are impressive, the Quakies wetland was simply built as large as possible, rather than built to a size we were sure would permit total removal of iron. Hence we occasionally have as much as 3 mg/l of iron remaining in the effluent. As the effluent is always net-alkaline, however, we know that simple aerobic wetland treatment should be able to reduce this iron concentration further.

We have also commenced detailed hydrogeological studies of the spoil heap at Morrison Busty, with a view to identifying (and eventually eliminating) the main sources of acidity (probably by topical grouting of pyrite generation "hot-spots"). If all of our plans come to fruition, the wetland will be able to "take early retirement" in a few years and become a simple amenity feature.

Fig 2

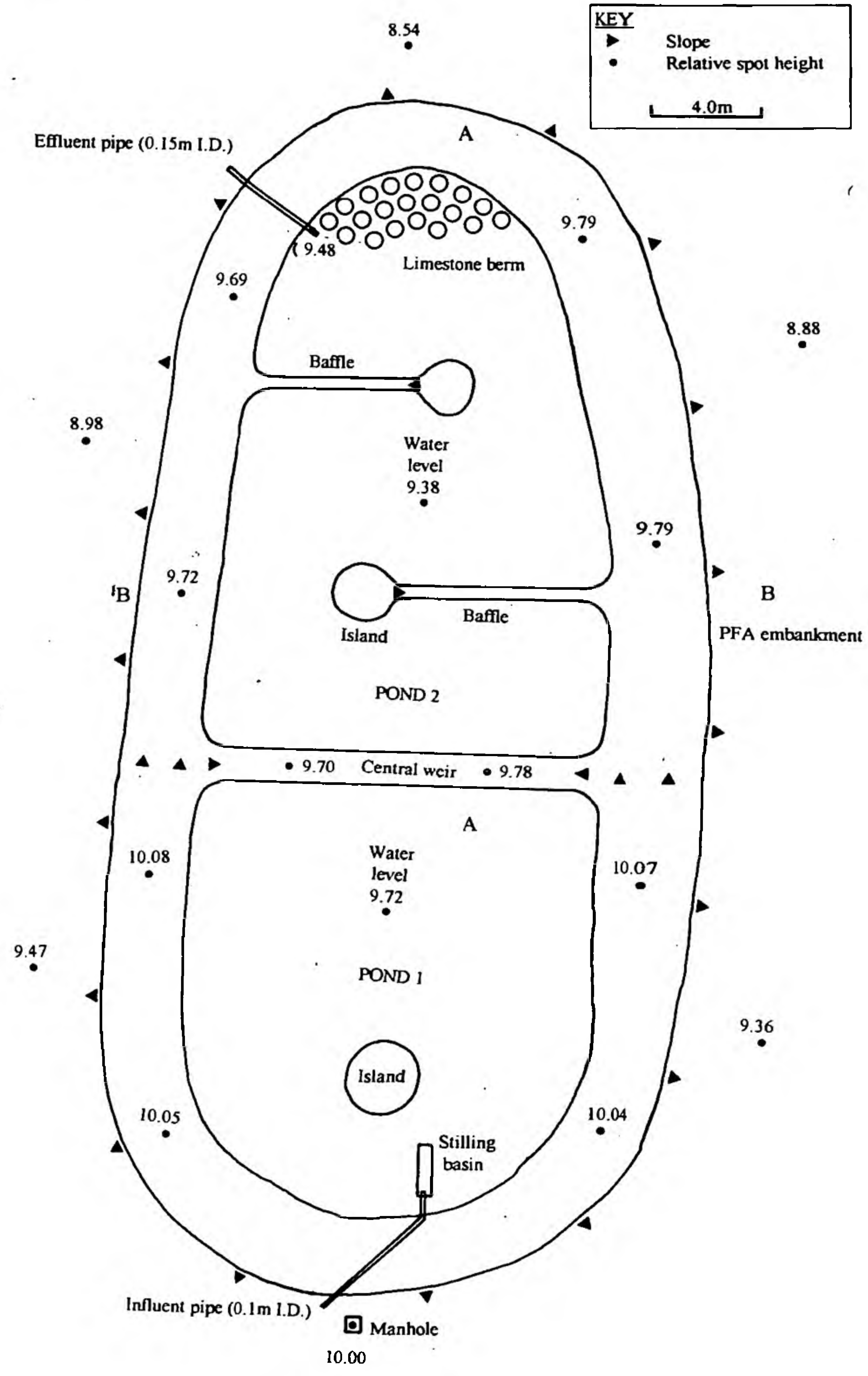


Figure 2: As-built plan of the full-scale wetland at Quaking Houses

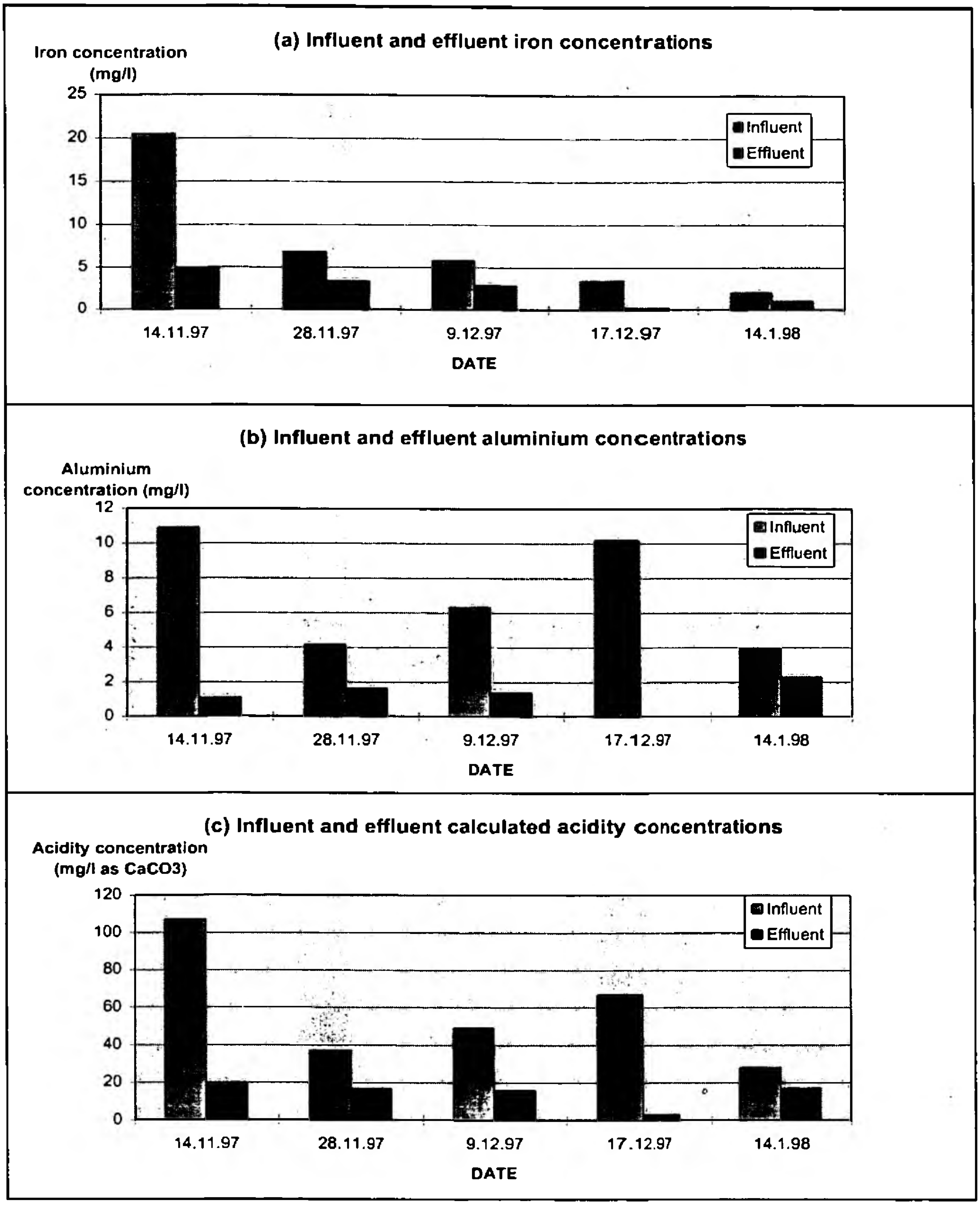


Figure 3: Performance data: Quaking Houses full-scale wetland

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THE RIVER PELENNA MINEWATER TREATMENT PROJECT

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ABSTRACT

The River Pelenna, in the Tonmawr area of the western valleys of South Wales, is stained a vivid orange for approximately 7 km 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 has 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.

Keywords: coal mines, iron, minewater, passive treatment, pollution, remediation, wetlands

THE PROBLEM

Tonmawr, in common with many other villages and towns in the "valleys" area of South Wales, grew alongside the coal industry, which arrived in the valley in the 1850s. Approximately 15 small drift mines developed over the next 100 years working several seams in the Upper Coal Measures including the Wenallt, Glyngwylim and Wenallt Rider. Following the First World War, two larger collieries developed: the Garth Tonmawr drift mine in the Nant Blaenpelenna valley and Whitworth colliery, a deep mine in the Gwenffrwd valley. At their peak, these two collieries together employed some 500 men. Coal mining had ceased in the area by the early 1960's, leaving behind spoil tips and other physical scars of industrial dereliction. Also, economic and social scars arose from mass redundancy and from loss of identity and purpose for the village communities. These problems were common to coal mining communities elsewhere in South Wales, Britain and across Europe.

Although many of the physical scars left behind by the decline of the coal industry have now been remedied by land reclamation schemes, the aesthetic and ecological impact of the highly polluting discharges from some of the abandoned mines in the area remains a startling legacy of the coal mining past. The source of the pollution is iron pyrites (FeS_2), which is commonly associated with the seams of the Upper Coal Measures in South Wales. When a mine is abandoned, and the pumps used to de-water the mine are switched off, the products of pyrite oxidation (ferrous iron, sulphate and hydrogen ions) are brought into solution as the mine becomes flooded. The characteristic orange staining of the gravel substrates in the Pelenna catchment is due to the precipitation of iron oxyhydroxides or ochres, which are formed as a result of the oxidation and hydrolysis reactions that occur when the ferruginous minewater drains into a receiving watercourse.

Of the six known discharges of minewater in the Pelenna catchment (Fig.1), five have been identified as requiring treatment to achieve the European Inland Fisheries Advisory Council (EIFAC) standard for mean dissolved iron concentrations in salmonid fisheries (ie. < 1 mg/l). These discharges are listed in

Table 1, with their respective mean daily iron loadings.

Table 1. Mean daily iron loadings from Pelenna minewater discharges (1995/96).

Discharge (name of adit)	Abandoned colliery	Mean Iron* (mg/l)	Mean Flow* (l/s)	Daily Load (kg Fe/day)
Whitworth A	Llantwit Merthyr	75.5	8.3	42.3
Whitworth B	Welsh Main	8.5	0.6	0.5
Gwenffrwd	Wenallt	10.1	8.9	6.9
Whitworth No.1	East End	21.6	2.7	6.3
Garth Tonmawr	Garth Tonmawr	34.2	13.6	35.8

* based on monthly spot sampling/gauging from May 1995 to April 1996. All minewater samples were collected as close to the source of the discharge as possible.

On occasions, these minewater discharges can be directly toxic to aquatic life due to the elevated concentrations of dissolved iron they cause in their receiving watercourses. The blanketing of the substrata with iron oxyhydroxides also causes more chronic effects on invertebrate habitats and fish spawning gravels. It has been estimated that approximately 7km of watercourse has been adversely affected in the Pelenna catchment as far downstream as its confluence with the main River Afan at Pontrhydyfen. On the social and economic level, the gross aesthetic impact is considered to be a constraint to the successful regeneration of the area.

THE ORIGINS OF THE PROJECT

Following closure of the two largest mines, Whitworth Colliery and Garth Tonmawr, predecessors of the Environment Agency began collecting information to characterise the discharges and their impact on the receiving watercourses. During the reclamation of the Whitworth Colliery site in the mid 1970's, the then West Glamorgan County Council (WGCC) constructed the Whitworth Lagoon in an attempt to reduce the impact of two of the discharges (Whitworth A and B). Also in the 1970's, the local angling club (Afan Anglers) put forward detailed proposals to deal with the Garth Tonmawr discharge. Local concern over the problem had always been an issue, but the situation gained wider attention during the late 1980's as the South Wales Coalfield was being run down, creating the potential for more widespread problems to occur.

In 1992, The BOC Foundation for the Environment funded an investigation into the water quality of the catchment, to identify the levels of treatment necessary at each minewater discharge to achieve acceptable standards downstream. This work was managed by the NRA, which provided water quality data for the Institute of Hydrology to run its QUASAR (QUAlity Simulation Along Rivers) model. The study recommended that the iron concentrations in the Nant Gwenffrwdd and Nant Blaenpelenna be reduced by 95% and 50% respectively to achieve EIFAC standards and make the watercourse suitable for recolonisation by salmonid fish(1). Following on from this work, a contract was let by the NRA in spring 1993 to consultants Richards, Moorehead and Laing (RML) Ltd to undertake a feasibility study of the most suitable and cost effective methods of achieving the required treatment levels. Potential treatment methods for minewater contamination include:

- physical options - not always technically feasible;

- chemical treatment - an established method, but with major financial implications in terms of revenue expenditure; and

- passive treatment systems (eg. wetlands) utilising biological processes such as bacterially-mediated sulphate reduction - a relatively low cost solution.

The feasibility study report concluded that the required treatment could be achieved by treating the Whitworth A and B, Gwenffrwd, Garth Tonmawr and Whitworth No.1 discharges by a combination of passive systems including anoxic limestone drains, settlement ponds, aerobic and anaerobic wetlands[2]. Such treatment systems were deemed preferable to physical or chemical options because:

- passive treatment systems require little or no day-to-day process control;

- operational costs can be low when compared to alternative systems;

- capital costs are relatively low; and

- the systems can provide additional environmental benefits such as diversified wildlife habitat.

The feasibility study report was used by WGCC on behalf of the project partners (WGCC, the National Rivers Authority (NRA) and the Welsh Development Agency (WDA)), as the basis of a successful bid for funding under LIFE (the Financial Instrument for the European Unions's 5th Action Programme for the Environment). Funding of £505 K was confirmed by the European Commission (EC) in November 1993, with the WDA providing 50% in principle towards design and construction costs.

WGCC contributed significant management costs (totalling over £100K) as lead partner, and the NRA also contributed over £100K for environmental monitoring associated with the project. The role of the NRA in this project was inherited by the Environment Agency on its creation in April 1996 and that of WGCC by Neath Port Talbot County Borough Council (NPTCBC) following local government reorganisation, also with effect from April 1996.

Work on the project started in earnest in January 1994, with a programme to construct five wetlands over a five year period (Fig.2).

PROJECT AIMS AND OBJECTIVES

The application to the European Union (EU) LIFE programme stated four objectives which have become the primary objectives of the project[3].

1. To create a large scale demonstration wetland treatment system capable of improving watercourses contaminated by coal mine effluent.

2. To evaluate water purification and therefore rehabilitation of contaminated watercourses.

3. To assess and develop opportunities to enhance the conservation aspects of such a treatment system.

4. To produce comprehensive data to contribute to the information base on minewater treatment and its applicability to the European Union including the dissemination of that information.

ASSOCIATED WORK

In addition to the main restoration project, the Environment Agency and its predecessors have carried out or initiated several associated projects, including:

(i) **Fisheries, biological & water quality studies.** Detailed investigations have been carried out to assess the status of fish populations, biological quality and water quality in the catchment and determine the impact of the minewater discharges[4]. The results of these investigations will provide baseline data so that any improvements resulting from the wetland treatment systems can be assessed.

(ii) **Acidification studies.** The above studies identified a surface water acidification problem in the catchment, which could undermine the success of the minewater project by limiting the recovery of fish, invertebrate and riverine bird populations. A feasibility study into addressing this problem has been completed[5].

(iii) **Sediment studies.** As part of the work to measure the impact of the minewater discharges and provide baseline data, investigations were carried out to quantify the deposition of iron compounds on the substratum and assess the impact on visual amenity[6].

(iv) **Investigations into natural wetlands.** The iron removal processes in 'natural' wetlands associated with abandoned minewater discharges in the Pelenna catchment have been investigated[7].

(v) **Ecological/conservation studies.** As part fulfilment of one of the project objectives, baseline surveys into the ecological status of the catchment have been carried out, including a vegetation survey[8] and a survey of riverine bird populations[9]. Further surveys will be carried out to assess the benefits of the wetland treatment systems.

(vi) **Minewater Treatment Computer Aided Design Package (MTCADPak).** This project is being funded by The BOC Foundation for The Environment and follows on from work funded by the foundation during 1992, involving water quality modelling of the catchment. The aim of this project is to produce a freely available piece of computer software which will allow others with abandoned minewater problems to assess them and develop a passive treatment solution based on the experiences of the Pelenna project. The contract has been awarded to Environmental Technology Consultants Ltd (ETC) of Newcastle, and will cover four main areas: (i) background information and environmental data gathering needs, (ii) treatment level definition (catchment water quality modelling), (iii) treatment system design and (iv) treatment system process model (management tool). Further details of this package are given in the paper by James and others (this volume).

PROJECT PROGRESS

To date, the first of five wetland treatment systems has been constructed, and has been operating since October 1995. The Whitworth No.1 wetland treatment system (Phase I) was designed by the WGCC Design and Construction Consultancy with specialist advice from Steffen Robertson & Kirsten (UK) Ltd. The treatment system was constructed between March and July 1995, and was commissioned and planted in September/October 1995.

The treatment system (Fig.3) comprises four discrete wetland cells of equal area, totalling 900 square metres, constructed from precast concrete with a geosynthetic base liner (bentonite sandwich). The influent (3-4 litres/second) drains via headworks at the mouth of the adit into a flow monitoring chamber with a v-notch weir, followed by a flow distribution chamber. The four wetland cells operate a parallel flow system which is controlled by decanting weirs in the flow distribution chamber. Flow distribution across the width of each cell is achieved using perforated pipes which discharge onto highly permeable gabions prior to treatment in the wetlands. The treated minewater passes through another flow monitoring chamber before discharging to the Nant Gwenffrwd.

A number of demonstration features have been incorporated into the Phase l treatment system, partly fulfilling one of the project objectives. The system includes both surface flow wetlands, which encourage aerobic iron removal processes, and sub-surface flow wetlands, which tend to favour anaerobic processes such as bacterially-mediated sulphate reduction. Differing substrate types (mushroom compost and wood bark mulch) and differing plant types (nursery grown *Typha* sp. and the locally occurring *Juncus* sp.) are also utilised in this experimental system.

Prior to construction, the site was prepared by removing approximately 700 cubic metres of iron sludge which had accumulated in a colonised wetland area outside the adit mouth. To facilitate this, the minewater was first diverted around the wetland area for several months to partially dry the sludge. Further potential problems were caused by iron sludge which had accumulated behind the adit mouth. A serious pollution incident was avoided by constructing substantial temporary lagoons, with reserve pumping, to prevent the accumulated sludge from entering the receiving watercourse during construction of the adit headworks.

Other factors constraining wetland construction included the relative remoteness of the site and the limited area available. Also, the steep topography and the poor ground conditions required the use of concrete retaining walls and an impermeable membrane. Although these structures may inhibit the conservation potential of this wetland, they will facilitate accurate measurement of wetland performance.

WETLAND PERFORMANCE

Monitoring of the performance of the wetland has been carried out on a monthly basis since October 1995, by analysing the water chemistry of the inlet to the treatment system, the outlets of each of the four wetland cells and the discharge to the receiving watercourse, and by continuously gauging the flow rate of the inlet and outlet of the system. Results of this initial monitoring indicate that the outlet from the wetland treatment system contains on average approximately 80% less iron than the untreated minewater, and has a neutral pH. Wetland performance to date is summarised in Table 2 and Fig.4.

More detailed monitoring of the biological and chemical processes occurring within one of the wetland cells (Cell 3) has been carried out as a PhD project at Leeds University. Another ongoing PhD project, with University of Wales Bangor, involves a study of enzyme activity around the root systems in Cell 4. Analysis of substrate composition in July 1996, as part of an MSc project with University of Wales Aberystwyth, demonstrated that the two types of substrate used had significantly different patterns of iron fraction accumulation. Cells containing mushroom compost were found to contain predominantly organically bound and sulphide bound iron fractions and lower oxides, while the bark mulch had a dominance of non-crystalline and crystalline oxides or hydroxides. The dominant iron fractions accumulated in the whole wetland system were non-crystalline oxides or hydroxides[10].

Although the treatment system performed well for iron removal during the first year of operation, some problems have been experienced regarding flow distribution to the wetland cells. Deposition of iron oxyhydroxides in pipes entering the system has caused blockages, resulting in uneven flow distribution and precluding an accurate assessment of the relative performance of the four cells. In extreme circumstances, a significant amount of untreated minewater was bypassing the treatment system via the overflow. These problems were solved in the short-term by using drain rods and pressure hoses to remove the blockages. In order to prevent the problems recurring, modifications are to be made to the pipework to increase flow velocity and reduce blockages. Overcoming these problems will provide valuable lessons that will be applied to the later phases, thus reinforcing the demonstration value of the project.

Table 2. Water quality data from Whitworth No.1 Wetland Treatment System (monthly analyses from October 1995 to March 1997).

		pH	Total Iron (mg/l)	Sulphate (mg/l)	Dissolved Oxygen (mg/l)
Inlet to system	mean range	6.5 (6.1-7.2)	23.7 (11.7-37.4)	340 (249-471)	7.5 (5.1-9.2)
Outlet from Cell 1	mean range	7.4 (6.8-7.9)	3.4 (0.5-16.2)	318 (250-460)	5.6 (3.0-10.1)
Outlet from Cell 2	mean range	7.2 (6.6-7.8)	5.6 (0.3-16.3)	317 (236-442)	6.3 (3.4-8.9)
Outlet from Cell 3	mean range	6.9 (6.6-7.9)	7.8 (1.3-15.2)	322 (235-539)	8.8 (6.1-13.0)
Outlet from Cell 4	mean range	7.2 (6.8-7.9)	2.0 (0.9-7.3)	340 (231-486)	3.5 (2.67-4.05)
Outlet from system	mean range	7.3 (6.7-8.1)	4.6 (0.4-9.3)	289 (81-461)	9.0 (6.0-11.4)

THE FUTURE

The remaining four wetland treatment systems will be designed and constructed during the next two years, and will extend the scale of demonstration by incorporating features such as aeration cascades, settlement lagoons, ochre accretion terraces and successive alkalinity producing systems (to increase alkalinity in the more acidic discharges). Existing features such as natural wetlands will be retained and incorporated into the treatment systems as far as possible, to minimise the visual impact of the scheme and to enhance the conservation value of the treatment systems.

The designs for the Phase II (Garth Tonmawr) wetland treatment system have been completed by WGCC/NPTCBC Design and Construction Consultancy, based on conceptual designs produced by Steffen, Robertson and Kirsten (UK) Ltd. This treatment system will consist of a number of aerobic and anaerobic cells operating in series (Fig.5). Construction of the Garth Tonmawr treatment system has been re-scheduled to coincide with a land reclamation scheme in the Blaenpelenna valley in 1998. Combining these two schemes will minimise disruption to the local community and will also result in considerable cost savings.

Treatment systems for Phase III were designed by NPTCBC Design and Construction Consultancy in 1996, with specialist input from Dr Paul Younger of University of Newcastle-upon-Tyne. This phase will involve the construction of passive treatment systems to treat the three remaining discharges in the Gwenffrwd valley, namely the Whitworth A, Whitworth B and Gwenffrwd discharges (Fig.6). Construction of these treatment systems was scheduled to commence in May 1997.

During the remaining phases there will be continuous monitoring and evaluation of the first phase, with the lessons learned applied to the later phases. In addition, the associated studies mentioned previously will be progressing and producing information that will add to the data bank and assist in the dissemination process. Following completion of all the phases, the environmental assessment studies will be repeated to assess the improvements to the catchment resulting from the wetland treatment systems. Ultimately, it should be possible to demonstrate an improvement in the water quality and visual amenity of the River Pelenna, and the wider conservation and environmental benefits of the project. A final report will document all the successes and failures of the project, and the lessons learnt.

PARTNERSHIP AND INFORMATION EXCHANGE

Partnership is the key to the resolution of the minewaters problem and the River Pelenna Minewater Project is an excellent example of the partnership approach. The project has involved and interested people from the local community, local authorities, the academic sector, statutory agencies (Environment Agency & WDA), private sector, universities, professional institutions (eg. Chartered Institute of Water & Environmental Management, South Wales Institute of Engineers and the Royal Town Planning Institute) and government, including the Parliamentary Welsh Select Affairs Committee in 1992. Differing priorities and interests of the partners have produced a complementary package; none of the organisations involved could have achieved this initiative independently.

Information dissemination about the technology is a fundamental objective for LIFE and the WDA. There is considerable potential for the development of a Welsh skill base and extension of technology transfer opportunities will further add strength to the partnership. Existing linkages and networks include:

- UK Coalfields Communities Campaign;
- EURACOM (set up with EC funding from Exchange of Experience programme (Article 10, ERDF Regulations);
- EURADA (EUropean Association of Development Agencies);
- Natura 2000;
- Wales European Centre (Brussels); and
- UK Land Reclamation Panel (formerly SLAOPLR).

The problem of pollution from abandoned coal mines is common throughout Europe. A large number of European contacts have been established through the Pelenna project, including agencies in France, Germany, Spain, Malta, Cyprus, Sweden, Portugal, Slovakia and Latvia. A specific initiative was set up within the project to establish these links, and was completed in April 1995; further information can be provided on this aspect. To date, the majority of work to address the problem of coal mine drainage has been carried out in Eastern USA and South Africa, the Pelenna project being one of only a small number of projects developing this technology in Northern Europe. If successful, the Pelenna project will have applications not only in South Wales and the rest of Britain; it will also be "a local solution to a European problem".

CONCLUSIONS

1. Five iron-laden discharges from abandoned coal mines in the Pelenna catchment were found to be adversely affecting biological and water quality and causing discolouration of approximately 7 km of the Nant Blaenpelenna, Nant Gwenffrwd and the River Pelenna.

2. A project to treat the minewater discharges is being implemented by a partnership between Neath Port 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.

3. Wetland treatment systems were deemed to be the most appropriate method of removing iron from the minewater discharges, because of relatively low capital and operational costs and also because these systems can provide additional conservation benefits.

4. To date, the first of the five wetland treatment systems has been constructed, and has achieved 80% iron removal on average during the first eighteen months of operation, as well as neutralising its acidity. Treatment systems for the remaining four discharges will be constructed in 1997 and 1998.

5. The problem of pollution from abandoned coal mines is common throughout coalfield areas in Europe. The experiences of the Pelenna project, including successes and failures and the lessons learned, will have important application elsewhere. Dissemination of information is therefore a fundamental objective of the project.

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Fig. 1 Minewater discharges in the Pelenna catchment area

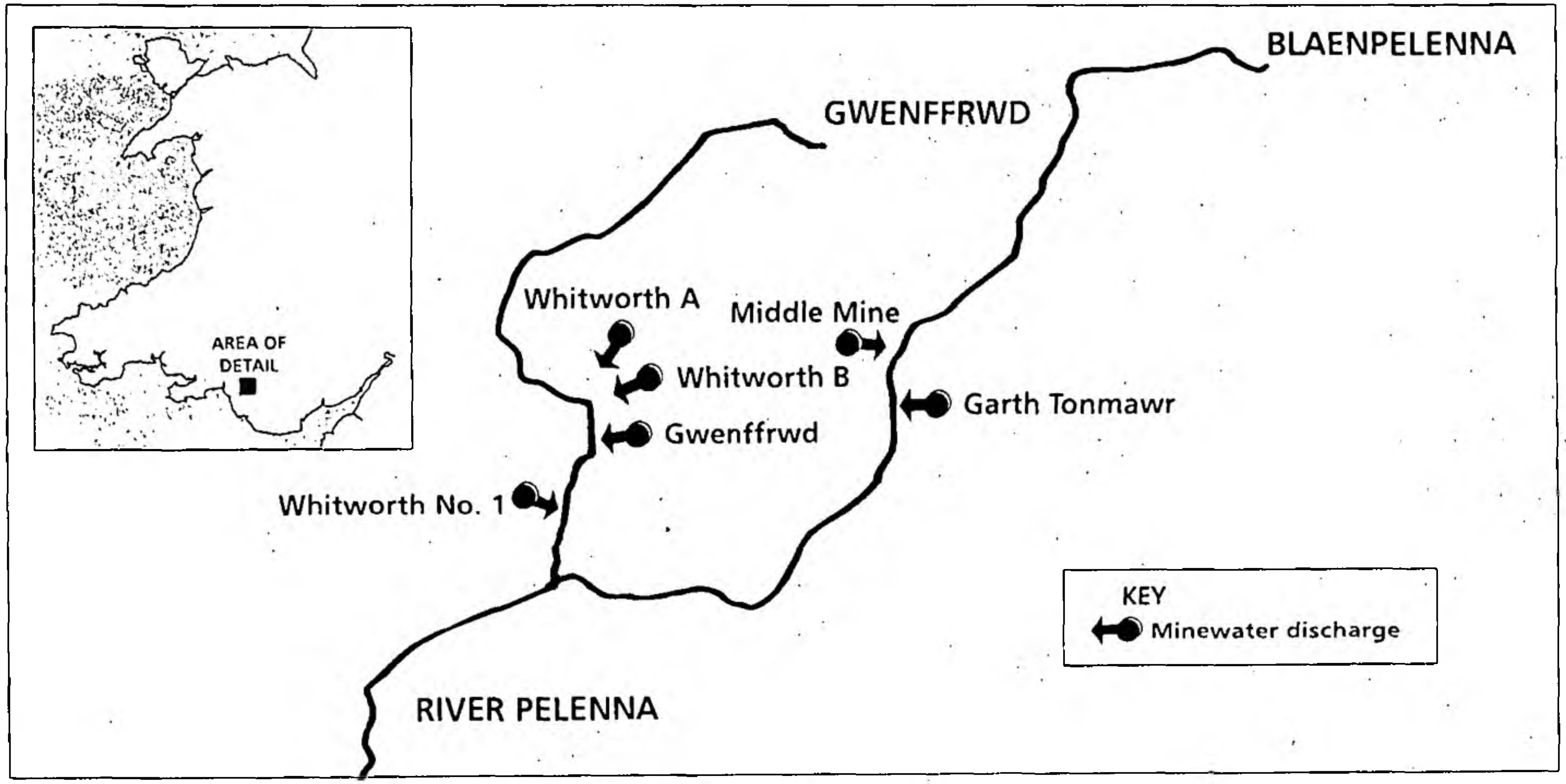


Fig. 2. Design & construction programme

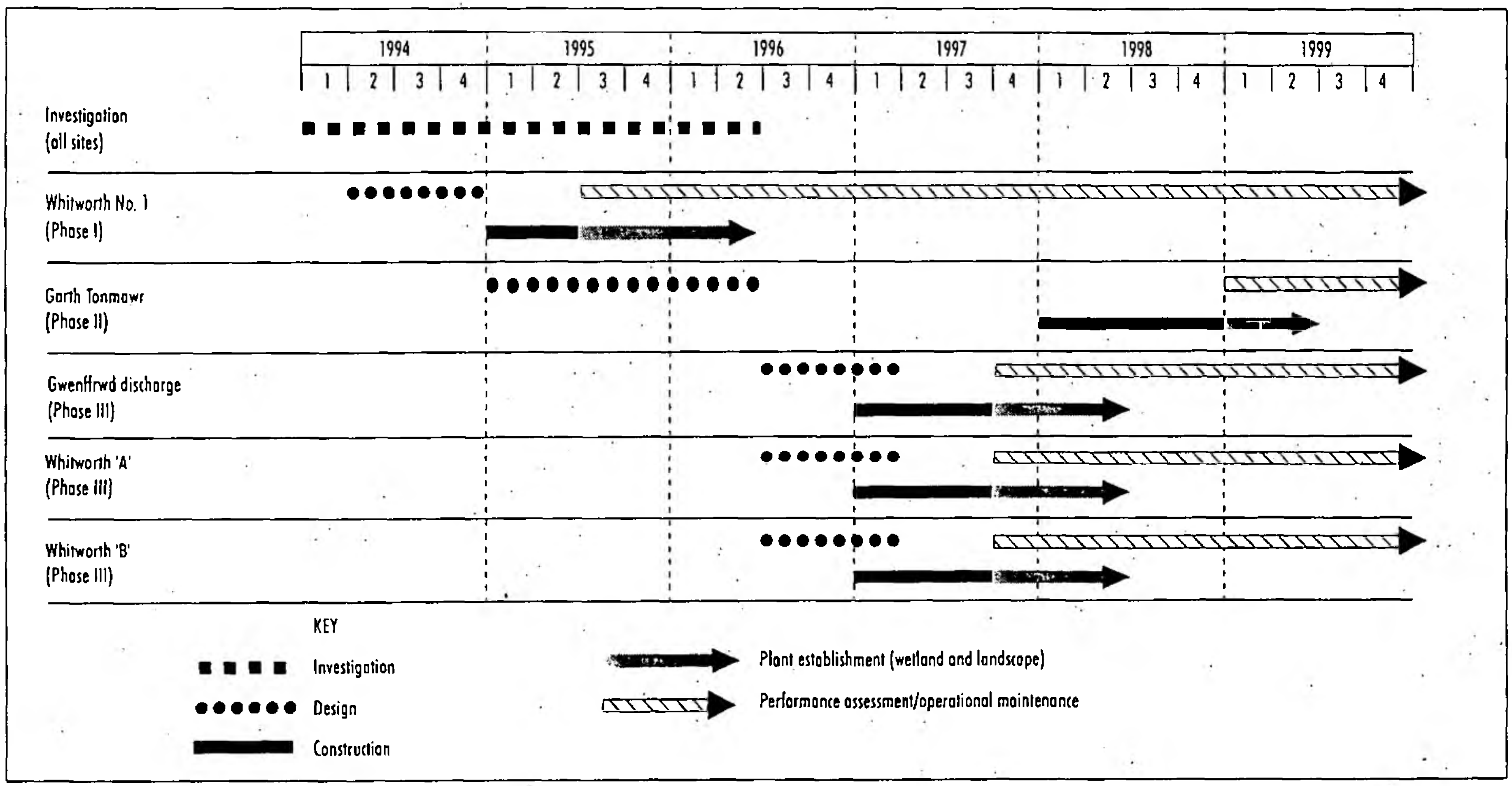


Fig. 3 Whitworth No 1 constructed wetland treatment system

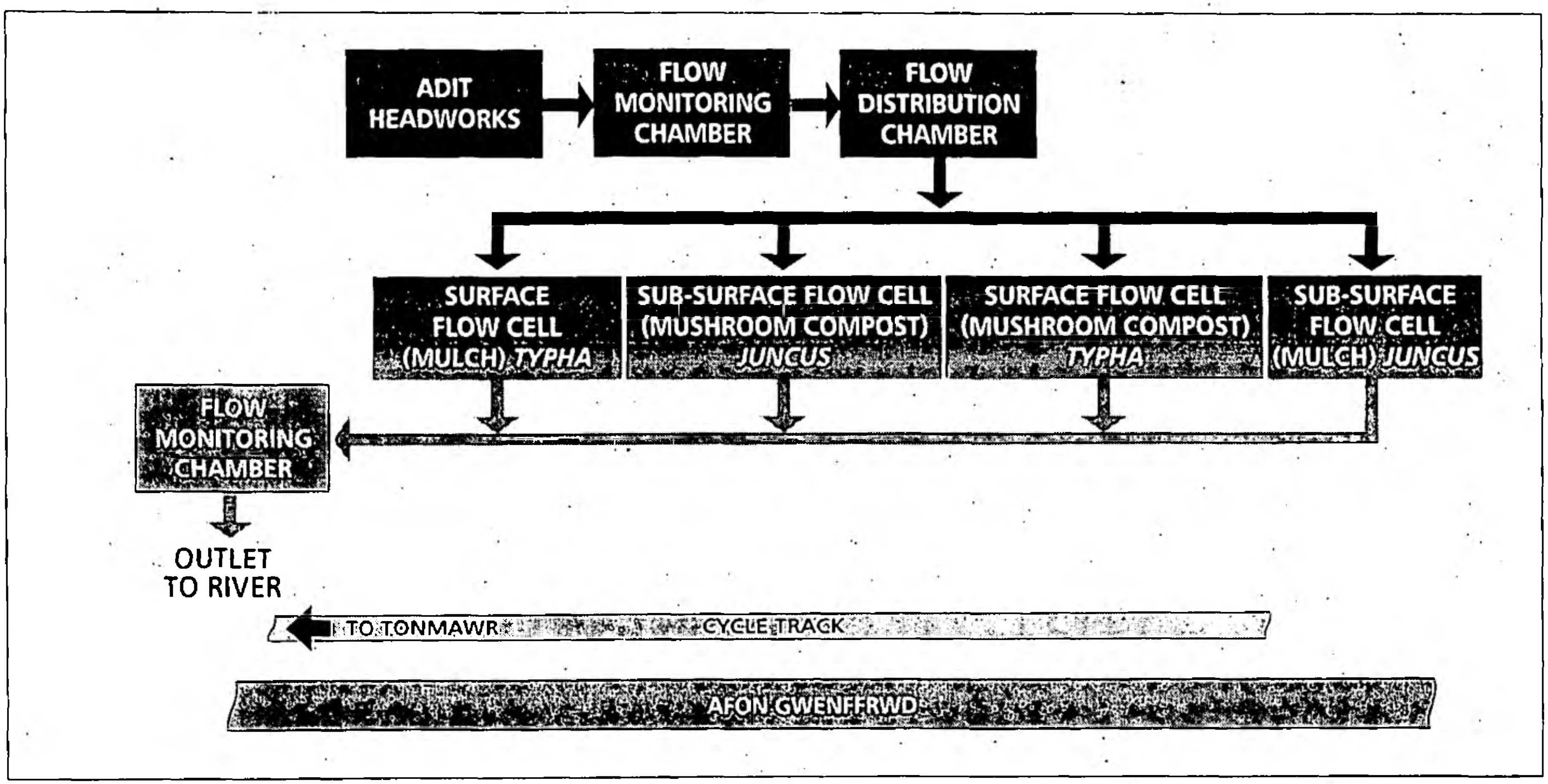


Fig. 4. Iron removal in Whitworth No 1 constructed wetland

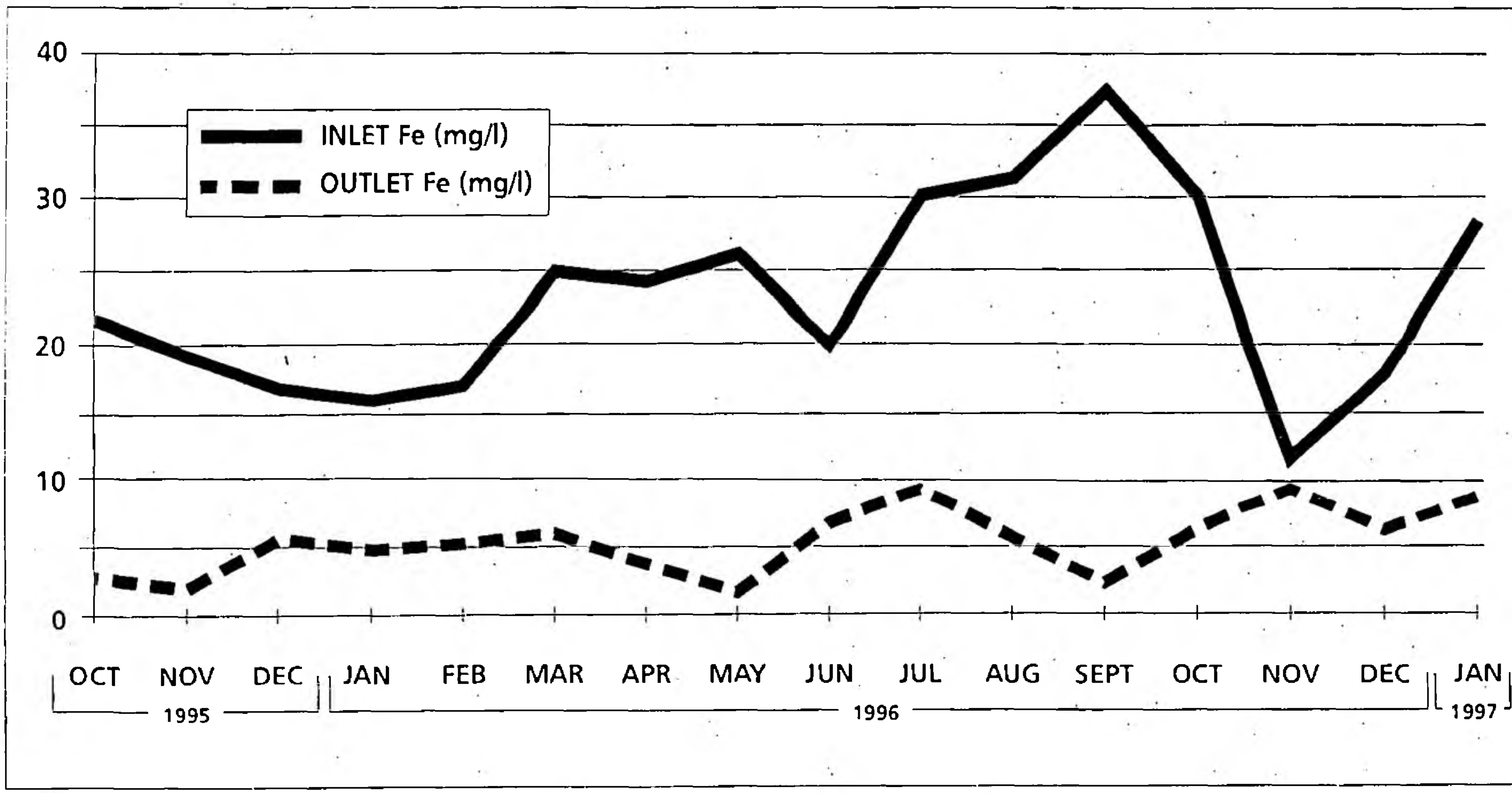


Fig. 5 Layout of Garth Tonmawr wetland treatment scheme

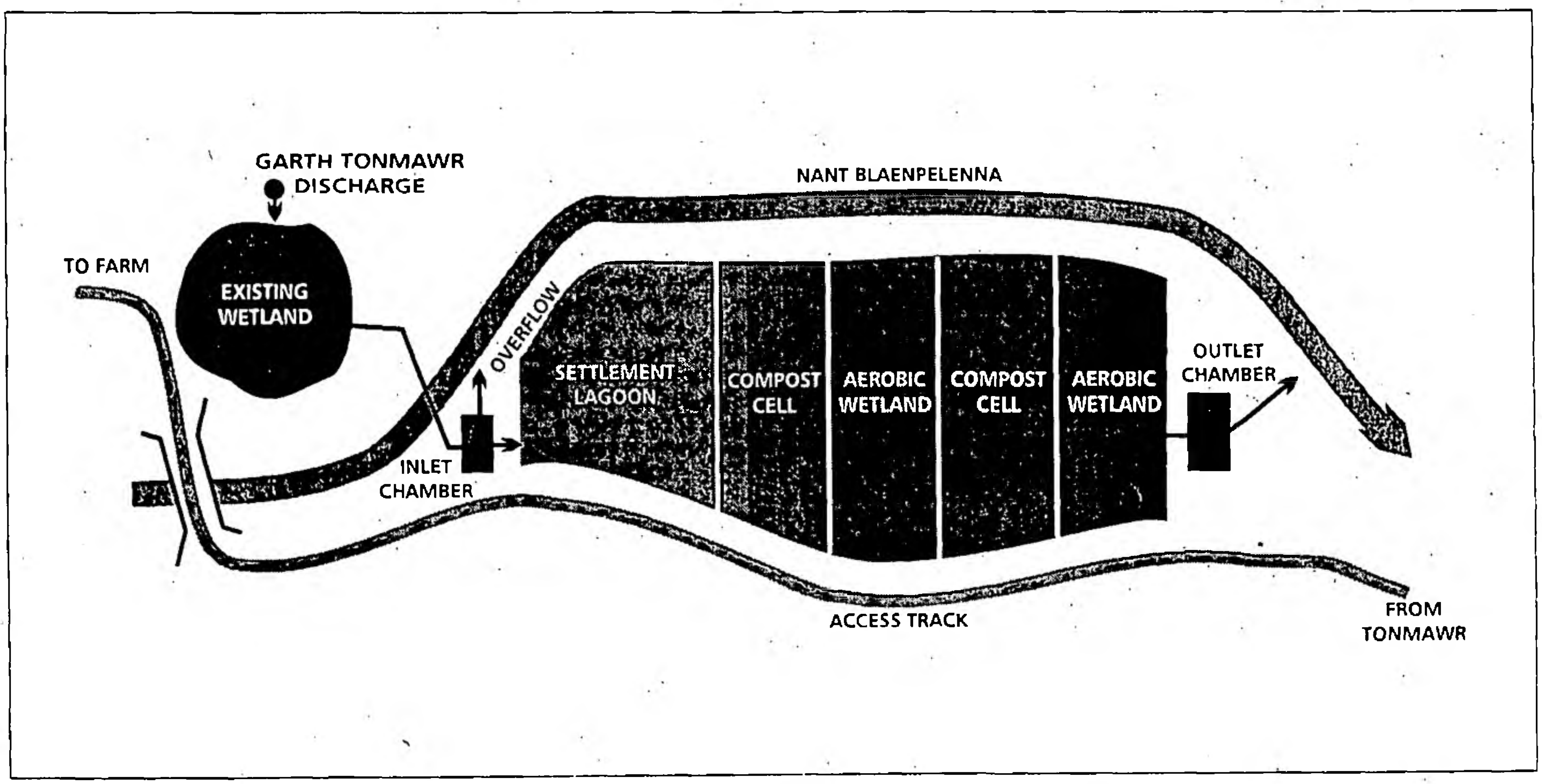
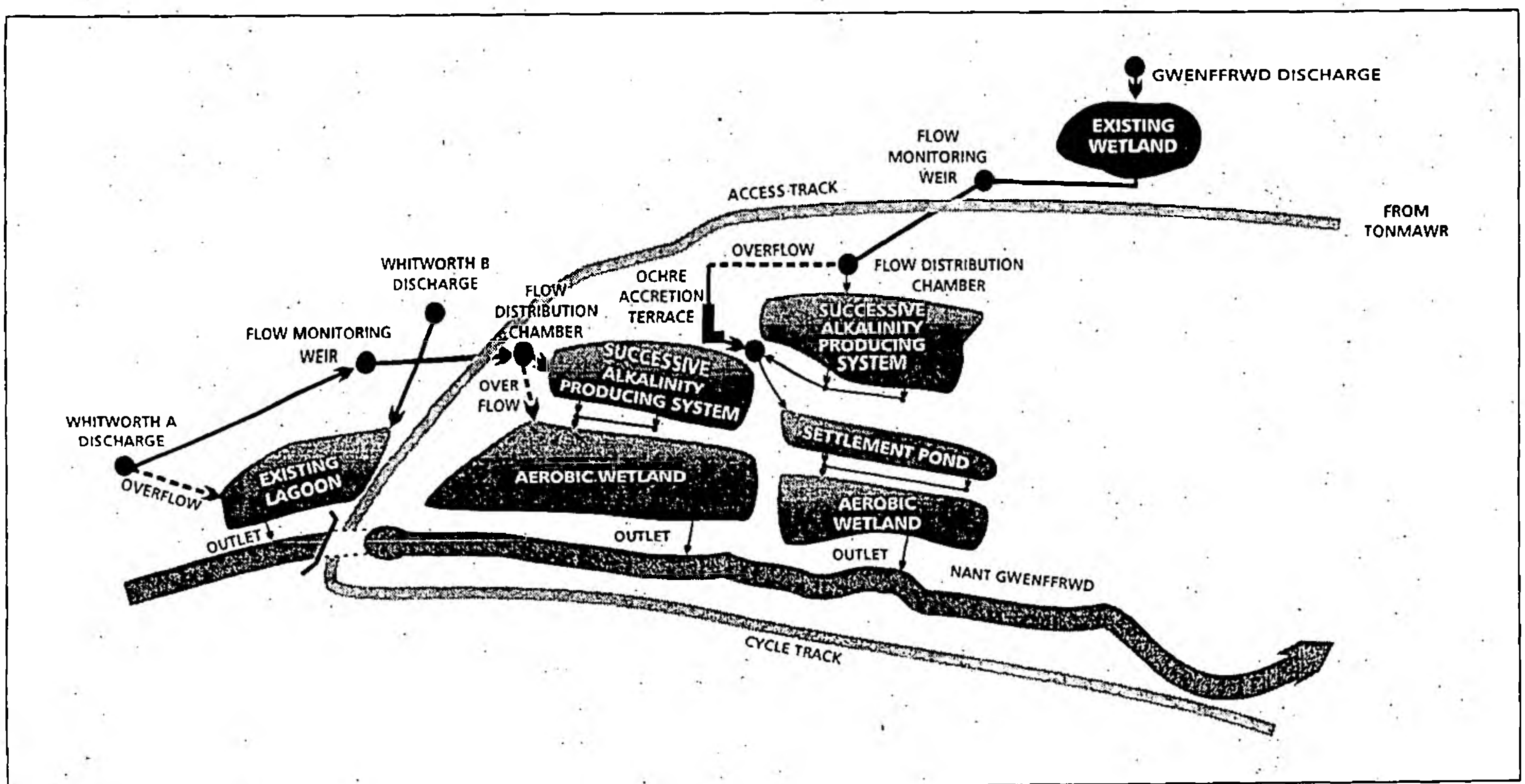


Fig. 6. Layout of constructed wetlands to treat Whitworth A, Whitworth B and Gwenffrwd minewater discharges



MINEWATER INVESTIGATION AT WHITTLE COLLIERY, NORTHUMBERLAND

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1. INTRODUCTION

In the Northumbria Area of the Environment Agency there has been an active programme of minewater investigation and monitoring for a number of years. This has concentrated mainly on the minewater pumping in the Durham Coalfield. More recently, however, attention has focused on an imminent problem of minewater recovery following the recent closure of Whittle Colliery in mid Northumberland.

1.1. Geology

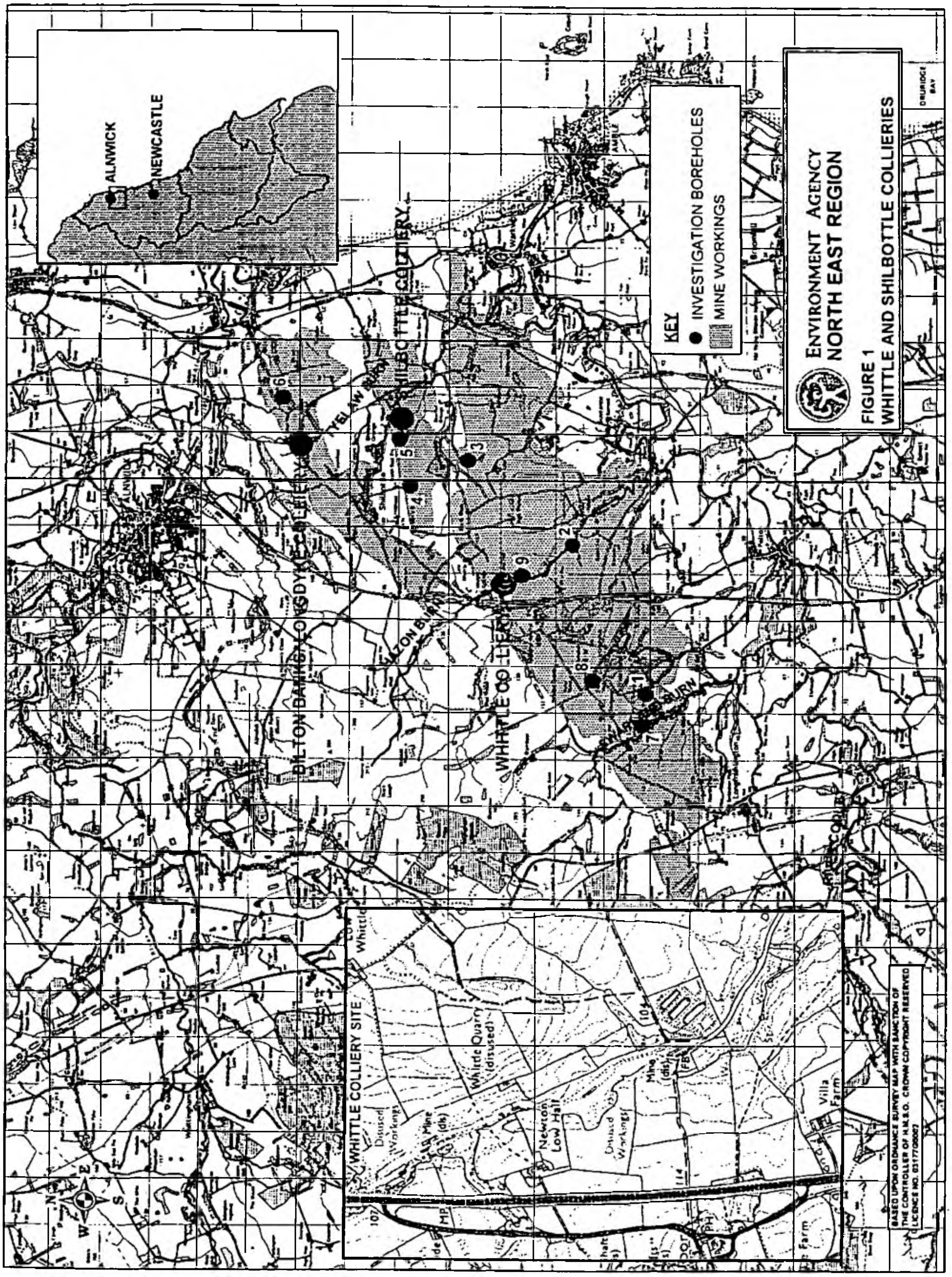
Whittle Colliery is located 40 km north of Newcastle (figure 1). Whittle Colliery, together with the former Shilbottle Colliery to the north east, worked a single seam, the Shilbottle Seam, of the Middle Limestone Group. The workings of the two collieries are joined by roadways that have been driven through an east-west trending fault which downthrows strata by up to 100 metres to the north. The coal from the Shilbottle Seam supplied the domestic market and was famed as the best house coal in northern England (Carruthers *et al*, 1930). The Middle Limestone Group comprises a sequence of limestones, sandstones, mudstones and coal seams (table 1). A second notable coal seam is present in this sequence, the Townhead Coal, but was not worked by Whittle Colliery. In addition to the workings shown on figure 1, there are many ancient workings and bell pits close to the seam outcrops. The dip of the strata is about 7° to the south east and east south east. The Middle Limestone Group is hydraulically isolated, by low permeability mudstones, from the main Coal Measures of the south east Northumberland Coalfield.

1.2. Ownership history and liability

The original drift at Whittle Colliery was sunk in 1917 by the South Shilbottle Coal Company. The Cooperative Wholesale Society began to sink Shilbottle Colliery in 1925 and took over the South Shilbottle Coal Company and Whittle Colliery in 1930 (Tuck, 1993). Both collieries were transferred to the ownership of the National Coal Board upon nationalisation in 1947. In 1978 roadways were driven to join the mines and 1982 saw the closure of Shilbottle with all production centred on Whittle. Mining reached a peak in 1982, with over 700000 tonnes of coal produced each year (Tuck,1993). The mine was closed by British Coal in March 1987 and the

Figure 1. Location of Whittle and Shilbottle Collieries

Key to borehole locations: *Shilbottle Seam* - **1** Swarland Wood, **2** Hazon, **3** Hart Law, **4** Shilbottle, **5** Grange Pit, **6** Spy Law, *8 Yard Limestone* - **7** Overgrass, **8** Black Wood, **9** Low Whittle.



recent ownership history is somewhat complex. British Coal sold the mine in 1988 and a series of private operators followed. The latest operator went into receivership and minewater pumping ceased, without warning, in March 1997. The surface area was subsequently sold to the present owner and no further mining will take place. As the former operator is in receivership and the present land owner doesn't own the mine workings, there is no one legally responsible for preventing polluting overflows (Environmental Data Services, 1997).

Table 1. Simplified geological sequence (based on borehole investigation)

Age	Lithology	Thickness (metres)
Upper Limestone Group	Great Limestone	10
Middle Limestone Group	Mudstone	7
	Townhead Seam	0.5
	Mudstone/sandstone	44
	8 Yard Limestone	8
	Mudstone/sandstone	25
	6 Yard Limestone	6
	Mudstone	10
	Shilbottle Seam	0.8

1.3. Minewater pumping

In 1971, 3830 m^3/d were pumped from the mine to keep the workings dry (Northumbrian Water Authority, 1973). During the peak of mining under British Coal in the 1980's pumping rates were around 6500 m^3/d. More recently, during private operation, the pumping rates decreased as the deeper workings were allowed to flood. Recent pumping rates were reported to be around 2500 m^3/d (Harrison *et al*, 1989; British Coal, 1992). The mine is isolated from the dewatering in the Northumberland Coalfield, and without pumping at Whittle the workings will fill until an overflow pathway can be found.

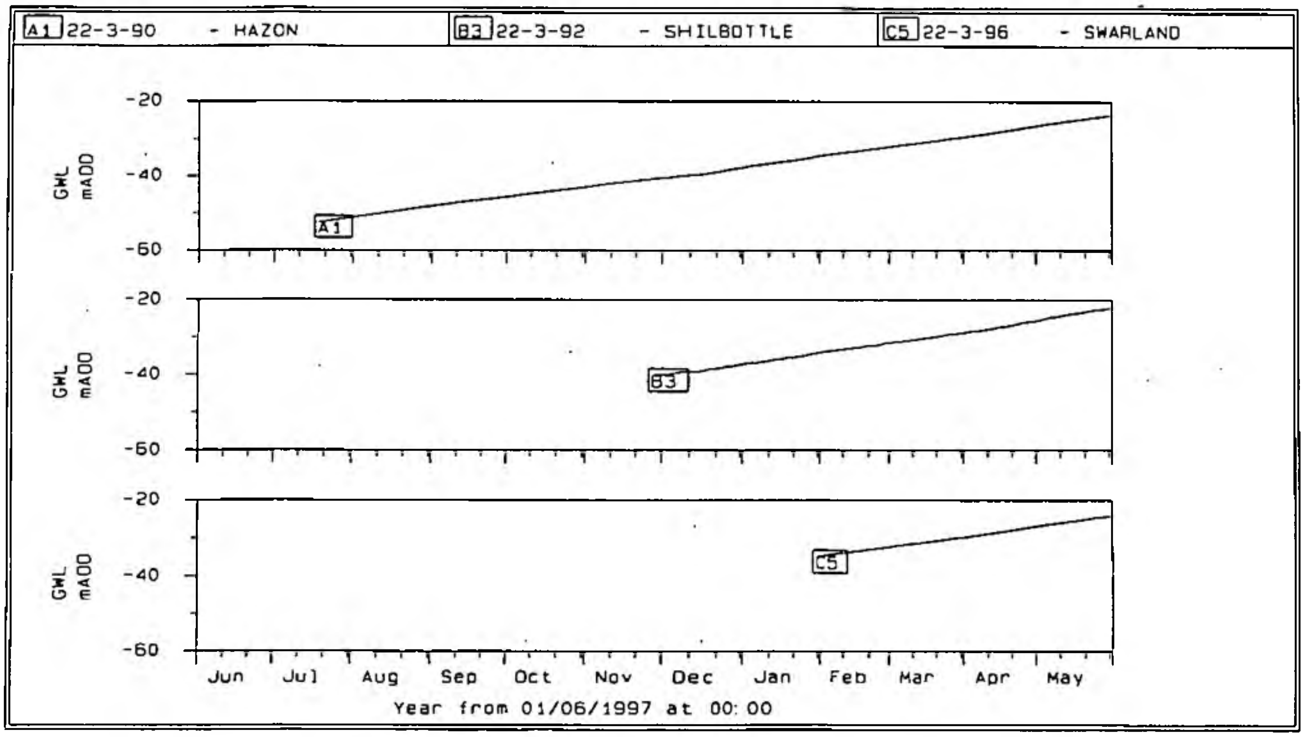
The area is crossed by the valleys of the Swarland, Hazon and Tyelaw Burns. These north west to south east flowing streams are all tributaries of the River Coquet. The Coquet is designated a Site of Special Scientific Interest. The river is also important for migratory fish, otters and is used for public water supply (45 Ml/d supplying much of surrounding Northumberland and also areas of Newcastle). This area of Northumberland and the nearby coast are not typical of a coalfield, being of high amenity value and supporting an important tourist industry. Polluting overflows could have a damaging effect on the ecology and economy of the area.

2. HYDROGEOLOGY

2.1. Monitoring boreholes - Shilbottle Seam

The Agency was able to locate a borehole at Hazon (NU 186046) that was used by British Coal for dewatering the mine. A groundwater level logger was installed and data collected. The hydrograph in figure 2 shows water levels have risen 30 metres since July 1997, a rate of 10 cm per day. Two additional deep boreholes have been drilled into the workings, one near to Swarland (NU 153030) and another near Shilbottle (NU 198077). Water levels in all three boreholes are rising at the same rate and all have similar water levels OD (figure 2). There is therefore a good hydraulic connection between the workings of Shilbottle and those of Whittle. Another deep borehole was drilled into the workings of the former Bilton Banks/Longdyke Colliery, at Spy Law (NU 217103). The water level measured in this borehole is 70 metres higher than in the workings of Shilbottle and Whittle to the south. This suggests that there is no direct connection between these workings, although a route via the overlying strata (6 and 8 Yard Limestones) may exist.

Figure 2. Groundwater levels for the Hazon, Shilbottle and Swarland boreholes



2.2. Monitoring boreholes - 8 Yard Limestone

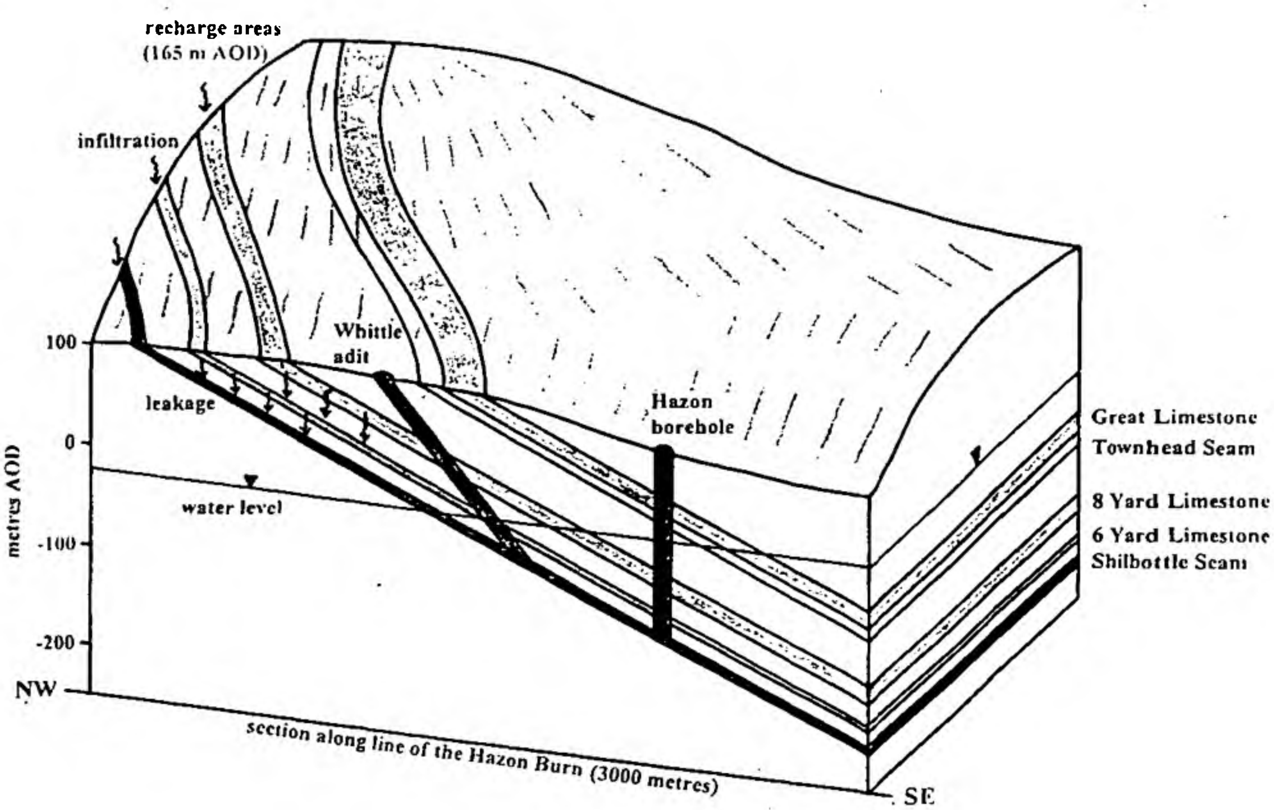
Shallower boreholes were also drilled close to the Swarland Burn at Overgrass (NU 147031), next to the Hazon Burn at Low Whittle (NU 179056) and also between the two streams at Black

Wood (NU 157042). These boreholes were to investigate the 8 Yard Limestone above the coal seam. They were found to be dry, with downward leakage of water into the mine workings. The Swarland Burn is known to leak into the Eight Yard Limestone where it outcrops in the stream bed (NU 144034). Work has been undertaken at this location in the past to seal the bed of the burn to maintain flows. The Swarland Burn is therefore leaking, via the limestones into the mine workings. The same is considered to be occurring in the Hazon Burn, although there is no direct visual evidence.

2.3. Recharge areas

Inflow into the workings is via direct infiltration at seam outcrops and from leakage through stream beds. In addition, indirect recharge is occurring via leakage from the overlying limestones. These strata outcrop at an elevation which is considerably higher than that of the workings, resulting in a hydraulic gradient. The name Whittle means "hill with an expanse of dry land" (Watson, 1970), describing the free drained limestones which outcrop at a high elevation and serve as the main infiltration areas. Figure 3 shows a conceptual model of the hydrogeology in the area of the Hazon Burn. The low permeability mudstones above the 8 Yard Limestone act as a confining layer, limiting downward leakage from, or upward leakage to the Great Limestone. This is evidenced by a borehole at Hazon (NU 186047) which is overflowing at the surface and also by perched water levels above the 6 and 8 Yard Limestones encountered during drilling.

Figure 3. Conceptual model of the hydrogeology in the Hazon Burn area.



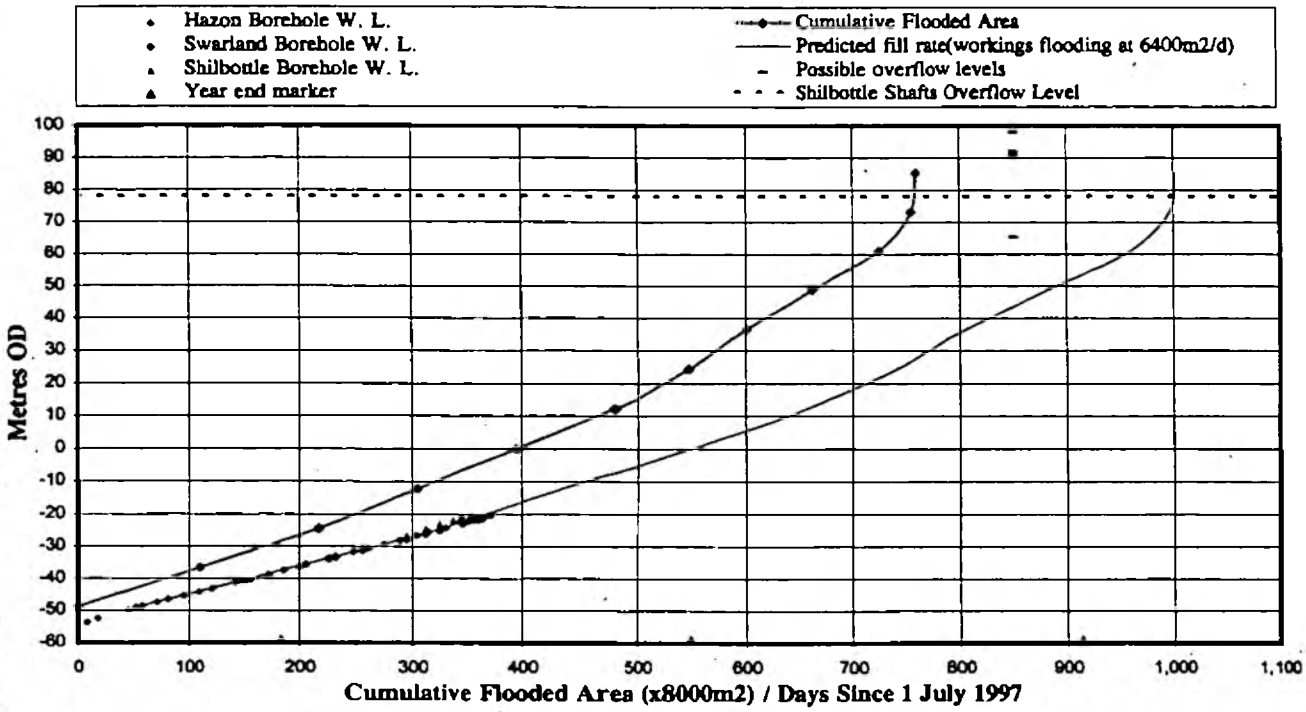
3. RATE OF GROUNDWATER LEVEL RISE

The rate of infill has been modelled using a simple spreadsheet, albeit with a number of limitations. The assumptions and steps involved in the process are as follows:

- summary mine plans (1:10560) were used to calculate the area of workings between each contour interval. This cumulative area is shown on the graph in figure 4. Note that the area of workings between each contour interval reduces with elevation.
- water levels are presently rising at almost 10 cm/day. This equates to 6000m^2 of workings filling each day.
- the open void thickness has been assumed as 0.8 m. The seam thickness varies from 0.76 to 0.84 m. This may have reduced due to subsidence and the collapse of the mudstone roof. It is assumed that the void is still present in the overlying strata (limestones and sandstones). With this assumption the daily infill volume is 4800 m^3/d. (The calculations do not include any storage in the overlying strata resulting from water draining into the mine workings).
- using this volume the time taken to fill the workings between each subsequent contour can be calculated. If the present infill volume remains constant, the water will rise more rapidly with time as the volume of workings reduces with elevation.
- using this predicted fill rate, the water levels will reach a possible overflow point early in the year 2000. If the system is head dependent (unlikely given the elevation of the infiltration areas) then overflows may be delayed.

In spite of the assumptions made and the simplification of the mine system, the data obtained so far support the predicted rate of rise (figure 4). The calculated volume of infill also matches the previously reported pumping rates.

Figure 4. Graph showing cumulative void, predicted fill rate, actual water level data and possible overflow points



4. OVERFLOW LOCATIONS

A number of overflow locations have been identified. These are listed in table 2, in order of elevation and therefore timing.

Table 2. Locations of possible overflow points

Overflow location	Elevation (m AOD)	Comments
Hazon borehole (NU 186046)	65	Steel lined so borehole can be sealed to prevent overflows to the Hazon Burn
Shilbottle shafts (NU 214080)	78	Overflows to the Tyelaw Burn will depend on the permeability of fill material
Whittle adit (NU 180054)	91	Overflows to the Hazon Burn
8 Yard Lst - Hazon Burn (NU 177059)	91	Leakage downwards, therefore leakage upwards
8 Yard Lst - Swarland Burn (NU 144034)	98	Leakage downwards, therefore leakage upwards
Unknown and unsealed boreholes, shafts and adits		

The recharge areas are at a significantly higher elevation (around 165 m AOD) than the overflow points. There will therefore be a considerable hydraulic gradient into the workings even when the mine is full. An overflow from the Shilbottle Shafts would enter the Tyelaw Burn. The Tyelaw Burn joins the River Coquet only 500 m upstream of the Northumbrian Water intake at Warkworth (NU 238061), providing little opportunity for dilution.

5. MINEWATER CHEMISTRY

There is, at present, no information on the water quality of possible overflows or how water quality varies with the flow route through the mine. There are, however, some indications:

- poor quality discharges from disused mines in similar geology elsewhere in Northumberland. An example of this can be seen at Acomb mine, near Hexham in Northumberland (NY 926660). The colliery closed in 1952 but the discharge still has a mean iron concentration of 48.3 mg/l and has an impact on a 1 km stretch of the Red Burn (Environment Agency, 1997).
- the strata of the Middle Limestone Group were deposited in an environment of marine transgressions (Johnson, 1984). The coal seams and associated strata are likely to have a high pyrite content. This is noted on the 1:10560 scale geology map.
- quality of the leachate from the Shilbottle Colliery spoil heap is poor. It is this material which forms the mudstone roof and collapsed strata in the mine workings.

An overflow of 4800 m^3/d with an iron concentration of 250 mg/l, would result in an iron concentration of 1.7 mg/l in the River Coquet at average flows (ignoring the precipitation of iron and background concentrations). The drinking water limit for iron is 0.2 mg/l. The first flush is likely to be of poor quality and regard must be paid to the longevity of pollution (Younger, 1997), particularly when considering treatment schemes.

6. POSSIBLE SOLUTIONS

The favoured solution is a pump and treat system operated from Whittle, with water levels maintained below possible overflow points. It is assumed that the lowest of these points, the Hazon borehole, will be sealed. The Agency is negotiating to buy the existing water treatment lagoons from the owner. Boreholes would be drilled into the Whittle adit to a depth of around 50 m. Water could be pumped from the adit to maintain levels at around 58 m AOD. This would keep levels 10 m below ground level at Shilbottle shafts, giving a gradient between Whittle and Shilbottle of 0.002 (Kershaw, 1997). This figure is similar to gradients in the Durham Coalfield, where minewater pumping has been continued following mine closures. Pumped water will be treated in the lagoons, probably with the addition of chemicals, and the final effluent could be polished with a reed bed prior to its discharge to the Hazon Burn.

An alternative, longer term solution, is to drill deep boreholes into the workings close to Warkworth. The hydraulic head available would give a gravity overflow which could be piped the 2.5 km to the sea. The borehole would need to be 425 m deep. There would be a problem in hitting a void with a good connection to the workings which allowed sufficient flow. The capital cost of such a scheme would be high but the long term revenue costs substantially lower. It may prove to be more attractive if the quality of water pumped from the colliery is too poor to be treated in the lagoons.

7. CONCLUSION

The problem at Whittle Colliery is therefore an imminent one, compounded by the complex ownership history and legal position. It is not the remit of the Agency to undertake long term treatment, nor is it funded to do so. To ignore the problem, however, would be contrary to the environmental protection aims of the Agency. The input of the local community has been sought and discussions have taken place with other relevant parties in an attempt to affect a solution. Although none of the parties has any legal obligation to tackle the problem, agreement must be reached quickly if pollution is to be averted. The problem has been widely publicised in the media. All parties would be roundly condemned if a solution could not be found and pollution of the nationally important River Coquet was to occur.

8. UPDATE

This paper reflects the situation that surrounded the Whittle Colliery investigation in April 1998. Since the conference, however, further information has been obtained.

Water levels have continued to rise, thus far at a rate matching that predicted (the water level at Hazon has now risen by 40 metres since monitoring began). Two additional deep boreholes have been drilled. The first at Hart Law (NU 204066) to check whether the connection between the workings of Shilbottle and those of Whittle was as good as originally thought. Water levels confirm a good hydraulic connection via the roadways between Whittle and Shilbottle. The second borehole is close to the Shilbottle shafts (NU 212079). The shafts are the lowest possible overflow point assuming the Hazon borehole has been sealed. A borehole in this locality is vital to the success of any future pump and treat scheme. It will show whether water levels can be maintained below ground level at Shilbottle by pumping at the Whittle Adit.

A limited programme of sampling has taken place. Where possible, pumped samples have been obtained, supplemented by depth samples at sites where the depth to water is excessive. This has revealed marked spatial variations in water quality in the mine. A summary of the water quality data is given in table 3.

Table 3. Summary of water quality information obtained (based on a total of 6 pumped samples and 2 depth samples)

	Fe mg/l	Mn mg/l	Alkalinity mg/l $CaCO_3$	SO_4 mg/l	pH	Conductivity $\mu S/cm$
Range	6.9 - 864	3.1 - 12.1	10 - 587	2126 - 4610	5.6 - 7.2	3330 - 7260
Mean	250	6.6	221	3611	6.3	5599

Consultants have been commissioned to assess the findings to date and to design a treatment system. Discussions are currently ongoing between the partnership organisations to agree a way forward.

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The Law of Pollution Control and Abandoned Mines

Paul Smith

Eversheds.

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The problem of pollution from abandoned mines is significant. In 1994, the NRA found that close to 100 discharges, mostly originating form underground workings were the cause for concern. 212km of classified waters were "significantly affected" a figure which did not include many unclassified waters which were similarly significantly affected.

In 1995, the Environment Act contained provision for the repeal of s,89(3) of the Water Resources Act 1991 which permits the pollution of watercourses by water escaping from abandoned mines. Unfortunately this might be a case of too little, too late.

Outline

- ◆ Existing legislation
- ◆ New legislation
- ◆ Overlap with European legislation

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I'm going to deal with three areas

1. A brief summary of the existing legislation on the control of pollution from abandoned mines which was introduced by the Environment Act 1995 and consists of amendments to the WRA 1991.

2. An outline of new Regulations which are due to come into force in July of this year which prescribe the manner in which mine operators must give notice when they are proposing to abandon a mine.

3. Finally I will examine the way in which domestic legislation overlaps with European legislation. In particular I will look at the possibility of European law being used as a tool to take action against owners and operators of mines which were abandoned before 1 January 1999 which presently fall outside the controls which are to be introduced later this year.

Existing Legislation

- Environment Act 1995
  - s.58 (WRA 1991 ss.91A and 91B)
  - s.60 (WRA 1991 ss.89 and 161)
- Environment Act 1995 (Commencement No.11) Order 1998

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The Environment Act 1995 amended two provisions of the Water Resources Act 1991 which related to water pollution from abandoned mines.

- section 58 inserted new sections 91A and B into the 1991 Act. These sections require operators to give the EA six months' notice of their intention to abandon a mine or part of a mine.

- section 60 amended sections 89 and 161WRA 1991. The former amendment removes the statutory defence to a water pollution prosecution from owners and operators where the mine is abandoned after 31 December 1999. The latter amendment provides a similar exemption in the case of the costs recovery and works notice provisions under s.161 WRA 1991.

These two sections will be brought into force on 1 July 1998 by the Environment Act 1995 (Commencement No.11) Order 1998.

Existing Legislation

- Definition of "abandonment"
- Definition of "mine"

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In addition to the main function of removing the statutory defence, the existing s.91A also contains two important definitions:

- what constitutes "abandonment" of a mine or part of a mine (something I will return to later

- the term "mine" is given exactly the same meaning as found in the Mines and Quarries Act 1954.

Interestingly, the Act does not define the key phrases "owner" and "operator". This is not merely an administrative oversight. As we shall see the statutory obligation to notify falls upon the operator of the mine which is to be abandoned. In the absence of a specific statutory definition it is suggested that the operator will be the person who is actually carrying out mining operations.

"Owners" is similarly not defined but in the case of the water pollution offence it would be the owner for the time being at the time the pollution was occurring.

Offences

- failure to give adequate notice of proposed abandonment
- supply of false or recklessly misleading information

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The amendments create one new offence (as opposed to amending an existing offence).

It will be an offence to fail to give notice to the EA of any proposed abandonment at least six months before the abandonment takes place.

Two other offence are also relevant.

First, the general pollution offence under s.85 WRA will of course apply to discharges from mines abandoned after 31 December 1999.

Secondly, it is an offence to furnish false or recklessly misleading information. Thus the notices which are supplied to the EA must not be misleading or knowingly false.

Defences

- ◆ Other statutory regimes?
- ◆ Emergency
- ◆ Receiverships

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There are two defences to the offence of failing to notify of abandonment, with a third enforcement "concession" which amounts to a practical defence.

No offence is committed where the abandonment happened in an emergency in order to avoid danger to life or health. In addition notification of the abandonment must be given as soon as is reasonably practicable after the abandonment has occurred (see s.91B(4)).

If a mine operator is the official receiver (or acting in a similar capacity) there is no offence committed if they fail to give six moths' notice of abandonment. There is, however a requirement that they notify the EA as soon as is reasonably practicable whether before or after the abandonment (see s.91B(5)).

The Guidance Note which accompanies the new regulations puts forward a third "defence" (although it has no force in law). The note suggests that where it is not possible for the mine operator to comply with the notification requirements because of the requirements of other statutory regimes. In such cases the note suggests that the EA has accepted that any decision to prosecute will be affected by such requirement. This would seem to suggest that although this will not provide a legal defence it would be difficult to prosecute someone which had failed to give the requisite notice solely as a result of other regimes. The Guidance note gives as an example the requirements of a lease from the Coal Authority.

Abandonment

- Section 91A(1)
  - discontinuance of any or all operations for the removal of water from the mine
  - cessation of working of any relevant seam or vein
  - cessation of the use of any shaft or outlet
  - cessation of "other activities"

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What then constitutes abandonment? Section 91A(1) provides that abandonment includes

- the discontinuance of any to all of the operations for the removal of water from the mine

- the cessation of working of any relevant seam, vein or vein system

- the cessation of use of any shaft or outlet of the mine

Where mines are used for "other activities" (e.g. tourism) a mine can be abandoned where the cessation of the activity is accompanied by any substantial change in the operations for the removal of water from the mine.

There will be some cases where the situation is not clear cut (e.g. where internal pumps are moved around within a mine). In such cases the question of whether the action(s) constitutes is for the Courts to decide.

Notification

- At least six months before the proposed abandonment
- Starting date 1 July 1998 (for abandonment post 1/1/99)
- Exception in the case of an emergency
- Phased abandonment

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The Regulations which require the notification of abandonment come into force on 1 July of this year. There is than a six month "initial period" from 1 July to 31 December inclusive. *Abandonment* can take place within this initial period without any notification

Once this initial period has concluded (i.e. from 31 December 1998) an operator who intends to abandon a mine or part of a mine must give the EA at least six months notice beforehand. This means that where there is an intention to abandon after 1/1/99, *notice* must actually be given within the "initial period". One can imagine that the "initial period" might be preferred time to abandon for most operators contemplating abandonment within the short term.

In cases of emergency the operator does not have to give six months notice. Emergency, in these circumstances only includes "danger to life or health" and would not include operational emergencies.

Where the abandonment is likely to consist of a number of phases, notification can include all of the phases together, thus avoiding repetition . In cases of "phased abandonment". Notification must take place six months before the first of the stages of abandonment.

New Legislation

- The Mines (Notice of Abandonment) Regulations 1998
- Guidance Note for Mine Operators

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Although the Environment Act amendments have been with us for some time they could only be implemented when the Secretary of State passed Regulations which prescribed the content of the notices which were to be served on the EA. These provisions can now be found in the Mines (Notice of Abandonment) Regulations 1998 which were laid before Parliament on 1 April and are due to come into force on 1 July 1998.

The Regulations are accompanied by a useful Guidance Note which has been published by the DETR. This Guidance Note provides a useful overview of the Statutory Provisions with a costs assessment of the impact of the new legislation on affected companies.

Schedules 1 and 2 of the Regulations prescribe the information which must be contained in the notification to the EA and the public advertisement of the proposed abandonment which is to be published in a local newspaper.

As far as the notification is concerned, there will be an official EA form which should avoid any confusion over the contents of the notice. The Guidance Note suggests that the EA will advise relevant local authorities and water companies when it has received notification of an intended abandonment.

Contents of the Notice

- ◆ Operator and owner
- ◆ Nature and date of each proposed abandonment
- ◆ Location and details of the mine

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What should the notice contain?

- The name and address of the operator and, if different, the owner. Where Companies are concerned the name and the registered office should be given. Where there are any changes in ownership anticipated before the actual abandonment, details should be given.

- The nature and date of abandonment should be given with specific reference to the various definitions of abandonment found in s.91A(1).

- The name and address of the mine must be given, including OS grid reference. A description and schematic drawing showing the area extent nd depth below the surface must be given. Where only part of the mine is to be abandoned, the relevant seam, vein or vein system shall be identified.

Contents of Notice

- ◆ Current handling of water in the mine
- ◆ Proposals for handling water until abandonment or during phased abandonment

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Other matters to be covered in the notification include:-

- the volume of water discharged to the surface from the mine or any part of the mine to be abandoned, for at least the two years prior to the date of the service of the notice (preferably longer).

- the latest information available on the extent and chemical composition of underground water in the worked areas of the mine.

- the projected volume of water discharged to the surface from the mine nd from any part of the mine to be abandoned, for the period from the date of the notice to the date of the proposed abandonment specified in the notice.

- proposals for monitoring of groundwater levels and the chemical composition of the water in the worked areas of the mine from the date of the notice to the date of each abandonment specified in it.

Contents of Notice

- Proposals to prevent to treat minewater discharge

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Other required information includes:

- details of any proposals or actions to be taken to treat, reduce and divert or prevent any anticipated discharge of minewater from the mine; or to treat water in the mine.

Contents of Notice

- Opinion as to the consequences of proposed abandonment

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Probably the most crucial part of each notice is the inclusion of an opinion as to the consequences of the proposed abandonment. This must include the likelihood of any of the following matters occurring:

(a) the flooding of worked areas. These areas must be shown on a plan or a schematic diagram identifying the location and extent of the workings.

(b) the migration of water to any other mines

(c) the recovery levels of ground water within the mine workings being reached and the period of time within which those level will be reached

(d) the discharge of water on to land or into surface water and the location and chemical composition of such a discharge.

Supporting information must be included. Finally, the operator must give an opinion of the projected volume of water which is likely to be discharged to the surface from the mine. This is required for a period of at least two years from the date of the last abandonment.

European Law

- Are the present exemptions under the WRA incompatible with EC law?

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Having examined the position in relation to mines abandoned after 1/1/99 I will now turn to consider the very difficult situation of mines which were abandoned before that date. As I have al;ready pointed out, there is impunity form prosecution and costs recovery which are to be found in s.89 and 161 of the Water Resources Act 1991. The pollution from mines which fall within these exemptions is significant and under domestic law there appears to be little that one can do about it.

However when one examines the position under European Law there are arguments which might suggest that these exemptions mean that the UK Government has unlawfully failed to implement EC water pollution law.

At this stage I should point out two weaknesses

- some of the arguments which follow are highly speculative but nevertheless they can be theoretically supported by previous judgments of the ECJ.

- time constraints mean that I will not be able to develop these arguments fully, I will only be able to give a brief overview

European Law

- Principles
  - state implementation
  - criminal law
  - state liability

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Before looking at the detail I must first set the scene with a few basic principles of European Law.

Implementation of directives requires member states to fully and correctly implement any Directive within the time limit specified under the Directive. Although the choice of the implementation method is open to the MS it must be enshrined in law. Failure to implement could leave the MS open to action by the European Commission.

A Directive cannot impose criminal liability upon any individual in a MS where the domestic legislation does not make provision for such liability.

Finally where a directive has not been fully implemented, in certain circumstances, individuals can claim any damages which they suffer as a result of that non implementation from the State

EC Law and Pollution from Mines

- Has there been a failure to implement?
- What are the consequences

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Taking these general principles we must then apply them to the case of pollution from abandoned mines.

First, does the lack of regulatory control over pollution from mines abandoned before 1/1/99 mean that there has been been a failure to implement relevant directives? In this case this would include directives on Groundwater, Dangerous Substances, Shellfish and Freshwater Fish. I will consider this in a moment.

Secondly, even if there has been a failure to implement, there can be no way in which operators/owners of abandoned mines can be made criminally liable under EC law.

Thirdly, if there has been a failure to implement can an individual bring an action against the UK Government for any losses which have resulted from that failure?

Finally, can the UK Government be taken to the ECJ?

Relevant Law

- Directives on
  - Groundwater (80/68)
  - Dangerous Substances and the Aquatic Environment (76/464)
  - Shellfish (79/923)
  - Fish Life (78/659)

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The relevant Directives which must be considered are:

- Groundwater (80/68)
- Dangerous Substances and the Aquatic Environment (76/464)
- Shellfish (79/923)
- Fish Life (78/659)

The obligations under each of these directives are arguably being breached by the failure to take any action against water pollution from abandoned mines.

Groundwater Directive

- Effect
  - take necessary steps to prevent introduction of List I substances
  - take necessary steps to avoid pollution from List II substances
  - take "appropriate measures" to limit indirect discharges

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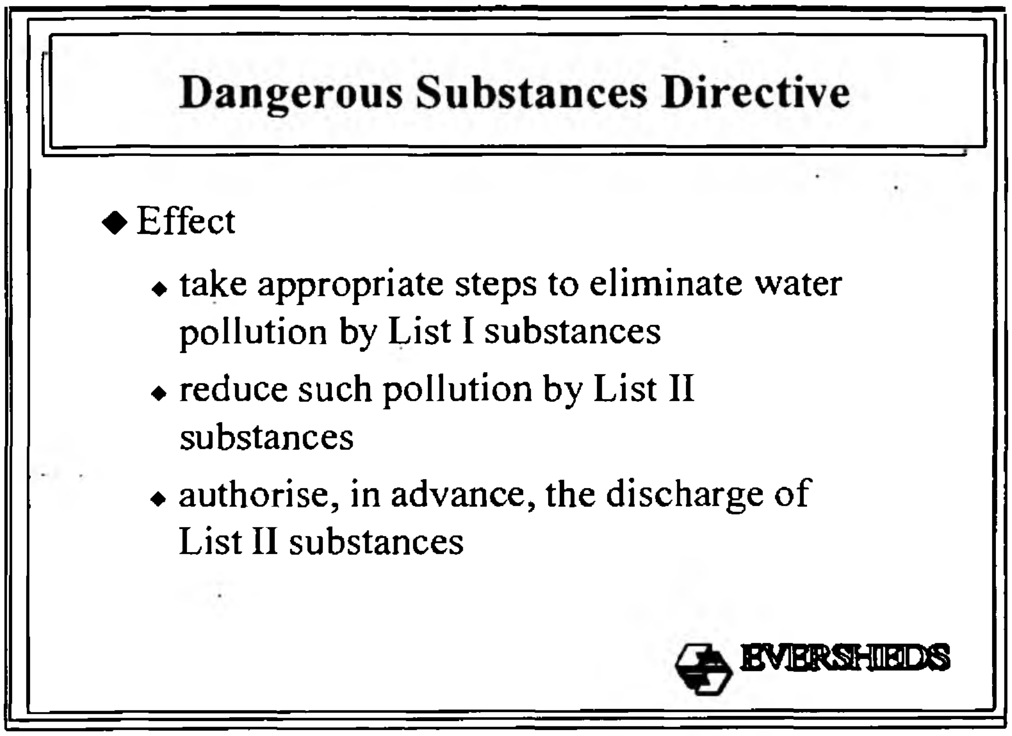
The Groundwater Directive (80/68) concerns the protection of groundwater against pollution caused by dangerous substances. The provisions of the directive are designed to ensure that MS

- take necessary steps to prevent introduction of List I substances
- take necessary steps to avoid pollution from List II substances
- take "appropriate measures" to limit indirect discharges of List II substances

In the case of pollution from abandoned mines, there are List I and List II substances involved. It is arguable that by ensuring that pumping from abandoned mines takes place, a significant reduction of List I substances into groundwater via waste water should, in most cases be achieved.

Thus it might be possible to argue that where the UK Government fails to require the pumping in order to avoid such discharges to groundwater it is, in fact, infringing important provisions within the groundwater directive.



Similarly, the Dangerous Substances Directive requires MS to:

- take appropriate steps to eliminate water pollution by List I substances
- reduce such pollution by List II substances
- authorise, in advance, the discharge of List II substances

Where waste water from abandoned mines contains List II substances which pollute to any significant extent, they cannot be said to have been authorised within the meaning of the directive. In addition, where pumping would prevent the build up of such concentrations of contamination, the failure to take any legislative action to enforce such pumping could be said to be in breach of the Directive. In this case to it would appear that there is an argument which would suggest that the UK has failed to carry out its duty to implement.

Shellfish and Fish Life Directive

- Effect
  - designation of protected areas
  - specified parameters
  - establish programmes
  - ensure designated waters conform to standards within six years

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The Shellfish and Fish Life directives are similar in structure and effect. They require the designation of certain waters which need protection and improvement in order to support shellfish or fish life. Once designated there are standards laid down which must be complied with within six years of the date of designation.

Furthermore, there must be a programme developed by which those waters can be improved.

Evidence of the breach of these Directives can be seen where designated waters have been polluted by abandoned mines. For example, the Wheal Jane Tin Mine in Cornwall discharged mercury, cadmium, zinc and copper and these discharges affected two designated shellfish sites: Turnaware and Percuel.

It was evident that the cessation of the pumps at Wheal Jane would lead to infringement of the relevant standards set in the Directive. It would be possible to argue that the UK Government had a positive duty to ensure that the pumping was maintained in order to ensure actual compliance with the directive.

Effects of EC Law

- UK has failed to implement these Directives fully
- State responsibility to maintain pumping
- Possible Consequences
  - Infringement Proceedings under Article 169
  - Action for damages under the *Francovich* principle

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What then are the effects of these arguments?

Firstly, if, (and it is probably a big "if") these arguments are correct, it would mean that the UK Government was under a duty to ensure that pumping was maintained and that the relevant directives were implemented fully.

It must be said, however, that although it might be possible to demonstrate that there has not been compliance with the relevant directives, this is not the same thing as saying that enforcement action will be taken against the UK Government. The process of enforcement of European legislation is undertaken by the European Commission under Article 169 of the Treaty of Rome and it is well known that the commencement of such enforcement action is a political as well as a legal decision.

In addition, it might be possible for individuals to seek damages from the UK Government for loss caused by water polluted by discharges from abandoned mines (this could include farmers or anglers) and could cover economic loss such as tourism or leisure interests).

[Draft of paper presented at the Environment Agency National Minewaters Conference held on 20-21 April 1998, Tapton Hall, Sheffield University]

THE BULLHOUSE PROJECT: TECHNOLOGY AND CONSTRUCTION

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1. Introduction

Following a 4-year development the Bullhouse minewater treatment system is due to be opened in September 1998. As outlined at the previous Environment Agency Conference in Sheffield (April 1997), ochreous minewater emerging from long abandoned coal workings on the Halifax hard seam near Penistone will be treated before discharge to the River Don by means of a settling lagoon constructed in the former Bullhouse Quarry of Hepworth Building Products. This will improve the quality of water in a 4-6 km stretch of the river immediately below the current discharge.

During the treatment process, iron dissolved in the minewater emerging from the Bullhouse drainage adit will be oxidised by air and the resulting ochre sedimented to provide an overflow of purified water. For these purposes, the minewater (some 2000 tonne per day containing about 60 mg/l ferrous iron at pH 5.6) is to be diverted from the adit to a 300 m^3 sump and pumphouse and thence via an 800 m pipeline and aeration cascade to a 50 000 m^3 settling lagoon and polishing pond before return to the river (Fig. 1). The planning and economic issues governing this choice of process route were discussed in the earlier paper.

The objectives of the current paper are to provide an update in terms of the technical options available for operating the system (the associated research objectives) and the construction work which has been in progress during the last 12 months.

2. Technology

2.1 General considerations

As should be the case for an environmental control process, the technology adopted at Bullhouse is essentially low risk, simple and cost effective. However, the fact (notwithstanding a century of research and practical experience worldwide) that significant R&D continues in the UK and abroad on minewater technology, suggested the likelihood of underlying complexity. Such complexity soon became evident in the different types of processes and equipment (considered in the earlier paper) which could be employed and in the different options available in principle for harnessing and controlling the minewater chemistry within a selected equipment configuration. For this reason a detailed research programme was indicated.

Thus, the Bullhouse project is unusual in having the dual objective of (i) providing a robust system for efficient and long term treatment of the minewater and (ii) seeking to advance the generic understanding and further development of minewater remediation technology. In other words the Bullhouse system has been designed to solve a serious environmental problem on the Upper River Don and to incorporate the flexibility necessary to assess alternative operating options at the full scale.

2.2 Chemistry

The two main reactions (1) and (2) are superficially uncomplicated, but have subtle characteristics which are both fascinating and (in process terms) demanding. The interrelationship between them and the formation of ochre is illustrated in Fig. 2.

$$Fe^{2+} + 0.25O_2 + H^+ = Fe^{3+} + 0.5H_2O \qquad (1)$$

$$Fe^{3+} + 3H_2O = \text{'}Fe(OH)_3\text{'} + 3H^+ \qquad (2)$$

The oxidation of ferrous iron (reaction 1) consumes hydrogen ion and is strongly pH-dependent. For instance, other things being equal, it is 100 times faster at pH 7 than at pH 6 and becomes very slow between pH 5 and 6. The reaction may be catalysed by microbial action (particularly at low pH) or interaction with solid surfaces (particularly ochre surfaces) and, of course, may be enhanced by the addition of lime or alkali. The rate of supply of oxygen (which is very sparingly soluble in water) is crucial: although only one molecule is required for every four ferrous ions, simple diffusion from the air is usually too slow and forced aeration by injection or cascading is needed. Thus, the primary treatment of the Bullhouse minewater, which typically emerges at pH 5.6 and generally at less than 50% of full saturation with respect to dissolved oxygen is not obvious at the outset and practical consideration of several options will be required.

The hydrolysis of ferric iron (reaction 2) precipitates particles of hydrated ferric oxide, conventionally written as ferric hydroxide, and produces three hydrogen ions for each ferric ion removed from solution. These are initially of colloidal dimensions ($<10^{-7}$ m) and may contain as many as 100 molecules of water for every molecule of oxide. The particles aggregate into small flocs which sediment very slowly in water. The sediment, which initially contains < 0.1% solids, slowly but steadily expels physically and chemically bound water. Under water the solids content may eventually reach some 6% and out of water in the open some 50% or more.

The rate of sedimentation of first-formed ochre particles may be enhanced by addition of small concentrations (about 1 mg/l) of an anionic flocculant, such as the long-chain organic substance polyacrylamide. This type of reagent binds to the surfaces of the particles (and between particles) causing them to form larger, faster-settling, groupings. However, the efficiency of flocculation is greatly affected by the conditions prevailing: the degree of turbulence (which needs to be enough to cause particles to collide but not enough to cause particle disruption), the particle size and concentration (which need to be enough for the particles to collide and interact effectively) and by the pH of the medium (which generally needs to be slightly alkaline). For these reasons the method and point of addition of a flocculant require careful design.

Overall, reactions (1) and (2) are acid-generating, and therefore self-inhibitory. Coalfield minewaters often contain bicarbonate, which reacts with the acid (with evolution of carbon dioxide) and prevents a decrease in pH. However, at Bullhouse there is usually insufficient bicarbonate for this purpose. If left to age for several days, samples of the minewater finally precipitate most of the contained iron but usually reach pH values as low as 3.3- 3.5. Thus, neutralisation before or after precipitation is indicated.

2.3 Pumping sump

Fig. 3 shows a simplified diagram of the pumping sump. Minewater enters under gravity and, after a certain residence time determined by the sump volume and steady state degree of fill, is pumped into the pipeline. Although in principle, the control of the residence time (by controlling the degree of fill of the sump) provides a process option, in practice the degree of fill must be minimised to provide as long a time as possible to overflow (minimum 2 hours) in the event of a pump failure. Under these conditions, the residence time is expected to be at most one hour and the main operating options become:

(i) to pass the minewater through the sump to the pipeline largely unchanged or
(ii) to maximise oxidation of iron and pump an ochre suspension to the pipeline.

Experience indicates that option (i) will obtain in the absence of forced aeration or chemical dosing. As the sump is underground and enclosed, free ingress of air can be prevented. Option (ii) can be realised by minewater recirculation, forced aeration and alkali dosing. These processes can be established and monitored under secure conditions (but at significant cost) by means of standard technology. Of course, subsidiary options are available to assess the effects of each process individually.

The differing impacts on the pipeline and lagoon are described below.

2.4 Pipeline and cascade

Dual upflow pipelines of 200 and 160 mm od are installed (together with a 200 mm od return pipeline) with access hatchboxes at 100 m intervals. At a volume flow of 2000 m^3/day the maximum linear flow rate will be about 1 m/s (giving turbulent flow) and the maximum pressure approximately 7 bar. The minimum pipeline residence time will be about 13-18 minutes. The enclosed cascade will provide a disrupted drop of approximately 3 m.

Option (i). As the dissolved oxygen content of the minewater will be low, minimal reaction can occur in the pipeline. Following passage through the pipework, the minewater will become partially aerated in the cascade before discharging to the lagoon. Subsidiary options will be available for dosing with alkali and flocculant at the cascade.

Despite the low oxygen content of the water, slow accretion of ochre and calcium salts can be expected on the inner surfaces of the pipes. This is partly because of iron adsorption and catalytic oxidation (Fig. 2) and also because a proportion of ochre particles (pre-formed underground and carried out periodically with the stream) are likely to adhere and become annealed onto the pipe surfaces by the action of the turbulent water flow. The layer is likely to build-up in thickness, age and harden with time.

Option (ii). If oxidation is essentially complete in the sump, a turbulent flow containing finely dispersed ochre particles will enter the pipeline. Most of these are likely to remain in suspension until discharge to the lagoon. However, enhanced ochre accretion can be expected in the pipework both from pre-formed particles and surface oxidation of residual ferrous iron. The option would be available to dose with flocculant at the cascade.

Clearly it will important to monitor and, if necessary, control the accumulation of deposits in the pipeline. For these purposes, it is planned (i) to insert recoverable glass slides directly in the water flow and (ii) to assess the effects of commercial dispersants in reversing the effects of accretion.

The glass slides will be used for microscopic examination of the thickness and composition of ochre layers. They will be mounted on a former reaching to a position parallel with the inner wall of the pipe and emplaced by means of a pressure tight fitting. The insertion and recovery of the slides will be made via the hatchboxes. The second pipeline will allow the flow to be continued in one pipeline while the other is emptied and depressurised.

2.5 Lagoon and polishing pond

The nominal residence time of water in the lagoon will be 20-25 days, long enough to complete the oxidation and precipitation of iron, even under acidic conditions, provided sufficient oxygen is present and the temperature is not too low. The actual residence time may be less because of streaming effects. Efficient ochre sedimentation can also be expected provided the surface wave action normally present can be avoided by injection of the discharge from the cascade below the surface of the lagoon. The polishing pond has a much shorter residence time (< 1 day), but will nevertheless promote residual ochre sedimentation and, once reeds become established, filtration. The inflow to the pond also offers an opportunity for final pH adjustment or flocculant addition.

Option (i). The minewater entering the lagoon will have been partially aerated in the cascade. If the simplest course of action is taken, i.e., with no alkali or flocculant addition at the cascade, reactions (1) and (2) must both occur (together with sedimentation) largely in the lagoon. Under these conditions the water will become slightly acidic and will need to be neutralised, at least partially, at the polishing pond. Flocculation at the same point will probably be advantageous. This course of action may only be feasible in summer when the alkalinity deficit is likely to be least and the pond temperature greatest. Under other conditions, neutralisation (and flocculant addition) may be undertaken at the cascade.

Option (ii). Minewater entering the lagoon will be largely aerated and oxidised. The lagoon will function merely as a sedimentation basin. The efficiency of the system will be assessed with and without the addition of flocculants.

2.6 Operating options

Fig. 4 illustrates the two main options and the various subsidiary options available for treating the Bullhouse minewater. These options are of the type 'to dose' or 'not to dose'. They should provide information on the practicality of carrying out a particular operation at a certain location (e.g., from the point of view of making equipment and reagents available at that location) and on its effectiveness in treating the minewater or preventing failure (e.g., in removing iron from suspension but not fouling-up the pipework). The options take no account of different possible levels of dosing (which must be largely derived from past experience).

It is planned to systematically assess these options as far as possible during a 2-year R&D programme. The main criterion will be 'overall practicality', which includes cost, technical robustness, convenience, security, sustainability and environmental acceptability. In order to optimise this criterion a series of weighted indicies will be defined which can be summed to provide an overall 'score'. The largest 'score' should represent the most efficient process which should then be recommended for long-term operation of the system.

3. Construction

Construction work commenced in spring 1997.

3.1 Overland pipeline

The initial works involved the excavation and placing of the overland pipeline system to connect the pumphouse at Bullhouse Bridge to the treatment site in Bullhouse Quarry, a distance of about 800 metres. The pipeline system comprises twin delivery pipelines of 160 and 200 mm diameter and a return water pipeline of 200 mm diameter. The pipelines were placed at a nominal depth below ground to invert of 1200 mm and a granular bed and surround was applied both to protect and secure the system. Hatch box access points were fixed into each of the pipelines in manholes at 100 metre intervals to allow access into the pipeline to enable jetting of ochre accretions to be readily accomplished to maintain the fill area of minewater flow. Progress in pipelaying across agricultural land was rapidly achieved although a significant delay in purchase of the former railway track imposed a four month delay before completion of the full length of the pipeline was achieved.

3.2 Minewater treatment lagoon

In the early summer of 1997, construction of the minewater treatment lagoon in the Bullhouse Quarry commenced. The scheme involves the construction in the quarry void of an earth-lagoon having a capacity of 50,000 cubic metres and a surface area of about 6,000 square metres. The depth of the lagoon is about 8 metres. The lagoon was constructed under the Mines and Quarries Act 1954 and the Mines and Quarries Tips Regulations 1971 and was based on the technical requirements applied by the former British Coal for the construction of Tips and Lagoons.

The construction works involved the excavation and placing of 140,000 cubic metres of coal measure sales and superficial clay deposits which formed the backfill resulting from the former Hepworth Building Products Quarry. Close selection of materials took place throughout the earth moving contract to ensure that impermeable materials were used to form lining seals to retain water in the lagoon whilst more permeable spoils were used either to provide drainage layers or as support to the heavily compacted seals. Placing of the seals in thin layers 300 mm in thickness was carried out by compaction with a heavy vibrating roller. Permeable materials and drainage layers were placed in one metre thick layers with a lesser degree of compaction being applied. The whole of the structure had been subject to a detailed geotechnical analysis to ensure that minimum factors of safety against failure of 1.5 would be achieved.

Excavation of materials was by 360° machine-loading using 6 wheeled dump trucks to transport the spoil to the point of placing where spreading and compaction was achieved using a bulldozer towing a vibrating roller.

Heavy inflows of ground water to the excavation limited the depth of the lagoon to less than that which had been anticipated. The shortfall of material required a revised profile to be engineered for the restoration of the quarry which generally involved the inclusion of berms into the profile to reduce the amount of fill necessary to achieve a high standard of restoration. The planning authority has subsequently approved this revised profile. Restoration of the site was completed by the placing of 400 millimetres of soil materials over the restored slopes ofthe quarry. Subsequently a full planting scheme has been completed in Easter 1990 as the final step of the restoration of the lagoon area. About 20,000 native species of trees have been planted on the slopes which will in future years allow the area to present a pleasing vista to pedestrians using the adjacent Trans-Pennine trail.

3.3 Building works

Commencement of building works involving the construction of both the delivery and return water pumphouses and the inlet cascade aeration system also commenced in Easter 1998. Commencement of works was at the raw water pumphouse located adjacent to the Bullhouse Adit near to Bullhouse Bridge. The excavation of a sump 6 metres in depth adjacent to the River Don was difficult because of the heavy inflows of ground water which were encountered. The contractor employed a large purpose-designed settlement tank to control discharge quality whilst he completed the concrete blinding of the base of the excavation, which significantly reduced the volume of inflow. Construction of the underground storage tanks was then commenced.

The underground storage tanks are being constructed in reinforced concrete and comprise twin tanks each 15 metres in length and 3 metres in width. The height of the tanks is about four metres and as a result the top of the tanks will be 2 metres below finished ground level which will be restored to pasture land. The tanks provide a storage capacity for the inflow of water from the adit of between two and three hours to provide a safeguard in the event of power failure stopping the pumping of water for treatment in the quarry. The adjacent pumping equipment is also located below ground level and on completion of a construction and restoration of the work, only a stone built pumping station about 5 metres square will be visible above ground level.

The return water pumping station is a simpler construction comprising only a surface stone constructed building housing pumps. The storage capacity for these pumps is provided by using an existing earth walled lagoon as a balancing sump providing water to the pumps. The return water will be delivered back to the point of abstraction through the overland pipeline system.

The inlet system proposed for the lagoon utilises the difference in level between the adjacent rail track and the lagoon surface to enable a cascade aeration system to be introduced to oxidise the raw minewater. This will be achieved in a six metre high reinforced concrete manhole constructed above ground and adjacent to the rock face which forms the northern perimeter of the quarry. By the use of landing stages with the access hatch alternated, a simple means of aeration of the minewater will be achieved. Consideration has also had to be given to the ingress of air into the manhole system, security to prevent unauthorised access and the provision of means of jetting-out ochre deposits at regular intervals. Distribution of water from the cascade into the lagoon is by a simple layout of twin wall plastic pipework to spread the flow over the full area of the lagoon. Intermediate manholes have been introduced to allow the research contractor access either for measurement of water flow and quality or the introduction of chemical treatment into the minewater.

3.4 <u>Mechanical and electrical works</u>

A total of 6 pumps will be purchased to furnish both the raw and return water pumphouses. The pumps will be identical 40 litres/second centrifugal devices installed in a submerged suction arrangement. These pumps provide an economical and reliable solution to the efficient pumping of minewater on the scheme. Five pumps will be installed and will be available for operation whilst the sixth pump will be maintained as a spare. However, with all pumps being identical, the ability to switch pumps should unforeseen contingencies occur is readily available and this should limit the potential down-time that could occur In the raw water pumphouse, two pumps will be installed to convey discharged the water into the overland pipelines. A third pump will be utilised to recirculate water in the raw water storage tanks by means of submerged pipe work and jets to agitated the water and maintain suspended ochre solids in suspension. This will minimise build up of solids in the sump and assist their being pumped overland to the quarry for settlement. A further advantage of this system is that turbulence caused will assist the oxidation of the raw minewater, which will help to minimise accretion of solids in the pipeline.

In the return water pumphouse, two pumps will be installed on a duty and standby basis. They are both connected to a single overland return water pipeline. The adjacent polishing pond which is elevated above the pumphouse intake, provides a positive flow into the pump section as well as providing a flow balancing element for the return water clarified in the main lagoon. The security of operation of systems in this pumphouse will be monitored by a PC and modem in the raw water pumphouse with data transferred by radio link.

The normal mode of operation of the pumps will be to maintain a minimum level of water in the sumps at both pumphouses. This is to enable the flowbalancing element to be available to prevent discharges of unclarified water occurring to the river in the event of short power failures. This will be achieved by monitoring of the water level in the sumps and linkage to the operation of the pumps by an electronic control with the ability to vary the speed of operation of pumps to maintain a constant water level.

The proposed mode of operation of the pumping system is essentially viewed for the long term since Imperial College will be researching to improve methods of treatment of the minewater and advantages may be apparent in variation of the envisaged regime.

3.5 Liaison between construction and research

The success of the scheme, particularly in its ability to allow maximum flexibility to vary parameters in the research phase depends upon close cooperation between the design consultant and the research contractor. The scheme incorporates the options to introduce monitoring or addition of chemicals wherever feasible and the capacity to vary operating modes. In addition, during the research phase, the same cooperation will be essential to engineer changes to the lagoon and mechanical systems to ensure that the integrity of the system is not compromised and the cost effective construction methods are adopted.

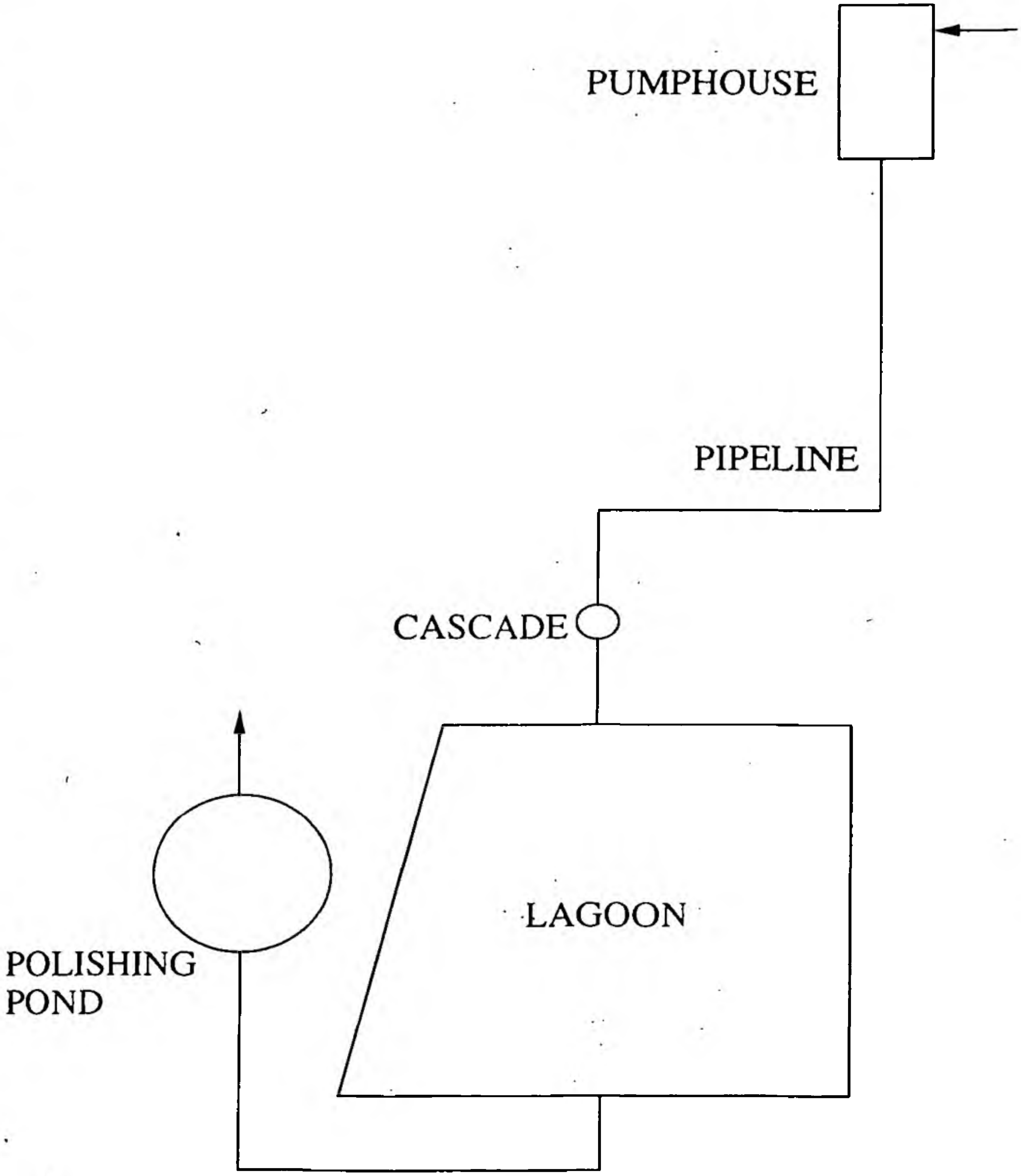

Fig. 1 Simplified plan of the Bullhouse system
(not to scale)

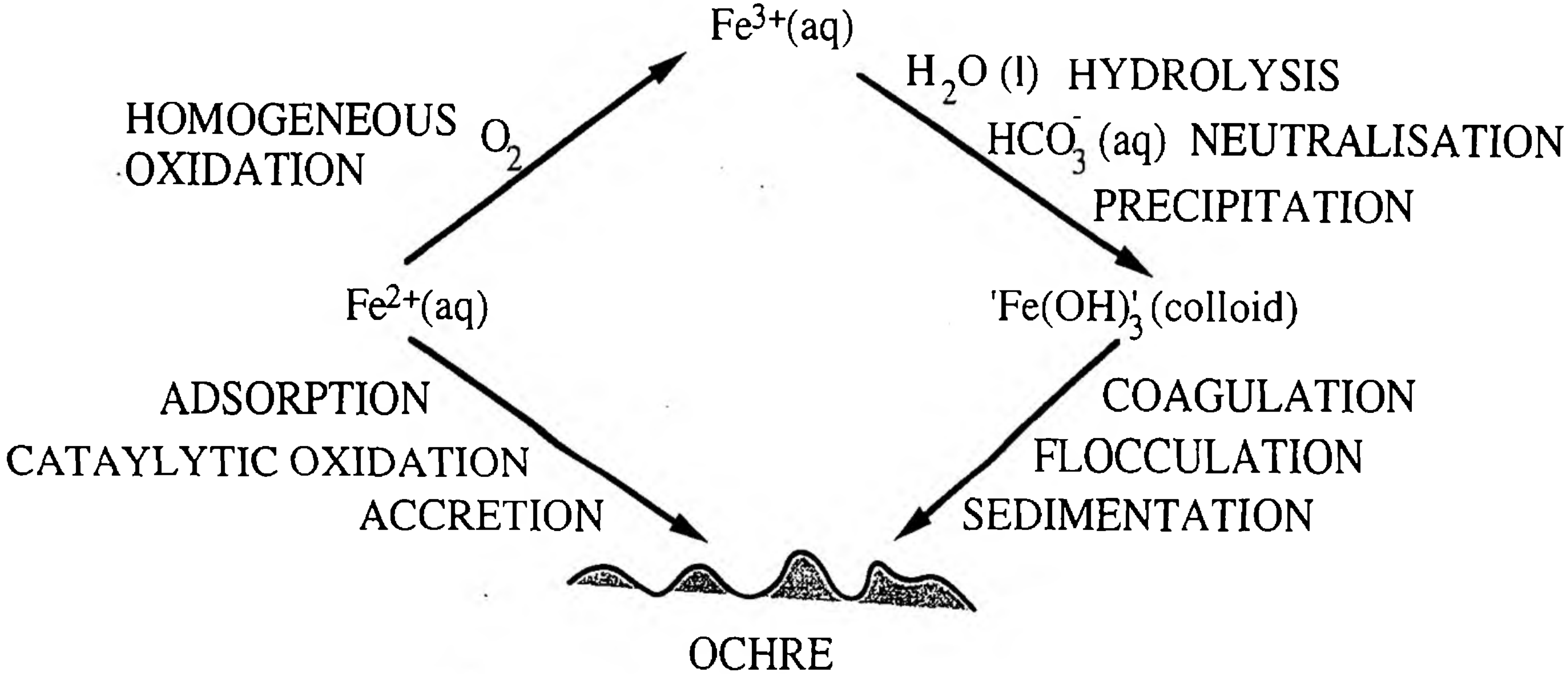

Fig. 2 Scheme of iron oxidation and ochre formation

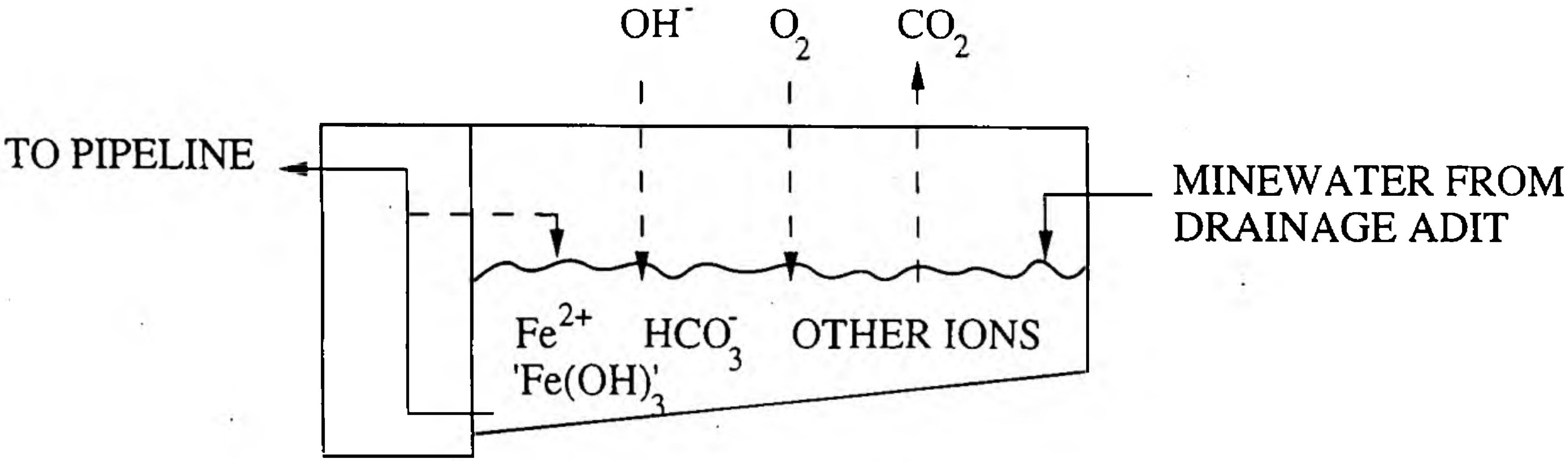

Fig. 3 Interacting species in the pumphouse

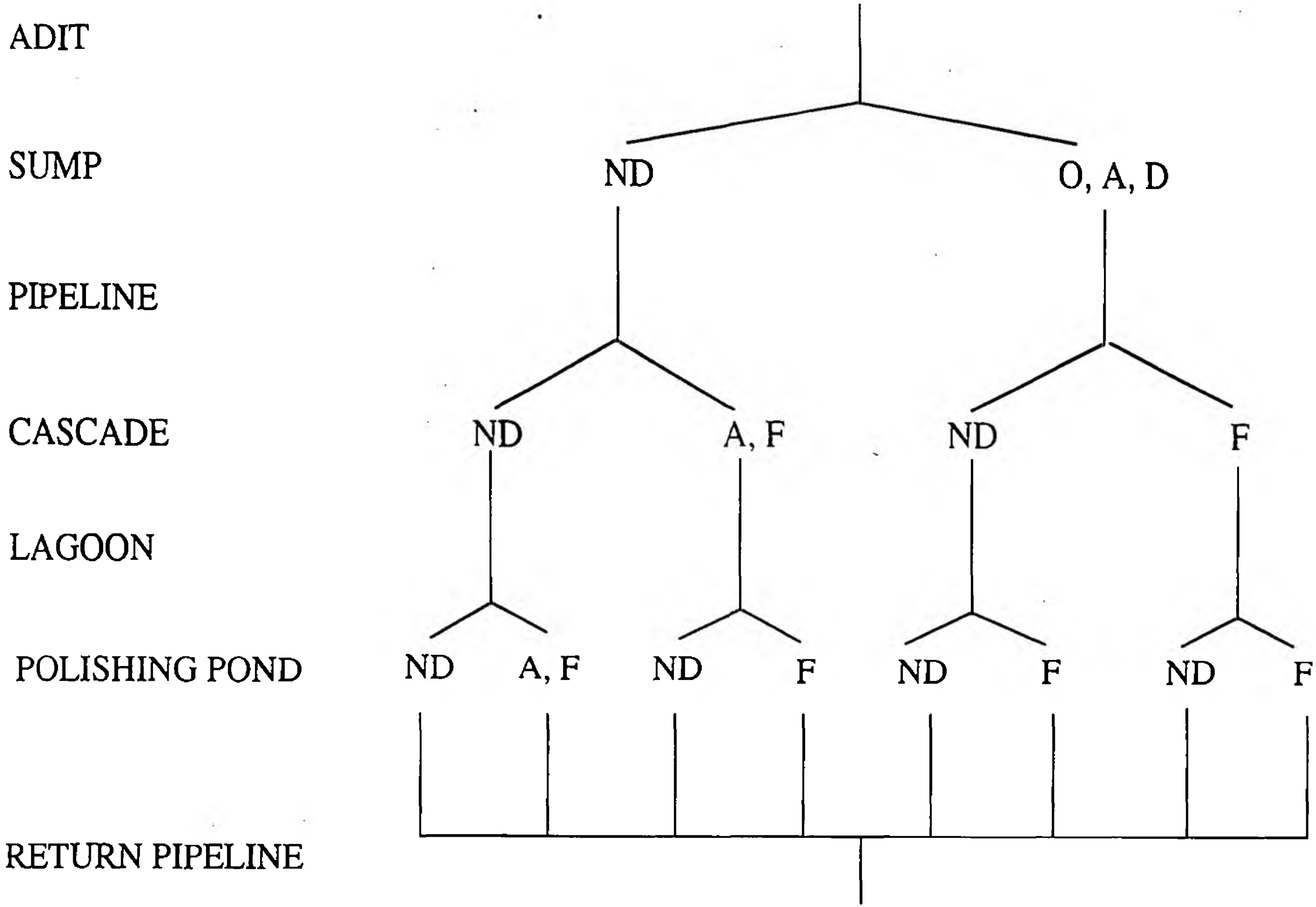

Fig. 4 Scheme of options for treating the Bullhouse minewater: O, forced aeration; A, alkali addition; D, dispersant addition; F, flocculant addition; ND, no dosing

Lagoon and Reed-Bed Treatment of Colliery Shale Tip Water at Dodworth, South Yorkshire

by

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Abstract

Acidic run-off from a reclaimed colliery spoil heap at Dodworth, Barnsley, South Yorkshire, containing elevated levels of Potentially Toxic Elements, is causing the down-grading of a reportable water course. The history of this and the steps taken to try and alleviate the problem, including the use of reed beds, are recorded and discussed. A key conclusion is that it is not easy to meet EA Discharge Consents by passive methods, especially where the site area is a constraint.

Key Words - Acidity, colliery waste, mine drainage, minewater, pollution, reclamation, reed beds, reeds, remediation, tips, tip water, water treatment, wetlands

History of the Site

Dodworth Colliery Spoil Tip is a dominant landmark immediately to the west of Junction 37 of the M1. According to the available records, the first shaft on the Dodworth Colliery site was sunk prior to 1862, the second in 1927; therefore it is a reasonable assumption that tipping also started on the site around the 1860's. The oldest tipping is at the southern end of the present tip complex. Subsequent aerial photos show that this early tip was built up around a washery waste lagoon, shale was used to construct bunds and as the lagoon was filled, further tipping was used to raise the bunds until a conical tip approximately 40 metres high with a semi liquid centre was created. This General Development Order (GDO - i.e. having no Planning constraints) tip was soiled and seeded in the early 1970's. In the mid 1970's a mass tree planting scheme was carried out by South Yorkshire Metropolitan County Council (SYCC) on the bulk of the tip apart from that face which was going to join onto the tip extension. It was funded 50% by the National Coal Board (NCB) and 50% by SYCC using Derelict Land Grant (DLG) from the Department of the Environment. SYCC took on the responsibility for the maintenance of the planting but had no responsibility for the tip itself. During this period, Planning permission was granted for a massive extension northwards to form what was to become basically a whale back tip approximately 600 metres long overall attached to the original part of the tip and only slightly less in height. There may well have been some limited washery waste disposal within this new part of the tip, but the main constituent was shale from the Dodworth Pit and others which had been linked underground and were now using Dodworth as a waste disposal point. This extension to the tip thus grew much faster than the original tip. The Colliery, which at its peak had employed 1,000 people, was closed in 1984. The tip extension was soiled and seeded for agricultural use, with tree planting on the steeper side slopes, it remained with the NCB even for tree maintenance.

After the closure of the Colliery, the release of the site was blocked by British Coal Opencast Executive, as they saw it as a possible opencast coal distribution centre. Finally, in 1989, Barnsley MBC managed to get hold of the Colliery site (c.22 ha) in order to subsequently reclaim it for much needed industrial use at a cost in excess of £3.6 million using Department of the Environment (DoE) 100% Derelict Land Grant (DLG). With what might appear later to have been great fore-sight, British Coal insisted on the whole tip complex being included (for a nominal amount) as part of the sale package. Barnsley MBC became responsible for the tip from that date.

Apparently the Yorkshire Water Authority, and later their successors the National Rivers Authority (NRA), had been monitoring the outfall from the northern end of the site (north end of the tip extension) since the early '80's and, even after the sale to BMBC, continued to send water quality reports to British Coal. These reports were not passed onto BMBC and BMBC was not aware of any NRA concerns at the time of purchase nor for some years afterwards.

The outfall in question is fed from a perimeter toe drain catching surface water from the tip as well as numerous acid wet patches where water oozes out of the tip and works its way down the slopes. The outfall forms the source of a small watercourse (in Langford Wood) which then feeds into the Silkstone Beck. While the regulatory bodies where aware of the potential problem, while-ever Dodworth Pit was working and the pumping of high quality mine water from the adjacent Higham shaft pumping station into a culvert and thence into Silkstone Beck continued, the problem was manageable due to the high dilution factor. The problem was thus restricted to the watercourse itself from the tip to the pumping outlet, so that there was not a problem for Silkstone Beck itself.

Unfortunately, as noted above, the Colliery closed in 1984 and pumping ceased in the early 1990's, the Higham pumping shaft being filled with rubble in 1994. A porous rubble mix was used to allow any water backing up the shaft to reach the surface and find its way into the culvert and hence into Silkstone Beck.

During the first few years of ownership, the only acid patch on the tip giving cause for concern to BMBC was on a section of the old tip face, with a slope of almost 1 in 2, overlooking the future industrial site. Ironically, this did not contribute to the flow to Silkstone Beck. The acid water had destroyed the grass cover and, over the years, created a massive erosion gully. This has now been completely dealt with, as part of the works described below.

The Remedial Works Carried Out On and Off the Tip

In 1991 BMBC approached the DoE with a view to doing some work on the tip itself to repair the scar noted above. This work was detailed and expanded in 1992 and consisted of:-

- repairing the acid patch erosion gully mentioned above;
- reshaping the top of the tip to remove standing water (which it was feared was soaking into the tip) including subsequent restoration of the disturbed areas
- installing drainage systems to pick up the minor acid patches;
- constructing reed beds for drainage water treatment

This successful application for DLG money formed the basis of all the works on the tip, works which are still in progress today under the funding regime of English Partnerships (EP).

During 1993 the top of the old part of the tip was reshaped and "sealed" with clay cap in order to reduce water penetration into the former lagoon underneath. The rest of the tip top (basically the extension area) was reshaped to get better gradients to shed surface water and thus remove the tendency for seasonal ponding. The surface was then treated with sewage sludge to allow a vigorous agricultural grass sward to be established, so minimising water entry into this section of the tip.

During 1993 a complaint was received by BMBC from a local resident that the watercourse in Langford Wood to the north end of the site had its banks covered in white material. The outlet from the tip at the north end of the site forms the source of the stream in question and it quickly became obvious that the white deposit consisted of aluminium compounds, in all probability emanating from the tip. This complaint prompted even more active NRA involvement and the recognition that although they had had concerns about the quality of this water for some years only now did they discover that the tip was no longer in British Coal ownership. They recorded that during this period Silkstone Beck itself was suffering, to the extent that it was failing the Environmental Quality Standards (EQS) for certain metals This was the start of an ongoing relationship with the NRA (now the Environment Agency - EA) which has been productive and non-confrontational. BMBC explained that they were becoming aware that there were problems with the tip and had started to put initial works in hand. This process obviously gained new momentum with the concerns expressed from the public and the NRA.

In the summer of 1993 a two stage trial reed bed was designed and constructed by Yarningdale Nurseries (Warwick). It consisted of an anoxic limestone entry drain, a Typha reed bed planted in a peat/topsoil mix, followed by a Phragmites reed bed planted into pea gravel. The whole bed was only about 50 sq.m. of active area but it was a start and equal to, if not ahead, of any other similar project in the UK..

Unfortunately this activity had not gone un-noticed by the local children with regard to their weekend entertainment. Each Monday the reeds had to be collected from around the site, where they had obviously been flung in childish enthusiasm, and re-planted; the various pipes had to be re-levelled to ensure the correct flows; and the anoxic drain had to be unblocked. Fairly early on, this unwelcome activity resulted in the anoxic drain being reluctantly abandoned. Weekly replanting hampered the growth of the reeds and by the autumn it was obvious that something fairly drastic had to be done. Authority was obtained to erect a high tensile netting fence, topped with barbed wire and surrounding coiled barb wire entanglements. No gates were installed, access being gained by way of steps brought to site when required. Free from interference the reeds flourished and by autumn 1994 it could be shown from samples taken that the reed bed was reducing the amount of aluminium in the water (Table 1). A year had been lost but a valuable lesson learnt about protecting reed beds on site, and the reeds were having the right effect.

At this time NRA expressed a keen interest in the work that BMBC was doing and was willing to wait and see what progress was being made, without taking the formal step of issuing a consent to discharge. However their view at that time was that reed beds were the "final polish" and thus a settling lagoon was also needed as part of the works. This lagoon would complement the liming work that was in hand in the vicinity of the ditch, all to try to increase the pH of the acid water. Work was thus put in hand to design and install a settling lagoon.

The lagoon as eventually constructed, consists of three compartments at different levels connected by pipes with spill-ways. The hope is that as the water drops down from one compartment to another this will encourage mixing and help prevent layering within the water body An added benefit is that the resultant aeration helps to oxidise the Ferrous iron and encourages it to precipitate out as Ferric iron. Within the compartments are gabion barricades filled with lump-limestone, these are designed to try and ensure mixing within the lagoon and, although subject to armouring, contribute towards the raising of the pH. The gabions also provide a secure platform for soda ash application.

Unfortunately there was some delay in getting funding approval for this lagoon work. The running of the DLG programme was handed over from the DoE to EP in April 1995 and unfortunately the lagoon was a victim of that handover process. The formal approval arrived in the autumn of 1995 and the lagoon was installed immediately. In the meantime NRA's patience had been exhausted and seeing no real progress on site for 12 months they insisted on BMBC applying for a Consent to Discharge.

The NRA consent involved much discussion between the two parties. The original idea was to have a three stage consent:-
I) Levels as per existing readings at that time

ii) Reduced levels from October 1995
iii) Final levels from October 1996 (Table 2 Consent Levels); by this time it was thought that the lagoon and the final reed beds should be in place. These standards would be based on Environmental Quality Standards. It is interesting to note that their main concern is/was aluminium, however there is no EQS for aluminium. What they therefore accepted was that by consenting other parameters, the actions needed to bring these levels down (i.e. mainly making the water more alkaline) would by definition, if successful, also bring down the aluminium levels.

In the event negotiations were protracted and the first stage was omitted. It has to be recorded however that it is BMBC's view that the final consent levels (Table 2) are unrealistically low and are unlikely to be met in anything other than the summer and early autumn months, no matter what is reasonably done.

During the period late 1995 to early 1996 Yarningdale were again employed, this time only as consultants, to design the final reed beds. Unfortunately, before Yarningdale started their work, a decision had had to be made about land purchase. As on many tip sites, there is little or no flat land left at the right levels on the site, as owners are inclined to want to tip on all the available land. During 1995 it became known that an adjacent field, farmed by a tenant and owned by British Coal, was being sold. A quick decision was required to try and get hold of some of this land. It was decided to limit BMBC's purchase to the flat area of the field adjacent to the tip site, and of that, only the portion that was not affected by overhead power cables. This plot was thus removed from the package sold to the tenant by British Coal, and instead sold to BMBC. Once Yarningdale got started with their calculations it became quickly evident that the land available within the site, even including the newly purchased land, was still grossly inadequate for the area of Reed Bed required. However there was no choice at that stage but to shoe-horn in the maximum area of reed bed possible within the land available. In the autumn of 1996 therefore a contract was let to construct two reed beds, one within the original site, upstream of the lagoon, the other "off-site" on the land purchased from British Coal. This second reed bed (Reed Bed 2) is in a better situation in so much as it is down-stream of the lagoon and treats all the water from the site.

The two new reed beds were planted with pot grown Typha at 4 per square metre, into topsoil salvaged from the site and enriched with bark compost. The beds were rather dry at the time of planting due to a fairly dry late summer and there was a problem trying ensure that all the water on site flowed through the reed beds rather than bypassing the reed beds in the storm by-pass pipe system. The water levels did increase in the autumn, to about 100mm depth; this may well have been too deep. For whatever reasons or combination of reasons, the net result is that in spring 1997 there were significant numbers of the reeds that do not appear to have started into life after the winter and also unfortunately significant signs of grass weed growth (mainly in Reed Bed 2). The weed grass growth was addressed by hand pulling. After a number of agonising weeks suddenly the "dead" reeds leapt into life in April and the summer of 1997 saw the beds full of very vigorous and healthy looking reeds.

The other remedial activity on site has been the use of chemical ameliorants. This started with the use of agricultural lime applications around the perimeter ditch, onto the water in the ditch, in and around the stream immediately off site, and on and around the lagoon. This was first done in January 1994, moving onto a more regular treatment in May 1994 and the last lime was put on in February 1996. The bulk of this was hydrated lime (c.3 tonnes in total - excluding Jan to May) but a small amount was 1.5" single size limestone (c2.25 tonnes in total). In the autumn of 1996 (and again in 1997), this was reinforced by the addition of lime onto the agricultural fields on the tip itself. An application of five tonnes of Calcitic Agricultural Grade Limestone was spread over 8 hectares. The application of the lime (other than onto the fields) was changed in January 1996 to soda ash on the advice of the EA. This was added by placing on the gabion divisions in the lagoon and in special constructed mesh boxes in the perimeter ditch network at strategic points. This does seem to have some effect although it is sometimes short lived. The application rate varies depending on flow rates and pH but is around 200 kilos per application, 3 times a week, i.e. 600 kilos per week during high flow periods. In the first 12 months 13.6 tonnes has been used. It is fully appreciated by all concerned that a dosing plant (as used for example at Wheal Jane) would be a better option technically; however, with the vandalism record on site it is fully accepted by BMBC and E.A. that such an option is just not practical. During 1997 Soda Ash was changed to Lycal, which in theory should give better results. However, Lycal was found very difficult to handle (physically) on site because it is very fine and blew everywhere. After the one batch of Lycal, Soda Ash is thus being used again.

Having added so much material to try and raise the pH and encourage precipitation of the PTE's, it is obvious that it has to go somewhere. Thus in the Autumn of 1997 c.80 tonnes of sludge was sucked out of the lagoon for disposal.

The detailed nature of the discharge problem

A summary, showing the number of times that the final consent levels would have been met if in force for the past three and a half years to early '97, is shown in Table 3. It should be noted that the figures relate to the end-of-pipe discharge after all treatments then in operation had been applied. The sampling point was originally the discharge pipe from the lagoon, and then, after construction of the reed beds, it was moved to the discharge pipe from reed bed two.

The results obtained from the trial reed bed, at the end of the first successful growing season were as shown in Table 1. It has to be noted however that the trial reed bed (See Figure 1 for location) was constructed further south within the site and thus picked up the flow before some of the more contaminated flows join the ditch. This was because, for such a small bed, it was felt necessary to fit it up stream or the flow and pollution load would simply have been too great for it to deal with.

The other problem with dealing with the pollution from this site is the variability of the flow. The flow increases within 24 hours of rainfall and the tails off over a number of days. As one would expect the flows are highest in winter months, but early figures also showed that the pollution loadings were at their highest when the flows were highest. Thus instead of a dilution effect in winter there is obviously a flushing-out effect. This seems to take a while to get going, and similarly tails off in the spring. This is obscured in later readings as they are end-of-pipe readings for the most part and any trends are obscured by the treatments.

OHP's will be displayed at the conference to show the effects of the Reed Beds on the PTE's.

Conclusion

1. The works on site have shown the difficulties of trying to meet EA Discharge Consents imposed on Acid Mine Tip Drainage.
2. It is hoped that the first year's improvement to discharge quality will continue so as to result in considerable improvement when the reed beds are well established.
3. Informal analysis of the early figures would seem to show that the treatment so far is having a very useful effect on the iron, chromium, aluminium and solids but little effect on the pH. However, the zinc, copper and cadmium figures might not be responding so well.
4. What was not yet clear from early figures was whether the quality of the water being treated was getting worse overall, as the figures were "end of pipe". However readings are now being taken throughout the system, including prior to any treatment, and these should give a better indication of the effectiveness of the treatment. OHP's of these will be shown at the conference.

References

The paper is based on the personal knowledge of the author since first being involved with the site in 1975 and working files held by BMBC. It is based on a similar paper given by the Author at the CIWEM Conference at Newcastle 5.9.97

Acknowledgements

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Disclaimer

Any views expressed in this article are those of the Author and are not necessarily those of Barnsley MBC

Table 1 Original Trial Reed Bed - Performance Figures

	Date	Inlet	Outlet
pH	28.09.94	6.7	7.6
	11.10.94	6.4	7.1
Total Iron mg/l	28.09.94	14.2	1.2
	11.10.94	41.3	0.6
Total Aluminium mg/l	28.09.94	0.9	0.2
	11.10.94	6.0	0.1

Table 2 Consent Levels

	From 1.10.95	From 1.10.96
pH	6 to 9	6 to 9
Iron	26mg/l	4mg/l
Nickel	1200ug/l	800ug/l
Solids	100mg/l	30mg/l
Copper	150ug/l	100ug/l
Zinc	2000ug/l	1500ug/l

Table 3 Percentage of readings over three and a half years to early 1997 where the final consent levels would have been met, if they had been in force

pH	12%
Iron	13%
Nickel	35%
Solids	36%
Copper	53%
Zinc	84%