LINK PROJECT COMPLETION FORM

Please enter details (in lower case) in the boxes below. Guidance on completing this form is contained in the LINK Best Practice guidelines.

Name of LINK programme:
Biological Treatment of Soil and Water Programme

Name of LINK project:
Bioremediation of Acid Mine Drainage in Constructed Wetland Ecosystems

Project reference:	Project start date:	Completion date:
QCBC/C/3/1 (BTL/2-0/71)	1 October 1999	31 October 2002

Project manager's name: Alan Gibbon

Organisation: Mineral Industry Research Organisation

Address: 1 City Square Leeds LS1 2ES

Project costs (£)

	Government Department	Research Council	Industry	Total
Original commitment	£283,152.00		£283,152.00	£566,304.00
Actual spend	£276,629.65		£276,629.65	£553,259.30

Project success

Indicate in the box the overall success of the project on a scale of 1 - 10

Participants
List all project participants by the following categories:

Industry		**Research base**		**Other**
Large enterprises	**SMEs**	**HEIs**	**Other research base partners**	**Others**
Rio Tinto Plc Knight Piesold Ltd TVX Hellas A E CL:AIRE Wardell Armstrong National Physical Laboratory Biffa Waste Services Ltd IACR-Rothamsted	Baseresult Holdings Ltd. Aquatonics ltd Clean Rivers Trust Mineral Solutions wRace Technology	Reading University Bangor University Camborne School of Mines Imperial College	Centre for Ecology and Hydrology, Windermere	Neath Port Talbot Borough Council National Assembly for Wales

<u>Brief Summary of research and results</u> *(Include targets and objectives indicating progress made towards achieving them, or reasons for those not achieved. Also include highlights, outputs, deliverables and any unexpected benefits)*

The Wheal Jane pilot passive treatment plant, the largest controllable and instrumented example in the world, was designed to investigate the potential for sustainable treatment of minewater drainage. The plant consists of three treatment schemes including:- i) 5 artificial reed-beds (aerobic cells) designed to facilitate the precipitation of iron as ferric hydroxide/oxyhydroxide (ochre) and also the co-precipitation of arsenic, ii) a single anaerobic cell to promote bacterial sulphate reduction, increase alkalinity and thereby precipitate chalcophilic metals (e.g. copper, zinc, cadmium and iron) as sulphides and iii) shallow rock filters to promote algal growth and consequent high pH to precipitate manganese. Each scheme differed only in the pre-treatment of the raw minewater (pH 4.1) before discharge to the aerobic cells of each scheme. These were a) lime-dosing to pH 4.5 (LD), b) flow through an anoxic limestone drain (ALD) and b) no pre-treatment (LF). Initial studies published in 1998 examined the gross chemical changes over the plant whilst this study studied the microbiological and chemical processes in more detail. The multidisciplinary research on the Wheal Jane PPTP has shown how shortcomings in the original design might be overcome. In addition a unique model based approach representing a valuable design tool has been produced which could be used to determine how the operating capability of Wheal Jane and AMD plants worldwide could be improved. The key findings follow.

1. The mechanism of iron precipitation was shown to have a strong biological component in all three treatment systems. The activity, which was associated with the sediment from the reed beds. The dominant iron oxidising microorganisms were shown to be a novel group of moderately acidophilic bacteria whose activity was very low at pH values <3. The current operation of the plant is such that when the pH falls to these values the concentration of Fe(II) is so low that colonisation by the classical acidophilic iron oxidising bacteria is not favoured. Additional work has shown these moderate acidophiles to have a widespread distribution in minewaters throughout the UK.

2. Detailed study of the distribution of Fe(II) concentrations within the aerobic cells showed there were significant differences between the treatment schemes. Over one year the concentration of Fe(II) varied from 5 – 90 mg/l. Typically the first aerobic cell of the LD system removed 52% of the Fe(II) - an areal removal rate of 167 mg $m^{-2}h^{-1}$. In the ALD system approximately 90% of Fe(II) was removed over the first aerobic cell - areal removal rate of 316 mg $m^{-2}h^{-1}$. In the LF system the aerobic cells were larger,in anticipation of slower reaction rates. However, 77% of the Fe(II) was removed using only one quarter of the area of the first cell - areal removal rate of 243 mg m^{-2} h^{-1}. In all systems low concentrations of iron (up to 20 mg/l) remained in solution and only occasionally did concentrations approach zero. The co-precipitation of arsenic was shown to be very rapid in all three systems. Importantly, the total area of aerobic cell provided was far in excess of that required to precipitate the Fe and As under the operational conditions used. However, capacity of the plant could not be saturated by simply increasing flow rates. Oxidation of Fe(II) and subsequent hydrolysis of Fe(III) results in a decrease of the pH of the environment. The activity of the moderate acidophilic bacteria was strongly dependent upon pH. Indeed, laboratory experiments showed that if pH was maintained the reaction was independent of concentration of Fe(II). As the pH was not controlled in the aerobic cells the rate of oxidation of Fe(II) decreased as the reaction progressed. Any increased flow would need to be distributed to different areas of the aerobic cells.

3. The first aerobic cells of all systems, precipitated iron very efficiently and deposits of ochre accumulated rapidly. The ochre deposits in the aerobic cells of the ALD were closely associated with the plant root systems and recovery of the iron would necessitate removal of the plants which could affect the efficiency of the system. However, in the LF system the iron deposits consolidated and removal would be a simpler operation than from the LD system where re-suspension was more likely. In all systems the ochre contained >0.1% As and would be classified as hazardous waste under current UK landfill regulations.

Brief summary of research and results/ continued

4. The second component of the treatment systems is the anaerobic cell (or compost bioreactor), underground chambers filled with a mixture of straw, sawdust and manure. The straw and sawdust provide physical support and a long-term source of organic carbon. The manure provides an immediate source of organic carbon and inoculum for sulphate-reducing bacteria (SRB).

5. Monitoring revealed that the ALD and LD bioreactors were not functioning as expected - the effluent contained more soluble iron (exclusively as Fe(II)) than the influent. Moreover, the pH of the water draining these bioreactors was had only increased from ~ 3.0 to ~5.5. At this pH, iron sulphides are not stable and hence residual iron was poor. The effluent from the bioreactors was discharged to the rock filters and the combination of low alkalinity and oxidation of Fe(II) and free sulphide led to a drop in pH (to as low as 3) which inhibited colonisation by algae and prevented the rock filters in the LD and ALD systems operating as designed.

6. Operational problems in 2001 led to the closure of the LF system for twelve months. To protect the compost bioreactor the system was closed such that rain water would not enter. Upon resumption of the flow of minewater to the LF system, a change in the effluent chemistry from the compost bioreactor system was noted. The pH of the effluent increased to between 6 and 7 and the sulphide and iron (again exclusively Fe(II)) decreased. After 4 months of continuous operation, sulphide, zinc and iron decreased to below the level of detection. During the same time period, SRB were detected at much higher numbers in the LF effluent than from the ALD or LD bioreactor effluents. Thus the period of the shutdown seemed to condition the bioreactor of the LF system to operate as predicted in the initial design.

7. The final component is the rock filters, small pools containing pebbles to encourage colonisation by algae and thereby raise the pH of the water as a result of oxygenic photosynthesis. The increase in pH is desirable to encourage the oxidation and precipitation of manganese (about pH 8). Only the rock filters of the LF system produced sufficiently high pH levels and resulting manganese concentrations ~ 0.5 mg/l.

8. The work has shown the potential for biological removal of soluble iron from untreated mine effluents and also the importance of maintaining iron concentrations low in the feed to the compost bioreactors. Moreover, the microbiological work has demonstrated the potential for natural attenuation of minewater pollution.

9. Good progress has been made on the development of a mathematical model. The complex issues of hydrology and chemistry have been addressed and the model incorporates residence times and the effects of external elements, e.g. seasonal variations. The model does not use a full thermodynamic equilibrium approach as the system is controlled by the microbiology and the rate coefficients are dictated by the microbiological results. It is based on the individual unit operations in which the major parameters and variables can be altered and predicted from a set of differential equations.

10. Although refinement was required, it is now possible to alter the number and criteria for each of the unit operations, e.g. proportion of cells, depths and sizes and uses the “reach number” to define the conditions at any point of the process under consideration.

Future R&D resulting from this project *(Include any other non-tangible benefits and state any TCS actions)*

The project was been linked to a Camborne project supported through Objective 1 funding “Building Capacity in Environmental Research” with the aim of investigating future uses for the Wheal Jane site. Three options were considered in the feasibility study:- i) Decommissioning – likely cost £1 million, ii) Continue in present form - £4 million spent to date and iii) Modify and improve the facilities and achieve a return. It was concluded that the scheme should be sustained and improvements were necessary, together with a long-term funding stream if a financial return was to be realised.

The current focus is a proposal from the Clean Rivers Trust and Camborne. A flagship project learning from the success of the EDEN Project making good use of the forty hectares as a laboratory – exploiting the now contaminated land as a research laboratory for remediation and revegetation schemes. The project aims to create 35 jobs and hopes to attract 35,000 visitors a year. It is also complimentary the Gevor Mining Museum and plans for a Heritage Centre in Camborne.

Complimentary with this scheme it is proposed to investigate the global research network – INAP as a means of supporting and funding further practically focussed research in this area with the ultimate aim of transferring the technology throughout North America, South Africa and Australia as well as Europe, particularly the emerging Eastern European countries and new EU members.

Industrial relevance and plans for future commercial exploitation

The project has highlighted the potential for the viable commercial exploitation of bioremediation in the context of acid mine drainage prevention and protection.

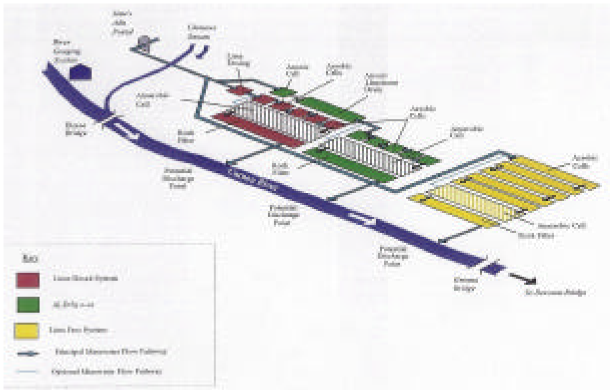
As a result of the exciting and industrially significant findings from the research further discussions are planned early in 2003 to determine how the site (below) can be altered to carry out large scale site trials to establish the economic viability, including efficacy, kinetics and costs will need to be investigated. The team will be extended as appropriate. Use of the model approach developed will be made in the design phase.

It is anticipated that the EA will play a key role in the future development.

Effort will be directed at developing a technique based on the LF aerobic cells - shown in yellow

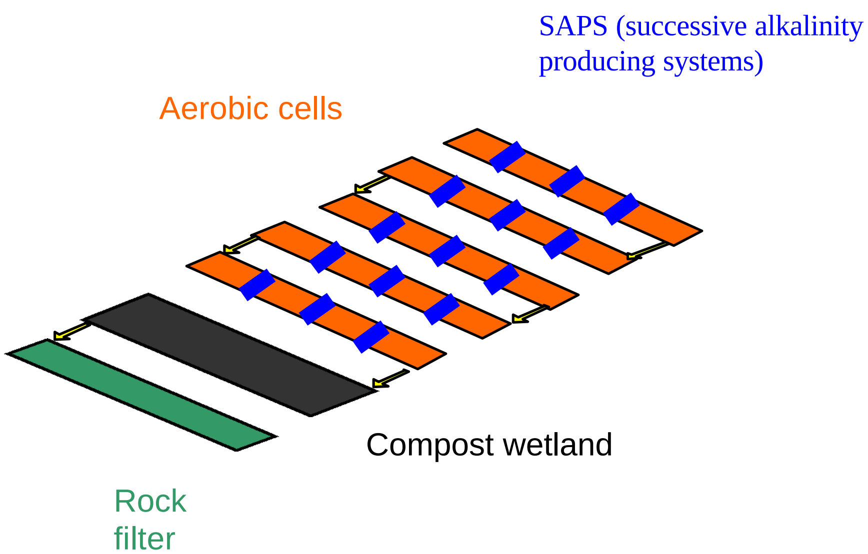
These represent a small part of the current land area and research has demonstrated that they are very efficient and oversized capable of perhaps ten times the throughput offering the potential for commercial exploitation.

A possible scheme is shown below.



Modified Scheme of the Wheal Jane Passive Treatment Plant

To assure more even water flow through each cell, all water flows into a cell through a spillway that traverses the width of the respective cell, rather than through the current "pipe" flow.



Patents and publications ***(Including those pending)***

There are no immediate plans to patent arisings from the project. A wide range of publications has been produced, some examples follow:

Johnson, DB and Hallberg, KB. Microbiology of acid mine drainage. Research in Microbiology
Hallberg, KB and Johnson, DB. Passive mine water treatment at the former Wheal Jane tin mine, Cornwall: important biogeochemical and microbiological methods.In: Mine Water Treatment: a Decade of Progress.
Johnson, DB and Hallberg, KB. Pitfalls of passive mine drainage. Re/Views in Environmental Biotechnology.
Hallberg, KB and Johnson, DB. Novel acidophiles isolated from moderately acidic mine drainage waters. Hydrometallurgy.
Johnson, DB Chemical and microbiological characteristics of mineral spoils and drainage waters at abandoned coal and metal mines. Water, Air and Soil Pollution Focus.
Hallberg, KB and Johnson, DB Novel biological systems for remediating acidic, metal-rich waters. Proceedings of the 23rd Annual SETAC meeting. Salt Lake City (abstract)
Hallberg, KB, Hall, G and Johnson, DB (2002) Importance of Newly Isolated Acidophilic Microorganisms to Iron Oxidation in a Constructed Wetland Receiving Acid Mine Drainage. Poster presented at BIOGEOMON 2002, Reading, U.K., 17-21 August, 2002 (abstract).
Prior, H, Hallberg, KB, Hall, G and Johnson, DB (2002) Macrophytes: friend or foe? the importance of microbiological processes in the bioremediation of AMD. Presented at the Society of Wetland Scientists Annual meeting in Lake Placid, USA, 1-7 June 2002 (abstract).
Hallberg KB and Johnson DB (2001) Biodiversity of acidophilic prokaryotes. Advances in Applied Microbiology 49:37-84.
Johnson, DB (2001) Importance of microbial ecology in the development of new mineral technologies. Hydrometallurgy 59:147-158 .

A special issue The Science of the Total Environment is planned covering the research undertaken by the consortium including Imperial College. It will comprise eighteen papers covering each facet of the project.

Declaration

The contents of this form have been approved by all project participants, the project monitoring officer(s) and the Programme Management Committee (PMC).

Signed: **Date:**
(PMC Chairperson or Lead Secretariat)

When this form has been completed and the above declaration has been signed please send a complete copy to:
Jeanette Wilde
LGC Ltd
Queens Road
Teddington
Middlesex
TW11 0LY

Department of Trade and Industry