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TDP 13 - Passive Treatment of Severely Contaminated Colliery Spoil Leachate Using a Permeable Reactive Barrier

Originally published November, 2006

Executive Summary

The Environment Agency concluded, as part of its River Basin Characterisation exercise, that some 1,800 km of England and Wales' watercourses were 'at risk' from mining-related pollution. Many of the worst quality waters arise as drainage from spoil heaps, wherein the processes of sulphide mineral oxidation and dissolution which are the root cause of mining-related pollution, are particularly vigorous. The major pollutants associated with discharges is a persistent form of contamination, with discharges remaining polluted for centuries or even millennia. For this reason the preferred option for remediation of such discharges is passive treatment. Such technologies rely on naturally-occurring and biological reactions to effect treatment, and therefore do not require ongoing inputs of energy and / or chemicals. Consequently long-term costs are kept to a minimum, and such systems may also offer amenity benefits.

At Shilbottle, Northumberland, the spoil heap of the former Shilbottle Grange Colliery was a source of very severe contamination of the adjacent Tyelaw Burn. Staff and students at Newcastle University first began evaluating the problem in the late 1990s. These investigations led to the design, by the Newcastle team, of a full-scale Permeable Reactive Barrier (PRB), settlement lagoons and aerobic wetland, for the treatment of the spoil heap drainage. In July 2002 Northumberland County Council commenced construction of the system, which was completed in September 2002.

Although a number of technologies exist for the passive remediation of acidic, metal-rich, spoil drainage, without installation of water pumping facilities, none of them are appropriate for the interception and treatment of diffuse, subsurface leachate. This was precisely the problem at Shilbottle, where subsurface drainage, arising from a perched aquifer within the spoil heap, was causing diffuse contamination of the Tyelaw Burn along approximately 150-200 m of its length. This report describes the highly successful application of PRB technology to this problem. The 180 m long PRB intercepts the drainage and, through a combination of calcite dissolution and bacterial sulphate reduction, generates sufficient alkalinity to both neutralise a large proportion of the acidity and allow the subsequent retention of the contaminated metals within the settlement lagoons and aerobic wetland. The successful performance of the system is demonstrated in this report with analytical data spanning two years.

The settlement lagoons after completion and commissioning of the Shilbottle passive treatment system. The water flowing out of the lagoons is bright orange in colour due to the rapid hydrolysis and precipitation of iron in the presence of the alkalinity generated in the PRB.

Continued extensive monitoring of the site is being made possible by past and current logistical and financial support from CL:AIRE, Newcastle University's Science Research Investment Fund - second round (SRIF2) Earth Systems Laboratories project, the LINK sponsored Bioremediation of acidic mine waters by sulphate reduction in novel, compost-based field-scale bioreactors (ASURE) project, and the European Commission Framework Programme 6 (FP6) Coal Mine Sites for Targeted Remediation Research (CoSTaR) project. The latter funding stream in particular ensuring that the site is a significant focus of national and international research, the outcomes of which it is hoped will yield substantial benefits to many other owners of such contaminated sites, both in the UK and worldwide.

General Conclusions

Monitoring of the Shilbottle PRB since its installation has demonstrated the successful application of this novel passive treatment technology to the remediation of highly acidic and metal-rich spoil heap leachate. Concentrations of both iron and aluminium are typically reduced by in excess of 90% (approximately 500 mg/L to < 20mg/L in the case of iron), and acidity concentration through the treatment systems decreases from a mean of 2,500 mg/L as $CaC0_3$ to < 500 mg/L as $CaCO_3$.

Not only is the treatment system a demonstrable success in its own right, but this report has outlined how the partnership of landowners, regulators, research scientists and engineers has effectively worked to develop and implement a unique technology to improve the quality of a local stream, with marked benefits for downstream users.

The Shilbottle PRB continues to be a site at which there is vigorous research activity. The site is a particular attraction for research visitors from across Europe, visiting Newcastle University under the auspices of our EU Access to Research Infrastructure CoSTaR programme (Coal Mine Sites for Targeted Remediation Research). Notwithstanding research by these visitors, specific areas of interest include determining the precise roles of bacterial sulphate reduction (BSR) and calcite dissolution in the generation of alkalinity, investigating the hydraulics of the PRB to establish why some sections of the PRB work more effectively than others, and examining carbon and sulphur cycling within the system with the ultimate objective of predicting PRB longevity (Jarvis *et al.*, 2006).

Limitations of the Technology

The Shilbottle PRB Technology Demonstration Project has illustrated many of the strengths of this approach to the remediation of acidic and metalliferous leachates. It nevertheless also has its limitations. There are limits to the levels to which alkalinity can be raised in a single flow-through system before kinetics become sluggish and further increments in alkalinity could only be gained at the expense of far longer residence times. In this case, total alkalinity never rises much above 300 mg/L as $CaCO_3$ (see Table 6.1 of full report) and never exceeds 600 mg/L (see Appendix 1 of full report), even in those parts of the PRB which are inferred to have the highest residence times (on the grounds of relatively low permeabilities as measured by slug tests to remain in excess of 2,000 mg/L as $CaCO_3$ (often more; Table 6.1), so that the water leaving the PRB is still markedly net-acidic. Only a system of sequential anaerobic / aerobic reactors (adopting the principle of 'successive alkalinity producing systems' first proposed by Kepler and McCleary 1994) could completely overcome this constraint, but such a strategy would require far more land area and site relief (i.e. exploitable hydraulic head) than are available on this site.

As with all treatment systems (active or passive) PRBs generate large quantities of waste solids which will eventually have to be dealt with. At present, effective disposal options are restricted to permanent submergence (to prevent oxidation by limiting diffusional access by oxygen) or dry entombment. In this particular case, there is no problem with the latter, given the availability of a licensed waste disposal facility on site. At other sites, conditions may not be so favourable and more careful planning for long-term disposal (*in situ* or to another site) will be required during project design.

Applicability and Potential Future Developments

It is clearly feasible to propose the straightforward transfer of the technology demonstrated at the Shilbottle site to other sites with similar problems, without any need for further process development. Nevertheless, it may well be that higher performance efficiencies could be gained by improvements in the specification of the reactive substrate. There is so little difference in performance between the blast furnace slag and limestone gravel sections of the PRB to render the choice between those two inorganic components of the substrate a non-issue: a simple comparison of costs will be the deciding factor in each case. With regard to the organic fraction of the substrate, it is now clear (in the wake of the ASURE project and similar work recently completed in South Africa and the USA) that there is some scope for improving reactivity by specifying more refined sources of carbon, which will require less prior attack by lingo-cellulose degraders before they release the short-chain acids which are the preferred metabolites of iron- and sulphur-reducing bacteria. This is an area of active, ongoing research at HERO and elsewhere. The possibility of obtaining large quantities of cellulose fibre at modest cost, from steam autoclave treatment of municipal wastes, has recently emerged due to the development by Graphite Resource Ltd of the first industrial-scale plant in the UK to use this process (scheduled for construction during 2006-07 at Derwenthaugh, Gateshead). Although subject to future experimentation, this type of development offers the possibility of specifying carbon fractions which are far better characterised than the typical horse manure / straw / compost mixtures used to date.

There remains the intriguing possibility of applying technology along the lines of that demonstrated at Shilbottle to the treatment of other metalliferous effluents, such as those associated with various branches of manufacturing. As head limitations are unlikely to be a constraint in active industrial plants where pumping is routinely practised, it is unlikely that this particular form of a PRB would be required; a configuration akin to that described from the Bowden Close RAPS system (CL:AIRE TDP 5 Report) is more likely for such applications; however, most of the lessons about reactivity learned at Shilbottle will still be applicable.

To view the full report (CL:AIRE Member accounts only), log in to www.claire.co.uk and visit the Publications Library.

Originally published November, 2006