8 The scientific and engineering context of the Quaking Houses community wetland

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The concept of passive treatment

Passive treatment of various kinds of waste water has become increasingly widespread in the last two decades of the twentieth century. By 'passive treatment' we mean the improvement of water quality by means of simple, self-sustaining constructed (or natural, but co-opted) ecosystems and associated features (e.g. subsurface reactive drains). It differs from conventional treatment (now increasingly termed 'active treatment') in that passive treatment implies no regular inputs of artificial energy or reactive substances (reagents). The ideal of passive treatment is that we can make a once-for-ever intervention on a site, and then leave the system to take care of itself. In reality, this is seldom completely achievable (for all but the most over-sized of systems), but the pursuit of this ideal at least has the potential to deliver treatment systems requiring minimal maintenance, minimal site security, no power lines or deliveries of chemicals, and no permanent on-site staff.

There are two motivations for passive treatment: one commercial, the other 'ecological'. The commercial motivation is based upon the attractive prospect of making a single capital investment to solve a long-term problem, with little or no requirement for operating expenditure. In the context of abandoned mine sites, for instance, passive treatment might offer a mining company something approximating a 'walk away solution' (notwithstanding the difficulties in truly achieving self-sustaining functionality). The ecological motivation for passive treatment lies in the perceived advantages of adopting a more 'natural' as opposed to 'hard engineering' approach to waste water treatment. Ideally, a passive treatment system should be designed such that it can gradually 'go native', ending up as an integral part of the wider local ecosystem, making a contribution to the maintenance (or even expansion) of biodiversity, as a happy by-product of its primary role of water quality improvement.

The evolution of passive treatment systems reflects this duality of motivations, drawing elements from both conventional, commercial waste water engineering (e.g. Moshiri, 1993; Pescod and Younger, 1999), and from the fields of ecological conservation and restoration (Hammer, 1992; Younger, Large and Jarvis, 1998). These two elements co-exist throughout the existing literature on passive treatment, though it would be fair to say that, on balance, the links to conventional waste water engineering currently remain the strongest. Nevertheless, it should be acknowledged that one of the principal inspirations to the developers of passive treatment has been the observation that many natural wetland systems manage to improve the quality of the waters passing through them (Hedin et al., 1994; Younger, 1997a).

The earliest developments in passive treatment were implemented to improve sewage treatment for small, isolated communities (e.g. Hammer, 1992). Subsequent developments have included applications to agricultural and urban drainage, landfill leachates and mine waters (Moshiri, 1993). Acidic mine waters, such as that found at Quaking Houses, represent something of a special case in passive treatment history, as they differ from most other applications of passive treatment concepts in being concerned with removal of ecotoxic metals and adjusting pH. Most other applications of passive treatment (for sewage, agricultural effluents, urban runoff, landfill leachate and, indeed, net-alkaline mine waters contaminated only with Fe and Mn) are primarily concerned with oxidation of organic matter and/or ferrous iron, and are therefore almost exclusively based on oxidation processes (principally aeration). Only in the passive treatment of acidic mine waters do we see concerted efforts to employ reduction rather than oxidation.

The passive treatment of net-alkaline mine waters contaminated only with iron is achieved simply, by means of oxidation and subsequent precipitation of ferric hydroxides in aerobic reed beds (Hedin et al., 1994). Although certain aspects of this technology remain topics of active research (e.g. Tarutis et al., 1999), passive treatment of net-alkaline mine waters is now sufficiently well understood that it can usually be implemented with confidence (Hedin *et al.*, 1994; Younger, 1995, 1997b; Laine, 1998). Net-alkaline mine waters contaminated with more soluble metals (particularly Zn and Mn) are more challenging, though progress has also been made recently for these metals in research projects underway at Newcastle (see Nuttall and Younger, 1999).

Passive treatment of net-acidic waters, on the other hand, remains a significant scientific and engineering challenge. This is because of two features common to all 'successful' passive treatment systems for net-acidic mine waters developed to date:

1 They rely on a combination of microbial processes which are not sufficiently well understood that their long-term performance can be predicted with great confidence.
2 They involve subsurface processes of both dissolution (of organic carbon and limestone, most commonly; Hedin *et al.*, 1994; Kepler and McCleary, 1994) and precipitation (of sulphides and hydroxides), which physically alter the geometry (and therefore the hydraulic behaviour) of the passive system over time, in a manner not yet predictable (Hedin, 1997; James *et al*, 1997; Younger, 1997b; Younger *et al.*, 1997).

The net result of these factors is significant uncertainty in the prediction of the long-term performance of passive systems treating net-acidic waters. The uncertainty in the prediction of the long-term performance of passive systems treating net-acidic mine waters appears to be acting as a disincentive to the wider application of an otherwise successful technology. For instance, of five full-scale passive systems constructed by the Coal Authority (CA) since 1996, not one has been for a net-acidic water.

The recognition that passive treatment of net-acidic mine waters is difficult and challenging was one of the key motivations for the Newcastle University scientists to become involved in the Quaking Houses issue. The Quaking Houses wetland represents a virtually ideal 'outdoor laboratory', in which the Newcastle University scientists can begin to probe some of the key questions relating to the application of passive treatment to such 'difficult' waters. The other motivations for the University team were primarily social and environmental (see Younger, 1999), relating to a vision of why and how science (and universities) should be servants of the real needs of the human and natural communities.

The scientific/engineering pedigree of the Quaking Houses wetland

The Quaking Houses wetland, or more particularly the pilot-scale Gavinswelly wetland, was the first system of its kind in Europe. Although Barnsley Metropolitan Borough Council had installed a reed bed to treat acidic leachate at the foot of Dodworth Colliery spoil heap in early 1994 (Bannister, 1997), that system was based on conventional sewage treatment wetlands, and did not incorporate any anaerobic or alkalinity-generating processes (these processes are now being retro-fitted at Dodworth with specialist advice from the Newcastle team). Hence, when the Gavinswelly system was hand-dug and commissioned in the February half-term holiday of 1995, it was truly the first European application of passive, compost-based, sulphate-reduction technology to an acidic mine water.

However, the Quaking Houses wetland did not arise in isolation from the wider world. In particular it drew detailed inspiration, and design rules, from the USA experience, which was (conveniently for us) summarised and codified by the 'three Bobs' (Bob Hedin, Bob Nairn and Bob Kleinmann) of the (now sadly defunct) US Bureau of Mines in Pittsburgh, Pennsylvania (see Hedin *et al.*, 1994). I first became aware of the US experiences with passive treatment in 1993, when a draft copy of the manuscript of the report by Hedin *et al.* (1994) was mailed to me by Bob Kleinmann. I had previously become aware of the drafting of the report through my involvement as External Technical Review Consultant to the National Rivers Authority (now the Environment Agency) on their Wheal Jane Mine Water project in Cornwall. Already by 1994 there were advanced plans to undertake some passive treatment experiments at Wheal Jane (which were to be designed by Jim Guseck, an employee of the American branch of the lead consultants at Wheal Jane, Knight Piésold and Partners Ltd), and this necessitated my becoming familiar with the US experience. Although the Wheal Jane pilot passive treatment plant was never replaced by a 'full-scale' system, it is testament to the volume of water involved at that site that a system receiving only 2.5% of the total mine water make was substantially larger than the full-scale systems subsequently constructed at other sites in the UK.

With the Gavinswelly wetland functioning, and with the Wheal Jane Pilot Passive Treatment Plant under construction, I visited the US Bureau of Mines team (and particularly Bob Hedin, who had by that time left USBM and established his own business) in Pittsburgh in the summer of 1995. This afforded me the chance to see at first hand some of the best documented and longest established passive systems in the world, the best example being the Howe Bridge system in Clarion County, PA. It also gave me the chance to learn how the so-called SAPS (Successive Alkalinity Producing Systems; Kepler and McCleary, 1994) were beginning to replace simple compost wetlands as the systems of choice for acidic waters like that at Quaking Houses.

A SAPS comprises a bed of limestone gravel overlain by a compost layer. Water is forced to flow downwards through the compost and the limestone in turn. In the compost layer, the water is stripped of dissolved oxygen and its ferric iron is converted into the ferrous form (which renders it incapable of clogging the underlying limestone bed with ochre). Dissolution of the limestone raises the pH and puts alkalinity (primarily bicarbonate) in the water. Subsequent oxidation of the water after leaving the limestone bed results in rapid precipitation of ochre, with the pH being maintained at an elevated value thanks to the buffering afforded by the alkalinity. SAPS systems require a higher level of engineering than simple compost wetlands, and also need a reasonable drop in head (i.e. net water level) across a prospective site. We always knew that head on the Quakies site would be tight, but we considered that excavation of a deep pond and back-filling with limestone and compost might give us scope for Europe's first SAPS. We persisted in this hope until 1997 (Younger *et al*, 1997) when the site investigations revealed that the site was underlain by unrecorded colliery washery slimes, which were so acid-generating that they precluded wholesale excavation. (In the end, the Newcastle team *did* design the first SAPS in Europe, but this was constructed at the Pelenna III site, Tonmawr, South Wales; see Ranson and Edwards, 1997; Younger, 1998b).

It was in the detail of the response to this unforeseeable design constraint that the Quakies wetland was turned from a foiled attempt at a SAPS into a system with further novel attributes not previously implemented elsewhere. Of course, the main unique characteristic of the Quaking Houses wetland is the community-artist-scientist linkup, so amply documented in the foregoing chapters. Yet even as a technical entity the wetland has a number of unique attributes. The first was the bund itself, which was formed by painstakingly compacting grey, powdery pulverised fuel ash (PFA) to form the outer barrier, central dividing bar and islands of the wetland. The suggestion to use PFA was made by my senior colleague, Iain Moffat, a specialist dam engineer and Senior Lecturer in the Department of Civil Engineering at the University of Newcastle. Iain also gave Adam Jarvis invaluable advice on the critical width-to-height ratio of the bund, advice which has since been borne out in faultless performance (with neither structural failures nor leaks) to date. The use of PFA allowed (or rather, required!) the participation of volunteers from Quaking Houses village, operating the compacting machine for many hours in the summer heat. Although PFA has found a number of practical uses, the most well-known being in the manufacture of breeze blocks, this is as far as we can ascertain the first time it has been used in constructing a mine water treatment wetland. The alkaline properties of PFA made it particularly suitable for this application, as it offered the prospect of a 'pH holiday' for the wetland until such time as the microbial communities required for the principal sulphate-reduction process could become fully established.

Another novelty of the Quakies system is the blend of compost substrates used. Apart from horse manure and straw (as used in the pilot system), we used cow manure and straw (from the University's teaching and research farms in Northumberland) and composted municipal waste from Castle Morpeth Borough Council's waste composting facility (a suggestion made by Professor Ken Anderson at the University). As far as we can tell from our sampling to date, all three composts are performing very well.

In essence, the Quakies system is an example of how one source of waste (in this case, solid wastes such as composted municipal waste and PFA) can be used to 'cancel out' another (acidic mine water). Parallel developments in South Africa, where tannery wastes and sewage have been co-treated with acidic mine waters (Rose et al., 1998), demonstrate the wider applicability of the kind of lateral thinking which characterises the engineering design at Quakies.

Through a combination of unplanned delays in construction, and the planned timing of the first national conference on 'Minewater Treatment Using Wetlands' (held at Newcastle University in September 1997 under the auspices of the Chartered Institution of Water and Environmental Management; see Younger, 1997b), it happened that Bob Hedin was able to visit the Quakies system under construction, and give his unofficial benediction on the traditional and innovative aspects of the new wetland.

Wetland treatment processes and performance in scientific terms

The foregoing chapters have described well the theory and practice of mine water treatment at Quakies, which may thus be summarised very briefly here as (see Younger et al, 1997, and Jarvis and Younger, 1999):

1 Removal of acidity, raising of pH and generation of alkalinity by means of

limestone dissolution (hundreds of kilograms of limestone cobbles are mixed with the substrates, and stacked in a thick bed at the end of the second pond).

2 Removal of acidity, raising of pH and generation of alkalinity by means of bacterial sulphate reduction within the compost substrate.
3 Trapping of iron as a sulphide within the substrate, by reaction of the iron with sulphide produced by the sulphate-reducing bacteria.
4 Trapping of aluminium as a hydroxide ($AlOH_3$) when the rise in pH makes this phase insoluble.

The synthesis of previous US experience put together by Bob Hedin (*et al*, 1994) had led us to expect average rates of acidity removal amounting to about 7 $g.d^{-1}.m^{-2}$. In the event, the pilot (Gavinswelly) wetland achieved an average of 9.6 $g.d^{-1}.m^{-2}$ (Younger *et al.*,1997). We were not so rash as to expect this happily elevated rate to be matched in the full-scale system, and yet we were proven too cynical, as the full-scale system achieved an average rate of 10.4 $g.d^{-1}.m^{-2}$ (Jarvis and Younger, 1999). As the graphs in the Appendix show, the performance of the system fluctuates over time. It is a matter of simple observation that the wetland seldom looks the same on two consecutive visits. Sometimes a sheen of aluminium hydroxides will cover most of the surface. At other times, a 'slick' of floating bacterial colonies (*Leptothrix spp.*) will lie on the water surface. Often, the water will be clear, and a greenish-tinged substrate will be clearly visible, pock-marked where streams of gas bubbles (the sure signs of microbial activity down below) leave the substrate via mini underwater vents. Such variation is only to be expected in a semi-natural (and presumably still acclimatising) ecosystem. Certainly the quality of the incoming water varies considerably over time, and the treatment process appears to be at least first-order with respect to influent concentrations. Variations in temperature and nutrient availability are inevitably reflected in changes in bacterial metabolism, and hence in the rate of sulphate reduction. At the time of writing, the details of these processes, and their ramifications for the long-term performance of the wetland, are key foci of research (proposed and in progress) at Newcastle University.

'Little Quakies is turned into a giant world!'

At the time of the Wounded Knee stand-off in 1973, the Lakota people were amazed and encouraged by the speed and vigour with which their protest against the injustices of US rule was taken up by sympathisers worldwide.

What had started as a local protest against the excesses of sadistic policemen quickly transformed itself into a beacon of hope for oppressed peoples the world over. Wallace Black Elk expressed the pleasant surprise felt by the Lakota people thus: 'Little Wounded Knee is turned into a giant world' (see *Akwesasne Notes*, 1974, p 91). Whilst not wishing to compare our humble achievements at Quakies with the re-awakening of Indian radicalism in the Americas which Wounded Knee'73 engendered, I can't help recalling Wallace Black Elk's exclamation at times. For Wounded Knee is a quiet little corner inhabited by people the world thought it could ignore; not so very different from Quakies, after all. When I contemplate the international interest that Quakies has aroused in the mining and environmental management fields, it is sometimes also a source of wonder to me that our 'little bit wetland' is emblematic to so many people around the world.

First and foremost, of course, was the winning of the 'Conservation Engineering' and 'Overall Winner' categories of the UK Conservation Awards 1998, as described in the earlier chapters. This prize brought us not only national publicity and much-needed cash to support the early monitoring of the full-scale wetland, but also took Alan McCrea and myself to Istanbul, where Quakies represented the UK in the European Conservation Award finals. Less obvious, but no less important in its way, has been the steady stream of international scientific visitors to Quakies, from the days of Gavinswelly onwards. Indeed, Almudena Ordoñez Alonso (now a lecturer at the School of Mines in Oviedo, Spain) worked day after day with Adam Jarvis and the Quakies volunteers on the construction of the full-scale wetland. Subsequently, in one memorable week in late 1997 shortly after the full-scale wetland was first commissioned, we had two separate delegations from Spain, both of whom returned home (one group to Galicia in the north-west, the other to Toledo in the south) to build mine water treatment wetlands of their own. Most recently, partly in recognition of the experience gained at Quakies, I was invited to advise the Junta de Andalucía on the possible role of wetlands in the long-term remediation of Europe's worst ever mine spill, at Aznallcóllar, near Seville. Quakies wetland has now been described in publications in the Spanish language (Ordoñez *et al*, 1998; Younger, 1998a), and in conference proceedings published in Johannesburg, South Africa (Younger,1998b). Research collaboration between the Newcastle University team and the team from Rhodes University, South Africa, who developed the systems for co-treatment of mine waters and sewage (Rose *et al*, 1998) is now burgeoning, with scientists from Cape Province scheduled to spend several months each year working on the microbiology of the Quakies system over the first few years of the twenty-first century.

Little Quakies is not doing so bad at turning into a giant world!

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