Design, construction and initial operation of full-scale compost-based passive systems for treatment of coal mine drainage and spoil leachate in the UK.

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ABSTRACT

Compost-based passive systems for the treatment of acidic and metalliferous discharges from deep mines and spoil heaps have a pedigree of a decade or more in North America. However, comparable systems are only just beginning to be used at full-scale in Europe. Construction of two compost-based, full-scale, passive systems was completed in the winter of 1997/98. The first is treating acidic, ferruginous and aluminous coal-spoil leachate at Quaking Houses, Co Durham; the second is treating three discrete, net-acidic coal drift mine discharges near Tonmawr, South Wales. The limit on the degree of treatment possible at both sites was land availability. Geotechnical design constraints at both sites derived from the geomorphology and the complex history of mining and mineral processing. Unrecorded details of the industrial history at both sites meant that site investigation data bore little relation to actual ground conditions encountered during construction, and major design amendments were necessary in both cases. These design amendments also militated against the desire to make the wetlands in both systems "as natural as possible". Nevertheless, both systems were completed to schedule and within budget. Early monitoring data reveal encouraging initial performances, with impressive removal rates for acidity and eco-toxic metals.

PASSIVE TREATMENT IN EUROPE

Passive treatment of minewaters and spoil leachates using wetlands, limestone drains and other simple technologies, was pioneered in the USA. Hedin *et al* (1994) have concisely reviewed the gradual evolution of wetlands and associated technologies. Regulatory acceptance of passive treatment has not been universal, and indeed there remains much scepticism about the technology in Canada and South Africa (Limpitlaw, 1996). As Hedin *et al* (1994) imply, this regulatory reluctance can be ascribed to the wide publicity given to a few prominent examples of failure which can (with hindsight) be seen to have been very poorly conceived and designed in the first place. Where design has followed sound scientific principles, successes have been far more notable than failures. This latter point is well illustrated by the UK experience: the earliest full-scale passive treatment systems in the UK were installed in 1995, and were able to draw upon the design recommendations of Hedin *et al* (1994), which were based upon more than a decade of prior experience in the USA (James *et al*, 1997). Consequently, the UK experience with passive minewater treatment has been extremely positive (Younger, 1997), and regulatory acceptance of the technology is high. At the time of writing there are 12 full-scale systems in operation in the UK (5 of them designed by the author), and a further 6 or so in planning and construction stages. Full details of UK experiences to September 1997 are given in the volume edited by Younger (1997). European Union - funded technology transfer is now assisting the establishment of passive treatment systems elsewhere in Europe, particularly in Spain (Ordoñez and Loredo, 1998; Ramírez, 1998; Younger, 1998a; Ordoñez *et al*, 1998; Laine, *this volume*).

In this paper, two case-studies from the UK experience are presented, illustrating the ways in which passive treatment is being applied under climatic and geomorphological circumstances somewhat different from those obtaining in Pennsylvania (where the techniques were pioneered). The manner in which regulatory acceptance was obtained is highlighted in both cases, along with notes on the participation of local residents in the design, construction and (critically) long-term maintenance of the systems. Further "European flavour" is also apparent in the strength of the desire to integrate the passive systems into the pre-existing landscape and the wider eco-systems (see also Cairns and Atkinson, 1994; Younger and Large, 1998).

CASE STUDY 1: QUAKING HOUSES, CO DURHAM

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.

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* (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).

Construction of full-scale wetland

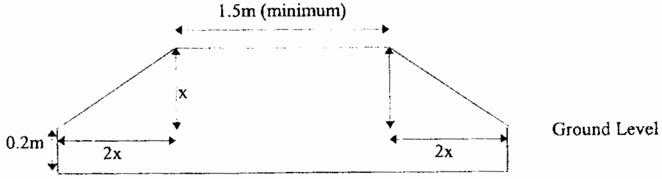
Encouraged by the success of the pilot scheme, the Environment Agency signalled its willingness to accept a passive treatment solution at the site. The pilot plant performance data also proved invaluable in persuading funding agencies to finance a full-scale system, and in 1996 a local philanthropic / 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 Burn 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.

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.

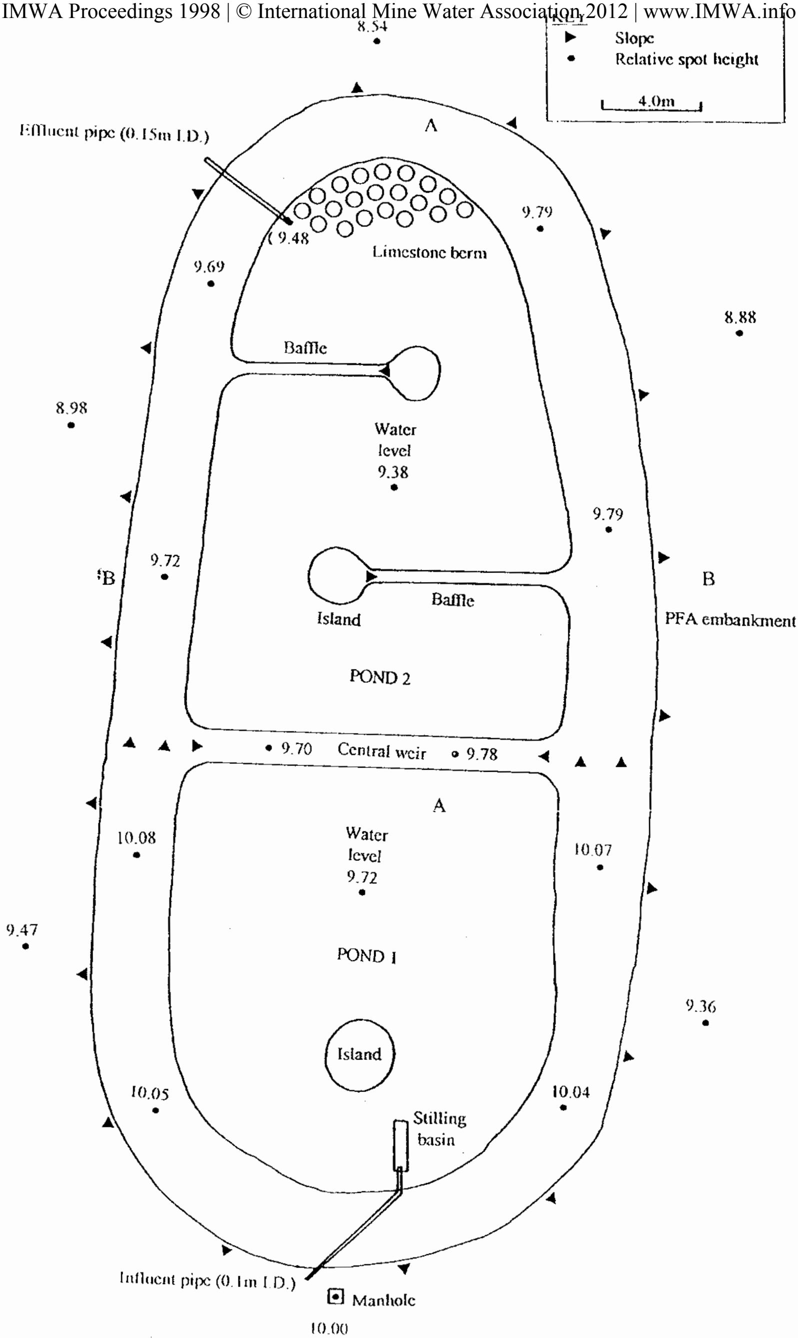


Figure 3: As-built plan of the full-scale wetland at Quaking Houses

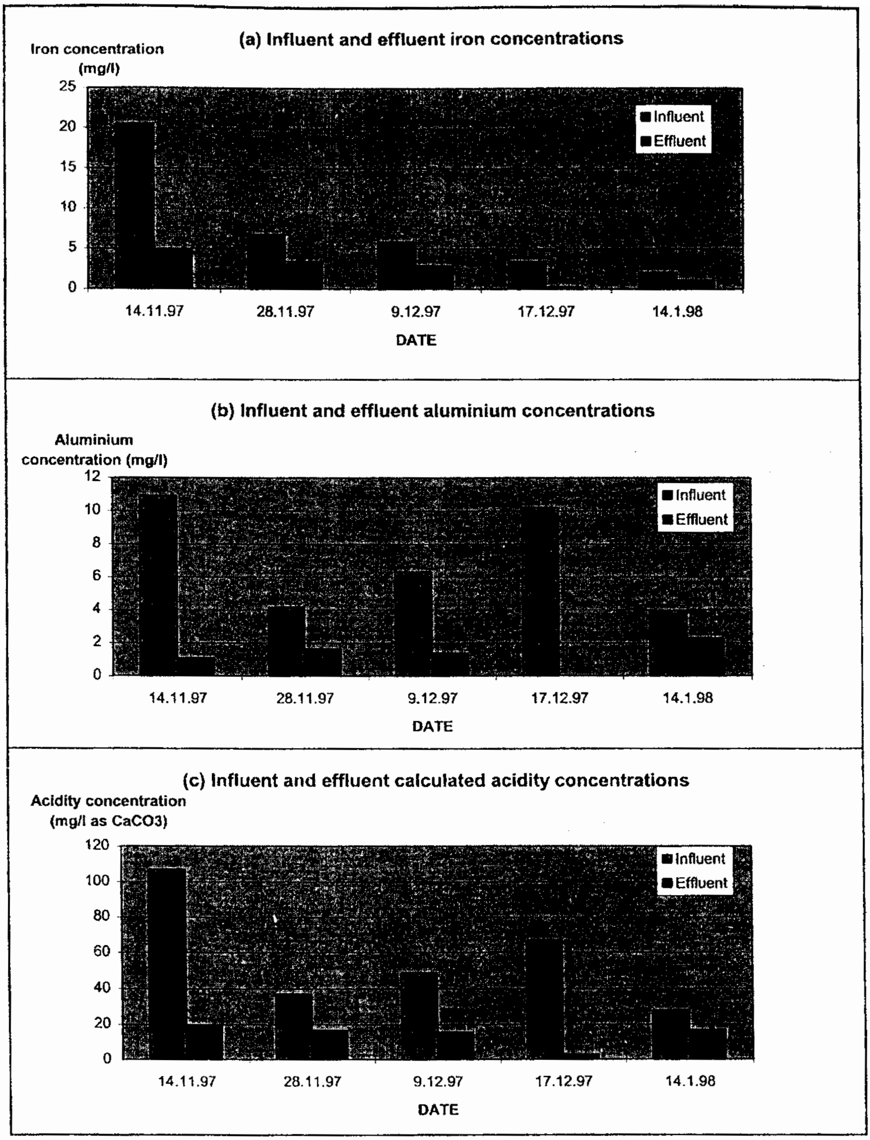


Figure 3: Performance data: Quaking Houses full-scale wetland

CASE-STUDY II: PELENNA PHASE III - EUROPE'S FIRST "SAPS"

The Pelenna Minewater Scheme

The Pelenna Minewater Remediation Scheme is a major project which aims to bring life back to the Afon Pelenna, South Wales, through the passive treatment of five minewater discharges (Edwards *et al*, 1997). Within the overall scheme, the largest single element is Pelenna Phase III, which is required to treat three minewater discharges near the village of Tonmawr. The discharges concerned are known as Whitworth A, Whitworth B and Gwenffrwd. Summary data for these discharges are given in Table 1. Of these, the first and last are the most significant, yielding net-acidic waters with total iron varying from 10 - 100 mg/l, at flow rates of 0.6 to 0.7 Ml/d.

Table 1: Summary flow and chemistry data for the Pelenna III Minewaters

Discharge	**Fe (mean) (mg/l)**	**Flow (mean) (l/min)**	**Net-alkaline or net-acidic?**
Whitworth A	75.5	500	Net-acidic
Whitworth B	8.5	36	Net-alkaline
Gwenffrwd	10.1	530	Net-acidic

Design of Pelenna Phase III

The principal constraints on the design of the Pelenna Phase III system were:

(i) the need to maximise the treatment of all three discharges within a total area of only 1 hectare.

(ii) the need to design a system which would be "buildable" on the steep valley flanks comprising the site.

(iii) the desire to create a system which will ultimately blend into the valley landscape and contribute to the ecological diversity of the area.

Development of a design which would meet all three criteria was achieved by a teamwork approach, with the author providing specialist minewater treatment advice and an outline process selection (Younger, 1996) and engineers employed by the local government (Neath Port Talbot County Borough Council) producing a detailed design for which construction tenders could be sought. Price (1997) has described the latter process, the principal complication in which was the need to incorporate geo-textile reinforcements for all banks and bunds on the site to ensure slope stability. This arose both from the inherent steepness of the site and from the bewildering nature of the in situ soil, which was far more weak and variable than the site investigation boreholes had indicated. The approval of the local residents in Tonmawr village was obtained at a public meeting, when the Quaking Houses experience was used to good effect to illustrate the environmental benefits to the village of working collaboratively to remediate minewater pollution.

The layout of the Pelenna Phase III system is given schematically in Figure 4, and essentially comprises three parallel systems (Younger, 1996):

- the existing Whitworth Lagoon is to be left to treat Whitworth B alone, by aerobic wetland processes.
- for each of Whitworth A and Gwenffrwd, the treatment systems comprise successive alkalinity producing systems or SAPS (Figure 5; see Kepler and

McCleary, 1994 for further discussion) followed by aerobic wetlands. These are to be constructed on the floodplain of the main river channel.

Because of the large flows and variable chemistry of Whitworth A and Gwenffrwd, provision has been made to allow easy construction of inter-connections between these two systems at various points, should this become desirable in the future.

The design of the SAPS units (Figure 5) was based upon the need to ensure a minimum retention time of 14 hours in the limestone bed below the compost (Hedin *et al*, 1994). With the limited space available on site, it soon became apparent that, in periods of high flows, even the largest possible SAPS would not be able to take all of the water coming from the Whitworth A and Gwenffrwd discharges. Bypass arrangements were therefore incorporated, so that water passing through the SAPS will always experience at least 14 hours of retention time, and will thus have the maximum feasible alkalinity when it is re-mixed with untreated minewater (which will have passed the SAPS in a bypass channel) in the settlement lagoon (Gwenffrwd) or Floodplain Wetland downstream. One further challenge in SAPS design is to specify the precise nature of the compost medium. In SAPS, all of the water passing through a SAPS has to flow through the compost (rather than merely across its surface as at Quaking Houses). The challenge is thus to find a medium which has the required organic matter content and oxygen demand, yet has a sufficiently high permeability to allow the passage of water through it with the available head gradient. In the USA, spent mushroom compost has been found to have the right combination of such properties (Kepler and McCleary, 1994). However, spent mushroom compost is not readily available in sufficient quantities in South Wales.

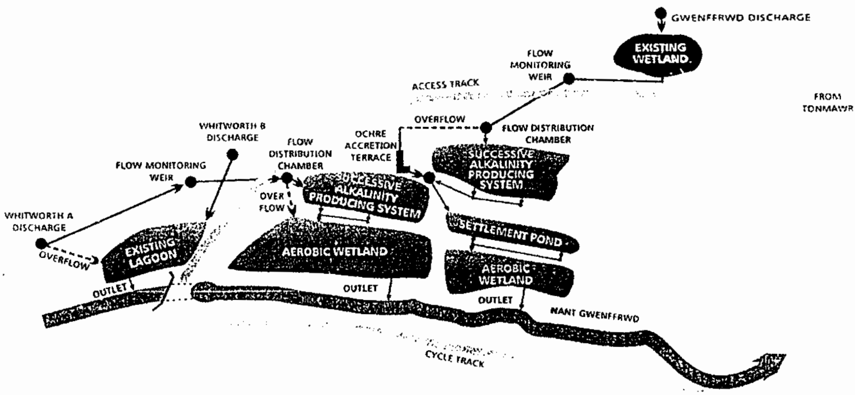


Figure 4: Layout of the Pelenna Phase III Passive Minewater Treatment System.

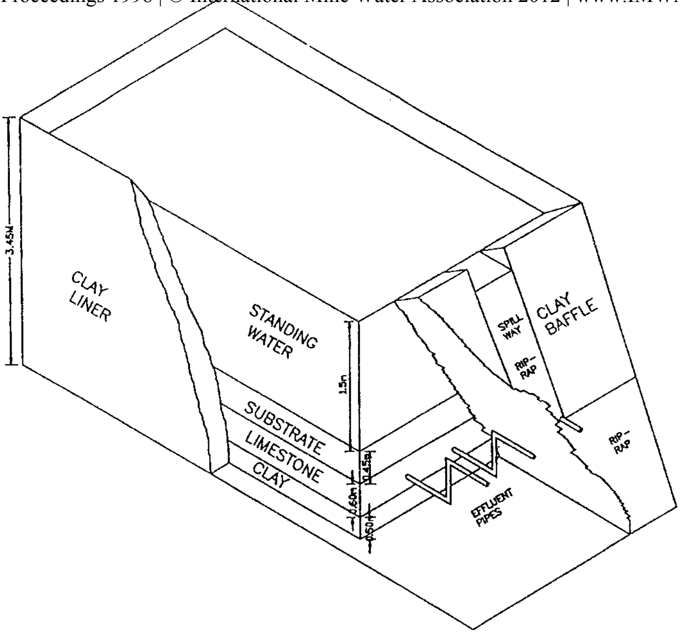


Figure 5: Schematic diagram of a typical SAPS unit.

Various alternative composts were considered, including cow manure and straw, chicken droppings, and composted bark mulch. Cow manure, though in many ways suitable, was not available in sufficient quantities to be used on its own. Chicken droppings proved to be acid-generating in laboratory tests. Composted bark mulch was available in large quantities from the local forestry industry, and had shown promising performance in the Pelenna Phase I wetland nearby (Edwards *et al*, 1997). It certainly has a fibrous texture which ensures that is retains permeability when wet. However, as the oxygen-demand properties of bark mulch were not clearly known (or predictable, given the variations in source material) it was eventually decided to use a combination of bark mulch and cow manure / straw.

Two particular features of the Gwenffrwd system are worthy of note. One is the retention of a pre-existing "volunteer" wetland, which had grown up (unaided) around the adit portal over the three decades since mine closure. This was dominated by *Juncus effusus*, a common wetland plant of the British uplands. Not only was it decided to leave this "volunteer" wetland in place; it was also decided to emulate its selection of *Juncus* over the more common USA wetland plant varieties (*Typha latifolia* and *Phragmites australis*) when advocating planting in other parts of the passive treatment system. The second notable feature of the Gwenffrwd system are the OATs: "Ochre Accretion Terraces". These were introduced because of the need to move the water downhill by several metres to the high-wall of the SAPS cut. As ochre accumulation in pipes or channels was to be expected anyway, it was decided to make a virtue of necessity, and spread the water thinly over a roughened surface, in the hopes of promoting surface catalysed oxidation of ferrous iron, and concomitant accelerated ochre accretion upstream of the wetlands proper.

It was originally hoped that the floodplain wetlands downstream of both sets of SAPS could be closely integrated into the pre-existing eco-hydrology of the floodplain. However, there were pressing treatment needs to maximise freeboard (to allow for accumulation of ochre) and ensure long retention times within the floodplain wetlands. It was therefore reluctantly concluded that, as was the case with Quaking Houses, a channel-edge bund would also be needed in this situation. The main concession to the original design ideal was to leave some small, pre-existing wetland areas within the floodplain intact (save for a slight raising of water level), so that their mature flora might be allowed to expand naturally into surrounding newly-flooded areas. Care was also taken to follow RSPB guidelines on reed-bed construction (Hawke and José, 1996) to maximise the potential wildlife value of the constructed wetlands.

Construction and initial operation

The Pelenna Phase III system was constructed by Cuddy Ltd under contract to Neath Port Talbot County Borough Council in the summer and autumn of 1997, and was commissioned in April 1998.

At the time of writing, only one set of influent/effluent samples have been analysed, and results are summarised in Table 2. They indicate exceptional performance in all cases, which bolsters visual observations on-site that none of the three effluent outfalls show any iron staining after several weeks of operation (P Edwards, EA Llanelli, personal communication). 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 SAPS for these discharges.

Table 2: Initial Performance Data: Pelenna Phase III System

	Dissolved Fe (mg/l)	Total Fe (mg/l)	pH	% Fe removal
Whitworth A - influent	81.7	81.7	5.95	- -
Whitworth A - effluent	0.091	0.162	7.17	99.8
Whitworth B - influent	5.38	5.38	6.36	- -
Whitworth B - effluent	0.108	1.46	6.62	72.9
Gwenffrwd - influent	12.9	13.1	5.04	- -
Gwenffrwd - effluent	0.213	0.938	7.21	92.8

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