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Review of design and performance of the Pelenna wetland systems

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Abstract

The Pelenna wetland system was designed ten years ago to treat various mine water discharges impacting the Pelenna river system. The treatment system was updated in 1994 and developed in four phases over the following few years. The objective was to design various methods of treatment to assess the best approaches for future schemes. The different designs included anaerobic sulphate reduction and aerobic systems, and they all performed fairly well. The dominant process is precipitation of iron oxyhydroxides. Limited initial data was a constraint on the design, and ongoing monitoring requires careful assessment to ensure that the necessary data is collected (e.g. flow rates, pH, total and dissolved iron concentration). Comparison of the Pelenna scheme results with the details for design and maintenance of other schemes should be carried out, to maximise the benefits of the lessons learned for the design of future schemes.

Key words: alkalinity, mine water, Pelenna, performance, wetlands

INTRODUCTION

The River Pelenna, Tonmawr, South Wales was one of the many rivers in South Wales affected by ferruginous mine drainage with approximately 40 t/yr of Fe entering the catchment from five abandoned coal mine discharges. Following feasibility studies in 1992/3, West Glamorgan County Council (WGCC) (later, Neath Port Talbot County Borough Council) with financial assistance from the NRA (later The Environment Agency Wales), the WDA and the EEC Life Fund, developed a project to demonstrate the potential for wetland technology in mine water remediation on an international basis. The discharges to be treated were Whitworth No. 1, Garth Tonmawr, Whitworth A and B and Gwenffrd. As the treatment schemes were some of the first of their kind in the UK, the approach adopted was to achieve a general improvement in water quality with an ultimate target of achieving a water quality that would support salmonids in the river. This required achieving an iron concentration of 1 mg/L and a pH of between six and nine. Preliminary studies were carried out by Richards, Moorhead and Lang, conceptual design was developed by SRK Consulting in 1993, and the detailed design was by WGCC. The project was developed in stages, with lessons learnt from the earlier phases being implemented in the later phases to optimise design.

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In the early 1990s, the wetland sizing criteria produced by the United States Bureau of Mines (USBM) (Hedin *et al*. 1994) was the only general design criteria available and was widely accepted and used as a basis for designing the entire Pelenna system. One objective of the Pelenna mine water treatment systems was to test the applicability of the US criteria for the UK. This paper briefly describes the development of the Pelenna wetland systems, outlines the concepts applied at the time and reviews the performance of the wetlands with respect to the original objectives.

BACKGROUND INFORMATION

Records for the discharges and the upstream and downstream water chemistry had been kept for some years. However, the records comprised a very limited suite of total iron, pH, alkalinity and occasional flow estimates. From the records available there was no clear correlation between flow and iron content. Average flows and iron content were used for the design, on the assumption that they gave a reasonable representation of conditions for a demonstration system. For instance, at Whitworth No. 1, the average flow was 3 L/s but some records showed flows up to 12 L/s.

The limitations of the existing data can be summarised as:

- very limited flow records;
- infrequent water chemistry sampling;

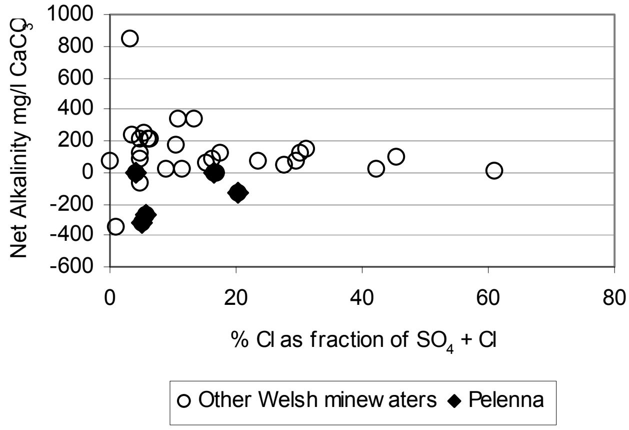

Figure 1. Classification of the Welsh mine waters

Table 1. Mine water chemistry

	Total Fe mg/L	SO_4 mg/L	Net Alk mg/L $CaCO_3$	pH	Flow L/s	Loading t/yr
Whitworth No. 1 (1995 – 2002)						
Average	23.32	336.3	–4.56	6.28	*1.34	0.79
Min	11.70	239	–53.66	5.41	0.00	0.04
Max	57.50	563	55.94	7.85	3.50	2.10
Median	21.60	319	–1.84	6.27	0.70	0.66
n	70	70	70	70	10	10
		*spurious due to poor data				
Whitworth A (1998 – 2002)						
Average	57.75	312.6	–74.73	6.05	7.46	12.78
Min	1.34	27	–191.09	5.59	3.00	0.13
Max	114.00	558	14.01	6.35	18.00	42.06
Median	59.80	326	–79.42	6.08	6.85	11.04
n	63	63	62	63	42	42
Whitworth B (1993 – 2002) – contains Gwenffrwd discharge from Oct. 1998						
Average	5.56	98.01	–4.11	5.83	9.64	2.14
Min	0.03	8.02	–46.10	4.31	0.30	0.00
Max	21.30	214	15.98	6.94	126.60	23.56
Median	5.89	99.1	–2.76	5.88	3.20	0.41
n	121	121	120	120	79	75
Gwenffrwd (1993 – 1998) – discharge combined with Whit B Oct. 1998						
Average	10.63	152.7	–16.37	5.83	9.64	3.73
Min	0.30	1.37	–33.69	4.31	0.30	0.20
Max	16.66	259.3	14.52	6.94	126.60	10.01
Median	11.00	151.7	–20.06	5.88	3.20	2.73
n	165	167	52	120	79	36
Garth Tonmawr (1999 – 2002)						
Average	33.25	271.7	–47.05	5.60	24.18	20.32
Min	11.50	145	–87.77	4.01	11.00	10.60
Max	56.70	358	–14.11	6.15	68.00	27.70
Median	35.40	285	–47.30	5.74	23.00	20.28
n	35	35	33	35	23	23

- a limited analytical suite, which made geochemical interpretation difficult;
- lack of understanding of the mining system to optimise the treatment system design and understand potential changes in hydrology and hydrogeology.

Treatment schemes

Using the classification scheme developed by Rees *et al.* (2002), the Pelenna discharges are marginally or net acid relative to the majority of Welsh mine water discharges (Figure 1). All of the discharges were either marginally or net acidic. Some form of alkalinity supplementation would have benefited some of the discharges. However, all of the discharges had developed wetlands at the adit entrances, with large amounts of ochre deposited over the years and the pH of the discharge water was around pH 6. This suggests that there was sufficient alkalinity to precipitate some iron. Table 1 summarises the mine water chemistry.

Phase I: Whitworth No. 1

The Whitworth No. 1 system was the first of the phased treatment systems and was completed in 1995. The design comprised four cells in parallel, each with a different combination of substrate, vegetation type and flow regime (surface *versus* sub-surface) to assess which combination worked best (Figure 2 and Table 2) The surface flow cells relied on aerobic iron removal and the subsurface flows were anaerobic to remove iron by sulphate reduction. Two cells had a substrate of mushroom compost and two had bark mulch. Mushroom compost was tested because this was the ‘control’ type substrate in the USA, and bark mulch because it was readily available locally. Sub-surface flow was achieved using a wooden boom set 4 m from the cell inlet to force the inflow through the substrate. Influent water is directed through PVC pipes to each cell and effluent water feeds directly into outlet chambers. Concrete cell walls were used to make best use of the limited space available. The design was based on the average flow of 3 L/s.

The average outflow from the four cells between 1995 and 2002 was 3.2 L/s (Tables 1 and 2). The inlet pipes became intermittently blocked by ochre precipitation. Wiseman (1997) and Rees (1998) noted that such blockages resulted in cells 1 and 4 receiving a large proportion of the influent water, and, on occasions, all the water. The excess water to cell 4 flows over the boom and the flow regime is no longer strictly subsurface, therefore the anaerobic cells are behaving more as aerobic cells. The outlet chambers were designed in such a way that it is not possible to measure the separate flow from each cell and water sample collection is difficult.

The iron reduction is variable and the total discharge averages 3.8 mg/L iron. Control between cells, especially in terms of the throughflow, is difficult. If the scheme is not intended to be monitored for further research then it may prove more efficient to modify the scheme to four cells in series.

Phase II: Garth Tonmawr

Site details

The Garth Tonmawr scheme started to receive mine water in March 1999. The adit was completely blocked by the accumulation of ochre, which helped to keep the water anaerobic. The discharge had a pH ranging from 4 to 6 and iron from 0.06 to 37 mg/L in the early years, but 11.5 to 56.7 mg/L over the period 1999 to 2002. Oxygen levels were high which meant that an Anoxic Limestone Drain (ALD) would be unsuitable for producing alkalinity, due to potential ‘blinding’ of the limestone due to precipitation of ferric oxyhydroxides. . The water enters an existing natural wetland from where it is piped across the Nant Blaenpelenna river to the constructed wetlands. The wetland embankments are constructed of honeycomb mat stabilised with local colliery waste. Red brick walls separate each cell. The system comprises five cells as indicated in Figure 2 and Table 1. Cells 2 and 4 comprise a SAPS (Successive Alkalinity Producing System) which works by adding alkalinity to the mine water as it passes vertically through a limestone bed which lies beneath a layer of organic substrate, such as bark mulch or mushroom compost. The purpose of the substrate is to stimulate bacterial processes under reducing conditions, and as a result SAPS have also become known as RAPS (Reducing and Alkalinity Producing Systems). If bacterial sulphate reduction (BSR) occurs, alkalinity and dissolved sulphide are generated (Postgate 1979). This sulphide can then potentially retain iron and other metals within the system through formation of metal sulphides, and the alkalinity also buffers acidity levels.

Some of the embankments have suffered from erosion and slumping. Water depths within cells 2 and 4 have risen considerably due to blockage of the substrate with ochre, and in places it is about 1 m deep. Consequently, water has overtopped the brick dividing walls, leading to partial by-pass of the SAPS and causing failure of some of the brick walls. This illustrates the difficulty of achieving subsurface flow and sulphate reduction. The result of these factors, is that aerobic oxidation is the main means of precipitating iron and the outflow concentrations have remained very low as shown in Table 2.

Phase III: Whitworth A, Whitworth B and Gwenffrwd

The final scheme started to receive mine water in April

Table 2. Wetland operating details and costs

Site	Area (m^2)	Hydraulic load (m/d)	Retention time (days)	System inflow			System outflow			Cost (£)
				Flow (L/s)	Fe (g/L)	pH	Flow (L/s	Fe (g/L)	pH	
Whitworth No. 1	900	0.29	1	1.3	23.3	6.2	3.2	3.8	6.9	214 000
Garth Tonmawr										
Cell 1 – Wetland	2480	0.31	~0.5							
Cell 2 – SAPS	970	0.79	<0.08							
Cell 3 – Wetland	980	2.01	<0.08							
Cell 4 – SAPS	980	1.99	<0.08							
Cell 5 – Wetland	960	1.99	<0.08							
Total	6370	2.03	<0.08	24.2	33.3	5.6	19.7	1.32	6.8	223 000
Whitworth A										
SAPS	1825	0.39		7.46	57.8	6.0				
Wetland	4500	0.16	3.8					2.0	7.1	
Gwenffrwd										
SAPS	2425	0.32		9.64	10.6	5.8				
Settlement pond	850	0.9	1.1							
Wetland	2000	0.38	1.6							
Total	11 600									360 000

Data from Brown *et al*. 2002

1998. The system is similar to the phase II as it also incorporates SAPS in the design (Younger 1995). An Ochre Aeration Terrace (OAT) is an additional feature, which is designed to increase dissolved oxygen and allow de-gassing of CO_2 (Figure 2).

In the October of 1998 the Gwenffrwd mine water discharge ceased to flow. Following a short period of concern that the mine water could emerge in the garden of one of the neighbouring houses, the mine water emerged from the Whitworth B adit. The new discharge loading was in excess of the treatment capabilities of the Whitworth lagoon, resulting in contamination of the Nant Gwenffrwd once again. This situation was not rectified until March 2001, when the Whitworth B and the Gwenffrwd combined discharge were re-routed to the Gwenffrwd treatment scheme, which had remained idle. The mine plans showed that the Gwenffrwd adit was a drainage adit and connected to the Whitworth adits. Closure of the Gwenffrwd adit could result in the discharge from Whitworth B or from other shafts.

Overall wetland performance

According to Wiseman *et al.* (2002), the mine water treatment schemes have progressively improved and diversified the ecology of the Pelenna catchment. The principal cause of this improvement is the significant reduction in iron that has occurred at each scheme, as shown in Figure 3. Coupled with the removal of iron, the SAPS systems treating the Whit. A and Garth Tonmawr discharges are responsible for decreasing the acidity, and by definition increasing the alkalinity of these discharges (Figure 4). Interestingly, the SAPS also have the highest iron removal rates (Table 3). Such significant Fe removal and alkalinity generation would suggest that the SAPS may be operating as RAPS. However, little sulphate removal is occurring, suggesting that BSR and iron sulphide formation are not responsible for the high rates of iron removal observed (Figure 5).

Table 3. Iron attenuation

	Fe retained kg/d	Removal rate $g/m^2/d$	Area m^2
Whitworth No. 1	5.2	5.7	900
Garth Tonmawr			
Cell 1 – Wetland	34.3	13.8	2480
Cell 2 – SAPS	15.1	15.6	970
Cell 3 – Wetland	0.9	0.9	980
Cell 4 – SAPS	4.5	4.5	980
Cell 5 – Wetland	–2.4	–2.5	960
TOTAL	52.4	8.2	
Phase III			
Whit A SAPS	36.7	20.1	1825
Whit A wetland	5.4	1.2	4500

NB: Data for Gwenffrwd systems not given due to diversion of mine water. Data from Brown *et al*. (2002) and EA monitoring data.

On the surface of each SAPS ochre accumulation is occurring indicating that the principle Fe removal process is oxidative, which is the reason little SO_4 is removed. As the SAPS rely on the vertical movement of the mine water for treatment, the continued surface accumulation of ochre could limit the SAPS effectiveness. Using a full scale laboratory reconstruction of the SAPS, the effect of increasing ochre thickness on verti-

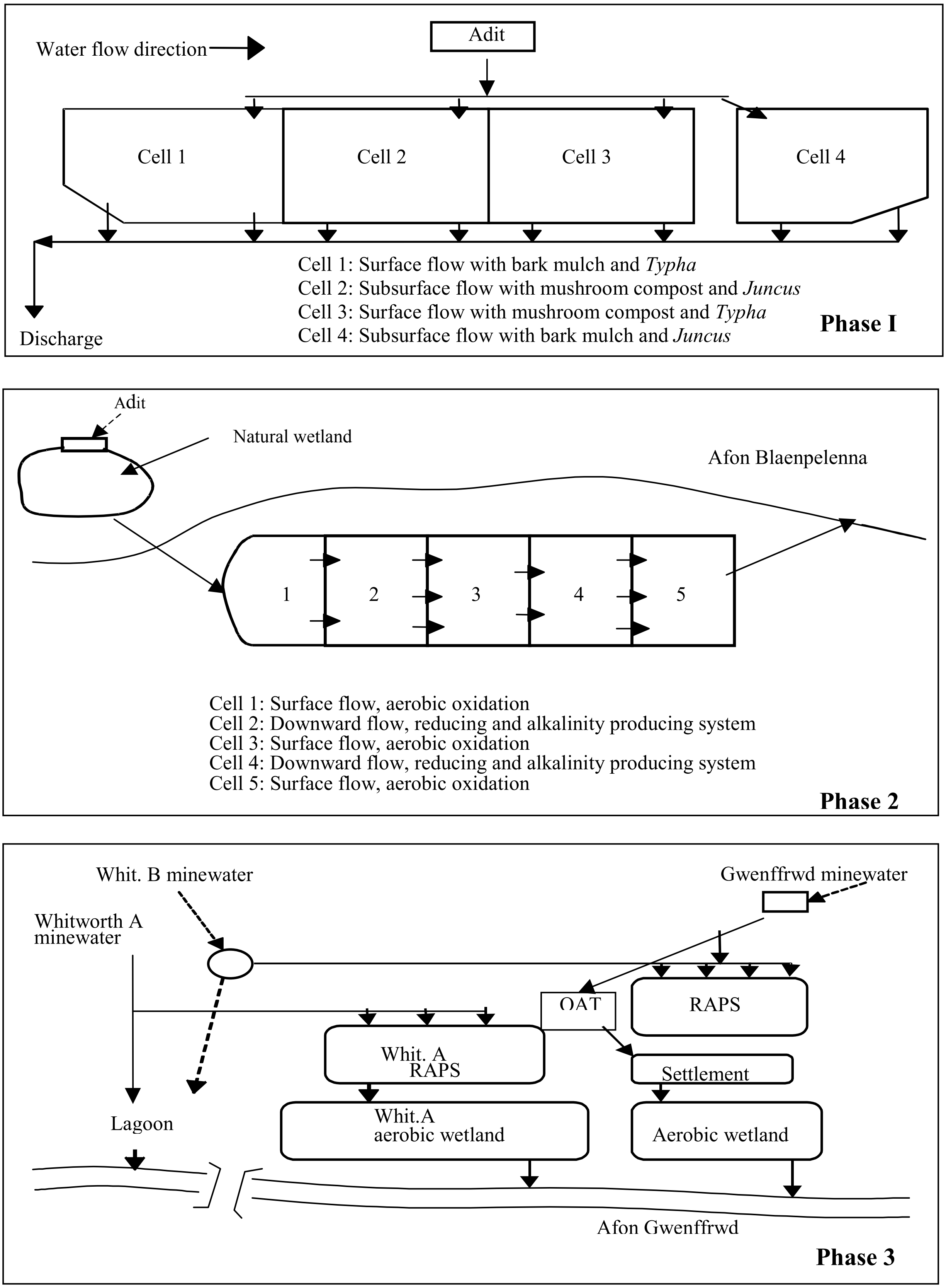

Figure 2. Pelenna treatment schemes (after Wiseman et al. *2002)*

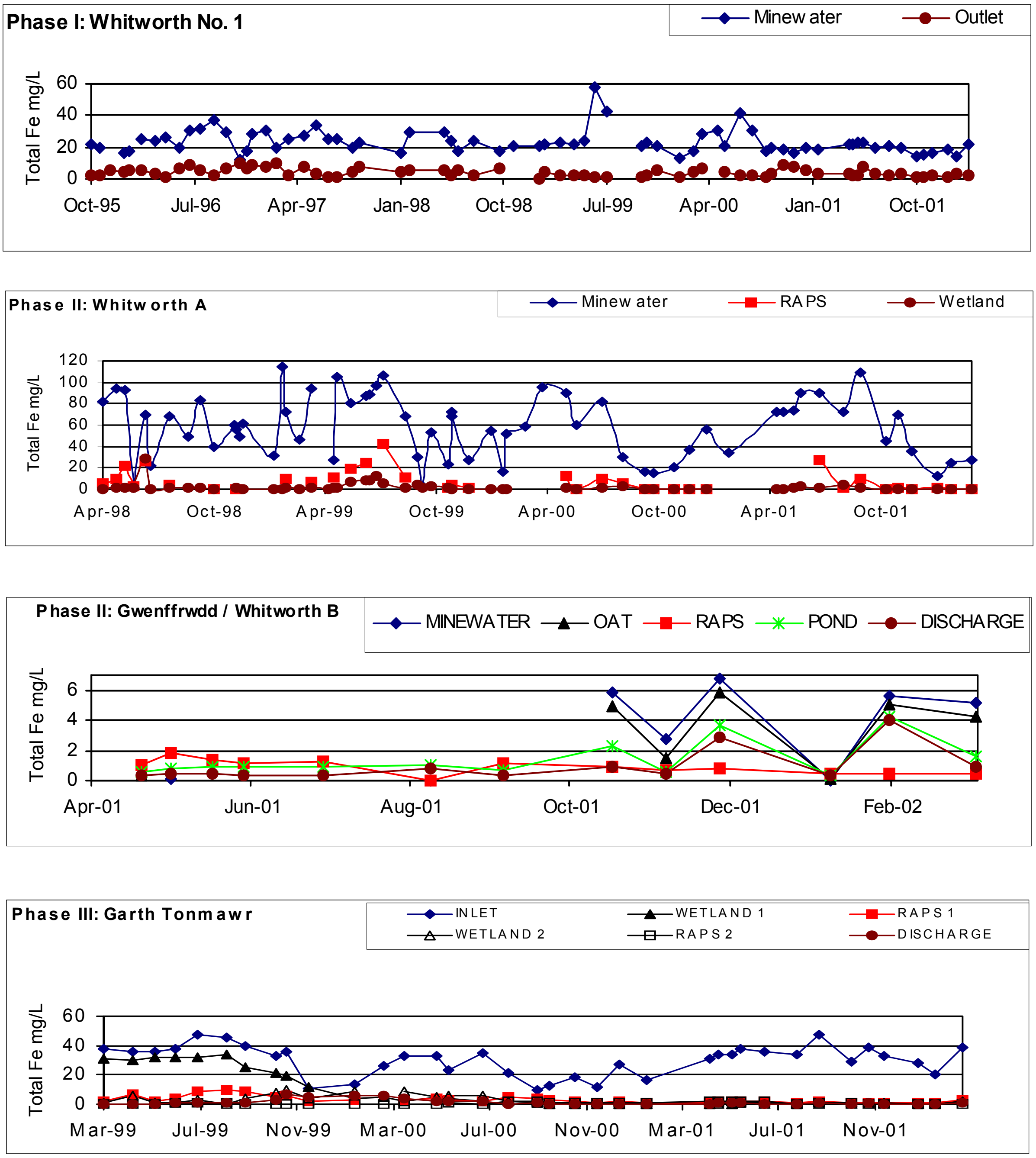

Figure 3. Iron removal at each treatment scheme

cal bed permeability was assessed by Dey and Williams and reported by Rees *et al*. (2001*a*, 2001*b*). They found that as ochre thickness increased, bed permeability decreased, potentially limiting the long-term effectiveness of the SAPS. This process may be the reason water is over-topping the brick walls at Phase II.

The rate of removal of iron and other contaminants from mine water is a function of numerous geochemical and kinetic processes, and retention time. For iron removal, the USBM guidelines were 10 mg/day/m^2 for net alkaline water to achieve 1 mg/L discharge in an aerobic wetland. As the pH of the mine water drops, the area requirement increases. This is a very complex subject, but it is worth reporting the latest results from the various wetlands for some comparison. Tables 2 and 3 summarise the key design parameters and the overall performance figures based on iron removal per m^2.

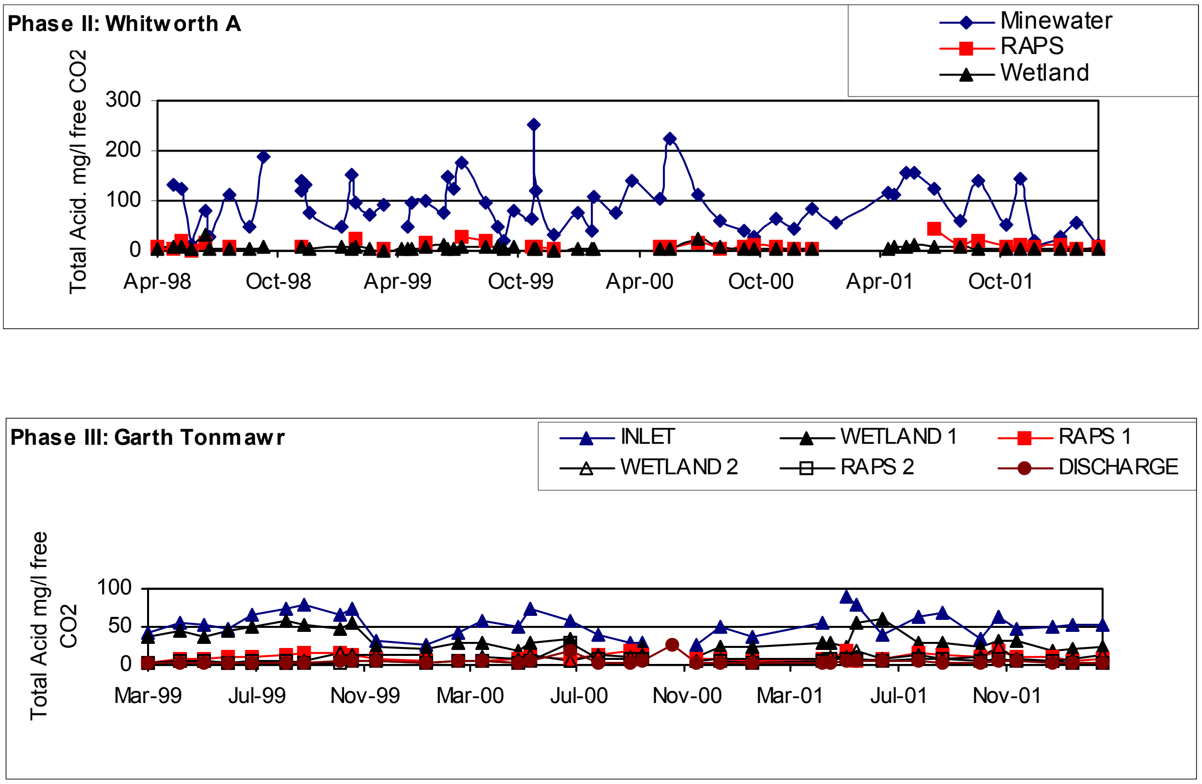

Figure 4. Acidity removal at Whitworth A and Garth Tonmawr

CONCLUSIONS AND LESSONS LEARNED

The Pelenna wetlands provide an excellent example of the various passive treatment technologies that can be used to successfully treat coal mine drainage. Unfortunately, due to the lack of flow gauging that has generally occurred, particularly between cells in each scheme, the detailed study of the removal processes responsible and the rates at which they occur is limited. Additionally, the following lessons should be learnt from the Pelenna scheme and applied to future treatment schemes:

- pipelines carrying mine water should not be perforated as this encourages ochre precipitation. Such pipelines may require routine cleaning.
- it is important to have a good understanding of the detailed geochemistry and flow relationships and variations before designing. A risk assessment is required to assess the impact of by-pass flows or peak flows on the receiving water;
- the background mining history and mine hydrology should be understood and the risks of future changes assessed;
- the majority of the systems for Fe removal can be handled in an aerobic wetland;
- alkalinity addition needs further refinement, but blinding of limestone by oxy-hydroxides may not preclude the value of using limestone in an oxygen rich water;
- the system must be designed to enable monitoring and sampling of water inflow and outflow and monitoring should be sufficiently detailed;
- various research projects have been carried out on Pelenna. All this information should be collated and reviewed to maximise what can be learned;
- it would be valuable to publish maintenance records on this scheme and other schemes to enable minimum maintenance systems to be designed.

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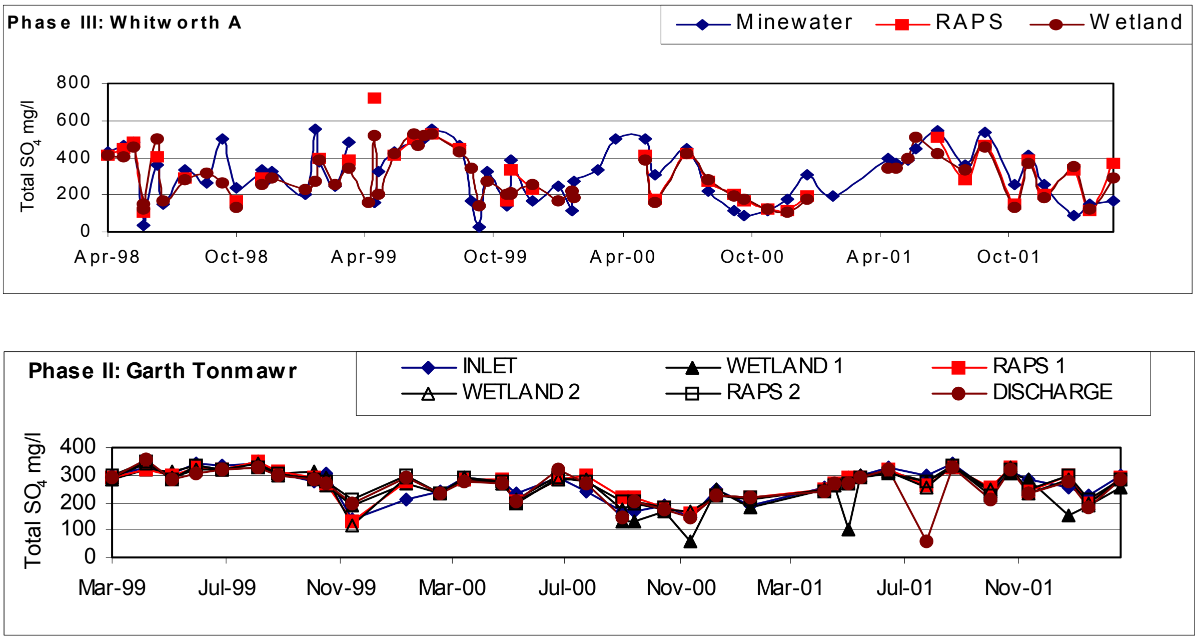

Figure 5. Sulphate removal at Whitworth A and Garth Tonmawr

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