

## Geochemical performance of a reducing and alkalinity-producing system (RAPS) for the passive treatment of acidic mine drainage at Bowden Close, United Kingdom

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### ABSTRACT

At Bowden Close, an abandoned colliery located in the northeast of England, a passive treatment system has been constructed to improve acidic mine water quality by the combination of bacterial sulfate-reduction and limestone dissolution. The performance of the first twelve months of full operation shows that pH values increased from as low as 3.6 to as high as 7.9 as the mine water passed through the system. Added alkalinity amounted to 5.91 t (calculated as CaCO<sub>3</sub>). Removal of iron and aluminium was very efficient: overall 89% of iron (1.81 t) and 93% of aluminium (0.91 t) were retained by the treatment system. In contrast, only 18% (6.20 t) of sulfate has been removed over the same period. Both sulfate reduction and limestone dissolution contributed to the removal of acidity and the generation of alkalinity.

### INTRODUCTION

Situated in the northeast of England, the former Bowden Close Colliery lies in the vicinity of Helmington Row in County Durham (Figure 1). The site underwent restoration by Durham County Council after the closure of the colliery in the 1960s. Mine entrances were sealed, derelict buildings were demolished and the voluminous spoil heaps were re-profiled and vegetated. The restoration works were carried out according to the best practice of the period, which did not address issues of subsurface pollution. Consequently, acidic, metalliferous waters began to emanate from various spring-like features and land drains within the site, affecting the quality of the adjoining Willington Burn.



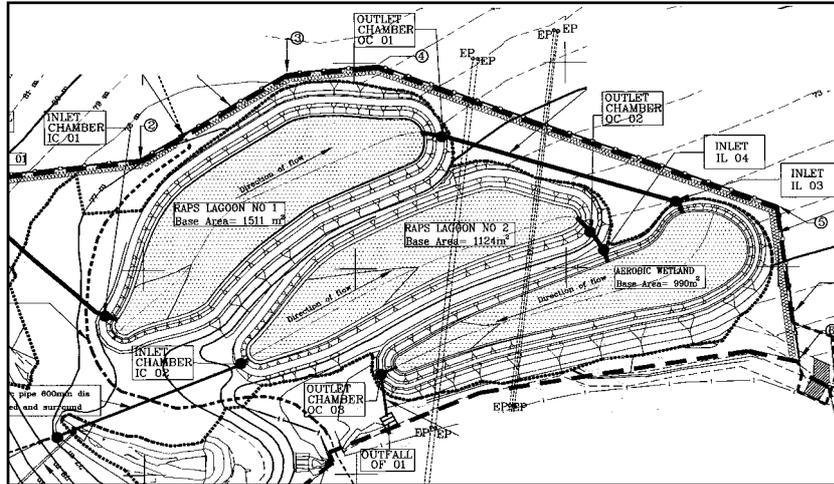
**Figure 1: Location of the Bowden Close treatment system between Crook and Willington in southeast County Durham (UK). Map at 1:25000 scale (Multimap.co.uk, 20/05/05).**

A series of studies were conducted at the Bowden Close site in the 1990s, revealing the nature of the acidic drainage (Younger 1995), assessing the ecological damage of the receiving watercourse (Jarvis & Younger 1997) and identifying the three main discharges (Younger 2000). Subsequently, a pilot passive treatment system was constructed and operated from 1999 to 2001. The design and performance of this system has been described in detail by Younger (2000, 2002) and Younger *et al.* (2003). Due to the encouraging performance of the pilot scheme, a full scale treatment system was constructed and commissioned in early 2004 (Younger *et al.* 2004). Geochemical parameters have been determined every two to three weeks since the construction of the full scale treatment system. This paper addresses the geochemical performance during the first twelve months of full operation (March 2004 to March 2005) of each lagoon and the whole system. The results give some first insight into the dynamics and mechanisms governing the processes in the treatment system.

### STUDY SITE

The passive treatment system at Bowden Close consists of two so-called “reducing and alkalinity-producing system” (RAPS) units and a polishing aerobic wetland (Figure 2). RAPS lagoon number one (RAPS 1) receives discharge from an old mine access drift and seasonal leachate from a small rill-cutting spoil. RAPS 2 is designed to treat the perennial aluminium rich discharge of a point source, associated with spoil toe drainage from a

perched water table within the spoil. The reactive substrate in the RAPS is a mixture of limestone and compost, designed to improve water quality by the combination of microbial iron- and sulfate-reduction and limestone dissolution. Before being discharged into a small local stream (Willington Burn), the discharge from both RAPS units is passed through a polishing aerobic wetland planted with *Typha latifolia*. Table 1 displays the hydrological parameters of the three lagoons.



**Figure 2: Layout of the passive treatment system at Bowden Close. The two RAPS units receive different mine water discharges. Both RAPS units feed the aerobic wetland in the lower part that discharges into the local stream (Willington Burn).**

	Surface area [m <sup>2</sup> ]	Mean hydraulic residence time <sup>1)</sup>
RAPS 1	1511	4-8 days
RAPS 2	1124	4-6 days
Aerobic wetland	990	2-3 days

<sup>1)</sup> Estimations based on tracer tests (Wolkersdorfer et al. 2005)

**Table 1: Hydrological parameters of the lagoons incorporated in the Bowden Close passive treatment system.**

## METHODS

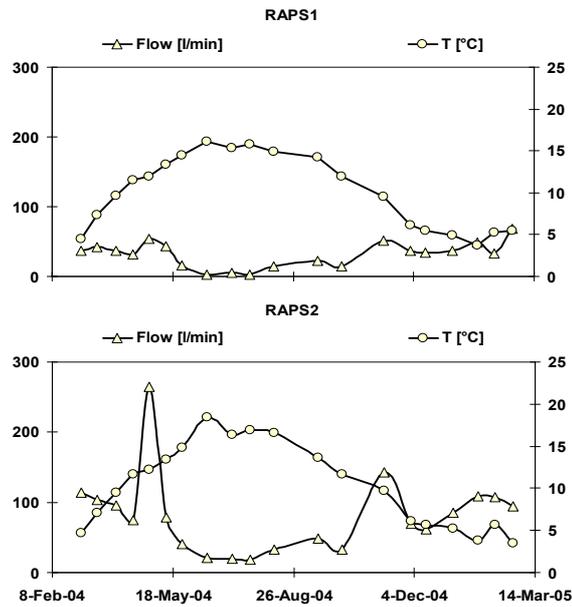
Flow conditions in the treatment system were determined by multiple measurements with bucket and a stopwatch at the inlet, outfall and eventual overflow at RAPS 1 and RAPS 2, and at the outfall of the aerobic wetland. Water samples were taken at these sites and filtered through 0.2 µm polycarbonate filters (Whatman plc, Middlesex, UK).

Field measurements of pH, redox potential, electric conductivity and temperature were taken with a Myron 6P Ultrameter (Myron L Company, Karlsbad, USA). Alkalinity was determined in the field by titration with sulfuric acid using a Hach AL-DT test kit (Hach Company, Loveland, USA)

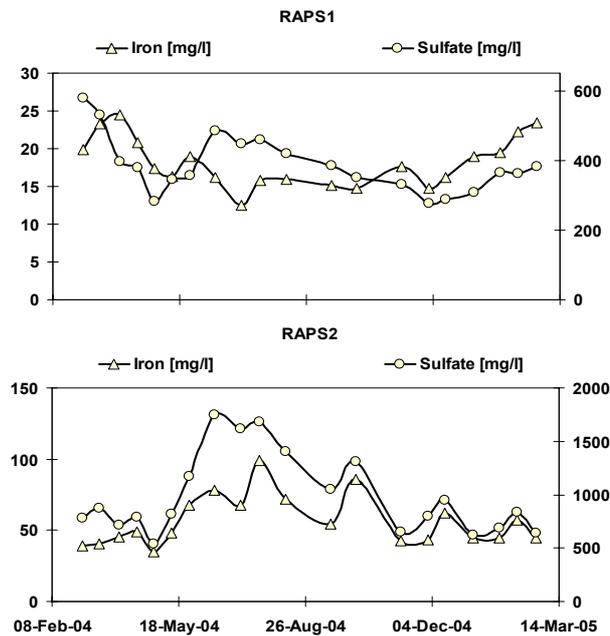
Anion analysis was performed in the laboratory using a Dionex IC25 ion chromatograph (Dionex Corporation, Sunnyvale, USA). Samples for cation analysis were acidified with HCl and analysed on a Varian Vista-MPX ICP-OES (Varian Ltd., Oxford, UK).

## RESULTS and CONCLUSIONS

The three lagoons at the Bowden Close treatment site are subject to seasonal variation. Flow conditions are severely impacted by heavy rain in spring and autumn and by dry summer months (Figure 3). RAPS 1 receives mine water from an access drift resulting in more stable flow conditions compared to RAPS 2. The water temperature at the outfall of each lagoon reflects ambient temperature and exposure to sunshine. Not surprisingly, the geochemical properties of the mine water feeding into the RAPS units display a substantial variation as well (Figure 4).



**Figure 3: Seasonal variation of temperature and flow at the outfall of the RAPS laggons. The distinct flow peaks in April and November 2004 represent periods of heavy precipitation.**

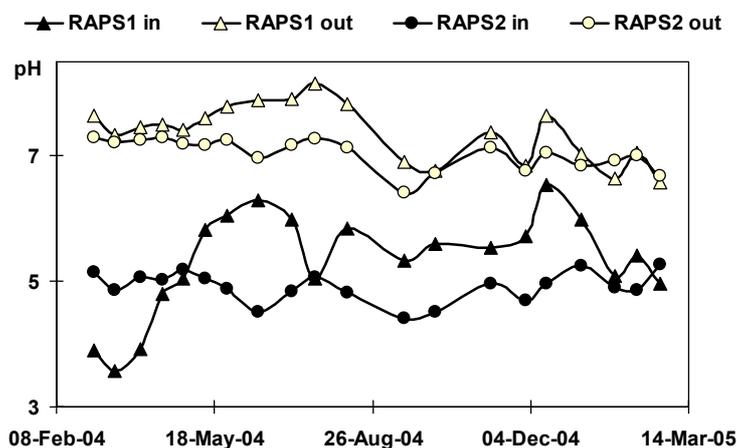


**Figure 4: Concentrations of iron and sulfate in the inflow of the two RAPS units. Note the good correlation between iron and sulfate in RAPS 2.**

The geochemical performance of the full scale system has been very satisfactory during the observation period. Throughout the year, pH increased to neutral values as the mine water passed through the system (Figure 5). The targeted pollutants iron and aluminium were retained in the RAPS units almost quantitatively (81-99%), whereas only about 16 to 27% of sulfate was removed (Table 2).

**Table 2: Retention of iron, aluminium and sulfate during the first year of operation of the Bowden Close treatment system**

	Iron removal	Aluminium removal	Sulfate removal
RAPS 1	0.22 t (81%)	0.08 t (95%)	1.41 t (27%)
RAPS 2	1.59 t (90%)	0.88 t (99%)	4.87 t (16%)
Entire System	1.81 t (89%)	0.91 t (93%)	6.20 t (18%)

**Figure 5: Comparison of pH at inflow and outfall of each RAPS unit.**

The addition of alkalinity and the removal of sulfate display a rather complex and variable behaviour, with the rain event in April 2004 even resulting in a washout and subsequent release of sulfate from RAPS 2 (Figure 6). In RAPS 1, the generation of alkalinity appears to be associated with the removal of sulfate, i.e. with microbial sulfate reduction. This process can be illustrated by reaction (1) in which CH<sub>2</sub>O represents carbon sources utilised by sulfate reducing bacteria.



No correlation between generation of alkalinity and microbial sulfate reduction can be found in RAPS 2. This lagoon receives a higher load of more acidic water than RAPS 1 and the dissolution of limestone and the subsequent release of Ca is clearly a dominating neutralisation process (Table 3). Generated CO<sub>2</sub> adds to the alkalinity but is also emitted to the atmosphere via CO<sub>2</sub> bubbles, which are visibly emerging from the lagoon.

**Table 3: Accumulated release of Ca, addition of alkalinity and neutralisation of acid during the first year of operation at the Bowden Close treatment system.**

	Release of Ca	Alkalinity generation (as CaCO <sub>3</sub> )	Removal of acidity (as H <sup>+</sup> )
RAPS 1	0.36 t (8.9 kmol)	2.58 t (25.7 kmol)	82.2 kmol
RAPS 2	4.42 t (110 kmol)	6.34 t (63.4 kmol)	217 kmol
Entire System	3.29 t (92.7 kmol)	5.91 t (59.0 kmol)	278 kmol

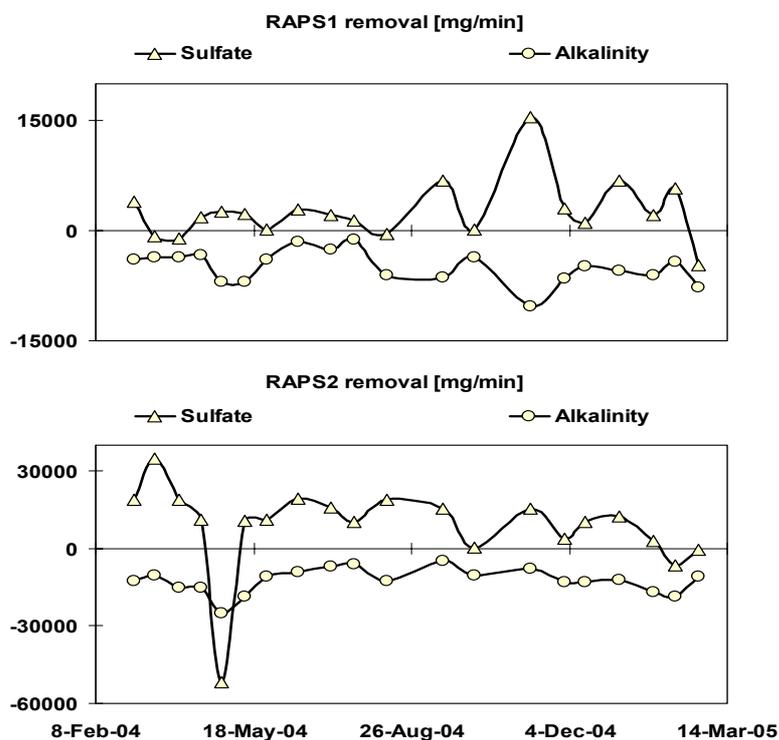


Figure 6: Sulfate removal rates and release of alkalinity (calculated as  $\text{CaCO}_3$ ) in RAPS 1 and RAPS 2.

The rapid dissolution of limestone in RAPS 2 is not only a concern for the projected lifetime of this treatment system, but remains an open question for passive treatment systems in general. Therefore our current research focus is to apply a combined geochemical (including stable isotopes) and microbiological approach to quantify the relative contribution of limestone dissolution and sulfate reduction to the generation of alkalinity.

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