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Acid Mine Drainage Treatment at Herbert Stream, Stockton

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Abstract

Herbert Stream, a tributary of the Waimangaroa River on the Stockton Plateau, has elevated metal concentrations and low pH characteristic of acid mine drainage (AMD). Dissolved aluminium concentrations average 8.3 ppm, iron 1.4 ppm, manganese 0.69 ppm, and zinc 0.12 ppm and pH ranges from 2.8 to 3.2. Flow rates range from 2.3 to 26.6 L/s with an average of 5.3 L/s. To determine the effectiveness of different treatment strategies, a small amount of the AMD was diverted through three small-scale passive AMD remediation systems over an eight month period. These included a reducing and alkalinity producing system (RAPS), a limestone leaching bed (LLB), and an open limestone channel (OLC). Both the RAPS and the LLB performed well, effectively removing metals and restoring pH. The RAPS lowered aluminium concentrations by up to 99%, iron 97%, manganese 95%, and zinc 80% and the LLB lowered aluminium concentrations by up to 99%, iron 99%, manganese 92%, and zinc 91%. The pH was restored to between 6.4 and 7.4 by the RAPS and to between 7.3 and 7.9 by the LLB. The OLC performed well as long as the residence time was similar to that of the other treatment systems. OLC removal rates for aluminium was up to 99%, iron 94%, and manganese 21%, and the pH was restored up to 5.6. Due to its simplicity and effectiveness, it is proposed the LLB be constructed to full-scale size to treat the entire Herbert Stream.

Introduction

Oxidation of sulphide minerals in West Coast coal measures can produce acidic drainage when disturbed through mining activities (Black, Trumm and Lindsay, 2005). Acid mine drainage (AMD) typically has low pH and high concentrations of iron and sulphate. Other common constituents of AMD include the metals aluminium, manganese, nickel and zinc, often in concentrations reflecting the mineralogical assemblage within the coal measures (Rose and Cravotta, 1998). The effects of AMD on the aquatic ecosystem in New Zealand can be severe, often resulting in an absence of fish, crayfish and eels and the presence of only acid-tolerant algae and occasionally a few invertebrate taxa (Winterbourn, 1998; Harding and Boothryd, 2004; Harding, 2005).

Although there have been many studies on the effects of AMD on the environment, and on the geochemistry of AMD in New Zealand (Lindsay, Kingsbury and Pizey, 2003; Hughes, et al., 2004; Pope, Newman and Craw, 2006), few studies have focused on treatment. Long term, treatment of AMD using passive treatment systems is typically more economic than using active treatment systems (Skousen and Ziemkiewicz, 2005). Passive systems typically rely on natural geochemical and biological processes to neutralise AMD and precipitate metals out of solution.

In this study, pilot trials were constructed at Herbert Stream, an AMD site on the Stockton Plateau, West Coast, to test the effectiveness of passive geochemical treatment. Site parameters were first evaluated to determine which type of systems to trial and the results of the trials were used in designing a full-scale passive treatment system for the site.

Methods

Initial water quality results for the site were used to identify which type of treatment systems to trial. Three systems were constructed: an open limestone channel (OLC), a reducing and alkalinity producing system (RAPS), and a limestone leaching bed (LLB). The OLC and RAPS were designed based on previous successes with small-scale systems (Trumm, et al. 2005; Trumm, Watts, and Gunn, 2006). The LLB was based on a design by Hellier (2000) for a similar system in the eastern USA. The systems were constructed out of low-budget materials such as PVC piping, plastic tubs, valves, and tarpaulins. The sizes of the systems were determined by the relative availability of construction materials. The OLC and LLB contained only limestone as the treatment media; the RAPS contained both limestone and mushroom compost. The OLC was 2.7m long, 0.5m wide, with a thickness of 15-20cm of limestone rocks. The RAPS container was 1.2m long, 0.73m wide, and 0.54m high. A limestone layer was placed at the base of the RAPS at a thickness of 12cm, overlain by mushroom compost at a thickness of 30cm. The LLB container was 1.2m long, 0.73m wide, and 0.54m high and was filled with limestone at a thickness of 45cm.

Piping and valves were placed to ensure evenly-distributed horizontal flow of AMD through both the OLC and the LLB and vertical downward flow through the RAPS. Flow rates were regulated to maintain the necessary residence times in each system. The systems were operated over an eight month period. Water samples from the inlet and outlet to each system were collected on nine occasions and laboratory-analysed for acidity, alkalinity, sulphate, and total and dissolved Ca, Al, Fe, Mn, As, and Zn. The first seven samples were collected weekly, the eighth sample three months after start-up and the final sample at the end of the trial at eight months.

Results

Over the eight month trial period, dissolved aluminium concentrations averaged 8.3 ppm, iron 1.4 ppm, manganese 0.69 ppm, and zinc 0.12 ppm and pH ranged from 2.8 to 3.2 in the untreated AMD. Forty-five percent of the dissolved iron consisted of ferrous iron (one analysis), and dissolved oxygen (DO) concentrations averaged 9.4 ppm. This water chemistry and the land area available for a full-scale treatment system (relatively large flat area), suggests the following systems are suitable for the site (Trumm, 2007):

- Limestone leaching bed (LLB)
- Slag leaching bed
- Vertical flow wetland (VFW) such as a RAPS
- Anaerobic wetland

An LLB, RAPS, and OLC were trialled. Although not considered a suitable system for this site, the OLC was trialled to determine the potential for armouring of limestone by iron hydroxides and oxyhydroxides in an open channel.

The residence time in the LLB and the RAPS mostly ranged between 11 and 35 hours (Figure 1). The OLC residence time was initially only two minutes, later increasing to 17 hours and then greater than 40 hours. Both the LLB and the RAPS units raised the pH of the AMD consistently to near neutral at all residence times. Once the residence time was above 17 hours in the OLC, pH was restored to above 5 (Figure 1).

DO in the RAPS unit was consistently below 1 ppm, indicating that reducing conditions were being achieved in the unit (Figure 2). In addition to DO, the percent of total iron in the ferrous state is an indication of the degree to which water is in a reducing state. All of the iron in the RAPS unit effluent was in the reduced ferrous state (one analysis).

In the LLB, above a residence time of 11 hours, aluminium concentrations were lowered to below 0.5 mg/L, iron to below 0.08 mg/L, manganese to below 0.6 mg/L and zinc to below 0.05 mg/L (Figure 3). In the RAPS unit, aluminium concentrations were lowered to below 0.1 mg/L, iron to below 0.4 mg/L and zinc to below 0.048 mg/L. Manganese was initially removed by the RAPS unit but later the concentrations in the effluent were greater than the influent. In the OLC, above a residence time of 17 hours, aluminium concentrations were lowered to below 0.4 mg/L, iron to below 0.3 mg/L, and manganese to below 0.6 mg/L.

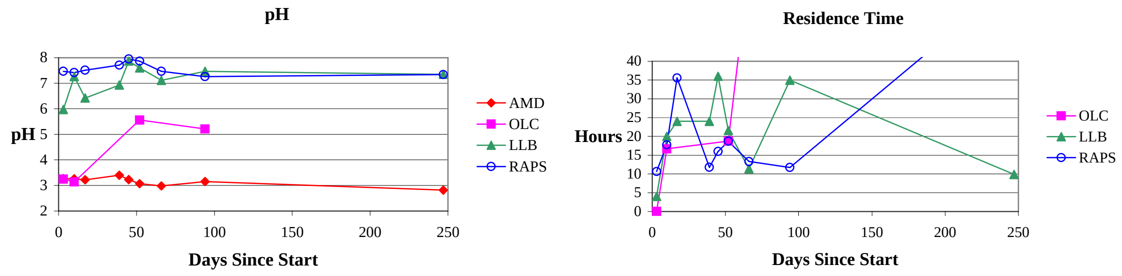

Figure 1. The field parameter pH for the AMD and outlet for each treatment system and residence times as calculated from flow rates and system volumes.

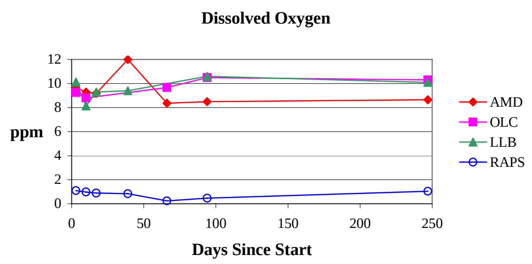

Figure 2. Dissolved oxygen content in the AMD and outlet for each treatment system.

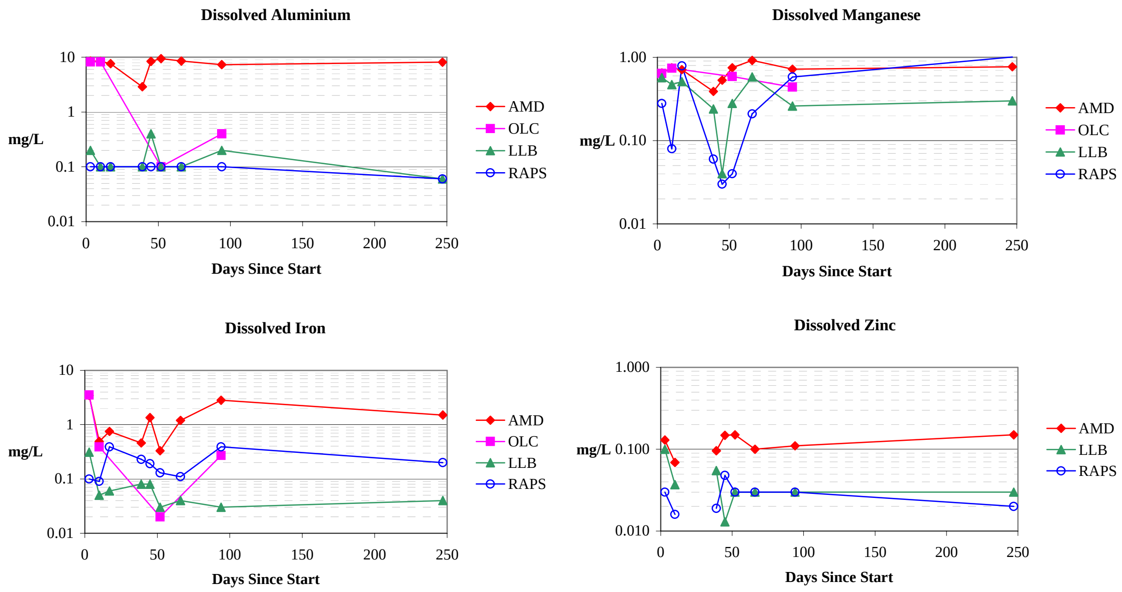

Figure 3. Dissolved aluminium, iron, manganese, and zinc concentrations in the AMD and outlet from each system.

The results suggest that each of these systems may be adequate to treat the AMD at Herbert Stream, however, the LLB has been chosen as the best choice of the three system to construct to full scale for the following reasons:

- The LLB is the simplest of the three systems.
- The area most suitable for system construction is a relatively large flat area adjacent to the stream. A full-scale OLC would require over five km of open channel in the stream bed which would permanently change the character of the natural watercourse. This type of system is suitable in constructed drains or where other options are limited.
- Total iron concentrations in the AMD are low, therefore armouring of limestone in an oxidising system is not a significant concern.
- Although aluminium concentrations are greater than iron in the AMD, aluminium does not armour limestone to same extent as iron and can be effectively flushed periodically from an LLB. In a full-scale system, the flushed precipitates are captured in a settling pond.
- Sites in the USA with similar chemistry and flow rates have been successfully treated using LLBs.

Acknowledgements

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