

Laboratory Testing to Determine the Effectiveness of Capping and Risk of Long-Term Metal Release from Mine Waste at the Abandoned Abbey Consols Lead-Zinc Mine, Wales, UK

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Abstract

The effectiveness of a proposed low permeability cover system for historical mining waste at the abandoned Abbey Consols lead-zinc mine, Wales, UK, was tested using laboratory columns. A reduced infiltration rate could still result in release of metals reducing the benefits of the cover system. Two column scenarios simulated average infiltration conditions and a reduced infiltration rate (the low permeability cover). Results showed the reduced infiltration column produced higher concentrations of key solutes (cadmium, lead and zinc) but a lower load. Zinc and cadmium loads narrowed between the two columns over time suggesting the low permeability cover benefit diminishes.

Keywords: Lead-zinc, Abandoned Mine, Column Tests, Remediation

Introduction

Abbey Consols mine is located near Pontrhydfendigaid, Mid-Wales, and derives its name from the nearby Strata Florida Abbey. A total recorded output of 1,236 tons of lead ore and 1,765 tons of zinc ore were mined between 1848-1909 (Jones 1922). The former lead and zinc mine has been abandoned since operations ceased in 1909 (Conflein 2019), and approximately 32,000 tonnes of spoil material remains on site (BGS 2012). An extensive ground investigation (GI) was undertaken in early 2019 to delineate the extent and composition of contaminated material, as well as understand how remediation options such as waste capping could improve waste stabilisation and seepage and runoff water quality from the site. As part of the GI samples of both mine waste and soil were gathered at the site.

Column leaching experiments on mine waste were set-up by Geochemic Ltd,

contracted by WSP on behalf of Natural Resources Wales (NRW). The primary focus of this study was to determine the contaminate contribution (mainly cadmium, lead and zinc) from leaching of spoil from the waste tips and to determine the potential benefits and risks of capping the spoil with a low permeability cover system. The tests were also intended to determine the potential for flushing-out of the stored soluble salts that may be released due to a rising ground water table during a storm event.

Methodology

Sampling

The column tests used a bulk waste composite from a mix of individual samples of waste material collected during the GI (tab. 1). The seven samples of spoil incorporated in the composite sample had a range of sulfur, lead and zinc contents and was classified as gravelly mine spoil.

Table 1 Individual waste sample depths, composition and location.

Geochemic Sample ID	Weight received (kg)	Depth	Sulfur total (%)	Pb (mg/kg)	Zn (mg/kg)	Location within the waste tip area (N / S / Mid)
GCL0076-002	5.55	2.50-3.50	0.119	5700	1290	Mid
GCL0076-003	7.04	1.20-2.50	0.107	5340	3480	N
GCL0076-004	32.5	1.00-	1.59	4820	34200	N
GCL0076-005	6.7	0.10-	0.145	697	5320	Mid
GCL0076-007	18.86	0.80-	0.518	26100	4920	Mid
GCL0076-012	17.54	1.00-1.00	0.229	8030	4990	S
GCL0076-014	17.12	0.40-	0.0508	1230	1420	S

Sample Preparation

The samples were screened at 25 mm and any oversized material was removed. The screened samples were blended together to make a single composite sample of roughly 90 kg. A representative 10 kg sub sample was obtained through cone and quartering and the remainder was further split into four separate 20 kg portions.

The 10 kg sub sample was weighed and then dried at 60 °C for 48 hours prior to being re-weighed then crushed to 90% passing 6.5 mm with a jaw crusher. This was then riffle split to obtain two test portions. The 100 g test portion was further dried at 105 °C to determine the residual moisture content and then pulverised to >80% passing 75 µm. This test portion was sent to ALS Hawarden for elemental characterisation including sulfur and carbon speciation, elemental abundance and mineral composition.

Column preparation and operation

Two 200 mm internal diameter columns were constructed from clear Perspex® acrylic (Fig. 1). The columns were 1 m in height and featured a suspended floor at the base to facilitate draining. The false floor was drilled to allow draining of collected leachate on to which a layer of polypropylene felt filter material was placed to prevent fines from being washed out of the column. Each column was loaded with two of the 20 kg test portion splits. The samples were loaded at field moisture content to prevent changes to the material characteristics that may occur during drying. The columns were covered with opaque foam

material to prevent light ingress and minimize temperature fluctuations at the edge of the column. A standard laboratory temperature of 20 °C (+/-5 °C) was maintained throughout experimentation.

The columns were flushed weekly with ultra-pure 18.2 MΩ deionised water using an automated spray irrigation system. This allowed for a uniform dose to the columns at precise time intervals. As the primary objective of the columns was to identify the difference between application of a low permeability cover system and an uncovered system, the irrigation rate was varied with Column 1 receiving the equivalent of 1560 mm of infiltration per year and the Column 2 receiving the equivalent of 156 mm of infiltration per year. Leachate was collected at the base of the column in Tedlar® gas sampling bags to limit atmospheric interaction.

The columns were operated for 8 months with samples being collected on a weekly basis. Analysis of parameters pH, electrical conductivity, oxidation / reduction potential, alkalinity and acidity were determined immediately upon collection at Geochemic's Laboratory using a Metrohm® automated system. In addition, sulfate was determined turbidimetrically using HACH SulfaVer4® method.

Every four weeks, a composite sample of leachates was sent to ALS Hawarden for a detailed elemental analysis suite including major cations and anions and trace elements by ICP-MS. The composite sample was made from equal volumes of the weekly leachates



Figure 1 Laboratory columns and set-up (image: Geochemic Ltd).

from each of the weeks within the four-week period. A final flushing event was introduced to the column test methodology following the normal month 8 method. A volume of around 7.5 L was added to each column to fully saturate the columns (from the base, to simulate a groundwater flush). The water added sat above the height of the waste in each column by around 20 mm. The water was left for 24 hours, and then both columns were drained down. Following column draindown the volume of water was recorded, a slightly higher volume of water was retained in Column 2 low infiltration (1.04 L) than in Column 1 high infiltration (0.46 L).

Results

Composite characteristics

Analysis of the composite waste sample shows elevated concentrations of trace metals with lead and zinc concentrations at 1.58% and 0.67% by weight respectively. Cadmium which is often associated with zinc ores is also shown to be elevated at 15 mg/kg. The sulfur content of the composite was determined to be 0.19% of which 0.02% of which was shown to be water soluble sulfate.

Leaching test results

The low infiltration column (Column 2) was found to generate the lowest pH and highest concentrations of zinc (up to 1,400 mg/L), lead (up to 12 mg/L) and cadmium (up to 3.25 mg/L) (Fig. 2 to 7). In the case of zinc and cadmium, the concentrations were shown to be around 5 to 10 times higher than in the high flushing column (Column 1) whereas concentrations of lead were of a similar magnitude in both columns. Calculation of mass release from the columns (considering the lower leachate generation rate) shows that the concentrations are much higher for the low flushing columns, the release rate for each metal (measured in mg release per kg of spoil) is initially four to five times lower due to the lower volume of leachate generated. Mass loads were normalised using sample mass size.

Lead release in the columns appears to be solubility controlled by anglesite, based on the leachate saturation indices indicated using the thermodynamic modelling code PHREEQC. The load released narrowed over time between the two columns for zinc and cadmium. This increase in load is likely a combination of variation in flow paths

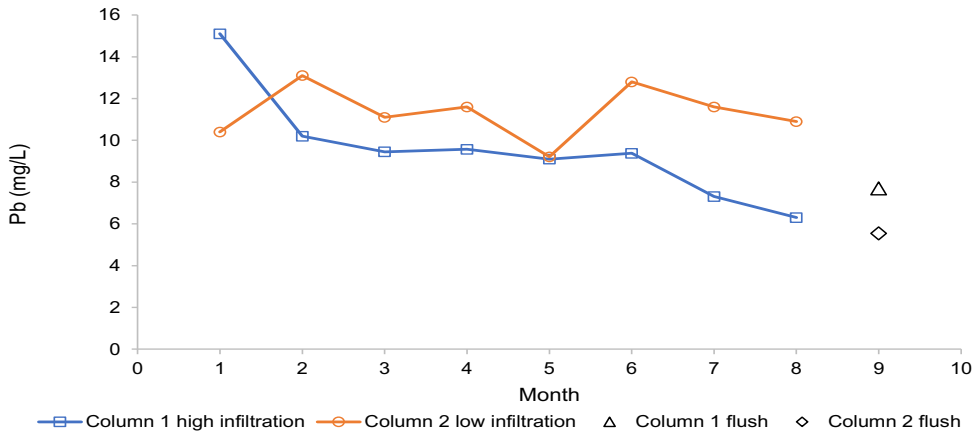


Figure 2 Dissolved lead in monthly column leachates and final flush event.

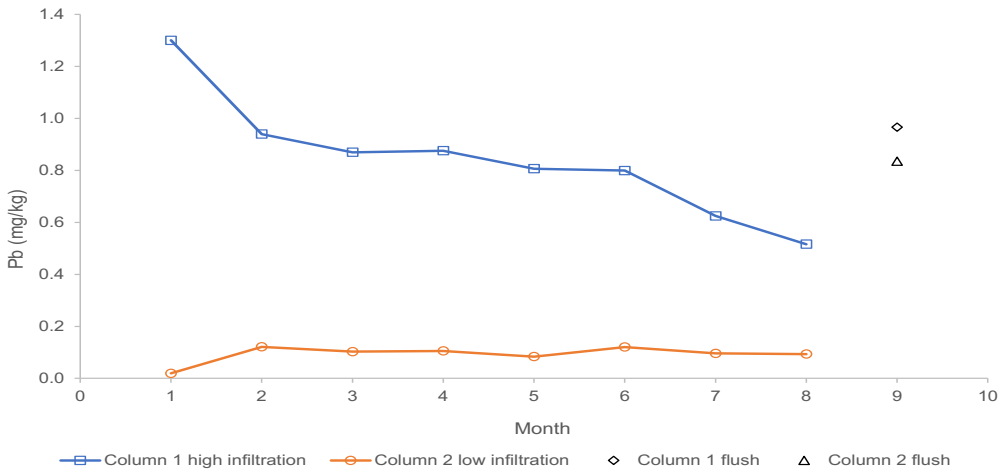


Figure 3 Lead mass loads by month.

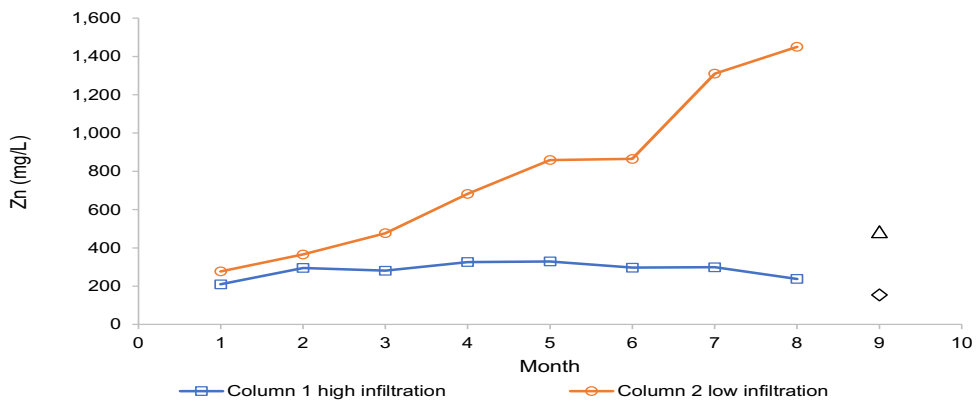


Figure 4 Dissolved zinc in monthly column leachates and final flush event.

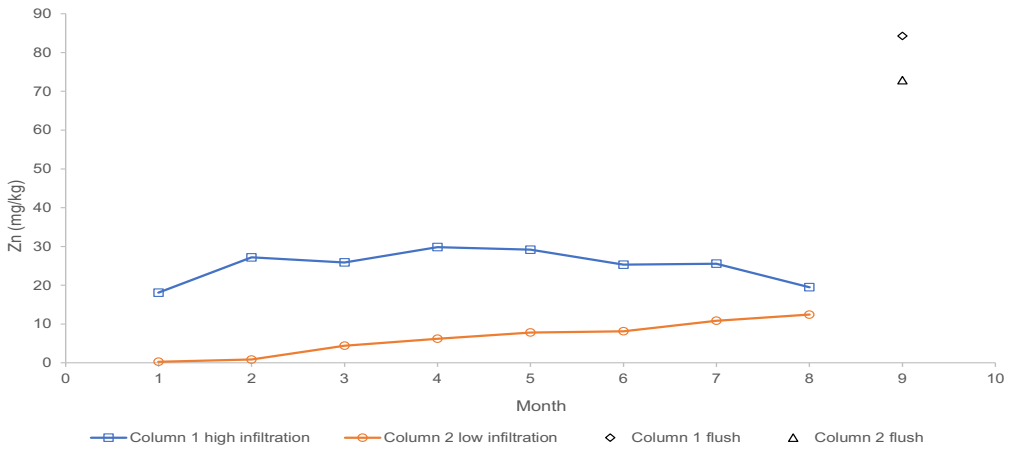


Figure 5 Zinc mass loads by month.

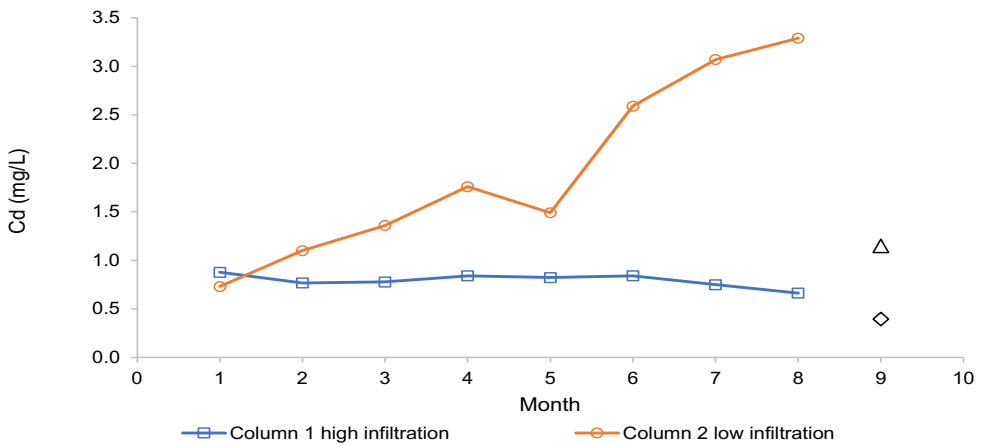


Figure 6 Dissolved cadmium in monthly column leachates and final flush event.

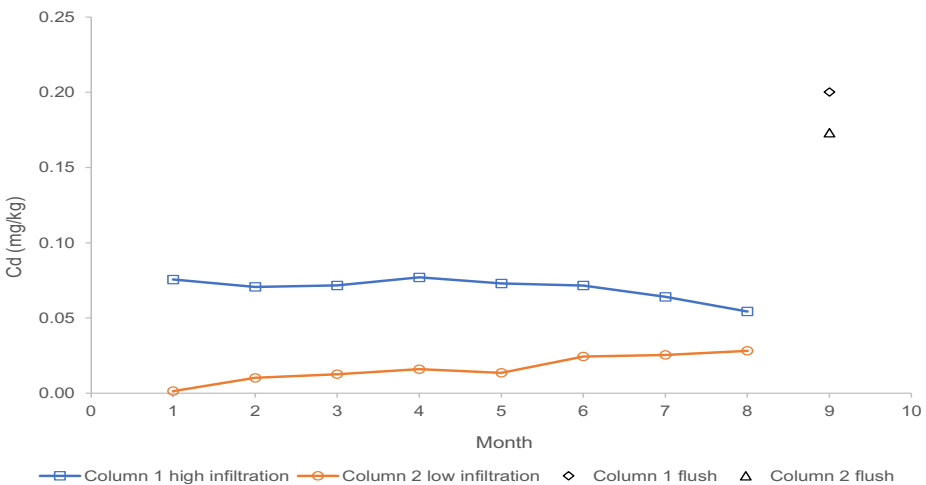


Figure 7 Cadmium mass loads by month.

and metal release pathways, an increased moisture content, saturation and potentially increasing load from finer material in the columns (whereas coarser material is flushed quicker). Zinc may also have some solubility constraints, as saturation indices for the leachate suggest some zinc minerals (particularly carbonates) are close to zero.

Zinc concentrations released in the average infiltration column remained relatively similar, around 200 mg/L across the weekly leachates and the flushing event. Zinc concentrations in the lower infiltration column increased through the test to 1400 mg/L, although around 500 mg/L in the flush event (diluted following the higher flow rate). The flood event leachate produced higher concentrations of key solutes (cadmium and zinc) in the reduced infiltration column, but the mass load of solutes from both columns was greater. The higher concentrations released in the flood flush are assumed to be a build-up of secondary minerals within the waste rock. The total solute mass released from the average infiltration column was greater than the lower infiltration column even when including the final flush event. The overall test mass loads released as a proportion of initial concentrations (tab. 2) shows that the higher infiltration rates (Column 1) releases higher metal loads than the lower rate, even after a flushing event.

Conclusions

The test results show that reducing the infiltration to the Abbey Consols spoil may effectively reduce the overall metals load being discharged from the waste material but

increasing zinc and cadmium concentrations in the low infiltration column discharge suggest that released loadings could end up being substantial, diminishing the remediation effect. Therefore, placing a low permeability cover on the surface of the waste may be a suitable option for reducing the load but is likely to be insufficient to meet the remediation targets for this site, which is dependent on a long-term, reliable minimisation of trace metal release.

The potential retention of trace metals within the spoil material under reduced flushing does raise questions on the possibility of a build-up of secondary minerals within the waste material that may be available to be flushed in the case where the groundwater table may temporarily rise and flood the tailings as may occur in a flooding event. Following a flush event remobilisation of cadmium and zinc was seen at greater concentrations in the lower infiltration column, suggesting a build-up of the secondary minerals within the waste.

The results were used to influence the remediation design, justifying the need for impermeable lining and specific groundwater drainage to further reduce or eliminate the contact between water and the waste. Leaking caps have the potential to cause substantial metal release, in the worst case providing similar results to an uncapped condition. The tests highlight the potential risk from stored solutes in mining waste located in an area liable to flooding or fluctuating groundwater levels, potentially driven by changing climates.

Table 2 Percentage released of initial concentrations.

Parameter	Percentage released of total (no flush) (%)		Percentage released of total (with flush) (%)	
	Column 1 (high infiltration)	Column 2 (low infiltration)	Column 1 (high infiltration)	Column 2 (low infiltration)
Zn	2.98	0.75	4.24	1.88
Cd	3.72	0.82	5.05	2.03
Pb	0.043	0.004	0.05	0.01

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