Former Galmoy Mines tailings restoration

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Abstract

Galmoy Mines completed the restoration of a tailings management facility (TMF), incorporating an engineered wetland, returning the site to a land use compatible with the surrounding countryside, while efficiently treating surface water runoff and creating an enhanced environment for local and migratory bird species. Increased breeding density of Curlews (IUCN Red List), in addition to nesting Little Ringed Plover and a Glossy Ibis were observed, demonstrating biodiversity support. The wetland system improved post-closure water quality. Ammonia in the revegetated caps of the TMF has stabilised and reductions in the sulphate were noted as the TMF remediation matures.

Keywords: Mine Closure, Wetland, Biodiversity, Little Ringed Plover, Ammonia, Sulphate

Introduction

Galmoy Mines zinc-lead deposit, located in south-central Ireland, discovered in 1986 (Doyle 2016), was owned and operated by the Lundin Mining Corporation since 2005. Most of the underground mine workings were between 100 m and 160 m below surface, hosted in extensively dolomitized and brecciated basal Waulsortian (Lower Carboniferous) "Reef" mudbank limestones Production of concentrates at Galmoy commenced in early 1997, with mine production carried out by room-and-pillar and bench-and-fill methods as reported by Lowther et al. (2003). During the operational phase, the excess non-acid generating tailings from processing ore were disposed of in the TMF, with drainage reclaim water pumped to the mine site, treated and discharged to the licensed discharge point (River Goul). The surface area of the TMF measures 33.64 Ha and is an engineered double HDPE lined ring dam built from local glacial materials with chimney and finger drains of sand (Derham 1999). While the original concept of three adjoining cells remained constant; the numbering, size, and sequence of construction changed due to revisions of the life of mine and discovery of new orebodies, affecting the underlying principles behind the original design. Most of the progressive rehabilitation of Phase 1 (9.36 Ha) and Phase 2 (14.02 Ha) of the TMF was completed during mine operation. TMF drainage design allowed for the safe discharge of water during the operational and post-closure stage. The three main sources of water identified were seepage water from the internal drainage within the cells (potentially contaminated), tailings surface water discharged from the TMF (potentially contaminated), and clean surface water reporting to the perimeter drains (Golder 2011).

The mine operated under an Integrated Pollution Control Licence, Planning Permissions, and State Mining Licences [Environmental Protection Agency (EPA) 2002; Local Authorities (Kilkenny County Council) 1994; Department of Communications, Climate Change, & Environment (DCCAE) SML 1, 6, 8-10 (1994–2005)]. All licenses and permissions referred to the rehabilitation of the TMF as an integral part of the Mine Closure Plan (MCP). In the MCP 1992, the preferred option for rehabilitation was the development of a "general amenity/wildlife sanctuary", with interim and final drainage schemes incorporated into the post-closure periods using a combination of wet/dry landscapes on the surface of the TMF. At that time, the long-term maintenance requirements were envisaged to be minimal and a "walk-away" end-point would not pose a threat to the environment. However, modern legislation, regulators, and Galmoy Mines recognised the retention of water below the crest of the dam wall did not offer a "walk-away" solution. The Second Interim Mine Closure Plan (2005) envisaged a wetland located externally to the southwest of the TMF, however at the announcement of unplanned early closure in 2009 Phase 3 of the TMF remained partially unfilled and the closure design of the TMF required modification.

Methods

TMF rehabilitation at Galmoy Mines began in 2001 with a pilot-scale tailings dam constructed to mimic the conditions in the TMF at closure. Pilot trial cells were established in compliance with planning permission requirements. The trial cells were subdivided, and a variety of grass species and depth of substrate were investigated with a mixture of topsoil and compost assessed. Nine cultivars were selected on the basis of a literature search and the experience gained at Tara Mines, Navan Ireland (Brady 1993). Vegetation trials demonstrated that the grasses selected for the large-scale TMF remediation (Festuca rubra cv. Merlin, *Agrostis castellana* cv. Heriot and *Agrostis capillaris* cv. Hyland) were based on genetic or physiological tolerance to metals, low uptake of lead and zinc to allow for the possibility of grazing animals, and good surface coverage and sustainability of vegetation density.

Based on these trials, capping and revegetation of TMF Phase 1 began in 2001, with subsequent monitoring of the performance of the cover through the collection and analysis of soil and vegetation samples. Calculation of a bioconcentration factor by Perkins et al. (2015) suggests no accumulation of the As, Cd, and Pb studied in the roots of grass growing on the Galmoy TMF. The data would suggest that grass species growing on the Galmoy TMF are relatively successful in excluding metals, taken up by the roots, from transferring to the remainder of the plant. Recent studies by Perkins et al. (2015) have shown that the maximum As, Cd, and Pb in herbage on Phase 1 and the trial cells are within the normal ranges for plants and that all maximum concentrations are below the upper threshold of the concentration ranges that could be considered excessive in leaf tissue. Perkins et al. (2015) suggest low translocation factors, noted at Galmoy TMF, indicate the positive potential future use of remediated TMFs for uses including pastoral agriculture, even where the soil layer is very thin.

Successful sheep grazing trials in 2008 and subsequent cattle trials in 2011 and 2012 were conducted on Phase 1 to confirm the agronomic value of the rehabilitated cap. Analysis was conducted on the grass; the animals' liver, kidney and muscle tissues; and blood samples at the end of each trial. The practical experience and analytical information from the grazing trials demonstrated the ability of the grassed cap to support livestock that, at slaughter, complied with all the relevant regulatory requirements for animals to safely enter the food chain.

A variety of organic materials and glacial till substrates were approved for use by the EPA throughout progressive remediation of Phase 1 and 2 (Figure 1), including black spent grains, limed sewage sludge, kieselguhr (a form of diatomaceous earth used in various manufacturing and laboratory processes), effluent screenings, sludge from Bulmers™ cider production, topsoil from the borrow area, and composted products. The aim was to provide a sustainable growing medium to support a natural and vibrant vegetation cover, however, the organic material cover on Phase 1 and 2 generated effluent with high levels of BOD, COD, ammonia, nitrate, phosphorus and potassium, during the early stages of remediation which would likely require passive treatment presenting a challenge to long-term discharge compliance, due to elevated ammonia concentrations in particular, in the interstitial layer of the vegetation cap.

A wetland trial was designed by Vesi Environmental Ltd., in 2009 whereby two cells were constructed adjacent to the TMF. Both cells were planted with four types of wetland species (*Glyceria maxima* (main species), *Carex riparia, Cladium mariscus* and *Alisma plantago-aquatica*) and irrigated using water from the TMF spillway and surface runoff, to assess the impact on the wetland plants of the parameters of interest.

Figure 1 *Final layout and design of TMF, wetland, and attenuation to licensed discharge (oriented North)*

The remediation of partially filled Phase 3 (8.29 Ha) presented an additional challenge in the closure process. Approval was received from the authorities to redesign TMF Phase 3 and develop an integrated constructed wetland (ICW) on the surface area of the partially filled Phase 3 (Figure 1). The innovative location of the ICW within Phase 3, was designed to reduce the footprint of the tailings runoff area and remediate Phase 3 simultaneously. The deposited tails in Phase 3 required resurfacing before the ICW could be constructed on the capped surface. Designed by Golder Associates (2011), Phase 3 was capped with glacial till and HDPE liner derived from the reduction in the height of the dam wall of the partially filled Phase 3. Based on the trial data in 2009, Vesi Environmental Ltd., developed the ICW to treat surface runoff water reporting from remediated Phase 1 (P1) and Phase 2 (P2).

Domed capping profiles for Phases 1 and 2 allowed surface water to migrate to the perimeter interceptor drainage system, thereby directing the surface runoff and interstitial drainage through redesigned spillway systems to the newly established ICW. Golder (2011) notes that very few mine operations considered doming their tailings facility to eliminate the long-term risks associated with containment and spillage of surplus water. Following the passive treatment of Phase 1 and 2 surface waters in the ICW, P4 discharge directed towards the attenuation pond located northwest of Phase 2 is polished, prior to discharge through the post-closure outfall to Glasha stream(Figure1). The surface area of the attenuation pond is approximately 2.4 Ha, with a capacity of 50,000m^3 and varies in depth due to the undulating nature of the limestone bedrock. Construction of the ICW commenced within the boundary of Phase 3 of the TMF in 2013, providing an HDPE lined area in which to locate the ICW. The wetlands were divided into four sequential ponds, Pond 1 to Pond 4, with Pond 1 subdivided into Pond 1A and 1B and were commissioned in October 2014 (Figure2).

Results

Table 1 outlines the results achieved during the wetland trial (2009) indicating large reductions in the concentrations of the chemical species monitored. Based on the trial results, the ICW design was finalised by Vesi. Construction of the full-scale wetland was

Figure 2 *Aerial view of Galmoy Mines constructed wetland (September 2016)*

Table 1. *Trial wetland results in 2009 (Carty 2017)*

Parameter	Inflow (max conc)	Outflow (max conc)	% Removal
Lead µg/L	275	26	91
Zinc µg/L	668	27	92
Sulphate mg/L	595	195	80
Total NH_4 mg/L	3074	36.6	98
Potassium mg/L	421	2.9	99
BOD mg/L O_2	130	50	79
COD mg/L O_2	6600	126	97

Table 2. *Wetland efficiency results in 2015 - 2017 discharge vs % removal (Carty 2017)*

Parameter	ELV*	Discharge quality 2015	Discharge quality 2016	Discharge quality 2017	% Removal 2015	% Removal 2016	% Removal 2017
Total NH_4 (as N) mg/L	0.065	0.04	0.03	0.05	99.8	99.8	99.3
Sulphate mg/L	400	105	161	231	82	84	74
Lead µg/L	7.2	1	1	2	85	90	97
Zinc µg/L	100	32	22	56	99	99	98

completed in 2014, with the wetland commissioned sequentially as each pond in the ICW was filled. Discharge through the spillway system from Phase 2 was commissioned in October 2014, with flow commissioned through the spillway at Phase 1 in November 2014. As each stage progressed, the quality of the discharged water was monitored. Discharge from the final pond to the attenuation pond commenced in January 2015. Discharge flow from the Pond 4 to the attenuation pond is managed using a low-flow sensor pump.

Based on the tailings hydrochemistry, wetland pilot trials (2009), and the proposed

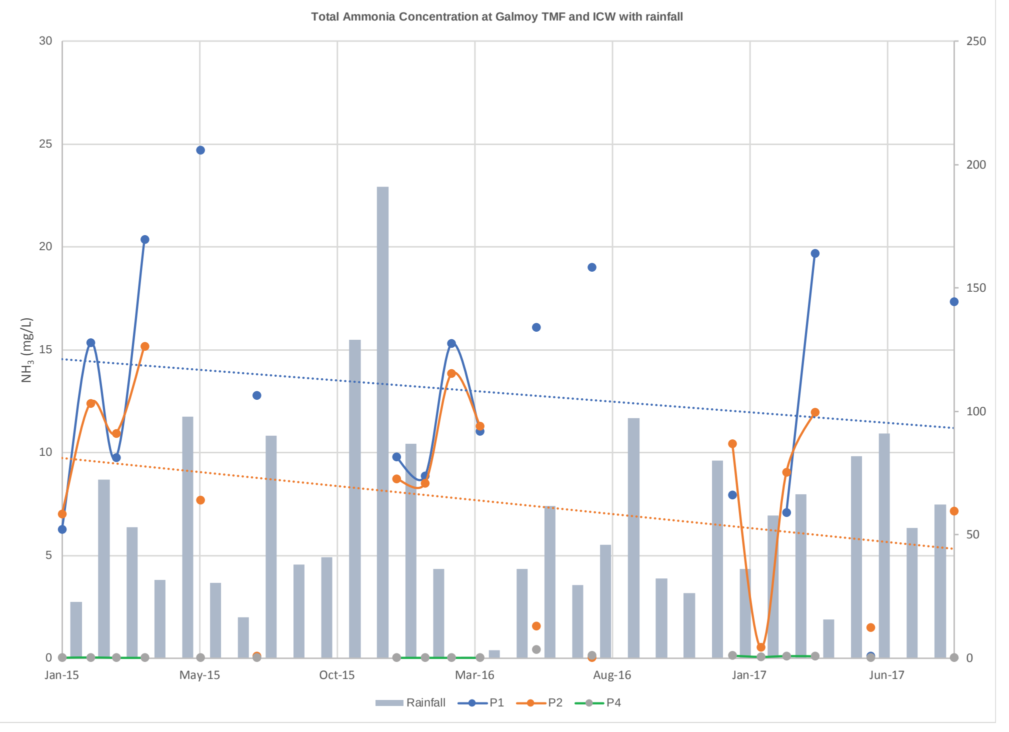

Figure 3 Total Ammonia concentration discharged from TMF Phase 1 (P1) and Phase 2 (P2) and ICW discharge point (P4) vs rainfall 2015 to 2017

discharge water quality limits, a number of parameters were selected to monitor the removal efficiency compared to the ELV since the commissioning of the wetland in October 2014 (Table 2).

Historical data shows that ammonia concentrations tended to be elevated above normal background levels at the spillways, with a maximum value of 3074mg/L noted in 2009 to 48.81mg/L in 2014, attributed to the high ammonium content in the various organic materials used to improve the growing medium on the capping layer, particularly on Phase 1. Figure 3 supports this with TMF Phase 1 discharge (P1) reporting consistently higher ammonia concentrations than water emanating from TMF Phase 2 discharge (P2). Figure 3 illustrates the decreasing trends in ammonia concentration at P1 and P2 in recent years (2015-2017) with the trendlines demonstrating the maturity of the remediated cap on Phase 1 and 2. Concentrations of ammonia in the discharge water quality from the ICW are denoted by ICW outfall (P4) demonstrate the effectiveness of the ICW to treat ammonia. The variable nature of the data is most likely due to the impact of rainwater on water quality discharge at the P1 and P2. The gaps in the data provided are explained by no discharge from either the spillways (P1 and P2) or the outfall of the ICW (P4). In addition, low concentrations of nitrate in the runoff water of TMF Phase 1 and 2 indicate reducing conditions in the organic material. Elevated concentrations of ammonium and metals appear to be correlated to lower flows.

Figure 4 illustrates that the sulphate concentrations are elevated during various periods, caused by oxidation of sulphite. Elevated concentrations of sulphate appear to be correlated to lower flows from the P1 and P2. Variations in sulphate concentration in the runoff water quality appear to reflect rainfall patterns, based on the available data. The trendline at P4 demonstrates that the sulphate concentration has stabilised. The reduction in sulphate concentrations between 2015 and 2017 in the ICW system are most

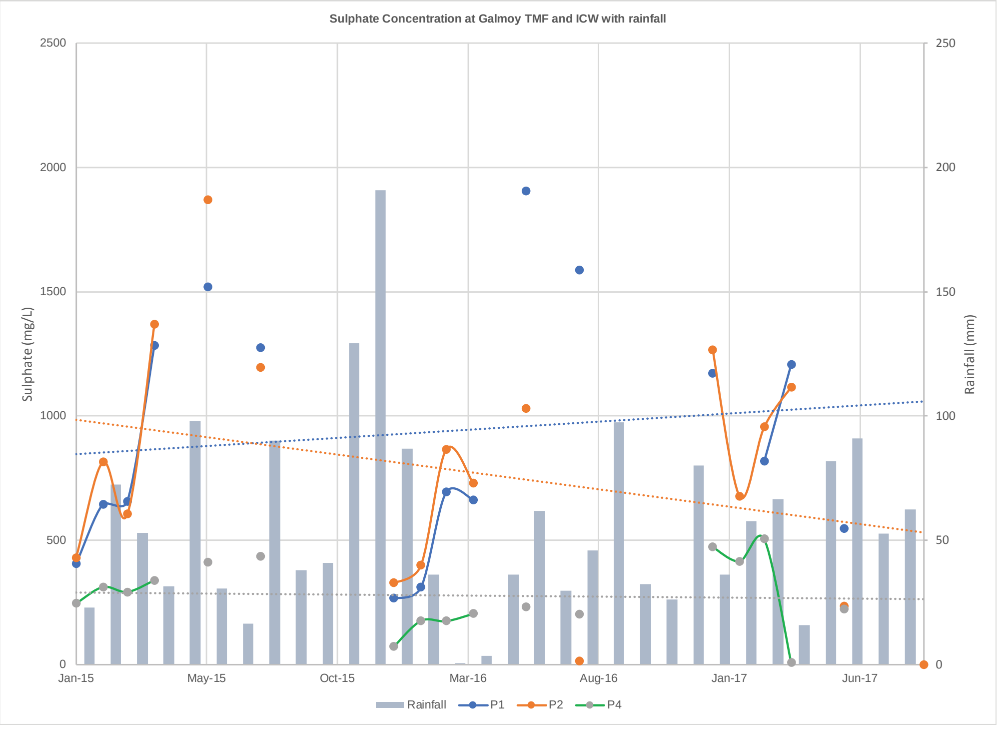

Figure 4 *Sulphate concentration discharged from TMF Phase 1 (P1) and Phase 2 (P2) and ICW discharge point (P4) vs rainfall 2015 to 2017*

likely attributable to rainfall. Further polishing of the discharge water occurs in the attenuation pond (approximately 50,000m^3) located on the northwest corner of Phase 2. As with Figure 3, the gaps in the data provided in Figure 4 are due to no discharge from either of the spillways or the outfall of the ICW.

Of note and in parallel to the remediation works, since 2008 Galmoy Mines commissioned biodiversity and bird surveys. Studies focussed on the TMF and a reference site located to the northwest of the TMF. During the course of the surveys, Kevin Collins2 noted dramatic increases in breeding density of Lapwings, Swallows, Sandmarks and identified a wide variety of resident and migratory species including the confirmed presence of the Curlew (IUCN Red List, Near Threatened, 2017). Collins also observed a nesting Little Ringed Plover at the wetland (2015) and a Glossy Ibis (2016), rare species in Ireland. Collins (2016) reported "32 species of birds were recorded on the tailing dam subsite and only 17 species recorded on the control site", "with the TMF study site attracting predators such as Merlin and Hen Harrier and the establishment of a Black-headed Gull colony (IUCN Red List, Least Concern, 2017) on the wetland ponds.

Conclusions

The successful restoration of the former mine site, consistent with surrounding land use, and the development of a fully functional ICW system within the TMF, was the first project to complete mine closure activities under the EU Mining Waste Directive since its introduction in 2006. Golder (2011) noted that the revegetation trial work, in addition to the environmental and restoration work is considered to be following and, in part, exceeding current best practice for closure in the metal mining industry. The construction of the ICW on the partially filled Phase 3 provides a sustainable passive wetland within the former TMF footprint, regulating water flow and improving water quality in compliance with regulatory requirements. In addition, the area provides a natural habitat for wildlife and migratory birds, contributing to a balanced and functional ecosystem. The remediated TMF and ICW act as host to both local, rare and migratory birds as noted by Collins (2015) and Collins (2016),

To utilise the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater (USEPA 2000), the Galmoy ICW was designed to take advantage of many of the same processes that occur in natural wetlands but do so within a more controlled environment. Due to the high organic nature of the cover materials on Phase 1 and 2, control systems incorporated into the ICW ensured the optimum removal of ammonia and sulphate from discharge water which had presented challenges at the announcement of early closure. Analysis of metals, suspended solids and arsenic from the surface water were monitored but are not discussed in detail in this paper.

It is important to note that the results at the ICW discharge point (P4) show a 99% reduction in ammonia (2015-2017) and an 82%, 84% and 74% respectively, in sulphate over the same period. The data serves to demonstrate that the ICW is functional, however P4 is not the licensed discharge point. Additional polishing is achieved downstream of the ICW at the attenuation pond prior to discharge to the environment at the licensed discharge point (Glasha stream).

Based on the criteria for success detailed in BREF-MTWR (EC 2009), the attainment of a self-sustaining ecosystem at Galmoy was contingent upon the development of a physically, chemically and biologically stable system founded upon habitat, species and community diversity, as well as the restoration of the mine.

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