THE CWM RHEIDOL METAL MINES REMEDIATION PROJECT – PHASE 1

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Abstract
The Cwm Rheidol metal mines complex in west Wales has been abandoned for nearly a century, but is still discharging high metal loads to the River Rheidol, which is failing to achieve its environmental quality standard for zinc. Environment Agency Wales is managing a project to improve the site and reduce its impact, in partnership with the Welsh Assembly Government and The Coal Authority, with further financial support from the European Union under the Objective 1 programme. Phase 1 aims to reduce water ingress to the mines and assess whether the mine water can be treated passively. To date, we have completed works to reduce water ingress, identified further work to manage the mine water flow and reduce its impact, and assessed the suitability of several substrates for passive treatment. We have also gathered chemical, ecological and flow data that will inform future remediation at this and other sites identified in our Metal Mines Strategy for Wales.

Introduction
The Cwm Rheidol metal mines complex is about 15 km east of Aberystwyth in Wales, UK (see Fig.1). The mines have not operated since the early twentieth century, but discharges of mine water threaten river water quality and wildlife. Environment Agency Wales (EAW) is managing a project to improve the mine site and reduce its impact, in partnership with the Welsh Assembly Government's Department for Enterprise, Innovation and Networks (DEIN) and The Coal Authority. The European Union (EU) has provided funding for the work through the Welsh Assembly Government under the Objective 1 programme.

Figure 1. Location map of the study area.

Discharges from the Cwm Rheidol abandoned metal mine complex contribute nearly half of the loading of heavy metals (e.g. Pb, Zn) to the River Rheidol and are contributing to the river's failure to achieve water quality targets for zinc over a length of 15 km. The River Rheidol is at risk of failing to achieve the "Good" chemical and ecological quality that will be required by the Water Framework Directive. The metals could be causing an impact on the aquatic flora and fauna, although the results of historical ecological impact assessment studies, mainly focussing on fish and macro-invertebrate populations, have been equivocal (Milne et al., 1981).
The earliest records of mining in the Cwm Rheidol mine complex are from the 18th century, but the history of mining in the area goes back as far as the Bronze Age. The mine workings were initially confined to the plateau above the valley, but in 1824 a connection was made to Cwm Rheidol, to allow drainage to the valley. This

connection was via a deep adit known as No.6 Adit. A second adit (No.9) was driven through the hillside later in the 19th century. These adits are now the points of discharge of acidic mine water containing high concentrations of zinc, lead and cadmium (Table 1) and are located approximately 100 m (Adit 6) and 60 m (Adit 9) above the river level. Production reached its peak around 1905, when 1537 tons of zinc blende (sulphide) and 46 tons of lead ore were sold in a single year. An aerial ropeway was used to transport the ore from a mill to the Vale of Rheidol Railway on the opposite side of the valley. Production ceased in 1914, but there was some intermittent mining activity in the area until the mid-20th century. In the early 1960s, construction of a hydroelectric power station on the Rheidol led to a reduction in river flow past the Cwm Rheidol mine, and therefore reduced dilution of the mine water. A limestone filter bed was constructed at the time to treat the acidic mine water as mitigation for this loss of dilution. This was initially effective in removing lead and zinc. However, a blow out of the No.9 Adit in 1969 blocked the filter with ochre and, despite an overhaul in 1976, it has since been ineffective at reducing the pollution to acceptable levels (Hughes, 1993).

Table 1. Water quality and flow data from Cwm Rheidol mine adits and receiving river (mean values from 2003-2006).

	Adit 6	Adit 9	River Rheidol upstream mine	River Rheidol downstream mine	Environmental Quality Standard
pH	3.73	3.16	6.77	6.76	Range 6-9*
Total Zn (μg/L)	13,832	69,383	52	170	8**
Total Pb (μg/L)	752	23	4	5	N/A
Diss. Pb (μg/L)	686	21	2	3	4**
Total Cd (μg/L)	38	96	0.13	0.32	1**
Flow (m^3/s)	0.011	0.003	2.76	2.78	N/A

*From Freshwater Fish Directive, expressed as 95 percentile

**From Dangerous Substances Directive, expressed as annual average, based on hardness in Rheidol

EAW investigated the Cwm Rheidol metal mine complex as part of the Metal Mine Strategy for Wales, which identifies the top 50 priority sites causing the greatest risk to the environment. EAW assessed the environmental impact of the Cwm Rheidol mine discharges and produced a feasibility report for remediation (SRK Consulting, 2004). The report suggested a number of actions and Phase 1 of the project addresses the key issues at the site, enabling us to make an informed decision with respect to future long-term remediation. The specific project targets are as follows:

- Identify points of surface water ingress to the mine workings and carry out work to minimise ingress where possible, subject to environmental and safety risk assessment. This should reduce the metals load to the River Rheidol, or to any future treatment system.
- Carry out laboratory-scale studies, followed by the installation of an *in situ* pilot plant, to assess whether the minewater can be effectively treated using a passive treatment system.
- Carry out water quality, flow and ecological monitoring for a 1-year period to measure the outcomes of Phase 1 and to provide baseline data for future phases of the project.
- Produce a final report on findings, with recommendations for a long-term remediation plan, including an environmental impact assessment.

Progress to date (February 2007)

1. Reducing surface water ingress to the mines

Atkins Ltd was commissioned by EAW to review the SRK feasibility report in the light of more recent monitoring data and to produce a specification for works to reduce surface water ingress to the mine workings (Atkins, 2006a). The SRK report highlighted two locations where surface water ingress could be reduced, including a collapsed mineshaft and a leaking streambed. However, flow data collected since 2004 has not identified significant losses through the streambed, so the remainder of this project has focussed on preventing ingress via the mineshaft and further monitoring to identify other points of ingress. Figure 2 shows a conceptual source-pathway-receptor model of the mine workings.

Previous work, including a dye tracer test (Mullinger, 2003), demonstrated a link between the collapsed mineshaft and Adit 6. Preventing ingress via the mineshaft required the excavation of a channel through a small area of wetland in the vicinity of a Special Area of Conservation and important archaeological features. Therefore, ecological surveys were carried out, relevant authorities were consulted and an environmental report

(Ove Arup and Partners, 2006) was completed to ensure that impacts were minimised. The diversion was completed in January 2007. The efficacy of this work is currently being assessed through continuous flow monitoring at Adit 6.

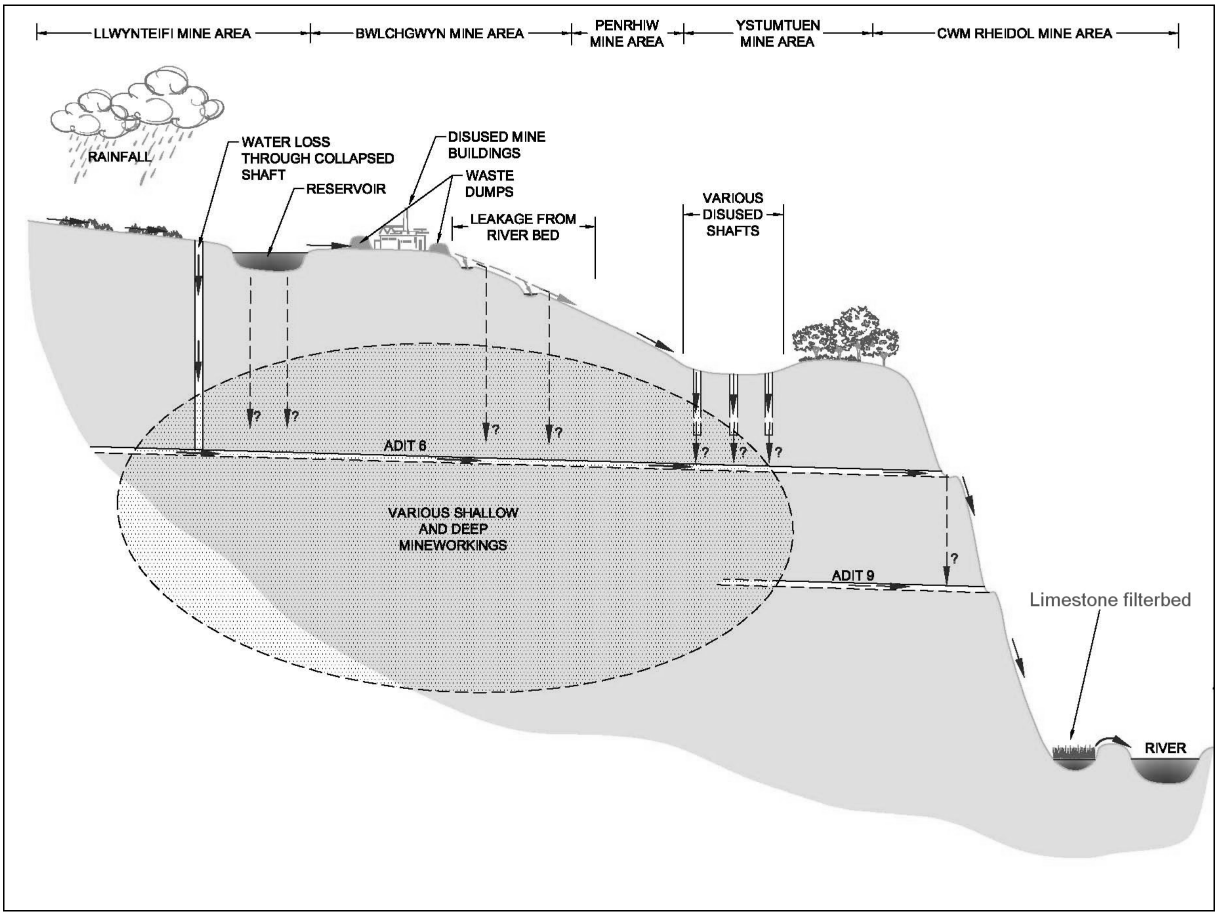

Figure 2. Conceptual source-pathway-receptor model (from Atkins, 2006a).

2. Treatability tests

Laboratory trials are being carried out by the HERO Group at Newcastle University to help inform the design and to identify suitable substrates for the pilot treatment system. There are few documented examples of full-scale passive treatment systems for attenuating metals such as zinc, lead and copper from metal mine water discharges. Laboratory trials form a key stage in the testing and evaluation of potential remediation technologies. Batch trials were carried out to test the suitability of various substrates to increase alkalinity, encourage adsorption, promote the microbial reduction of sulphate and precipitate metals (e.g. as sulphides, carbonates and oxides). The substrates investigated were:

- ochre pellets (manufactured from coal minewater treatment sludge),
- paper waste,
- farm manure and anaerobic digested sewage sludge mixed with either limestone or crushed whelk shells (from a local shellfish processing plant).

The batch tests results indicated that the paper waste was not suitable for further study. Further trials are in progress with the other substrates, which are being tested in continuous flow experiments. The results from these tests will permit better estimates of the rates of metal removal and the size of the treatment system that would be necessary when scaled up to pilot or full-scale treatment.

3. Mine water flow management

Site investigations in 2006 highlighted a need to capture the mine water where it discharged from the adits to enable better control, prevent site erosion and mobilisation of contaminants from the mine spoil heaps, and to maintain a constant and controllable supply to the proposed pilot plant. Atkins Ltd was commissioned to review options for capturing and transferring the mine water and to produce a specification for the works.

Flow data suggest that a substantial volume of the adit waters (up to 70%) are lost between the adit portals and the effluent of the filter beds, probably by percolation into the large spoil heaps over which the adit discharges flow, and then via shallow groundwater to the River Rheidol. Also, there is a substantial gain of water, believed to be from a cut-off wall adjacent to the river, which was installed in the 1970s to intercept contaminated shallow groundwater and direct it to the limestone filter bed. A mass balance of the adit water between the adit portals and the filter bed inlet shows that the metal loading in the water increases, possibly due to leaching from the mine wastes which form the mine water transfer channel. Furthermore, a mass balance of the limestone filter bed suggests that there is an additional source of zinc and cadmium entering the filter bed, possibly in groundwater intercepted via the cut-off wall.
Capturing the mine water at the adit portals and transferring it to the limestone filter bed in a sealed channel or pipe will prevent infiltration of the mine water into the spoil heaps and further erosion of these mine wastes. Whilst these works will not capture the water entering the filter bed via the cut-off wall, they may reduce the volume of this shallow groundwater by limiting infiltration of the adit discharges into the mine wastes (Atkins Ltd, 2006b).
Atkins recommended that the mine water from each adit be captured at each portal and transferred down the hillside in separate pipes. Before discharging to the existing limestone filter bed, lockable gate valves will be fitted to allow water from each adit to be diverted to the planned pilot scale treatment system. Water not required for the pilot plant will be allowed to flow through the existing culvert and into the filter bed.
At Adit 9, a pond of acidic (pH 3) water has formed outside the portal, and ochre deposits have accumulated. European standard leaching tests (BS EN 12457:2, 2002) demonstrated that the ochre sludge contains high leachable Zn (654 mg/kg) and is highly acidic (pH 2.7). Works are required at Adit 9 to drain the pond, and stabilise the ochre sludge before the adit discharge can be captured for transfer by pipe to the treatment system.
EAW intends to carry out the works to capture the discharges from both adits, and to manage the pond and ochre sludge at Adit 9 during spring 2007. This should allow a pilot plant to be constructed during 2007. Subject to agreement with local stakeholders, we would like to use the Cwm Rheidol pilot plant site to test different treatment media and identify the optimum passive technologies for metal mine discharges in Wales.

4. Water quality, flow and ecological monitoring

EAW has carried out water quality and flow monitoring to gather data to aid treatment system design, to measure the impact on the River Rheidol, to identify and quantify points of surface water ingress to the mines and to measure any reduction in metal loading to the river. A survey of salmonid fish populations was carried out by EAW with the support of an MSc student from Manchester University in summer 2006. Surprisingly this survey did not show any detrimental impact on salmonid fry populations downstream of the discharge from Cwm Rheidol mine, where mean zinc concentrations were approximately 20 times higher than the EQS (Shannon, 2006).
Results of water quality and flow monitoring were used to build a SIMCAT water quality model of the Rheidol catchment, to assess the current impact of the mine water and to predict the outcome of any future remediation (Edwards and Shannon, 2006). SIMCAT is a mathematical model that calculates the quality of river water throughout a catchment based on data from routine monitoring of river and effluent quality. The model showed that a significant proportion of the zinc from Cwm Rheidol adits 6 and 9 is bypassing the filter bed outlet and there is little or no zinc removal between the adits and the river. There is, however, a reduction in the dissolved lead load between the adits and the river, possibly due to precipitation. Cwm Rheidol mine is the main source of zinc to the Rheidol, but dissolved lead sources appear to be more diffuse or may be re-mobilised from sediments further downstream. Most of the Rheidol is compliant with the current environmental quality standard (EQS) for lead, but the entire river downstream of the mine (15 km) may fail the EQS for zinc regardless of any remediation work at Cwm Rheidol mine.
Biological monitoring has been carried out as part of a PhD study of mine water impacts in Wales, supervised by Birmingham University. This study included sampling of invertebrate populations at sites upstream and downstream of the mine discharge to the River Rheidol in spring and summer 2006, to provide baseline data on the current impact. The biological samples are currently being processed (M. Auladell, personal communication).

Summary and conclusions

To date, we have completed works to reduce surface water ingress to the mines, identified further work to manage the mine water flow and reduce its impact, and assessed the suitability of several substrates for passive treatment of the mine water. We have also gathered much chemical, ecological and flow data that will inform decisions about future remediation at this site and other sites identified in the Metal Mines Strategy for Wales.

Acknowledgements
The Cwm Rheidol Metal Mines Remediation Project (Phase 1) is being managed by Environment Agency Wales in partnership with the Welsh Assembly Government's Department for Enterprise, Innovation and Networks (DEIN), the Environment Agency's Science Department and The Coal Authority. Funding has been received from the European Union (EU), provided through the Welsh Assembly Government under the Objective 1 programme. The EU funding is for promotion of the development and structural adjustment of regions whose economic development is lagging behind – usually those regions whose per capita GDP is less than or close to 75% of the Community average.

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