Preventative methods to avoid Blow-out at Cwm Rheidol Adit 9, Ystumtuen Mine Sett

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Abstract

An adit roof collapse 15 m within Adit No.9 of Cwm Rheidol mine was observed triggering a requirement for detailed blow-out assessment, revealing 2,112 m3 of trapped mine water. Intervention works since included replacing deteriorated stream linings, flow gauging of river reaches and extending the blow-out lagoon. A new blow-out channel constructed from Adit No.9 to the lagoon was overlaying two new pipes conveying mine water to the original riverside filter beds. Detailed design of adit dewatering requiring an offline tunnel to be excavated through mine spoil and bedrock, entering the adit 40 m behind the portal, providing a permanent drainage solution.

Keywords: Blow-out, assessment, remediation, intervention, tunnelling

Introduction

Ystumtuen is situated 15 km east of Aberystwyth, Ceredigion. The lead-zinc mine complex comprises Ystumtuen, Penrhiw, Bwlchgwyn and Llwynteifi mines on the mountain plateau and Cwm Rheidol in the valley. The mines exploited the Castell Lode within mudstones and sandstones of the Llandovery Series of the Silurian. The mineralisation is of quartz cemented breccias hosting galena, sphalerite, marcasite and pyrite. Marcasite is more abundant in the west of the lode.

The Cwm Rheidol Adit No.6 and Adit No.9 are key features relevant to this project. The shallower Adit No.6 was driven in 1822 through bedrock at 170 m above Ordnance Datum (aOD) with ore initially processed close to the portal. Spoil and gangue were tipped down the steep valley side. The deep drainage Adit No.9 was driven in 1901 at 110 m aOD through 30 m of mine spoil. Both adits continue to discharge low pH, metal mine water.

Natural Resources Wales (NRW) captured both adit discharges in 2009, conveying mine water by pipe to limestone filter beds that discharge via cascade to the Afon Rheidol. The filter beds, installed in the 1960's were initially successful in removing lead and zinc but having become ineffective in the 1970's are now dilapidated.

Adit No.9 has a known history of blow-out or outburst. In October 1969, during enabling works for exploration drilling an outburst caused the Afon Rheidol to turn red down to Cardigan Bay (Jones et al. 1975). In 1992, a shale dam had formed from a roof collapse within Adit No.9 holding back an estimated 2,273m^3 of acidic mine water. Subsequent intervention works in March 1993 required draw down of mine water to a lagoon, in order to replace adit roof lagging and install of 6 m of 225 mm diameter drainage pipe to competent ground (Mason 2011). When the mine water levels were reduced during these works, it was found that the legs of the support arches had rotted away. In November 1993, a ground collapse at Nant Bwlchgwyn occurred resulting in the stream flowing to workings and contributing to flow from Adit No.6, the increased flow across mine spoil resulted in mass movement that smothered Adit No.9 below. The surface water inflow was mitigated

through the installation of a halfpipe in the stream bed (Plate 1) spanning the collapse. Basic restoration around Adit No.9 was also carried out with mine water in the Adit No.9 tunnel kept elevated to prevent access. In 2008, the mine water levels in Adit No.9 were drained down to reduce risk of outburst and in 2009 rigid corrugated plastic pipes were installed at the adit portals to convey mine water from Adits No.6 and No.9 to the now failing filter beds. During maintenance (rodding) of the Adit No.9 drainage pipe in March 2016 a rumbling noise was heard and a sudden discharge occurred. The released water was directed toward the former lagoon area to dissipate.

Analysis of flow and chemistry data for both discharges since 2010 showed little variation in chemistry, excepting a period from January to May 2012 when Pb increased at Adit No.9 (Coal Authority 2017). Adit No.6 has had flows measured volumetrically typically in the range 3 to 12 Ls-1 dependent on seasonality but has shown occasional large spikes of 20 to 30 Ls^{-1}, indicative of direct surface water inflows. Adit No.9 has generally been consistently at or below 1 Ls^{-1} except for the period following the sudden outrush in March 2016.

NRW and the Coal Authority are partners in the joint Metal (Non-Coal) Mine Programme (MMP) and when undertaking feasibility in 2019 observed a roof collapse 15 m inbye of the Adit No.9 portal. This observation triggered a detailed Blow-out Assessment which identified an estimated 2,112 m^3 of trapped mine water.

The Blow-out Assessment identified a need for repairs and upgrades to previous surface water inflow measures and to assess other potential losses to workings on the mountain plateau. The assessment also identified a need to re-establish and upgrade blow-out mitigation engineering below Adit No.9. Including the immediate provision of a channel and attenuation lagoon to manage water in the event of a blow-out and to allow work on the adit blockage. It also recommended installation of permanent flow gauging stations for Adits No.6 and No.9, maintenance of the mine water pipelines to the filter beds and monitoring of mine water levels within the mine system (Coal Authority 2019).

Limiting Surface Water Inflow

Surface water inflow to the mine system has long been a problem. The three upper stream catchments Upper Afon Tuen to the west, Nant-yr-Oerfa in the north, that enters Nant Bwlchgwyn in the east joining the Lower Afon Tuen downstream of Ystumtuen with an area of approximately 200 ha. They cross the worked lodes and in Nant Bwlchgwyn a 6m by 900mm section of corrugated steel Armco half pipe was laid over a collapse in the stream bed in 1994. Flow gauging of Nant Bwlchgwyn using an impeller flow meter on a gravelly river bed during January 2004 identified a loss of 2 Ls^{-1} coinciding with a shallow depression in a stream channel. The depression appeared to represent a crown hole on an open stope, upstream of the Llwyn Teifi reservoir (NGR 2741102909055). A further loss of 4 Ls^{-1} was identified across the temporary stream

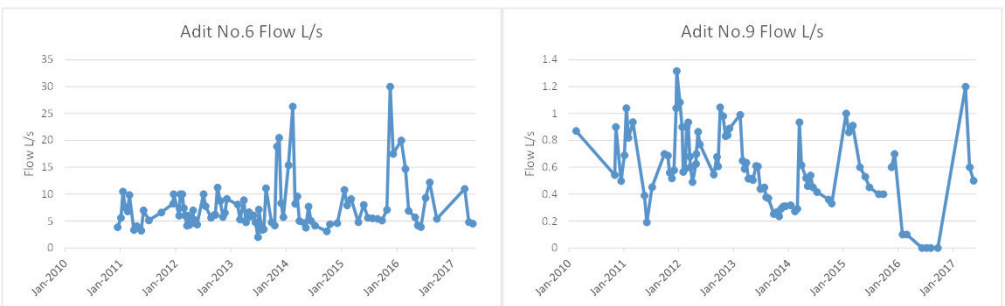

Figure 1 *Mine Water Flows at Adits 6 and 9 from 2010 to 2017 (Coal Authority 2017)*

bed (SRK 2004). Whilst there is uncertainty regarding flow observations and data, an estimated total 7 Ls^{-1} is lost to ground along the Nant Bwlchgwyn stream section. Rhodamine tracer testing in 2003 confirmed hydraulic connectivity between the collapsed shaft and Adit No.6. The estimated stream loss from Nant Bwlchgwyn would account for approximately half the flow discharging at Adit No.6. In 2007 a stream diversion was completed to prevent flow into the crown hole.

Further flow assessment was undertaken in June 2019 by Coal Authority and NRW. Flow in the Upper Afon Tuen reaches, Nant Bwlchgwyn and Adit No.6 was gauged using salt dilution methods. The fieldwork followed a period of rainfall when flows were greater than anticipated making gauging challenging. Flow measurements were as follows: Afon Tuen 145–282 Ls^{-1}, Nant Bwlchgwyn 17–31 Ls^{-1} and Adit No.6, 7 Ls 1. The results confirmed downstream increases in water volume with stream bed losses small, as such it was recommended that the exercise be repeated.

The condition of the steel halfpipe 1994 intervention (Plate 1)) had deteriorated over time with visible holes and opening lapped joints (Plate 2). Following removal and scanning the stone filled opening beneath, a replacement plastic half pipe with mortared headwalls was installed in September 2020 (Plate 3 and 4). Repeat flow gauging (Coal Authority 2021) during low flows indicated no losses on the Afon Tuen and no visible losses around the new half pipe though flows were too low to perform accurate flow gauging on Nant Bwlchgwyn.

A discharge into workings continues at Lee's Shaft above Nant Bwlchgwyn and downgradient of a 6 ha catchment with shallow and redundant reservoir that retains shallow pools, the reservoir area is now mostly vegetated in Juncus on boggy ground. The South lode runs parallel to and in front of the former embankment and has been worked to near surface and to surface in part. Lee's Shaft is at the eastern end of the embankment tucked into the hillside and the stream from the former reservoir crosses the lode northward toward Nant Bwlchgwyn that flows to the west.

The collapse around Lee's Shaft was large in 2018, but by September 2020 a further collapse into the stope of approximately 4 m occurred. The failure was likely related to water migration at the base of the weathered zone, with visible seepages seen at rockhead flowing to the void following the collapse. Six piezometers were installed, four on the embankment and two north of Lee's Shaft in clusters of two, which confirmed variable groundwater levels. Geophysical methods to identify preferential seepages along the embankment are being considered to appreciate if an intervention such as cut off

Plate 1 *Nant Bwlchgwyn 1994 halfpipe (Mason 2011)*

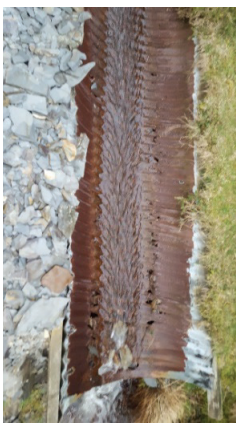

Plate 2 *Nant Bwlchgwyn 1994 halfpipe (NRW 2018)*

Plate 3 *Nant Bwlchgwyn replacement halfpipe (NRW 2020)*

Plate 4 *Nant Bwlchgwyn replacement 6m x 900mm halfpipe (NRW 2020)*

wall sections on the up gradient embankment have merit.

Cwm Rheidol Adit No.9 Interventions

During a feasibility site walkover in February 2019 with Cambrian Mines Trust members and eminent mineralogist John Mason to record important mine heritage and features a roof collapse 15 m inbye of the portal was noted. The photographs available from reconstruction (Mason 2011) identify the steel arches on timber blocks. Using these and more recent photographs one can conject 0.5 m of ochre in the Adit No.9 portal. It is also evident that the steel arches have deformed over time.

To understand mine working connectivity, old mine plans, conceptual sections (Lord 2018) and previous reports on intervention work (Mason 2011) were reviewed. It became evident that prior to 1993 a collapse in workings on Level 6 inbye of Penrhiw had enabled water to build up and flow to Level 9 via a connecting level and winze. The removal of this blockage and introduction of twin corrugated plastic pipes enabled mine water to discharge again via Adit No.6. It is reported that a collapse or a wall obscured by ochre close to the boundary between Ystumtuen and Penrhiw on the Great Lode in Level 6 is considered a barrier restricting or preventing water from passing from Level 6 to Level 9.

The deteriorating condition of Adit No.9 necessitated further surveys in order to develop interventions. Surveying the adit, the roof collapse and the surroundings has included visual CCTV, thermal imagery, topographic survey, geospatial laser scanning, gas monitoring and UAV drone inspections. The challenging conditions in the adit required the use of a push rodded floated craft to deploy robotic sewer CCTV camera with LED lighting and a GeoSLAM REVO mobile mapping laser scanner to access the adit from portal to blockage. Three survey control points were marked out around the adit portal and georeferenced using a Leica GPS RTK SmartNet GNSS receiver to OSGB 36 National Grid. Three spheres were placed over the survey control points and a laser scan survey of the spheres, adit entrance and adit surroundings carried out, using the GeoSLAM REVO mobile mapping laser scanner. The data from all laser scans were composited to generate a 3D representation of the surface and outer portion of the adit including the overlying collapse feature (fig. 2).

Later visits using roped access above the adit allowed laser scanning of the collapse feature, this data being added to the 3D model (fig. 2). The collapse feature was also installed with a telemetered pressure transducer to monitor and record water levels in the adit level inbye of the near surface blockages. This data has been used in conjunction with recorded mine plans, photographs and reports to estimate that 2,112m3 of mine water is trapped.

The Project has undertaken three ground investigations, with five boreholes and seven trials pits in the attenuation pond and Adit No.9 area in the first phase. A second investigated the original lagoon embankment crest by means of four window sampler holes. The third comprised eleven rotary boreholes, seven machine excavated trial pits and three hand dug pits in the attenuation lagoon and associated construction compound areas.

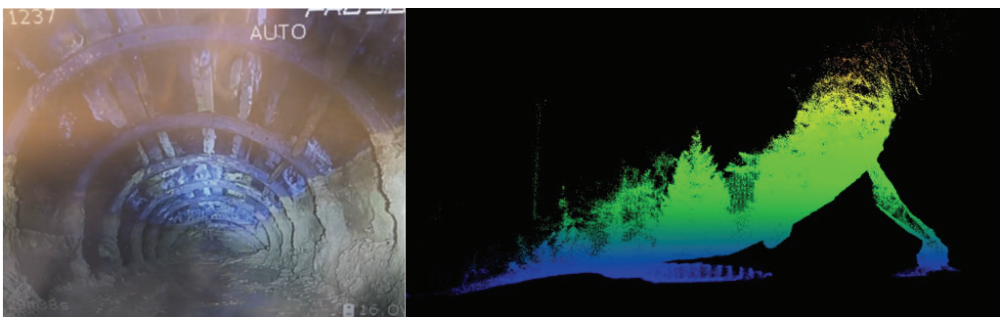

Figure 2 *Adit No.9 roof & combined laser scanned imagery (Geoterra 2019)*

The rotary boreholes were progressed to a maximum depth of 10 m. Investigations were completed with heritage and habitat watching briefs to enable access and micro siting. The evidence gained fed the Coal Authority's detailed design of Phase 1: the blow-out channel from Adit No.9, crossing the two new mine water discharge pipes; the manifold with trench box flow measurement stations for both Adit No.6 and Adit No.9 discharges and the attenuation lagoon capacity and freeboard expansion. Soil and core material sampling data was used to prepare a Materials Management Plan using the CL:AIRE definition of waste, code of practice. These Phase 1 works were delivered by Walters and completed in 2022. The potential blow-out risk is mitigated by a constructed concrete canvas lined bund at the adit portal and a flow control chamber that directs blow-out water to pipework and the lined channel. The water level in Adit No.9 is continuously monitored with alarms to alert of changed water level conditions.

The Phase 2 design aims to bypass the blockages in Adit No.9 by way of a 40 m long 1.5m diameter offset tunnel which will be progressed by means of pipe jacking. The tunnel is designed to enter the adit level behind support arches and props as recorded during original intervention work (Mason 2022). This work will entail the requirement to temporarily open the mine under the Mines Regulations 2014 with a designated Mine Owner, Mine Operator and Mine Manager (Competent Person). The new tunnel will include 160 mm diameter pipework with shut off valves to provide permanent blow-out resistant drainage, connected to existing mine water pipework. The original Adit No.9 portal and collapsed roof will be stabilised with cementitious grout or equivalent and with walling in local stone as recognition of the original feature.

Planning

The Cwm Rheidol Phases 1 and 2 works, and the Nant Bwlchgwyn halfpipe replacement, were carried out using permitted development rights NRW possess under the provisions of Part 15 Class A(b) of the Town and Country Planning (General Permitted Development) Order 1995. This enables development in, on or under any watercourse and required in connection with the improvement, maintenance or repair of that watercourse or those works. The Project was screened against the Environmental Impact Assessment (Land Drainage Improvement Works)(Amendment Regulations) 2017/585 to ascertain whether a statutory Environmental Impact Assessment (EIA) was required and an Environmental Statement needed production. Whilst the screening concluded a statutory EIA was not required, an Environmental Action Plan (EAP) was developed in accordance with NRW good practice and to ensure potential environmental risks of the Project were appropriately managed and mitigated.

An Ordinary Watercourse Consent under Section 23 of the Land Drainage Act 1991 was granted. A Water Framework Directive Preliminary Assessment and a Habitat Regulations Assessment was also completed by the Coal Authority. The Habitat Regulations Assessment concluded that the works would have no direct impact on the nearby internationally designated Rheidol Woods and Gorge Special Area of Conservation (SAC) and the downstream West Wales marine SAC and North Cardigan Bay Special Protected Area (SPA).

Habitat, Heritage & Landscape Constraints & Opportunities

The industrial archaeology and lower plant species provide rich heritage and habitat at the metal mine sites. In developing the EAP it was necessary to gather pertinent evidence and in relation to habitat, previous studies identified compartments and species at Ystumtuen, Penrhiw, Bwlchgwyn and Llwynteifi plus Cwm Rheidol (Simkin 2015). The lichens at Nant Bwlchgwyn include seven metallophytes, one with a conservation status of near-threatened, and four that are nationally scarce. Cwm Rheidol is undisturbed by livestock and hosts areas of mature calaminarian communities rich in lichens and bryophytes. Eighteen bryophytes and 71 lichens and lichenicolous fungi were recorded as well as a large population of the vascular plant *Silene uniflora* around the crusher house buildings. The lichenous species include twelve metallophytes, one with

a conservation status of near-threatened, two nationally rare and nine that are nationally scarce. The sites are identified as Regionally Important Geological Sites (RIGS) in Special Landscape Area (SLA-11), Rheidol Valley with promoted footpaths, cycle paths and Vale of Rheidol narrow gauge railway (LFS 2019). No bats were identified to be roosting or commuting in the immediate environs of Adit No.9 and a bridleway through the lagoon area has been temporarily diverted. Lagoon works presented opportunities to improve metallophyte succession by removing invasive scrub and creation of new substrate for lichen and bryophyte colonisation established by translocation.

Cwm Rheidol mine site is located within the designated Upland Ceredigion Landscape of Historical interest. The Historic Environment Record, National Monument Record and site archaeological appraisal visit (HRSWales 2019) identified that only a few significant historic features of importance remained including Penlefel Cottage and Magazine Hut by Adit No.6, crushing house walls, a former leat and yellow ochre spoil heaps. A recommendation included a need to be aware of buried heritage features and archaeology. Accordingly watching briefs for both archaeology and habitat were required for access with plant machinery, and during position selection for intrusive excavations. During these activities recording of features and translocation of rare Calaminarian grassland species was undertaken.

Conclusions

The site work is essential to reduce the risk of mine water blow-out should hydrostatic pressure exceed the resistive forces of the near surface blockage. The offset tunnelling provides a controlled means of gaining level entry rather than working in the original adit. Completion of the blow-out works will enable the MMP to focus on the metal mine water treatment scheme required to negate the polluting impact of the adit and diffuse discharges. The need to gather evidence prior to and during works is essential in delivering sustainable sympathetic solutions and necessitates careful multi-disciplinary coordination across partners, organisations and stakeholders.

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