A River System Approach to Mine Water Mitigation and Management

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Abstract

Natural Resources Wales (NRW) sought costs of metal mine intervention measures for ongoing River Basin Management Planning. A methodology was implemented reviewing and assessing the evidence base, including Reasons for Not Achieving Good Status (RNAGS), to identify where interventions could lead to status change or significant betterment.

Mines were classified Red/Amber/Green based on existing reports, experience, photogrammetry and GIS mapped layers. Estimated total costs for intervention measures like capping or water treatment systems at 129 Red mines and further assessment of 140 Amber mines are c.£282M. The Metal (Non-Coal) Mine Programme progressed 48 mine desk studies: example briefs are included.

Keywords: Catchment appraisal, Legacy mines, Water Environment Regulations, metal mine interventions

Introduction

The Water Framework Directive (WFD) was enacted initially by UK parliament as The Water Environment (WFD) (England and Wales) Regulations enabled in January 2004, since revoked and replaced by equivalent 2017 regulations. The regulatory requirements included the development of monitoring programmes to characterise River Basin Districts (RBDs), classify waterbodies, and identify a programme of measures to prevent deterioration and achieve Good status for all waterbodies. NRW as the appropriate Agency for Wales has a duty to set environmental objectives and define a programme to achieve these objectives for their RBDs in River Basin Management Plans (RBMPs), which are reviewed and published in six-year cycles. Cycle 3 is 2021–2027.

The objectives and measures are to prevent deterioration and protect, enhance, or restore each surface waterbody to Good ecological and Good chemical status. Heavily modified surface waterbodies should achieve Good chemical status within equivalent timeframes. Groundwater bodies should also be protected from deterioration, by preventing or limiting pollutant inputs and managing abstraction to achieve Good groundwater chemical status and Good groundwater quantitative status, reversing any significant and sustained upward trend in pollutant concentration caused by human activity.

NRW can stipulate reasons for not achieving deadlines for objectives, such as the scale of improvements required exceed the timeline, the interventions are cost-disproportionate or natural conditions do not allow improvement. The Cycle 3 timescale of 22nd December 2027 has exclusions for certain priority substances and in Wales is pertinent for Pb (priority substance 20). This timeline may under certain circumstances be extended to 22nd December 2033.

To assist WFD RBMP Cycle 3 planning, a Failing Waterbodies Assessment [Coal Authority 2020] reviewed where and why waterbodies were failing to achieve Good status in relation to metal mine pollution. This provided broad programme-level

budget estimates using key interventions at higher-risk polluting metal mines to achieve betterment or status change of failing rivers.

NB: For Welsh translation afon = river, nant = stream, mwyn = mine, cwm = valley

Methodology

NRW updates evidence of surface water and groundwater chemistry, resource potential of selected groundwater bodies and ecological health of river systems. This evidence enabled NRW to characterise waterbodies in RBMP cycles one and two, identifying 56 failing surface waterbodies, including two lakes, across fourteen river systems and one groundwater body with single or multiple metal mines identified as RNAGS. The waterbodies, the status, monitoring locations, waterbody classification points, metal mine locations, designations, base mapping and photogrammetry were used on a Geographical Information System (GIS), providing a database for screening mine sites within polluted waterbodies.

Metal loading data for waterbodies and mine sites, particularly point source discharges (adits), were used in combination with geo-environmental, habitat or heritage. NRW metal mine staff supplemented this using personal knowledge and experience of river system WFD reports, historical metal mine publications, known and uncertain metal mine pollution risks from point and diffuse sources, periods of exploitation, ore recovery, processing and production.

Simple estimates of the required loading reduction were made, based on the SIMCAT (Simulation of Catchments) model outputs used in the NRW WFD reports. Standardised metal mine treatment costs were adopted based on Coal Authority experience for passive Vertical Flow Pond (flows below 10 L/s) and active High Density Sludge (flows above 10 L/s) treatment systems. Capital and Operational Expenditure costs were estimated over forty years for treatment works.

Existing framework rates were used for estimating design and construction costs of capping or erosion protection engineering measures as surface water management systems. Quantitative estimates for each site used exposed mine waste tips with areas estimated from aerial photos and historical maps.

Parys Mountain, a Volcanic Massive Sulphide deposit heavily mined in the 18th and 19th centuries, was excluded from engineered mitigation measures due to the cavernous open-pits and exposed spoil. The flows and loading provide unique discharges in Wales that will require substantial water treatment systems, which costs were estimated on total flows and Afon Dulas seasonality.

All projected costs were discounted over a forty-year whole-life period in accordance with NRW economist advice and included major capital refurbishment after twenty years' service.

The methodology applied three simple questions:

1. Is the waterbody failing as a result of a metal mine input?
2. Would removal of metal mine input improve the status of waterbodies relating to metals?
3. Is there any evidence that treatment is technically infeasible?

Overview, Uncertainties and Implications for Future Actions

Fourteen river system reports and one groundwater report were published. For each failing waterbody in the river system, mines from the national inventory were assigned a RAG pollutant risk classification as follows: Red mines, known or highly likely to pollute; Green mines, unlikely to pollute; and Amber mines, requiring additional evidence to qualify their status as either Red or Green. Overall, 129 Red, 140 Amber and 278 Green mine sites were identified.

Confidence ratings of High, Medium or Low were attributed to the evidence base and assessments undertaken. Derived cost estimates were uplifted by 50% in the case of high confidence, 100% with medium confidence and 200% with low confidence (Table 1) reflecting the uncertainty associated with implementing improvement measures on limited evidence. Comparative target cost estimates for individual sites during detailed

design stage are typically uplifted by up to 40% to accommodate unknown risks. Poor evidence is a concern and the application of generic mitigation for site assessments means that cost estimates include a range of uncertainties. This extends to uncertainty over the cost effectiveness of the proposed intervention measures, recognising that accepted monetised benefits due to water quality improvements are only part of the well-being and future generation benefits gained from waterbody status change.

Table 1 *Mitigation Cost Summary (Coal Authority 2020).*

River System	SWB* affected	Length impaired (km)	Remedial Cost (£M)	Cost/km Improved (£M)	Length Status Change (km)	Cost/km Status Change (£M)	RCR*
Goch Amlwch	1	3.5	26.5	7.68	3.5	7.68	M
Goch Dulas	1	3.8	4.1	1.51	3.8	1.51	M
Conwy	3	84.3	30.7	0.36	73.1	0.42	H
Clywedog*	4	30.0	31.7	0.84	30.0	0.84	L
G & Dwyryd$	3#	39.5	5.7	0.14	14.9	0.38	L
Mawddach	4	32.5	7.5	0.23	25.6	0.29	L
Dyfi	4	53.8	17	0.32	38.1	0.45	L-H
Severn	9	113.6	3.6	0.03	37.1	0.10	L
Leri	3	32.1	14.2	0.44	18.4	0.77	L
Clarach	2	25.4	15.7	0.62	25.4	0.62	L-H
Rheidol	7#	68.1	53.7	0.79	41.8	1.29	M
Wye	6	55.3	6.6	0.12	47.2	0.14	L
Ystwyth	4	53.6	34.4	0.64	31.9	1.08	L-M
Teifi	3	41.8	11.4	0.27	41.8	0.27	H
Tywi	2	69.3	12.5	0.18	0	N/A	H

*SWB = surface waterbodies *RCR = Risk Confidence Rating *Clywedog, Trefnant Brook & Y Garth $Glaslyn & Dwyryd
#includes 1 Lake

A recent Defra consultation on Water Quality Targets in England proposes actions to improve 50% of their metal mine affected rivers to meet chemical Environmental Quality Standards (EQS) (Defra 2022). This river system methodology identifies the difficulties in such an approach, especially with highly-polluting sites like Parys Mountain and Cwmystwyth, those with diffuse pollution like Dylife, Wemyss, Gwydir mines or in river systems that have numerous polluting mines like the Rheidol, Ystwyth, Clarach and Conwy. Consideration of targets based upon significant reduction of metal loading, ecological health for individual river systems, or developed chemical targets above current EQS are considered more realistic and achievable for Wales.

Some RNAGS were observed with waterbody classification points upstream of mine point source discharges or, in the Afon Tywi, located on a tributary unaffected by metal mines. Coastal waters were not accounted for despite an NRW Area Statement relating to the marine environment. Relatively larger sediment loadings are anticipated from Parys Mountain and from the coastal confluence of the Rheidol and Ystwyth. Sediments already entrained in river systems are difficult to assess, characterise or address. Future management or treatment of river sediments or treatment media will need to align with Sustainable Management of Natural Resources and Natural Resources Policy principles despite their high metal content.

Prioritisation & Case Studies

Intervention at the 129 Red mines and simple assessment of 140 Amber mines was estimated to cost c.£282M, which with risk could double. Some individual river system reports identified single principal pollution sources - Nant y Mwyn on the Afon Tywi, Trelogan West on Afon y Garth, Pengwern on the Afon Tanat, plus Parys Mountain on Afon Goch Amlwch and Afon Goch Dulas. Other river systems were more complex

due to mineral exploitation at many mines providing multiple pollution sources, like the Conwy, Dyfi, Severn, Clarach, Ystwyth and the Rheidol, which has 124 abandoned metal mines associated with the seven waterbodies, 23 of which are Red sites.

Recommendations were made to help prioritise the Metal (Non-Coal) Mine Programme (MMP) for the long-term. Three strands of prioritisation were made, the first being to develop, design and construct mitigation schemes for those sites with high confidence. The second aspect was to undertake feasibility at sites with medium to high confidence, and lastly at low confidence sites and waterbodies, targeted investigations to gather evidence to provide greater confidence for feasibility or not. A Catchment and Mines suite of 48 mine studies was programmed to help assess the low confidence Red and Amber mine sites to ensure the MMP endures without construction gaps. Five Lots were prepared, the first four procured in 2020 primarily on the Conwy, Dyfi and Severn, Leri and Clarach, and Wye. Lot 5 covering selected mines on the Rheidol and Ystwyth was completed in July 2022. The following sites have now been brought forward into our MMP.

Afon Tywi: Nant y Mwyn is located near Rhandirmwyn, Carmarthenshire. It was exploited for long periods from the pre-Roman period until final closure in 1932, with current metal (Pb, Zn, Cd) loading of c.20 t/y. NRW has invested in source apportionment studies to establish key inputs on Nant y Bai and Nant y Mwyn, which contribute to Zn WFD failure for 25 km of the Afon Tywi. These studies enable progression to feasibility, with evidence gathering ongoing.

Afon Clarach: Cwmerfin & Bronfloyd mines are situated in the Upper Clarach catchment between 8 and 11 km ENE of Aberystwyth, an area heavily mined since Romano-British times. Cwmerfin is recorded as operating in the last part of the 18th century and then again from 1848 to 1889 producing 10,022 t of mostly Pb ore with minor Zn and Cu. The lode was worked to the NNE of Nant Erfyn, which when driving the Deep Adit encountered a rich orebody extending almost to the surface. Workings were extended to the SSE below the stream. Remediation work to the spoil tips and capping of shafts was conducted in the 1990s with slopes trimmed to 1 in 4 around edges with taped visqueen polythene membrane, a 40 cm cohesive layer and a 50 cm soil cover. Where 1 in 7 slopes existed, the same membrane and soil cover was applied. Surface water monitoring indicated upstream loading of 161 kg/y of metals (Pb, Zn) and downstream loading of 854 kg/y. Uncertainty remained over groundwater input as upstream flow was measured as 12.5 L/s and downstream as 95 L/s. Both data sets indicate another source, potentially mine workings, as the Deep Adit Level was not located during the site visit and is suspected to be discharging downstream of the lowest water sampling point used (WSP 2022b). Upstream are located several small mines and Bwlch Consols that received equivalent remedial work in the 1990s.

Bronfloyd mine is lower in the river system on the Nant Silo, below the confluence of the Erfyn and Symlog. It is one of the oldest recorded mines in the county, operating from as early as 1600, closing in 1645, and again from 1851 to 1892 when it recorded 6,607 t of ore, primarily Pb. The steeply dipping Camdwr lode strikes NNE-WSW has three branches each 30 m apart. The north and middle branches were productive, the south unproductive, and all converge to the East. Workings extend to 104 fathoms (190 m) (Jones 1922) and a collapse at No 3 Shaft, below 80 fathoms (146 m), extended to the surface as subsidence, providing ongoing geotechnical issues. Surface water monitoring in February and August 2021 with downstream flows of 1900 L/s and 4.5 L/s respectively indicated metal loss, with upstream metals loading (Pb, Zn) of 12,906 kg/y (February), 33.7 kg/y (August) and downstream 12,237 kg/y (February), 21.6 kg/y (August). Spot sampling did not indicate significant release of metals from obvious above ground sources, however Summer monitoring identified loss of almost half the stream flow to ground (WSP 2022a) and with subsequent re-emergence unknown. Decreased metal loading downstream could result from groundwater recharge dilution

or degassing of mine waters. Significant upstream sources include Cwmerfin, Cwmerfin Deep Adit Level, the dressing floor at Pont-bont Rhydybeddau, Darren mine and Cwmsymlog. A separate study at Cwmsymlog indicated metal loading of 523 kg/y (Pb, Zn), identifying key source uncertainties remaining. A further source apportionment study on the Upper Clarach river system is now programmed.

Afon Severn: Pengwern mine is on the southern flank of the Berwyn Mountains straddling the Afon Tanat, a tributary of the Afon Severn adjacent to the village of Llangynog, Powys. The Tanat flows easterly with most mine workings and main shafts south of the river, but the most recent Pengwern Shaft is to the north. Pengwern forms part of the South Llangynog mines operating from 1692 to 1899, though documented in 1656 and speculated as having Roman interest. It is considered one of the most productive Pb mines in Mid Wales, generating c.37,800 t of Pb ore in the 18th and 19th centuries. Part of the site was used by the District Council as a municipal tip between 1966 and 1971. Stantec (2021c) identified a discharge to the north contributing to failure of the receiving Nant Cwmdwygo and Afon Tanat, but the principal discharge was from a partially blocked adit to the east that contributed mostly Zn metal loading estimated at 640 kg/y.

Afon Severn: Van mine lies 3 km northwest of Llanidloes, Powys on Pen-y-Castell hill upstream of Llyn y Fan and the canalised Afon Cerist. The main Van lode strikes ENE-WSW, dips 74° South and is up to 14.6 m wide. The mine, one of the most productive in the UK, opened in 1850 and produced 95,739 t of Pb, 28,424 t of Zn, 756,142 oz of Ag, barytes and witherite before closing in 1920. Restoration work was conducted in the early 1990s. The tips benefit from taped visqueen polythene sheets, reduced slopes and cover materials similar to Cwmerfin. The blocked Deep Adit Level had a minor ochre stained discharge posing a potential blow-out risk and causing Zn and Cd failures in the stream to Llyn y Fan (Stantec 2021d). Recently recognised limestone filter beds from the spoil tip drainage provide point source discharges and with other pollution sources these are now being assessed for intervention measures.

Afon Dyfi: Rhoswydol and Bacheiddon mines both contribute to the WFD failure of the Afon Crewi, a tributary of the Dyfi. Rhoswydol is in a steep incised valley with Green's Mill straddling Nant y Fedw at its confluence with Nant yr Ych. Bacheiddon lies further south, spanning the catchment boundary between Nant y Fedw and Nant Cymdu. Both mines were active between 1840 and 1877, being worked separately and collectively, utilising the mill to produce 3,022 t of Pb. The Bacheiddon deep adit portal above Nant y Fedw is blocked by a collapse with saturated ground in front, but no continuous discharge, indicating a potential blow-out risk (Stantec 2021a). Spot monitoring identified a discharge of 1 L/s from the partially blocked Rhoswydol deep adit, contributing ≈10 kg/y of Zn, whilst the extensive spoil tips that bound the Afon Crewi downstream of the mill contribute 2,600 kg/y metals (Zn, Pb, Cd). Further assessment and source apportionment is now programmed.

Afon Dyfi: Havan mine is located 7 km east of Tal-y-Bont, Ceredigion, at the head of the Afon Cyneiniog, a tributary of the Afon Leri in the lower Dyfi catchment. The mine operated sporadically from 1620 until 1900 and was often worked in conjunction with Henfwlch within the Rheidol catchment to the east. Both mines worked the same E-W striking lode, with an inference of hydraulic connectivity through fractures and proximity of the Havan open stope to a collapse on Henfwlch workings. Recorded outputs are 652 t of Pb, Zn and Cu, primarily Pb. Surface water run-off enters mine workings before emanating from the deeper Adit 5 portal, which has collapsed. Spot monitoring calculated loading as 350 kg/y (Pb and Zn) (WSP 2022c) with surface water entry and a collapsed portal. Ongoing assessment will qualify mine hazards and metal loading incorporating studies at proximal Henfwlch and downstream Bwlchglas mines.

Afon Wye: Nantiago, Dolminers, Nantygwrdy and Nanty mines are on the Afon Wye headwaters, 6 to 13 km west of Llangurig, Powys. Dolminers and

Nantygwrdy are on the opposite banks of the Upper Wye and operated independently. Nantygwrdy operated from 1865 to 1879 producing 1,930 t of Pb and Zn. WSP (2021d) calculated loading to the Wye of 1,278 kg/y (Pb and Zn), a quarter of which is associated with the deep adit discharge. Dolminers operated from 1877 to 1884 producing 780 t of mostly Pb and Zn. Diffuse source metal loading from the dressing floor is indicated as a large contributor to the total of 1,088 kg/y (Pb, Zn), with potential blow out risks identified at the shallow and deep adits (WSP 2021a). Both these Amber mines are reclassified as Red. Upstream is Nantiago where the entire stream enters the workings. Although overall metal loading is low at 258 kg/y, a fifth of which is associated with the deep adit discharge, simple surface water management interventions will help reduce loading to the Wye downstream. Nanty is 5 km further downstream, operating prior to 1836, with main recorded production between 1856 and 1871 yielding 1,380 t of Pb and 9,482 oz of Ag. The mine contributes 852 kg/y metal loading, mostly Zn, with surface water entry suspected, a blocked deep adit level with stable flow rate providing potential blow-out risk and geotechnical issues associated with steep hillside spoil tips. Collectively these mines are being taken forward with a view to direct interventions across the Wye headwaters.

Afon y Garth: Trelogan West and Trelogan mines are located 8 km northwest of Holywell in Flintshire, North East Wales in the Afon y Garth catchment. The mines were active from c.1700 to 1913 producing Pb, Zn, Ag and calamine (smithsonite) hosted in Carboniferous strata. Trelogan Lead Mine records from 1848 identify 5,009 and 22,888 t of Pb and Zn produced respectively. The drainage adit level was driven south west in the 1780s from Saunders' Dingle stream at the confluence with Afon y Garth. It is partially blocked at the portal, but a continuous strong discharge has highly elevated metal concentrations demanding further evidence gathering on loading and acquisition of habitat and heritage evidence to aid future interventions.

Conclusion

The Failing Waterbodies Assessment provides a reliable method for better understanding of each failing river system and the metal mines which pollute them. The RAG ranking has been essential for enabling targeted desk study work to gather evidence for supplementary studies to future-proof the MMP, once the key sites of Teifi Mines (Abbey Consols and Esgair Mwyn), Cwm Rheidol, Cwmystwyth, Dylife, Frongoch-Wemyss, Nant y Mwyn and Parys Mountain are completed. The attribution of typical remedial costs has been beneficial when sharing the scale of the metal mine issue with our sponsor, the Welsh Government that is keenly interested in facilitating clean-up.

The river system reports, and outputs of the brief case studies outline the complexity of certain river systems, indicating that targets in Wales would be more realistic and achievable if measured against ecology/river health or significant reduction of metals for each river system.

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