Assessing the Impacts of Metal Mines in Wales

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Abstract

The Metal Mines Strategy for Wales (Howeth, 2002) has focused on the fifty non ferrous metal mines in Wales that were perceived to be causing the most environmental impact. Data used to select these mines arose from a database commissioned by Agency Wales in 1996. This database was originally designed to be a central source of all available information on the different mine sites and as a tool to assess their environmental impact. From the information available about each mine, a score was produced to give a rank order of mines having potential or observed environmental impacts.

As part of further information gathering exercises carried out under the Metal Mines Strategy, some of the mines that were highlighted in the 1996 report were found not to be having as significant an impact as predicted. The 1996 method took into account factors such as age and size of workings, which are not necessarily indicators of environmental impact. Given the value of many of the mine sites as an archaeological or ecological resource and the limited funding available for remediation it was essential that sites were suitably prioritized to ensure maximum environmental benefit. This exercise aimed to carry out this prioritization by identifying and gathering existing information, which could be used to construct a ranking model on environmental impact alone and indicating where further data collection is necessary.

1 Introduction

There is a long history of metal mining in Wales, with recorded workings dating from the Bronze Age. The Acer Environmental Metal Mines Database (Kitts and Smith 1996) contains over 1300 individual mine records with basic location information. Of these records, 204 mines have more detailed historical and environmental information collated in the database. The information gathered was used to provide scores for each mine based on observed and potential environmental impacts. The result was a prioritised list of mine sites in Wales. After a review of the highest ranking sites, fifty were taken forward in the Metal Mine Strategy for Wales (Environment Agency Wales, 2002). The Metal Mine Strategy sought to bring together the views and interests of the stakeholders of each site so that any future remediation plans could be made to take account of issues such as archaeological and conservation value.

In the collection of further data for the mine strategy it was highlighted that several of the prioritised mines may not be having the environmental impacts expected from the initial prioritisation. In several cases, the receiving watercourses are complying with water quality objectives. The next stage of the mine strategy is to progress some of the mine sites closer to remediation by carrying out scoping and feasibility studies. To do this effectively a clearer picture of the actual impacts of each mine was required.

This study's aim was to undertake a more in-depth analysis of each mine's impacts using existing information and to develop a prioritisation to target and support future work, focusing on the Environment Agency's main drivers of improving river water quality and ecological status.

1.1 Water Quality

Water quality assessments are driven by compliance with Environmental Quality Standards (EQS). Where possible this could be measured by the length or area of river affected, as was the case with coal mines in Wales (Butler et al., 1994). However, in the case of many of the top 50 mine sites there is a distribution of mine sites along a watercourse. This makes it difficult to attribute lengths of river failing a particular standard to individual mines, particularly where there is no obvious point discharge or a series of different discharges.

The following water quality directives specify the levels of metals that should be met in freshwater.

River Quality Objectives: These are agreed with the Government and define the criteria that should be met to achieve overall good water quality status. These are applied to 95 percentile concentrations of metals in river water as shown in Table 1. They are designed as targets to be met if the rivers are to be relied upon for water supplies, recreation and conservation. River Quality Objectives are measured nationally through the General Quality Assessment (GQA) monitoring program. This is one way the Environment Agency monitors standards and improvements in the environment.

Table 1. Relevant River Quality Objective and Freshwater Fish Directive Standards for Metals

River Quality Objectives - 95 percentile values Freshwater Fish Directive – annual mean values		
Determinand	Hardness ($mg\ CaCO_3/l$)	Salmonid Fish Standard ($\mu g/l$)
Total Zinc	0 - 10	30
	>10 - 50	200
	>50 - 100	300
	>100	500
Dissolved Copper	0 - 10	5
	>10 - 50	22
	>50 - 100	40
	>100	112

Freshwater Fish Directive: The majority of Wales' rivers are designated salmonid fisheries. The Freshwater Fish Directive defines the standards that enable a healthy population to exist and reproduce. They also provide the basis for the River Quality Objectives, but are applied to annual mean concentrations as shown in Table 1. There is currently derogation under this directive for the impacts due to abandoned mine workings. This applies to mines that were abandoned before 31st December 1999.

Dangerous Substances Directive: This prescribes a series of hazardous substances and is divided in to two lists. List I substances are those known to be particularly toxic, persistent and can accumulate in the Environment.

Cadmium is a List I dangerous substances. List II covers substances whose effects are less severe. List II dangerous substances include iron, lead, zinc and copper. The Dangerous Substances Directive standards shown in Table 2 are applied to discharges as the criteria that are to be met downstream for consent to be granted. If treatment is to be carried out on the minewaters, these standards may become relevant for discharge consents.

Table 2. Relevant Dangerous Substances Directive Standards for Metals

EC Dangerous Substances Directive Water Quality Standards - annual mean values						
Determinand	Units	Salmonid Fish Standards				
Cadmium (total)	μg/l	5				
Iron (dissolved)	μg/l	1000				
Hardness Related Determinands		Hardness (mg/l CaCO3)				
		0-50	>50-100	>100-150	>150-250	>250
Lead (dissolved)	μg/l	4	10	10	20	20
Zinc (total)	μg/l	8	50	75	75	125
Copper (dissolved)	μg/l	1	6	10	10	28

1.2 Ecology

Biological quality is monitored by the Environment Agency in a standard way nationally through Biological Monitoring Working Party (BMWP) scores. These are based on the composition of invertebrate life for particular sites taking into account its physical and habitat characteristics. Different invertebrate species are given scores based upon their sensitivities to pollution. The invertebrate population at a site then gives a total score for that site; high scores indicate a healthy invertebrate population. The scores derived can be compared with other sampled sites e.g. upstream and downstream sites, and with what would be expected, based on the RIVPACS Model (River InVertebrate Prediction And Classification System). RIVPACS is a statistical model, which predicts invertebrate fauna at a site based on its physical characteristics (Wright et al. 2000). Other keys exist to interpret the invertebrate populations of rivers such as the Acid Waters Key (Rutt et al., 1990). These keys are designed to detect the impacts of different types of pollution. BMWP scores are targeted at organic pollution. Therefore, acid and metal tolerant species that are sensitive to organic pollution may give a high score to a site even if the overall fauna is impacted by a mine discharge.

In a similar way to RIVPACS, HABSCORE provides a model of the fish population that a particular site may be able to support based on its habitat characteristics. From this, habitat quality and utilisation scores can be derived for comparative purposes. There is also the National Fisheries Classification (NFC), which grades sites by the abundance of different fish species and places them by class bands in a national context. The NFC allows temporal comparison for sites but is not as suitable for making comparisons between sites as it does not consider habitat features.

Field observations and toxicological data widely demonstrate the effects that metals can have on different organisms. Exposure to lead has been linked with lordoscoliosis (spinal deformity) in fish. Zinc, copper and cadmium cause damage to fish gills, increase mortality of eggs and inhibit growth and development. In complex ecosystems these effects can be hard to discern, particularly in the case of Welsh rivers where natural acidification is often observed.

It is hard to quantify the effect of chronic pollution i.e. that, which does not cause a sudden and observable loss in biota but may, over time, lead to a reduction in numbers and a greater susceptibility to other pollutants. The effects of metals may increase under certain conditions such as acid episodes. Where this occurs as a result of natural acidic flushes, metals that are present can become more available and toxic than under normal river conditions, resulting in fish kills. Fish in Welsh rivers have also demonstrated tolerance and acclimation to metals with some populations being supported at concentrations above environmental quality standards. There is also evidence to indicate avoidance of contaminated waters. This may affect the recruitment of fish populations to a river.

2 Ranking Mine Impacts

The following measures were used to rank the impacts of each of the priority mine sites.

2.1 Water Quality

There are three components of the water quality ranking score:
1. EQS Failure Score.
2. Determinand Increase Score.
3. Metal Loading Score.

EQS Failure

Failures have been identified and scored on the determinands and standards shown in Table 3.

Table 3. Water Quality Standards used in Ranking Metal Mine Impacts

	Standard		
Determinand	Dangerous Substances Directive	Freshwater Fish Directive Salmonid Standards	River Quality Objectives
Cadmium (total)	7	N/A	N/A
Copper (dissolved)	7	7	7
Iron (dissolved)	7	N/A	N/A
Lead (dissolved)	7	N/A	N/A
Zinc (total)	7	7	7

For each of the standards indicated in Table 3 two impact points are scored for each standard that is failed downstream of a mine, giving a maximum possible score of 18. If an environmental standard is failed upstream of a mine as well as downstream then it does not increase the mine's score.

Determinand Increase

Two impact points are scored for increases in concentrations between upstream and downstream sample sites for each of the metals in Table 3, giving a maximum possible score of 10. This score takes account of smaller impacts that are not sufficient to cause failures of water quality standards, but also recognizes additional impacts where the upstream sites are already failing water quality standards.

Anomalies with this system arise for mines that are at the top of catchments where no upstream sample point exists or where the mine forms the headwaters of the watercourse. Where this is the case the assumption is made that, without the presence of the mine, the river would comply with water quality standards. The EQS Failure Score is then based solely on downstream failures and a Determinand Increase Score is assigned for each metal that fails one of the environmental quality standards at the downstream site.

Metal Loading

A score is given for each metal based on the mean daily load as shown in Table 4.

Table 4. Metal Loading Scores

	Metal Load (Kg per day)			
Score	Cadmium (total)	Copper (dissolved)	Lead (dissolved)	Zinc (total)
0	< 0.01	< 0.01	< 0.1	< 1
1	0.01 < 0.05	0.01 < 0.1	0.1 < 0.5	1 < 5
2	0.05 < 0.1	0.1 < 1	0.5 < 1	5 < 10
3	0.1 < 0.2	1 < 5	1 < 2	10 < 20
4	> 0.2	> 5	> 2	> 20

Where available, measured loading data has been used. For some sites this is not available and so the flow prediction tool Low Flows 2000 has been used to provide mean flow data for sites that have water quality data. Low Flows 2000 is a computer model that allows flows to be estimated at ungauged river sites based on catchment size and physical characteristics. From the flow estimates and available water chemistry, metal loads were calculated and, for comparison, estimates made for sites where observed data were available.

Assessment is carried out on watercourses of varying size. In smaller rivers lower metal loads are required to cause significant increases in metal concentrations. It is a subjective matter whether a larger impact on a relatively minor stream is worse than a lesser impact on a significant river. The metal loading score will help to factor out this inequality. The impact of a given load will be proportional to the water body; i.e. a large metal load will contribute significantly in catchment terms whether it is discharged initially into a large or small watercourse and a smaller load is likely to have only localised effects. So when looking to improve the overall water quality of a river system the major contributors to the water quality at a particular point must be considered. This is important information to target what improvements can be made in GQA assessments of river quality.

2.2 Ecology

The fisheries and biological data available for the mines has been collected from many different reports. It is possible to indicate whether an impact has been observed, irrespective of its scale. Scores are assigned for the existence of an observed impact on invertebrates, fish populations and other biota. The biological impacts observed include reduced invertebrate populations and increased metal concentrations in biota. Impacts on fish populations noted were decreased abundance downstream of mine sites, the occurrence of black-tailing in salmonids (an indication of lead poisoning) and increased mortality of eggs and juveniles.

Visual impacts have been included in the ecology section of the ranking system and refer to observed indicators that have not been measured in the same way as invertebrate and fish populations. These include occurrence of blue-green algae that has been observed at some mine discharges as well as ochre staining of river substrates (Gething 1999).

- Observed impact on invertebrate population or other biota
  No = 0 points Yes = 2 points
- Visual Impact
  No = 0 points Yes = 2 points
- Reduced fish numbers or signs of metal poisoning downstream of mine
  No = 0 points Yes = 2 points
- Absence of fish population attributable to mine
  No = 0 points Yes = 2 points

The potential impacts of a mine on ecologically sensitive areas or sites of interest are considered by a Designations Score. This is to add a weighing where an area of ecological value or interest exists, which may be impacted by a mine. These designated sites include Sites of Special Scientific Interest and Special Areas of Conservation. The score is related to their distance downstream of a mine. As a measure of impact, it is not used where a designation is associated with the mine site in terms of the historical value or because of the habitat a mine provides. Table 5 shows the scores given according to the distance of the mine water discharge from the designated site.

Table 5. Designation Score

Distance to designation (km)	Score
< 1	4
< 5	2
< 10	1
> 10	0

3 Ranking Results

Further information about some of the fifty Metal Mine Strategy sites is still required to complete the current ranking, but many mines do have comprehensive data available. Table 6 shows the top ten ranked mine sites with the scores broken down between the different components of the ranking scheme. Some mines discharge to more than one watercourse and where this is the case they have been assessed separately.

Table 6. Top Ten Ranked Metal Mines in Wales

Mine	Watercourse	EQS Failure	Determinand Increase	Loading	Ecology	Total Score
Parys	Afon Goch Dulas	16	8	13	5	42
Parys	Afon Goch Amlwch	16	8	10	6	40
Frongoch	Nant Cwmnewydion	12	8	8	7	35
Cwm Ystwyth	Ystwyth	8	8	9	8	33
Dylife	Twymyn	10	6	12	4	32
Cwm Rheidol	Rheidol	6	10	7	8	31
Esgairmwyn	Nant Garw	16	8	1	5	30
Frongoch	Nant Cell	10	8	4	6	30
Cwm Symlog	Symlog	10	6	6	4	26
Gwynfyndd	Mawddach	4	10	4	8	26

4 Case Studies

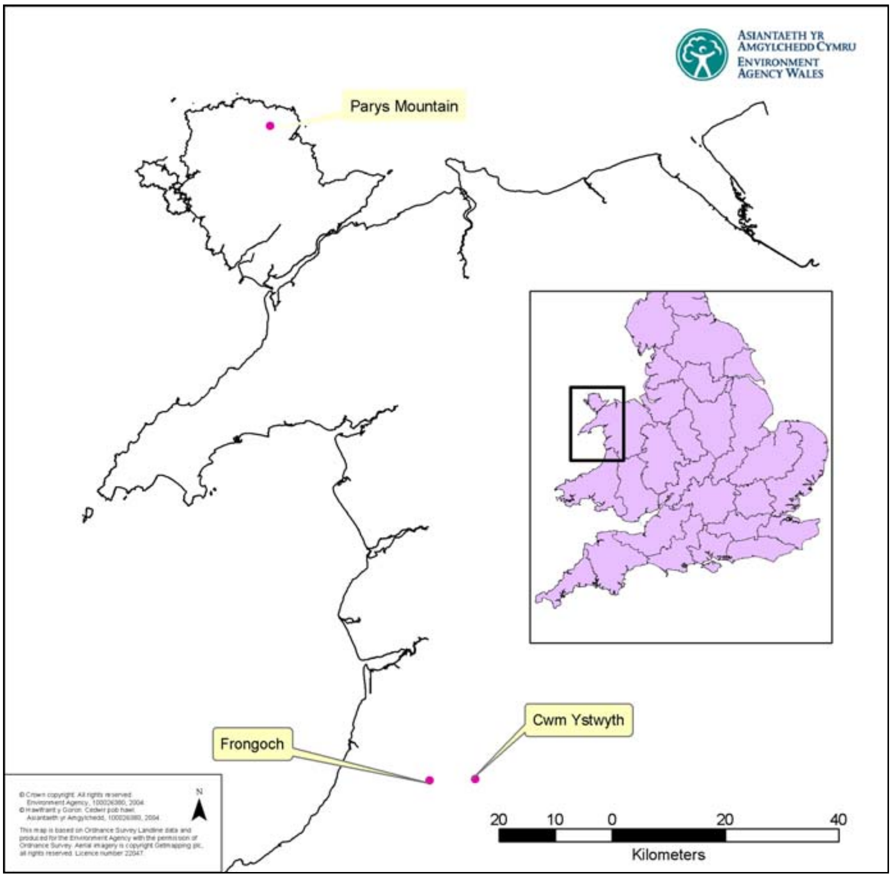

Figure 1. Location of Case Study Mines in Wales

4.1 Parys Mountain

Located on the coast of Anglesey in North Wales, Parys Mountain discharges via two watercourses, the Afon Goch Amlwch and the Afon Goch Dulas. This mine's impact has been assessed on both of these rivers and they are the highest ranked of all the assessments made so far.

The mine forms the headwaters of these rivers and so no upstream sample points exist. Both rivers fail all the water quality standards assessed except for lead, as indicated in Table 7.

Table 7. Water Quality Compliance for the Afon Goch Amlwch and Dulas

	Standard		
Determinand	Dangerous Substances Directive	Freshwater Fish Directive	River Quality Objectives
Cadmium (total)	Fail	N/A	N/A
Copper (dissolved)	Fail	Fail	Fail
Iron (dissolved)	Fail	N/A	N/A
Lead (dissolved)	Pass	N/A	N/A
Zinc (total)	Fail	Fail	Fail

The metal loads of these two rivers, shown in Table 8, are estimated from the available water chemistry and flow estimates from Low Flows 2000 and are comparable with previous estimates (Dixon et al., 1995).

Table 8. Estimated Copper and Zinc Metal Loads Compared for Parys Mountain

	Parys Mountain Study Low Estimates (Dixon et al) (Kg per Day)		Low Flows 2000 Estimates (Kg per Day)	
Watercourse	Copper (Dissolved)	Zinc (Total)	Copper (Dissolved)	Zinc (Total)
Afon Goch Amlwch	7.53	26.20	5.40	20.69
Afon Goch Dulas	19.19	50.44	40.52	81.83

There is no data available relating to impacts on the local fisheries. Studies show increased metal concentrations in the biota in the estuaries of the Dulas and Amlwch (Dixon, 1995). For example, copper levels of the marine algae *Fucus vesiculosis* in the Dulas Estuary and Amlwch Estuary (604 µg g^{-1} and 37 µg g^{-1} respectively) are significantly higher than in the surrounding waters, where levels range from 4 to 20 µg g^{-1}. Concentrations of zinc in this alga are also elevated; mean concentrations of 1294 µg g^{-1} and 559 µg g^{-1} in the Dulas and Amlwch respectively compared to a range of 47 to 138 µg g^{-1} in the surrounding area.

4.2 Frongoch Mine

As with Parys Mountain, Frongoch mine discharges via two watercourses, the Nant Cwmnewydion and the Afon Cell. These then join the Ystwyth River at different points. The Ystwyth fails River Quality Objectives for zinc for 37 kilometres due to the inputs from the different mines located within the catchment. Figure 2 illustrates the contribution Frongoch mine makes to the zinc levels in the Ystwyth.

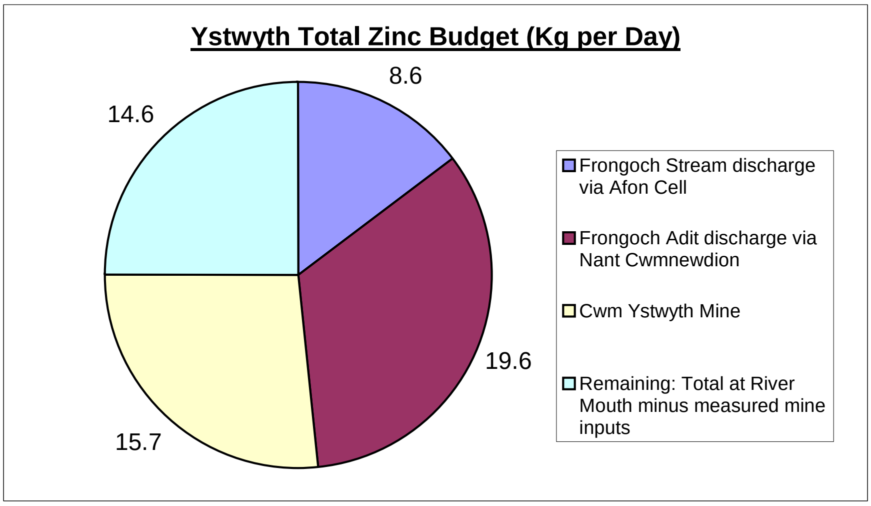

Figure 2. Afon Ystwyth Total Zinc Budget

Both the Nant Cwmnewydion and Afon Cell fail the Dangerous Substances Directive standards for copper, lead and zinc and the Freshwater Fish Directive and River Quality Objective standards for zinc. The Nant Cwmnewydion also fails the Dangerous Substances Directive standard for cadmium.

Invertebrate population assessments have been carried out on both the Nant Cwmnewydion and Afon Cell. No significant impact was found at the sites on the Cwmnewydion, but the invertebrate population of the Cell was significantly impacted by mine water inputs. At the Afon Cell sites, BMWP scores fell from 182 upstream of the mine to 97 downstream, a drop of almost 50%. This compares with RIVPACS predicted scores of 140 for the upstream site and 131 for the downstream site. Growths of blue-green algae were observed at downstream sites of both rivers: 70% substrate coverage on the Afon Cell and 40% substrate coverage on the Nant Cwmnewydion.

Absence of brown trout populations on tributaries of both rivers affected by minewater contamination has been observed. In both cases trout populations were present upstream of mine water contamination.

4.3 Cwm Ystwyth Mine

Cwm Ystwyth mine is located near the top of the Ystwyth catchment 10.5 kilometres above Frongoch mine. It has a major impact on the zinc levels in the Afon Ystwyth increasing the concentration from an average of 22 $\mu g\ l^{-1}$ upstream to over 300 $\mu g\ l^{-1}$ as far as the confluence of the tributaries from Frongoch Mine. Figure 2 shows that Cwm Ystwyth contributes a quarter of the total Ystwyth zinc load. There is also a significant increase in lead concentration from below the limit of detection of 2 $\mu g\ l^{-1}$ upstream of the mine to an average of 42 $\mu g\ l^{-1}$ immediately downstream of the mine. The result is that the Afon Ystwyth fails Dangerous Substances Directive standards for copper, lead and zinc and the Freshwater Fish Directive and River Quality Objective standards for zinc downstream of the mine site. Upstream of the mine only the Dangerous Substances Directive standard for zinc is failed.

Table 9. Metal Loads of the Afon Ystwyth and Cwm Ystwyth Mine

Site	Metal Load (kg per day)			
	Cadmium (total)	Copper (dissolved)	Lead (dissolved)	Zinc (total)
Cwm Ystwyth Mine	0.03	0.01	2.22	15.71
Afon Ystwyth at River Mouth	0.11	0.27	2.01	57.26

Not all of the lead measured at Cwm Ystwyth mine has been observed discharging at the river mouth (Table 9).

No impact has been observed on the invertebrate populations of the Afon Ystwyth that is attributable to Cwm Ystwyth Mine. However, the effects of the mine were thought to be masked by severe acidification of the catchment. This is shown by the difference between the observed and predicted scores for upstream and downstream sites. Upstream a score of 44 was observed compared to a predicted score of 150. Downstream the observed and predicted scores were 51 and 148 respectively. These results indicate a high level of environmental stress at both sites.

Fish populations have previously been absent immediately downstream of the mine, but the most recent survey data shows the existence of brown trout populations. There have been clear indications of the metal poisoning observed in fish populations downstream of Cwm Ystwyth mine with instances of black-tailing, increased body tissue concentrations and increased mortality of salmon and trout eggs (Milne et al., 1981).

5 Conclusion

This work has highlighted the mine sites making the most significant contributions to metals pollution of Welsh rivers. The prioritization results and the information collated are being used to focus current work on the highest priority sites. Work has already been carried out at Parys Mountain to control the existing mine drainage and a feasibility study at Cwm Rheidol mine has produced further understanding of the mine drainage and designs for a remediation scheme. Additional site investigations are being carried out this year at Dylife mine and the Frongoch complex of mines to better understand the sources of pollution, with consultants being commissioned to carry out studies on the feasibility of remediating these sites.

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