An Update on Parys Mountain Remediation and Welsh Metal Mine Management

Ben Rees

SRK Ltd. Cardiff, Wales, U.K.

ABSTRACT
At the IMWA Symposium 2004, several articles highlighted the legacy of abandoned metal mines in Wales. Building on these earlier publications, this paper describes the subsequent work undertaken at Parys Mountain. A feasibility study has been completed that has identified the overall preferred site management alternative. This involves allowing the system to continue to gravity drain, and requires two separate treatment schemes for the northern and southern sides of the mountain. Plans are now in place to conduct more detailed minewater treatability testwork.

INTRODUCTION
The mines on Parys Mountain constitute an industrial archaeological monument of international importance, the workings originating in the Bronze Age and dominating world copper markets in the 1780's *(Younger et al.,* 2004*)*. The whole area is under further consideration within the new 'European Route of Industrial Heritage' in the UK, and ultimately may be a potential candidate 'World Heritage Site'.
In addition to the historical and archaeological importance of the sites, the site also poses several risks. These are primarily related to the water environment as a consequence of sulphide oxidation and acidic drainage. Since 2002 several Phases of remedial action have been taken at the site to minimise this long-term legacy. Further details of the sits geology and geochemistry are given in *(Younger et al.,* 2004).

PHASE I – RISK MANAGEMENT
When deep mining ceased, a dam with valves was placed within the Joint level (sometime in the 1950's) which allowed water to flood both underground mines (Parys and Mona). Following the flooding, discharge from the artificially perched water table was manifest as an overflow through the Mona Adit to the East. From here, the drainage flowed through an extensive series of settlement ponds on the southern side of the mountain before confluence with the Afon Goch Dulas (AGD) and draining into the Irish Sea some 12km to the East.
In the late 1990's, access to the level was regained, where the drainage valves proved to be inoperative and the concrete showed signs of degeneration. This situation, where a large volume of highly acidic (pH 2) metal-rich water with a head of some 40m was impounded behind a dam of unknown stability was considered to pose a potential hazard to the town of Amlwch, located immediately downstream of the Joint Level. In response, the mine workings were successfully drained by a consortium comprising Anglesey County Council (ACC) and the Environment Agency (the Agency) in the summer of 2003. This was achieved by pumping from a 50m deep air-shaft (Gardd Daniel) located immediately behind the dam (see Figures 1 and 2) and Coupland et al., 2004.

Figure 1: Key site features

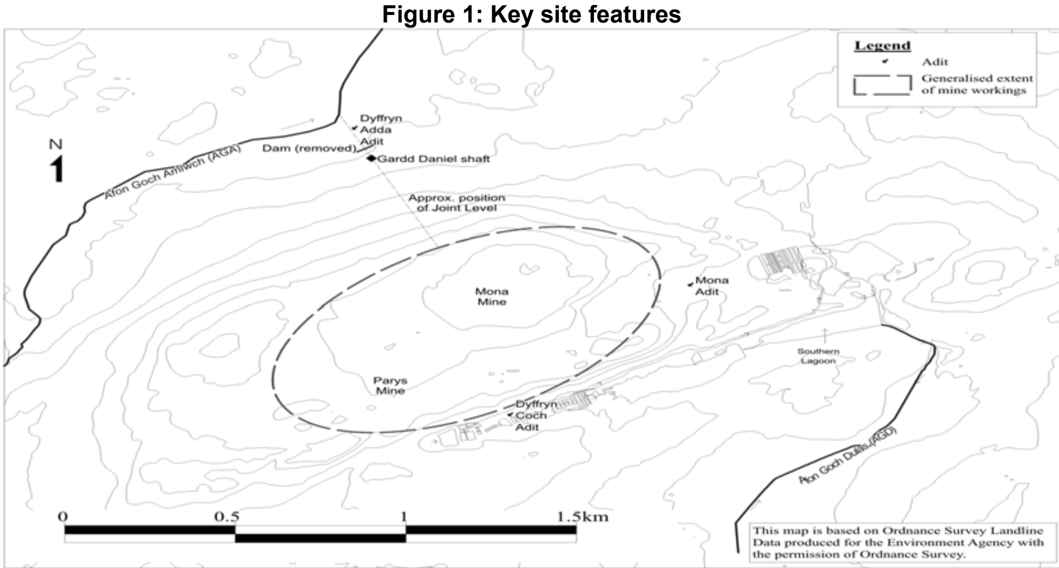
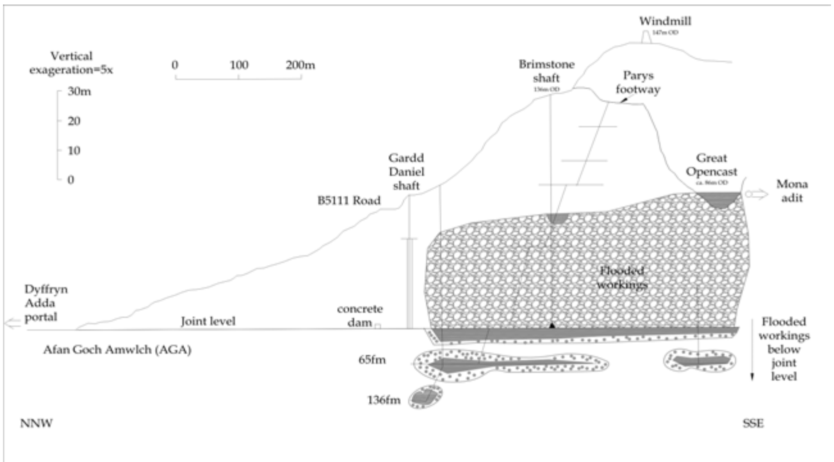


Figure 2: Conceptual cross-section of mine dewatering



Subsequent to the dewatering, the dam on the Joint Level was removed causing a significant change to the mine drainage. Minewater now moves northwards through the Dyffryn Adda adit, which, as the lowest drainage point, is the main discharge for the underground mine workings. As a consequence, the Afon Goch Amlwch (AGA) flowing to the North is now the main water course impacted by minewater discharge.
The dewatering project constituted Phase I of risk management at Parys Mountain. Phase II, as described here, is the subsequent protection of the AGA and AGD watercourses in response to the new mine drainage regime.

PHASE II – RISK MANAGEMENT
SRK Consulting (SRK) was commissioned by the Agency to undertake a feasibility study aimed at evaluating measures to protect the AGA and AGD watercourses under the new flow regime. The project objectives were to: -

- achieve water quality in the AGD that meets the EC water quality standards for freshwater salmonids at an agreed compliance point some 5km from the site; and
- to improve the water quality of the AGA, but not specifically to achieve water quality to support freshwater salmonids as the watercourse is considered to be of low ecological value.

Conceptual Mine Drainage Model
To ensure remedial measures were targeted at addressing the most significant risks to the watercourses, a site conceptual model was developed. This comprised:

- Desk study review of available reports;
- Assessment of the flow and hydrochemical spot measurements collected by the Agency at each mine adit and from the AGA and AGD for the period March – May 2004;
- Site walk-over with the Agency.

The dewatering indicated that there was a good hydraulic connection between the Mona and Parys mines and the Joint Level. Subsequent inspections underground by the PUG and other parties have confirmed this to be the case, although locally there remains ponded water in several stopes.
Based on the limited spot measurements, flow at each adit discharge was found to variably respond to rainfall. Flow from the Dyffryn Coch and Mona adits returned to levels typically less than 0.3 l/sec or too small to gauge. Flow at Dyffryn Adda was never below 5 l/sec (see Table 1). This data suggests that flow at the Dyffryn Adda adit has a baseflow component that is most likely the over-topping of the flooded workings below the Joint Level.

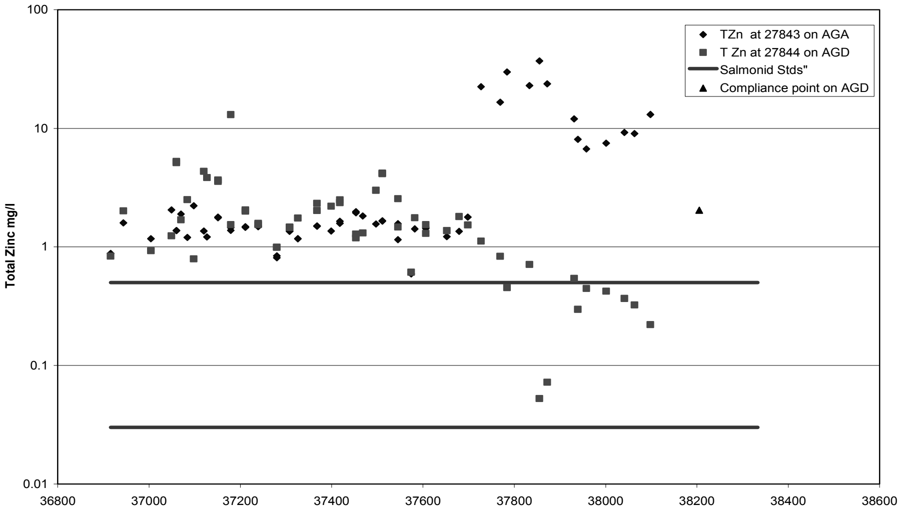
Table 1: Summary of adit discharge chemistry (March – May 2004)

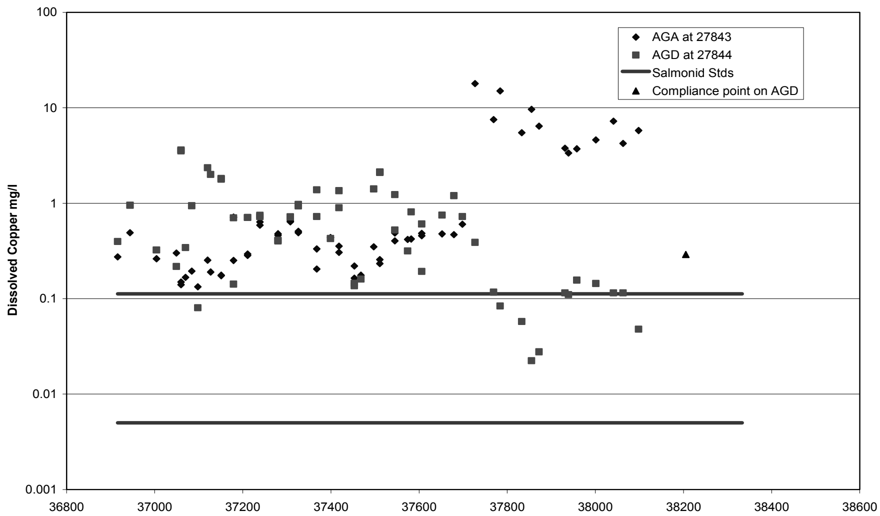
ADIT	FLOW (l/s)	pH (su)	Sulphate(SO_4)	Dissolved Oxygen	Aluminium (Al)
Dyffryn Adda Adit	1.4 - 12.7	2.67 - 3.08	1940 - 3020	1.6 - 2.99	76 - 0.004
Dyffryn Coch Adit	0.0 - 3.6	2.99 - 3.6	1120 - 1240	1.94 - 5.24	15.1 - 18.6
Mona Adit	No flow (ponded water)	2.48 - 2.93	375 - 1420	7.7 - 9.95	13.3 - 45.2
ADIT	**Cadmium (Cd)**	**Copper(Cu)**	**Iron (Fe)**	**Lead (Pb)**	**Zinc (Zn)**
Dyffryn Adda Adit	0.159 - 0.178	31.6 - 44.4	453 - 708	0.03 - 0.412	56.2 - 58.5
Dyffryn Coch Adit	0.146 - 0.166	7.37 - 9.28	135 - 179	0.393 - 0.492	55.9 - 66.6
Mona Adit	0.0561 - 0.2	13.3 - 36.8	66.5 - 268	0.601 - 1.79	14.2 - 61.7
All values in mg/l unless specified. [Other contaminants detected include boron, arsenic, thallium, nickel, selenium, antimony and vanadium].					

Impacts on Surface Water

Figures 3 and 4 illustrate the distinct changes that have occurred in terms of total Zinc and dissolved Cu within the AGA and AGD. At the compliance point on the AGD, the levels of Zinc and Copper are only slightly higher than the water quality targets without any remedial intervention.

Figures 3 & 4: Water chemistry in AGA and AGD rivers





SITE MANAGEMENT ALTERNATIVES

Preferred Alternative Determination

Several potential management alternatives were identified for their long-term protection of the water courses, as indicated in column 1 of Table 2. Stakeholders were asked to review each alternative and provide feedback regarding potential conflicts of interest, identify benefits and the overall suitability of the management alternative.

To resolve potentially conflicting interests and to identify the preferred site management alternative, a ranking matrix was developed. The aim of the ranking matrix was to provide an open and balanced mechanism for combining stakeholder views alongside the goals of the Agency, technical considerations and cost. Following feedback from the stakeholders, each alternative was scored against the criteria using a balanced scoring system. The results of this elevation are illustrated in Table 2.

The preferred option with the lowest score was to allow the system to continue to gravity drain and treat the discharges separately.

Table 2: Evaluation of management alternatives

Brief description of potential management alternative	**Technical Practicability**	**Regulatory acceptance**	**Stakeholder acceptance**	**Long-term liabilities**	**Comparative cost**	**Score**
Do nothing.	1	3	3	3	1	11
Capture discharge from Dyffryn Adda on northern side of mountain at surface and pump to south side of mountain. Combine in a single treatment facility.	2	1	3	3	3	12
Capture discharges / surface drainage from southern side of mountain and direct to northern side of mountain. Combine in a single treatment facility.	2	1	2	2	2	9
Treat the discharges on the northern and southern sides of the mountain separately.	1	1	1	1	2	6
Only treat discharges on northern side of mountain that are impacting AGA.	1	2	2	2	1	8
Only treat discharges on southern side of mountain that are impacting AGD.	1	2	2	2	1	8
Encourage natural biological processes within the presently flooded workings through the introduction of a carbon food source via suitable shafts / pumping. These processes would precipitate metals and decrease water acidity in the mine workings. Treat the partially treated discharge from the Dyffryn Adda adit on the northern side of the mountain.	3	2	2	3	2	12
Partially block Dyffryn Adda adit to allow minewater level to rise in mine workings. Encourage natural biological processes within the flooded workings through the introduction of a carbon food source via suitable shafts / pumping. These processes would precipitate metals and decrease water acidity in the mineworkings. Treat the partially treated discharge from the Dyffryn Adda adit on the northern side of the mountain.	3	2	2	3	2	12
Re-instate dam in Dyffryn Adda adit and only treat discharge from Mona adit on the southern side of the mountain.	2	3	3	3	3	14
Dam the periodic flows from Dyffryn Coch and Mona adits and allow minewater to drain into the existing flooded workings and discharge at Dyffryn Adda adit	2	2	2	2	2	10
Deposit sludge from minewater treatment and surface facilities (precipitation ponds / settlement lagoons) within flooded mineworkings.	3	2	2	2	2	11
Direct Dyffryn Adda discharge direct to the Irish Sea.	2	3	2	2	2	11
Re-profile and vegetate dump material that is releasing metals and acidity to surface water and potentially groundwater.	2	2	2	2	2	10

WATER TREATMENT
The overall approach to identify the preferred option for mine water treatment was similar to that used for the selection of the site management alternative. However, greater emphasis was placed on technical considerations, as it is this component that will determine ultimate achievement of the project objectives.

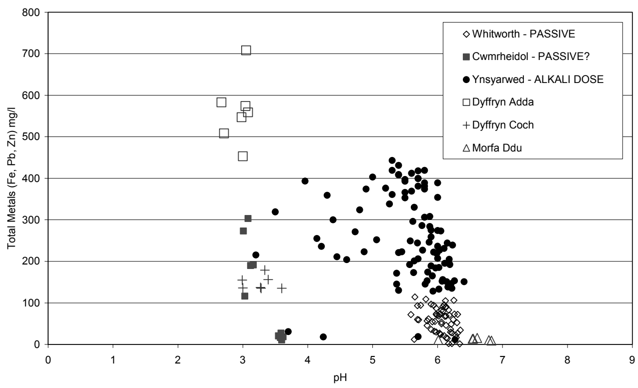
Treatment Methods
Following a review of potential methods, three potential surface treatment options were selected for further detailed consideration. These were:

- passive treatment, potentially using a Reducing and Alkalinity Producing System (RAPS)
- active alkali dosing using lime; and
- sulphide formation using liquid bioreactors.

The intention of this paper is not to describe in detail each method, but to demonstrate that equal consideration was given to each technology, as should occur during a feasibility study.

Passive Treatment
Best practice techniques within the EC for the passive treatment of acid mine drainage have recently been collated in the PIRAMID Guidelines (PIRAMID Consortium 2003). The most suitable methods for the passive treatment of the acid mine water at Parys would be several RAPS in series or possibly a compost wetland. These could be coupled to oxic limestone drains to increase alkalinity and settlement lagoons to capture precipitated ochreous sludge.
The extreme acid and metal rich characteristics of the water at Parys Mountain, particularly the Dyffryn Adda discharge, is clearly illustrated in Figure 5. Also included in the figure is water quality from several other UK coal and metal mine discharges for comparison. Where relevant, the treatment scheme used to treat the minewater is indicated in bold.

Figure 5: Comparison of UK minewater chemistry



This comparison enabled two important observations:

1. water chemistry encountered at Dyffryn Adda is more acidic and metal rich than most surface discharges in the UK and there is no current surface passive treatment system receiving similar water chemistry;
2. low flow periodic discharge of water from Dyffryn Coch adit is less mineralised and comparable to the discharge at Bowden Close that is being treated passively.

As a result of this assessment, the periodic discharge from the Dyffryn Coch was considered suitable for passive treatment while the Dyffryn Adda discharge requires active treatment.

Alkali dosing
For the treatment of mine drainage, lime is often the reagent of choice used to generate a hydroxide sludge within a High Density Sludge (HDS) treatment plant (REF). This method results in a sludge that is iron rich but which also typically contains co-precipitated phases of other trace metals such as Mn, Al, Cu and As, depending on the final treatment pH.

Sulphide Bioreactor
Under reducing conditions, sulphate in minewater can be reduced to sulphide and used to precipitate metal sulphides (REF). This can be achieved through the addition of a chemical source of sulphide or through the production of biogenically produced hydrogen sulphide (H_2S).
Such technologies have proven to be effective when integrated with an existing lime plant. In this system, a 2-stage metal precipitation and recovery circuit is used to produce separate concentrate products; one comprising iron hydroxide (trace metal poor) sludge and the other a metal sulphide (iron poor) sludge.

Preferred Method of Treatment

To enable the preferred method of treatment to be identified, several independent specialist active treatment contractors were commissioned to provide costed quotations and undertake bench scale experimentation. On this basis, the sulphide bioreactor was determined to offer the most cost effective alternative due to lower potential capital and operating costs. This method also offers the advantage of potentially generating two very distinct sludges with a lower total volume. The Agency is now hoping to conduct on-site pilot plant studies to finalise the designs considered during the feasibility study.

CONCLUSIONS

Several phases of remedial intervention at Parys Mountain have resulted in a situation where gravity drainage prevails and long-term water management methods have been evaluated to feasibility level. Pilot plant investigations are being planned to finalise designs. The implementation of the Strategy at Parys Mountain, and other Welsh mine sites has revealed many synergies between independent interested parties and the goals of the Agency. At Parys, there is great hope that preservation of one of Wales's finest mining legacies, the protection of the water environment and the opportunity for academic research will be integrated. Perhaps this will be the catalyst for the development of a Welsh Centre of Excellence at Parys Mountain for the treatment of metal mine drainage.

REFERENCES

Coupland, K., Rowe, O., Hallberg, K.B. and Johnson, D.B. *Biogeochemistry of a subterranean acidic mine water body at an abandoned copper mine.* International Mine Water Association. Mine Water 2004.

PIRAMID Consortium (2003) *Engineering guidelines for the passive remediation of acidic and/or metalliferous mine drainage and similar wastewaters. European* Commission 5th Framework RTD Project No. EVK1-CT-19999-000021 "Passive in-situ remediation of acidic mine/industrial drainage" (PIRAMID). University of Newcastle upon Tyne, Newcastle upon Tyne UK. 166pp.

Younger, P. L., Jenkins, D. A., Rees,. S B., Robinson, Jarvis,J. A. P., Ralph, J., Johnston D. N. and R. H. Coulton. *Mine waters in Wales: pollution, risk management and remediation.* In Urban Geology of Wales. National Museums and Galleries of Wales. Geological Series No.23. 2004.