# Sediment Harvesting using a Nautilus Pond™ within Surface Water Management at Esgair Mwyn.

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## Abstract

The abandoned Esgair Mwyn lead mine is situated astride a ridge in Mid Wales. Surface water run-off drains to the north in braided streams into the Nant y Garw, then Marchnant and Afon Meurig. Run-off to the south drains into the Meurig before entering the Afon Teifi. It presents the largest source of Pb to the Teifi, contributing to it failing Water Framework Directive (WFD) standards. A large steep conical tip contains ≈2% Pb, and planned surface water management includes a Nautilus Pond™ below the tip to harvest sediment, plus leat restoration with capping, conveying clean water away from spoil.

**Keywords:** Nautilus Pond™, surface water management, remediation, intervention.

## History

The Esgair Mwyn lead mine is located 21 km southeast of Aberystwyth. There has been mining in the district since Romano-British times. Lewis Morris claimed the Ancient Britons dug an open cast or trench along the vein after their manner for 100 yards, 20 yards wide and 18 yards depth (Lewis 1967). Hall (2012) considered the quarry subsidence from a roof collapse with the old or main lode 9 m wide carrying ore at the foot and hanging walls. The resource had apparently lain abandoned for centuries when rediscovered by poor miners and reported to Morris for the Crown in 1751 (Lewis 1967), making this mine socially and historically important. It is possible that portions of the main lode were the richest ever worked in Mid Wales (Hall 2012). Morris exported 1,767 tons prior to dismissal in 1756 with c.70 tons removed from site (Lewis 1967).

A new operator discovered appreciable quantities including a vein of sphalerite in 1765. Drainage into the old, flooded workings was secured in 1766, which enabled working down to the adit level, yielding 2,379 tons between 1767 and 1772. Another 970 tons were recorded by century-end, the miners extending the old workings to 50 fathoms below adit level, a remarkable achievement for the time (Hall 2012). Probably due to the roof collapse into the wide worked lode, the mine yielded only 250 tons between 1802-18 and then lay idle. Production recommenced in 1851, which through to 1917 yielded 10,430 tons (Lewis 1967) and between 1917 to 1927 2,304 to 2,784 tons (Hall 2012). The minimum recorded production is therefore 18,170 tons of galena or lead ore between 1751 and 1927.

The Engine Shaft (Penmynydd) at 410 mAOD was 64 m deep from surface around 1850, reaching 137 m under adit in 1857. Crushing rolls and the dressing floor operated close by. In 1878 Penmor or Western Shaft was sunk to ore at 55 m near adit entrance with a tramway laid, before closing in the 1890s. The mine plant was acquired in 1897 for dismantling, but the operator was persuaded by local miners to exploit the Penmor ore body which continued over 183 m vertically, where the solid galena was almost 1 m wide. Workings extended to 165 fathoms (302 m) below adit level of 330 to 340 mAOD, the deepest from surface in Ceredigion. Many thousands of tons were recovered until closure

in 1927 (Bick 1974), employing about 60 men. Renewed activity occurred in 1947 with plant installed to treat the large waste dumps, and an unsuccessful attempt to clear the adit to reach sphalerite reserves. Captain Nancarrow, the general manager at Glogfawr Mine, and who erected the mill at Gwaith Goch, had sampled the tips in the 1920s and estimated 60,000 tons with an average grade of 2% Pb (Hall, 2012). In 1973 Elenith Mining Company redesigned plant and produced some Pb that was subsequently stolen from site.

## Site Setting & Geology

Surface water run-off drains to the north in braided streams into the Nant y Garw, then Marchnant. Run-off to the south drains into the Afon Meurig, which is joined by the Marchnant before entering the Afon Teifi and Cardigan Bay. The site comprises areas of mine spoil, former rod mill, ball mill, tailings deposits, disused shafts, derelict structures and open works / surface pits along the mineral lode outcrop. A small tailings dam sits beneath the conical tip, its capacity extending to 2,273 m3 when the embankment crest was twice increased. Seepages along the original crest to the toe of the structure remain evident and caused a small translational failure. There is reference to three leats used to convey water originating at Llyn Fyrddon 4 km to the east. The lowest leat to the northeast of the conical tip was constructed around 1907 to pass used water via a turbine on to Glogfach Mine, which had reopened (Hall 2012). Sections of this leat have subsequently failed, allowing water to flow over fine mine waste, presumably periodically cleaned out of the leat when operating, and enter drainage channels 1.1, 1.2 and 1.3 (fig. 1).

Located in the Central Wales Orefield, the bedrock is the Devil's Bridge Formation of Llandovery Age in the Silurian. The lode strikes ENE, dip 64° NNW with outcrop sub-parallel to an east-west ridge line. The lode is defined as the Main lode in ENE, Hospital vein and Western ore shoot.

Site characterisation, run-off modelling and options assessment

Mining and mineral processing operations have resulted in elevated Zn, Pb and Cd concentrations above Environmental Quality Standards (EQS) in the Nant y Garw and Afon Meurig in Cwm Gwyddyl (Scorey 2012). This results in the Afon Meurig waterbody failing to achieve Water Framework Directive (WFD) 'Good' status and contributes to the 'Moderate' status of the receiving Afon Teifi waterbody.

An initial remedial options appraisal was undertaken, including a review of existing data and additional site characterisation (AECOM 2016). A single round of water quality and salt dilution flow monitoring was undertaken, and mine spoil was characterised using pXRF at 49 locations, supplemented by wet chemistry at seven locations. These seven samples were also subject to XRD analysis, identifying frequent cerussite (5), occasional anglesite (2) together with sphalerite (4) and galena (2) indicating some oxidation to more soluble carbonates and sulphates.

To the south the dissolved metal loadings from the adit into Afon Meurig were estimated at 68 kg/yr Zn and 1 kg/yr Pb. It was considered that mine water represents 20-25% of the normal flow in the river.

The primary sources of contamination to the Nant y Garw were identified as the former leat, where tailings have been deposited, the main conical tailings tip, the former dressing floor and sediment in drainage channels and the tailings dam. Two first-step intervention measures were recommended to reduce pollution and the amount of contaminated water requiring future treatment: surface water diversion/rationalisation and sediment arrest to reduce the off-site migration of contaminated sediments into the downstream catchment.

The data review also identified evidence gaps, in particular the availability of reliable flow data in the northern drainage network feeding the Nant y Garw. Between 2015 and 2022 NRW pursued a programme of concurrent water quality and flow monitoring, utilising salt dilution gauging where possible, in the Nant y Garw catchment. The data have been periodically analysed and reported to inform the optioneering and design of remediation measures (Hudson 2015; Francis 2018; Hudson *et al.* 2018). A summary of the full dataset is presented in Table 1.

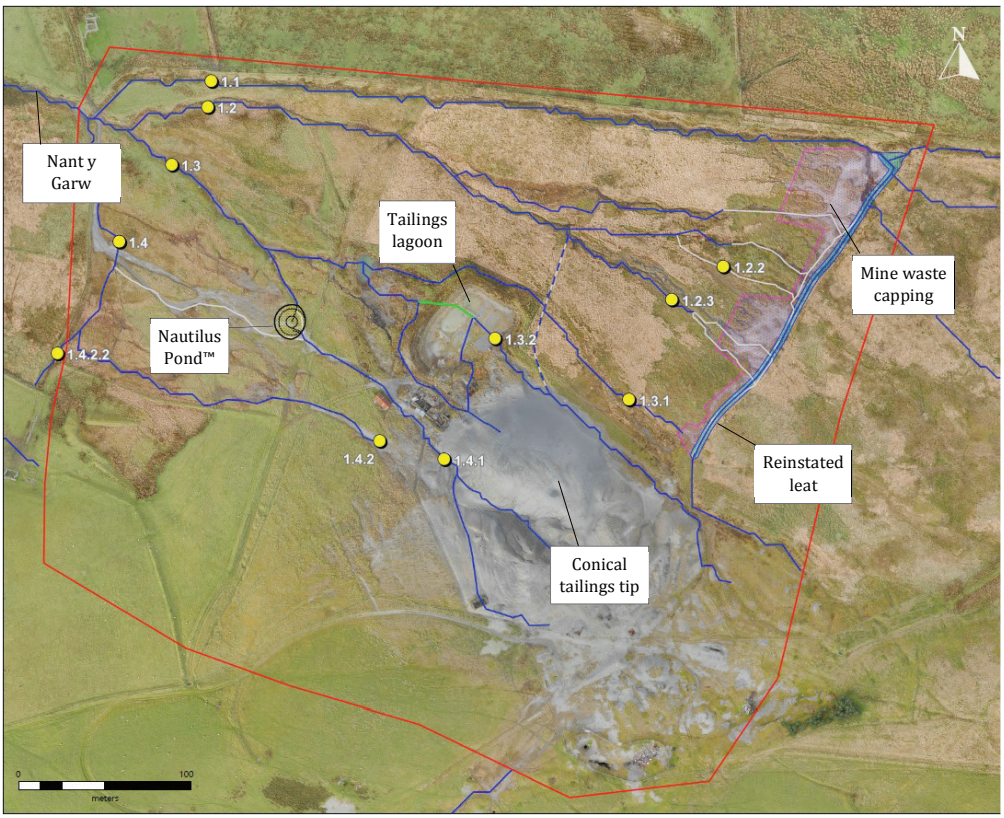


***Figure 1*** *Aerial image of northern site area identifying key features, braided network of drainage channels (numbered nodes) and proposed remedial measures.*

Metal loadings to the Nant y Garw from Esgair Mwyn are estimated as 1,897 kg/yr Pb, 766 kg/yr Zn and 3.2 kg/yr Cd. The primary source of Pb is ephemeral drainage channel 1.4 which originates from the main tailings tip (fig. 1). The second largest source of Pb is channel 1.2 which includes run-off from the historical leat and associated areas of tailings. This suggests that entrained sediments from tailings sources are the main driver of Pb contamination. The primary source of Zn and Cd is channel 1.3 which includes discharge from the tailings dam. It should be noted that the sum of loadings in channels 1.1, 1.2, 1.3 and 1.4 only accounts for 69% of the Zn and Cd loading and 37% of the Pb loading measured in the Nant y Garw. This could be due to measurement error, groundwater sources not captured by the monitoring locations and/or in-stream sediments between input channels and the Nant y Garw monitoring location.

***Table 1*** *Flow and metal loadings to Nant y Garw from NRW monitoring data 2015-2022.*

| Channel | Flow (L/s) | Metal loading (kg/yr) | | |
|---|---|---|---|---|
| | | Zn | Pb | Cd |
| 1 (Nant y Garw) | 20.4 | 766 | 1,897 | 3.2 |
| 1.1 | 9.0 | 11 | 97 | 0.1 |
| 1.2 | 6.3 | 38 | 130 | 0.2 |
| 1.3 | 2.0 | 294 | 83 | 1.4 |
| 1.4 | 1.1 | 184 | 383 | 0.6 |

NB: Loadings based on unfiltered water quality samples to provide dissolved and suspended metal load in the water column; not including particulate transport associated with stream bed sediments

To enable remedial options shortlisting, modelling of the site's existing drainage network was undertaken (AECOM 2018a). A topographic survey of the site was completed using an Unmanned Aerial Vehicle (UAV) to an accuracy of 30-50 mm, with a more detailed ground survey within the drainage channels to an accuracy of 20-30 mm. A TUFLOW rainfall run-off model was created and run, comprising synthetic rainfall over a Digital Terrain model (DTM) produced from the topographic survey. This identified the Nant y Garw as the receiving watercourse, with the four principal run-off channels 1.1, 1.2, 1.3 and 1.4 feeding it, with additional nodes on each channel (fig. 1). The TUFLOW model derived that in a 1% Annual Exceedance Probability (AEP) event (1 in 100 year) contribution to total site run-off (Nant y Garw) was 32% from 1.1, 45% from 1.2, 14% from 1.3 and 6% from 1.4. This demonstrated that most of the flow from the site is not conveyed through the existing tailings lagoon. It was therefore recommended that remedial options should focus on re-routing the flow paths associated with channels 1.2, 1.3 and 1.4.1 to a sediment arrest feature around 1.3 as this would require the least length of channel diversion.

Spoil erosion and sediment yield analysis was completed using the Soil Loss by Water Erosion in Europe Revised Universal Soil Loss Equation model (RULSE2015) and application of a Sediment Delivery Ratio (SDR), providing a modelled sediment yield for the site of 20-40 tonnes per year. This theoretical figure includes areas of visibly eroding mine spoil but requires confirmation through monitoring of sediment accumulation in the proposed sediment arrest structure.

Based on observation of on-site stream discharge rates and erosion / slumping of the main spoil tip, a large proportion of the mine spoil erosion and transport to the off-site surface water receptors is expected to be linked to high rainfall events. Flow monitoring indicates that the typical flow range in the Nant y Garw at the downstream site boundary is in the range 2-12 L/s, with flows up to 215 L/s recorded during storm events. TUFLOW modelling gives a 20% AEP peak flow of approximately 400 L/s – equivalent to a 1 in 5 year event.

Portable XRF and wet chemistry analysis of mine spoil samples confirm lead concentrations in the range 822–185,433 mg/kg (i.e. 0.8-18%), mean 27,683 mg/kg with the highest concentrations within the leat sediments. At the lower range of erosion rates and mean mine spoil concentration (20 t/yr, 27,683 mg/kg) the potential sediment based lead loading to the Nant y Garw is estimated as 550 kg/yr. The erosion and transport of high lead concentration mine spoil represents a major lead input to the surface water network and also represents a major secondary source of lead once incorporated into the downstream river bed sediments. Reducing transport of contaminated sediments from Esgair Mwyn is a priority for remediation.

Three potential locations were initially proposed for a sediment arrest pond (AECOM 2019a). At an optioneering workshop, reinstatement of the historical mining leat was suggested as an option to separate cleaner upslope flows from those routed through the existing leat alignment and associated areas of tailings. A subsequent leat modelling exercise confirmed that reinstatement of the existing leat alignment would reduce flows to channels 1.2 and 1.3 by 46%-48% (AECOM, 2018b). It was recognised that rainfall on the exposed tailings along the leat would continue to mobilise contaminated sediment into the leat and channels 1.1 and 1.2. The proposed solution was to cap the exposed tailings with a low permeability barrier, such as Geosynthetic Clay Liner (GCL).

The leat modelling informed a sediment analysis exercise which demonstrated that at least 20 tonnes of particulate sediment could be mobilised from the entire site each year, highlighting that previous options underestimated the size of the required sediment arrest pond, which may need to be up to 70 m diameter. With the reinstated leat reducing flows in channels 1.2 and 1.3, and the lower metals content of sediments in 1.3 (Francis, 2018), a smaller pond was proposed to solely capture sediments generated from channel 1.4, downstream of the main tailings tip. The preferred option taken forward to outline design (AECOM, 2019b) was

reinstatement of the historical leat with associated capping of tailings deposits and construction of a sediment arrest pond on channel 1.4, which would discharge into channel 1.3. The potential sediment retention on channel 1.4, following leat reinstatement and channel rationalisation, is expected to be considerably lower than the modelled 20-40 t/yr site total. Scaled by 25% of site catchment area would give an estimated 5-10 t/yr.

## Habitat, Heritage & Landscape Constraints & Opportunities

Selection of the proposed remedial interventions has included assessment and consideration of environmental constraints and opportunities. An Environmental Constraints and Opportunities Record and associated Environmental Constraints and Opportunities Plan have been prepared to document the constraints, plus develop opportunities for maintaining and improving environmental conditions at the site. Public amenity assets include a national walking route and public footpath, both Public Rights of Way (PRoW) to be retained.

Ecological and habitat conditions have been assessed through a Preliminary Ecological Appraisal (PEA) and supporting surveys, including a Lower Plant Species Survey, National Vegetation Classification Survey, Habitats Regulations Assessment (Test of Likely Significant Effect, and Appropriate Assessment) and a Raptor / Breeding Birds Survey. The PEA recorded a common lizard observed in 2018 with potentially suitable reptile habitat provided for slow worm and adder. A Reptile Mitigation Plan requires that winter working during brumation is to be avoided and an environmental watching brief will be required during construction activity.

The Historic Environment Record and National Monument Record identify 31 heritage assets on the site, with an additional nine identified through on-site inspection, all relating to the industrial heritage of the mining site / activities. An archaeological watching brief is anticipated for leat reinstatement works, an area classified as having high archaeological potential. Esgair Mwyn is within the registered historic landscape of Upland Ceredigion and the Banc Esgair Mwyn and Rhos Tanchwarel character areas.

The proposed remedial works have been designed to fit within these constraints without adverse impact and will be managed with an Environmental Action Plan and provide a number of opportunities for improvement. The works will avoid key areas of heritage interest around the lagoon and former process structures, plus lower plant species both here and on areas of bare spoil to the east of the conical tip. The principal opportunity for improvement is the reduction in contamination of surface waters, with the Afon Teifi being an important salmon and sea trout fishery. Additional opportunities for improvement include reinstatement of the PRoW along the leat, which is currently in very poor condition and difficult to traverse. Improving access and provision of interpretation boards will enhance the public amenity value of the site.

## Nautilus Pond™ & Leat Reinstatement

Sediment arrest was recognised as a primary requirement to reduce metal loading to downstream watercourses and the Nautilus Pond™ was identified as a potential solution. The pond uses an outer circular chamber with spiralling flows that minimises velocity across the whole area, enabling settlement of particulate matter. Cleaner water enters a central chamber that effects drainage. The diameter is anticipated at 15 m with normal water levels at 2 m, and bypass at 3 m depth. The outer chamber requires periodic removal of harvested sediment.

Reinstatement of an historical leat was determined an effective means of capturing cleaner upslope water and conveying it away from tailings deposits into channel 1.1 (fig. 1), as well as having heritage benefits. In-keeping with historical construction methods, puddle clay was initially considered for lining the leat. In view of the periodic flows encountered and the risk of desiccation, it was decided to use the more robust concrete canvas. The reinstatement will also incorporate capping of the downslope tailings deposits with GCL

and a 300 mm confining layer with 100 mm soil cover prior to hydroseeding with specialist seed mix, biochar and tackifier.

Detailed design of the leat reinstatement and capping is complete. The Nautilus Pond™ design is being finalised with support from the parent company Source2Source prior to construction.

When applied to legacy metal mine environments, the harvested sediment if determined as waste, as it currently would be, will be classed as hazardous, which doesn't readily comply with Natural Resources Wales's Natural Resources Policy or Sustainable Management of Natural Resources (SMNR). Being categorised hazardous waste, the harvested sediment must be transported to a suitable disposal facility, currently in England. This will incur expensive carbon and monetary costs for ongoing operation and maintenance unless policy or guidance is changed enabling valorisation, stabilisation or direct use in the upper catchment of origin, thus achieving SMNR.

## Conclusions

The Esgair Mwyn mine site is the largest single source of Pb contamination within the Teifi catchment. Monitoring data indicates that lead and zinc loadings to the Nant y Garw / Marchnant are approximately 1,900 kg/yr Pb and 800 kg/yr Zn. Sediment modelling and mine spoil analysis suggests that particulate contaminant loads to the Nant y Garw / Marchnant are likely to be considerably higher. Conservative modelled erosion rates and mean spoil lead concentrations predict 550 mg/kg Pb load to the Nant y Garw. The distinctive grey coloured mine spoil and tailings sediments can be visually identified in the Nant y Garw immediately downstream of Esgair Mwyn and represent an ongoing secondary metals source within the stream bed sediments.

Remedial intervention to reduce the transport of Pb-rich sediments to the Nant y Garw, Marchnant and Teifi represents the first and highest priority step to reduce the impact of the site on the downstream water body.

Reinstatement of a former mine leat and capping of mine spoil / tailings along the leat, will reduce surface water contact with contaminated sediments, with a modelled 45–50% reduction in flow within three currently contaminated surface water drainage channels. A corresponding increase in clean water flows will be routed around the site.

Installation of a Nautilus Pond™ to provide sediment arrest / harvesting on the principal outflow channel from the main conical spoil tip will reduce off-site transportation of contaminated sediments within the streams.

## Acknowledgements

This study is funded by the joint Metal (Non-Coal) Mine Programme of NRW and the Coal Authority sponsored by Welsh Government. We extend our thanks to Dr Nina Menichino, Team Leader, Evidence Portfolio, Programmes and Processes at NRW for supporting this paper.

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