Emerging Opportunities for Improving Legacy Metal Mine Water Pollution driven by Changing Regulatory Environments and Outputs of Novel Fieldwork in the Southern Uplands of Scotland

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Abstract

The Wanlock Water is polluted by relicts of a former lead mining and processing industry. The problem is well known but it has been difficult to justify funding bids for remediation due to uncertainty about the scale of the water quality improvement remediation works could deliver. Utilising opportunities created by a regulatory shift at SEPA, source apportionment work has been undertaken. Application of tracer injection and synoptic sampling in the Wanlock Water improved the understanding of key sources. Water quality improvements achievable by remediation have been estimated and collaboration towards improvement is progressing in the context of wider political objectives.

Keywords: Regulation, Collaboration, Source Apportionment, Tracer Injection, Synoptic Sampling.

Introduction

Metalliferous deposits in Scotland are generally small scale and scattered throughout the country (EnviroCentre Ltd *et al.* 2015). Accessible and productive galena and sphalerite veins resulted in the villages of Leadhills and Wanlockhead in the Southern Uplands of Scotland being at the centre of lead production for the country, especially in the 19th & 20th century. The Wanlock Water contains elevated concentrations of Cadmium (Cd), Lead (Pb) and Zinc (Zn) associated with former lead mining and production industry in and around the village of Wanlockhead. Evidence of this industrial activity remains prominent in the landscape and there are numerous potential mine pollution sources in the head waters of the Wanlock valley within the River Nith catchment (Figure 1).

The Wanlock Water has a Water Framework Directive (WFD) classification of less than Good due to the pollution caused by the mining that once thrived there (SEPA 2019). The Wanlock Water flows northwest for 8 km to the Crawick Water, where the Pb attenuates and is diluted, but Cd and Zn cause it to be of less than Good status. Cadmium concentrations continue to be elevated in the River Nith with a total of over 50 km of river at less than Good status.

The WFD requires countries to work towards rivers being of Good ecological status or above and required agencies such as SEPA to classify all water bodies. The monitoring of rivers in the areas under the WFD has helped to formalise the scale of the problem of mine water pollution. Yet legislation restricts the liability that can be placed on those who owned and operated mines that were abandoned prior to 1999 (Environment Agency 2008). This, in effect, severely restricts the likelihood of successful enforcement and creates a situation whereby alternative funding models are required to fund remediation. In Scotland, funding routes could be available to help improve the water quality, but the options and opportunities may increase by collaboration with other aims.

The pollution, the regulatory situation, and potential funding opportunities available for remediation gives cause for sufficient understanding of the numerous mine pollution sources that are known to be present. In particular metal loadings from both point

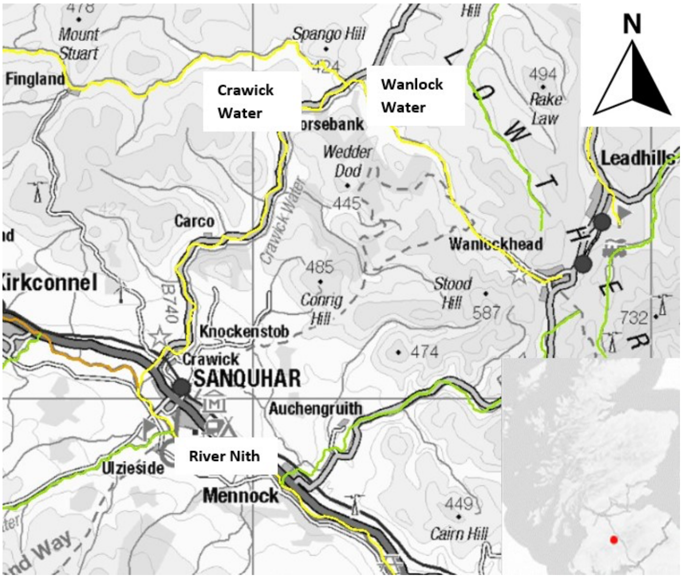

Figure 1 *Wanlock Water and Crawick Water in the River Nith catchment, Scotland.*

and diffuse sources are required to be able to understand the improvements that could be achieved by targeting specific sources and what the scale of any improvement in water quality would be to the wider catchment. This paper discusses the value of a source apportionment study in the Wanlock Water using novel techniques, and the remediation opportunities arising from it, in the context of the Scottish Environment Protection Agency (SEPA) regulatory strategy.

One Planet Prosperity

The Regulatory Reform Act (Scotland) 2014 gave SEPA its current statutory purpose, to protect and improve the environment in ways that, as far as possible, create health and well-being benefits and sustainable economic growth. The organisations' strategy to implement this purpose is called One Planet Prosperity (1PP) which highlights that as a country Scotland overuses it resources and that SEPA should be aiming to improve the environment while helping communities and businesses thrive within the resources of our planet.

While the approach does not alter any of the environmental regulations businesses must adhere to, or how they are enforced, it does change the approach taken to regulation with a push to work with communities and business to go 'beyond compliance' to improve their overall environmental impact in the climate emergency. This enables collaboration in a way that has a benefit to the environment and supports potential innovations in the field of mine water remediation.

In the context of the pollution issues known in the Wanlock Water, instead of just aiming to meet water quality standards, any projects to improve water quality are more likely to succeed if they have multiple aims and benefits. These could include supporting national climate change goals, increasing the amenity value of land to the local community, increasing the value of the industrial heritage or introducing the principals of circular economy into the solution. Using and building in other benefits to mine water remediation projects allows a variety of organisations to become involved to drive the water quality improvements.

A brief history of monitoring in the Wanlock Valley

In the former mining area of Wanlockhead and the adjacent village of Leadhills, knowledge of water pollution from the former mines is longstanding. The Clyde River Purification Board identified trout with blackened tails, an indicator of chronic Pb poisoning, with analysis of fish tissues revealing elevated Pb concentrations back in the 1980's in the Glengonnar Water flowing from Leadhills (SEPA 2011). In the same valley high levels of Pb have been found in the floodplain sediments (Rowan *et al.* 1995). As mining occurred in the same mineral veins, along with processing and smelting activity in the Wanlock valley similar pollution was anticipated to be present in the Wanlock Water.

Subsequent studies by the Coal Authority identified that there are numerous potential mine pollution sources in the head waters of the Wanlock Valley (Coal Authority 2011; Coal Authority 2014). The work confirmed previous findings that Cd and Zn are found in the river predominantly in dissolved (<0.45 µm) form while Pb is predominantly in particulate form. In total over 20 potential diffuse and point sources were identified, either by sampling run off and discharges or desk study researches, with potential for distinct sources within some of the larger features. Though some calculations were carried out on loadings from particular sources, source apportionment of the many identifiable sources had not been carried out. Some of the key features of interest and potential sources are shown in Figure 2 and Figure 3 which also show the change in the valley over the most industrious period of mining and processing between the mid 1800's and mid 1900's.

Local challenges and the benefits of source apportionment studies

The Environment Agency (EA) in England and Wales, and subsequently Natural Resources Wales (NRW) have both made good progress in securing funding for non-coal mine water contamination remediation. By comparison, Scotland has a smaller scale of problem with metal mine water pollution. Resource constraints can make it challenging to dedicate sufficient effort to gathering concurrent metal concentration and flow data by standard salt slug methodologies on the scale required to understand loadings from numerous mine pollution sources on a 3 km reach of river. Furthermore, in this area of south west Scotland the annual rainfall exceeds 1500 mm/a (Rowan *et al.* 1995). As a result collecting good quality metal loading

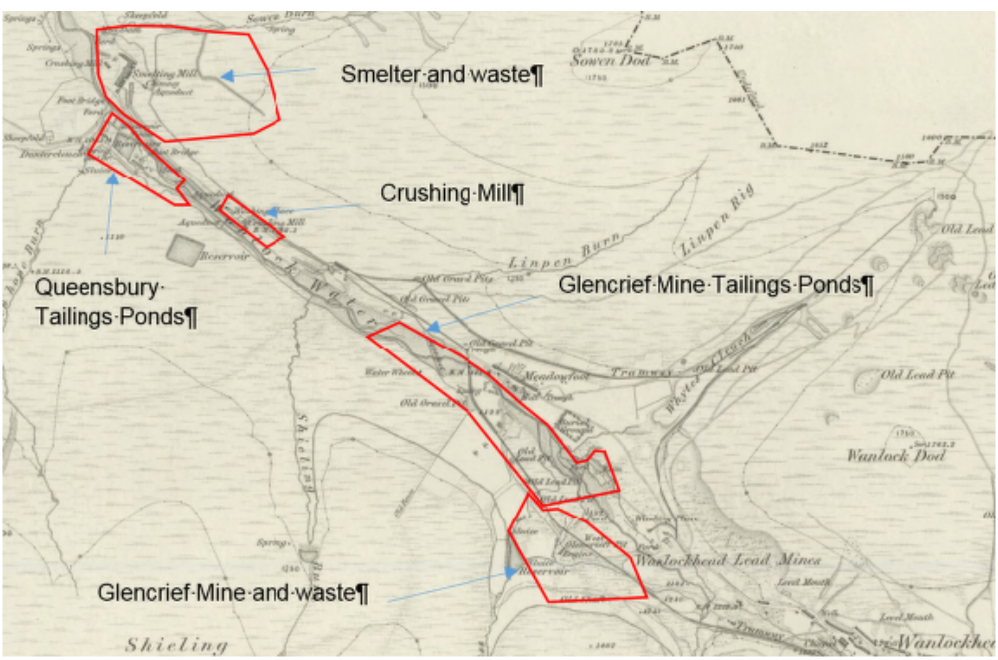

Figure 2 Potential diffuse sources in the Wanlock Valley on an extract of the Ordnance Survey Map of 1860 (OS 1860).

Figure 3 *Potential point sources in the Wanlock Valley on an extract of the Ordnance Survey map of 1962 (OS 1962).*

data at multiple locations and under a specific flow regime can be challenging when the site work required is likely to span a number of days, and the river is known to react rapidly to rainfall. Such work requires a level of reactive sampling that is not practical to deploy.

Knowledge sharing events such as those hosted by NRW in recent years have highlighted the benefit to their mine remediation program of a concurrent flow and water quality sampling method using continuous injection of conservative salt tracers (Byrne *et al.* 2020). The technique developed by the U.S. Geological Survey (USGS) to undertake source apportionment of mine water pollu-tion has since been used successfully to identify discrete pollution sources in rivers affected by mine water pollution (Kimball *et al.* 2002; Runkel *et al.* 2017).

In partnership with Liverpool John Moores University (LJMU), SEPA undertook a source apportionment assessment using a continuous salt tracer injection and synoptic sampling along a 2 km river reach of the Wanlock Water. The work was commissioned due to the potential to drive improvements in the context of the 1PP regulatory strategy.

Source apportionment results

The fieldwork and subsequent sample laboratory work and data analysis was carried out by SEPA and LJMU. The methodology is presented in Byrne *et al.* (accepted). The source apportionment data identified that under Q30 (medium to high) river discharge conditions, three mine water discharges contribute c.60% of dissolved Cd and Zn loading. An area of tailings deposits in the floodplain and a braided section of the river contributed c.60% of dissolved Pb, the tailings were also notable sources of Cd and Zn (Byrne *et al.* accepted). The work also demonstrated that tracer injection and synoptic sampling works well in small temperate rivers at flow rates of around 280 L/s, and could be scaled up further if necessary.

While it is acknowledged that this study was undertaken only on one occasion, when combined with the large amount of historic water quality monitoring data in the wider catchment, it adds substantial new detail to the available evidence. It identifies the largest pollutant loads to be from diffuse mine tailings source (Cd and Pb), a braided wetland section of the river likely affected by sediment deposition (Pb) and point source mine water discharges (Cd and Zn). The metal loading data provides simple visual tools to convey technical data effectively to stakeholders including government, landowners, local authorities and community groups such as the map and graph presented in Byrne *et al.* (accepted) and reproduced here by way of example in Figure 4.

Emerging opportunities

The outputs from the recent and historic monitoring data set were utilised by SEPA to inform Source Apportionment Geographical Information System (SAGIS) modelling to provide an indication of the metal loading reduction required to achieve status improvements in the wider River Nith catchment downstream from the study area. This indicated that a 20% reduction in Cd and Zn at source in the Wanlock Water could lead to improvement in status of the River Nith.

Potential reductions from five different remediation scenarios based on the pollutant loadings for Cd and Zn as shown in Figure 4[b] were undertaken by Byrne *et al.* (accepted). Given that achieving 100% reductions from a single source location is unrealistic, it is considered that to achieve a 20% reduction in Cd and Zn from more than one source would need to be targeted.

Upon completion of the work the outputs have been utilised to compile an up to date picture of our understanding of the pollutant

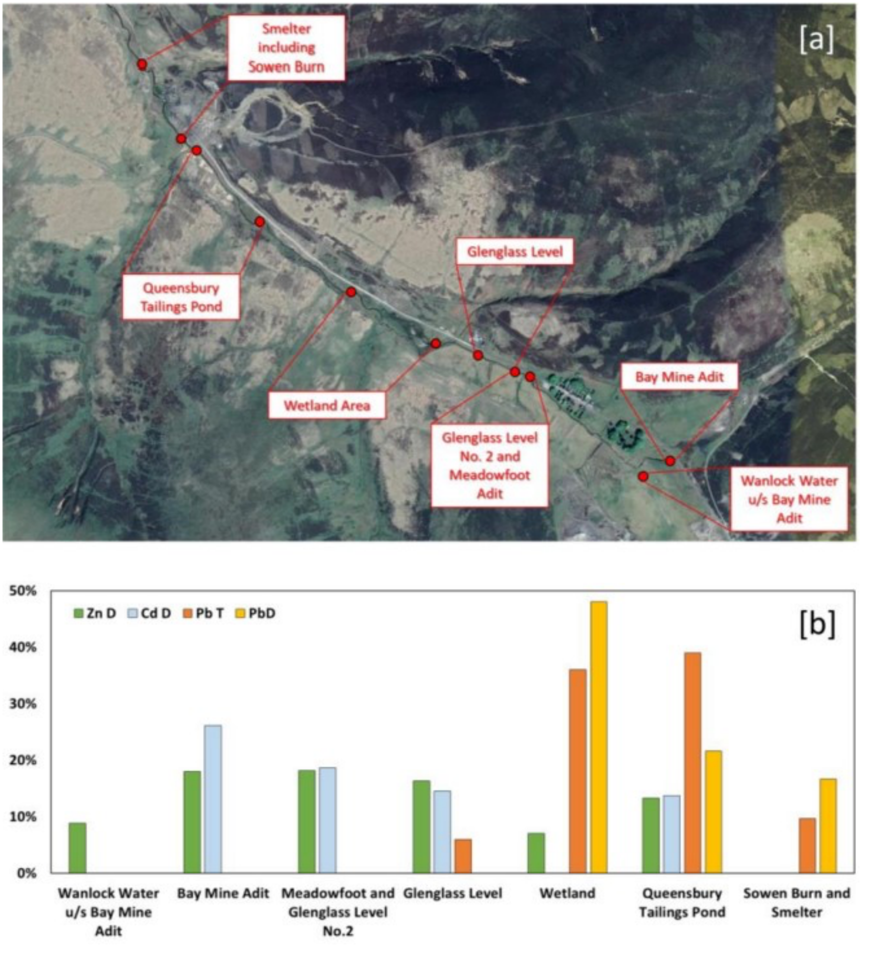

Figure 4 Locations [a] and percentage loadings [b] over the study reach of Wanlock Water from Byrne et al. (accepted)

sources in the area. It is clear that at least one of the point sources of mine water discharge needs to be targeted to reduce Cd and Zn, but in order to reduce the Pb loading work will also be required on the diffuse sources of legacy land contamination. One of these features is the un-vegetated former Queensbury tailings pond, located adjacent to the Wanlock Water and is eroding into the river, causing pollutant loading of Cd, Pb and Zn. It is therefore a good feature to consider for remediation, and the source apportionment backs up previous recommendations to remediate this feature by the Coal Authority.

Source apportionment allows us to highlight the important sites to researchers and as the environmental regulator working to the 1PP strategy we can collaborate to support and facilitate research work where appropriate within the bounds of SEPA's remit. Existing connections to academic and research and development projects in the field of remediation and the circular economy have presented opportunities such as an international project to trial planting of biofuel crops on contaminated soils, which could provide a purpose to many vacant and derelict sites to produce more sustainable fuels. It is hoped to use areas of tailings as test sites for this project. Trials are also planned of novel methods of mine water treatment that have potential commercial applications in many other water treatment scenarios. We are now better placed to identify the most appropriate site to trial water treatment techniques in the area.

Other opportunities can come from changing government policy in planning, introducing the concept of placemaking goals being embedded in environmental improvement projects. This could lead to outcomes such as improving tourism facilities, visibility of heritage sites, and amenity land for local people being provided as part of remediation works. Work is underway to bring together a wider stakeholder working group with the ultimate aim of it leading various projects to improve water quality, facilitated but not led by SEPA.

Conclusions

Understanding the significance of mine water pollution in the context of the wider political climate of a country provides a sound base to achieve the goals of watershed management plans. It can be seen how source apportionment work, in combination with existing data and the new regulatory environment is allowing us to highlight the legacy mine water pollution issues to the various stakeholders. This in turn helps promote the potential of remedial projects to deliver environmental improvements, while embedding other socio-economic principals. As action to combat climate change rises higher up the agenda, it will be critical to embed wider sustainability goals into projects to achieve funding. The challenge now in Scotland is to engage and collaborate with the right people and organisations to make that happen and deliver at least some improvement to the water quality in the Nith catchment.

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