Nent Haggs Mine Water Treatment Scheme

TN03a – Active Treatment Technologies Appraisal

The Coal Authority

Project Number: 60534600
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1. Introduction

1.1 Overview of the project

The Department for Environment, Food and Rural Affairs (Defra) set up the "Water and Abandoned Metal Mines" (WAMM) Programme in 2010 to begin to tackle pollution from the hundreds of metal mines across the country. The programme is delivered as a partnership between Defra, the Coal Authority and the Environment Agency.

The River Nent fails to achieve good status for cadmium, lead, zinc, fish and invertebrates. The Northumbria River Basin Management Plan (RBMP), published in 2015, includes steps for addressing pollution from abandoned mines and managing the impacts to 2027. The WAMM programme has ranked the River Nent as the lowest quality in the Northumbria RBMP, and one of the lowest quality rivers in England, with respect to mine water related pollution. The pollution from the River Nent contributes to pollution in the River South Tyne up to 40km downstream. Due to these impacts, the Nent Catchment has been a priority for investigation, assessment and targeted improvement measures.

AECOM has been appointed by the Coal Authority to undertake the feasibility and outline design for a mine water treatment scheme (MWTS) at the Haggs Horse Level Adit (Haggs Adit) which is one of the point source contributors to the failure of the River Nent under the RBMP. The aim is to reduce the metal loading (principally lead, zinc, cadmium) within the mine water discharge from the Haggs Adit by between 70% and 90%, providing betterment to the River Nent, whilst adhering to the conditions required for any consents, licences and permits. The construction of the MWTS is planned for completion by 2019.

1.2 Background

A review of treatment technologies (active, passive and hybrid) was undertaken and was included within the scoping and feasibility reports drafted in 2016 by AECOM for the Coal Authority for the Haggs and Nenthead (Capelcleugh and Rampgill) mine water discharges. A decision was made following those reports that VFP technology was the most appropriate for the sites environmental setting.

It is understood that, during stakeholder consultations, justification was requested on the reasons why VFP technology (which is widely considered to be a passive treatment technique) has been selected over the potential suitability/ application of an active treatment scheme.

1.3 Scope of the Report

This Technical Note (TN03a) presents a review of discussions held in March to May 2017 with suppliers of active mine water treatment technologies, and technologies capable of removing divalent metals from waters which are used in other industries.

Cost estimates are provided on the basis of the information provided by the suppliers consulted and should not be used for construction cost estimation purposes, rather they are indicative of the potential magnitude/ range of capital (CAPEX) and operational (OPEX) costs, to allow comparison of the potential applicability and likely costs / benefits.

2. Active Treatment Technology Appraisal

2.1 Introduction

To develop a detailed understanding of the possible cost of construction and operation of appropriate active mine water treatment technologies, AECOM contacted suppliers of proprietary equipment based on the case studies presented in AECOM's previous work (AECOM, June 2015, Scoping Study and Remediation Option Appraisal, Ref: 47072599/MARP001) and further research into potential suppliers.

Data for the Haggs adit discharge was provided to suppliers including mine water flows and chemistry to allow preliminary designs to be drafted and indicative estimates to be derived for both CAPEX and OPEX.

2.2 Consultations

The following information (based on Haggs) was supplied to potential suppliers of active treatment plant/ equipment to allow high level cost estimates to be developed:

- Flow: 10 l/s and assumed to be fairly constant.
- Metal loadings are assumed at the following levels: zinc 13 kg/day; lead 27 g/day; and cadmium 13 g/day.
- The pH of the water is circum-neutral to slightly alkaline at approximately pH 8.
- The aim of the treatment system is to achieve 70-90% reduction in metal concentrations within the Haggs discharge.

Colleagues within AECOM's global Mining and Geochemistry Technical Practice Group networks were contacted to discuss previous projects and the applicability of different technologies to treat the water from Haggs adit discharge. The information gained during these discussions informed further consultations with water treatment companies. The information from other AECOM schemes was not directly applicable to Haggs due to differences in the mine water chemistries and flow rates.

The following companies (Table 1) were consulted during this appraisal. Those which responded or considered their technology to be appropriate for the proposed scheme are captured in Table 2.

Table 1. Companies contacted

Company Name	Date of first contact	Outcome of discussion	Date costings received
Evoqua	10/04/2017	Initial discussions suggested they may have suitable technology however they did not have the time to provide costings without a fee.	-
GE Water	13/04/2017	Emails and phone calls to discuss the site. CAPEX and OPEX costings provided and presented in Table 2.	02/05/2017
Allwatertech	10/04/2017	We an initial phone discussion where it was suggested that pH correction may be more applicable than reverse osmosis or ion exchange, however due to workload and no fee available they were not willing to spend time calculating potential costs.	-
BQE Water	03/04/2017	Emails and phone calls to discuss the site. CAPEX and OPEX costings provided and presented in Table 2.	26/04/2017
PAQUES	21/03/2017	Emails, phone calls and meetings to discuss. CAPEX and OPEX costings provided and presented in Table 2.	02/05/2017
Chemiphase	13/04/2017	Initial discussions suggested they may have suitable technology however no response was provided when followed up.	-
Siltbuster	03/04/2017	Emails and phone calls to discuss the site. CAPEX and OPEX costings provided and presented in Table 2.	09/05/2017
Excelwater	03/04/2017	Initial discussions suggested they may have suitable technology however no response was provided when followed up.	-
BV Water	03/04/2017	No response to phone and email queries.	-
Veolia	11/04/2017	Emails and phone calls to discuss the site. CAPEX and OPEX costings	24/04/2017

Company Name	Date of first contact	Outcome of discussion	Date costings received
		provided and presented in Table 2.	
Oberlin Filter	04/04/2017	Email and call discussions, however their technology was not considered suitable for this application without pre-treatment	-
SGS	11/04/2017	No response to phone and email queries.	-
Atana	12/04/2017	Email and call discussions however their technology was not considered suitable for this application.	-
Suez	13/04/2017	Emails, phone calls and meetings to discuss. CAPEX and OPEX costings provided and presented in Table 2.	08/05/2017
Industrial Water Equipment	04/04/2017	No response to phone and email queries.	-
GEE	13/04/2017	No response to phone and email queries.	-

It is noteworthy that suppliers were typically confident in their CAPEX costs but were less specific with regards OPEX costs at this early stage. Where not actually provided by the supplier, indicative OPEX costs have been estimated by AECOM, based on the supplier provided assumptions regarding resource input and waste generation.

The budget estimates received are all calculated without having visited the site setting and are therefore based on a number of assumptions. The primary assumption being that in the absence of any other data waste sludges requiring disposal should be removed from site as hazardous waste.

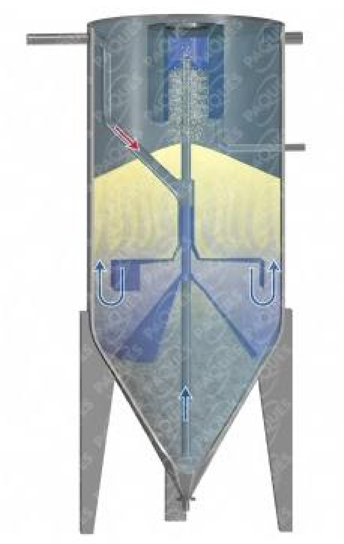
Table 2. Summary of Active Treatment Technology Options.

Remediation Option	Description of Applicability	Evaluation of Applicability	Description of Proposed actions	High Level Costing	Applicability for a Scheme in the Nent Valley
Sulphide precipitation using biogenically produced hydrogen sulphide (H_2S)	The principle of this technology is to create a bioreactor vessel, within which biofilm growth can be maintained on a suitable granular porous medium. H_2S is biogenically produced following the infeed of untreated mine water and reagent(s) e.g. glycerol, yeast extract, etc to act as electron donors for sulphate reduction. Sulphidogenesis occurs in the bioreactor medium causing metal sulphide precipitation and increase in pH. The adjustment of pH is used as a control mechanism to selectively target specific metals in the mine waters and precipitate them out of solution as metal sulphides. Metals of value can be recovered from the sulphide sludges where economically feasible, or where a market can be identified.	BQE Water have two examples of full scale working installations at Silvertip Mine in Northern BC, Canada and Wellington Oro Mine in Colorado, USA. Both these scenarios required treatment of multiple metals using a small footprint and to treat water and produce minimal solid waste. This method enables reduction of metal concentrations to ppb levels.	BQE Water recommend using ChemSulphide© to dose the adit discharge, precipitating metals as sulphides. The process produces less sludge than other methods and precipitates concentrated sulphides that may be suitable for refining or further use if an appropriate facility exists to process the materials. It is anticipated that this method could achieve a 99% reduction in metal concentrations based on the data presented to the supplier. The system can be constructed in standard sized shipping containers and can therefore be portable and have a small footprint compared to a VFP. The figures below show examples of how BQE Water equipment has been positioned on site in shipping containers and buildings designed to fit into the mining heritage of the area.	CAPEX: £0.9-£1.2 Million OPEX: Reagents: estimated at £4-£8K per annum (p.a.). Waste disposal: it is estimated that $11m^3$ of zinc concentrate will be produced yearly (40-50% zinc) which is suitable for smelting. BQE advise that this is unlikely to make a profit but may cover the cost of disposal if a suitable smelter were available. It is assumed that if disposed of this would be classified as hazardous waste with associated costs of circa £15-20K. p.a. Operation: a general operational cost of £50-£70K p.a. is estimated to cover operation of the plant and regular testing. Total OPEX: *C*. £57.5-81.5k p.a.	The containers would require a relatively small foot print and have been shown that they can be constructed to look like cladded buildings which may not be suitable in the North Pennines Area of Outstanding Natural Beauty (NP AONB). However, it is plausible that the structures could be set into earthworks to reduce height impact and structures sympathetic to the site setting constructed; alternatively the structures could be housed within an existing barn or engineering shed structure. Good site access will be required at all times of year to allow deliveries of reagents/ chemicals to site and for waste sludges to be taken off site to an appropriate facility.

Remediation Option	Description of Applicability	Evaluation of Applicability	Description of Proposed actions	High Level Costing	Applicability for a Scheme in the Nent Valley

Remediation Option	Description of Applicability	Evaluation of Applicability	Description of Proposed actions	High Level Costing	Applicability for a Scheme in the Nent Valley
High density sludge (HDS) chemical precipitation	Dissolved metals in mine waters may be removed from solution as metal hydroxides or oxyhydroxides, generally by the addition of caustic soda (NaOH), quicklime (CaO) or slaked lime ($Ca(OH)_2$). The use of caustic soda or lime is already very well established for treatment of municipal wastewaters, potable water and ferruginous mine waters over many decades both nationally and internationally. Chemical dosing at a treatment plant is readily measured, adjusted and controlled to match inflow rates and contaminant levels. Stepped removal of target metal contaminants at different pH levels is	The rate of chemical usage and sludge generation is proportional to the levels of contaminants in the mine water inflow and the quantities of other chemicals dosed. The storage and use of caustic soda and lime require specific management controls as they can be hazardous to health if improperly handled, and may trigger additional permitting requirements. The waste sludges will contain heavy metals and other contaminants that can make separation, storage and recovery or disposal difficult and are likely to lead to a Hazardous waste classification. The cost of treatment chemicals and sludge	Suez has recommended the addition of slaked lime ($Ca(OH)_2$) and a polymer to precipitate metals from solution based on the information supplied by AECOM and on a number of high level assumptions. Suez reported that this method is widely used and is a reliable method for treatment of metals from waste waters. The process produces a sludge which is a waste product which must be removed from site and disposed of appropriately. The equipment could be fitted into 3-4 shipping containers on site, occupying an area of approximately 15m x 20m.	CAPEX: £0.85-£1.1 Million. OPEX: Reagents: reagent costs are estimated at £40K a year. Waste: it is estimated that 0.5tonnes of waste will be produced daily resulting in an annual hazardous waste disposal cost (excluding handling and transportation) of £45-£60K p.a. Operation: a general operational cost of £50-£70K p.a. is estimated to cover operation of the plant and regular testing. Total OPEX: Circa £135-170k p.a.	The containers would require a relatively small foot print and have been shown that they can be constructed to look like cladded buildings which may not be suitable in the North Pennines Area of Outstanding Natural Beauty (NP AONB). However, it is plausible that the structures could be set into earthworks to reduce height impact and structures sympathetic to the site setting constructed; alternatively the structures could be housed within an existing barn or engineering shed structure. Good site access will be required at all times of year to allow deliveries of reagents/ chemicals to site and for waste sludges to be taken off site to an appropriate facility.

Remediation Option	Description of Applicability	Evaluation of Applicability	Description of Proposed actions	High Level Costing	Applicability for a Scheme in the Nent Valley
	also possible.	disposal can be disproportionately high over the life cycle of the treatment plant, and it is often difficult to argue that chemical precipitation is sustainable in the long term. However, chemical precipitation has relatively good predictability and consistency, is easy to optimise and has a well-established track record in wastewater and mine water treatment. A tank or vessel based HDS system would have a relatively small footprint compared to a VFP.	Siltbuster have recommended a High Density Sludge system using polymer dosing. The system would consist of a two stage reaction tank, dosing system and clarifier. A separate tank would be used to store the waste sludge. An on-site manual press would be used to weekly dewater the sludge. The system (excluding pipework) would fit within three shipping containers and require a footprint of approximately 10m x 20m.	CAPEX: Costs for the Siltbuster equipment is estimated at £265K. It is estimated that total build cost would be in the region of £800K. OPEX: Reagents: No details provided. Waste: it is anticipated that 40kg a day of waste will be produced and this will be pressed to dewater on site weekly. Disposal costs for this are approximately £5K a year. Operation: a general operational cost of £50-£70K p.a. is estimated to cover operation of the plant and weekly waste pressing. Total OPEX: circa £>55-75k p.a.	The system would require a relatively small foot print and have been shown that they can be constructed to look like cladded buildings which may not be suitable in the North Pennines Area of Outstanding Natural Beauty (NP AONB). However, it is plausible that the structures could be set into earthworks to reduce height impact and structures sympathetic to the site setting constructed; alternatively the structures could be housed within an existing barn or engineering shed structure. Good site access will be required at all times of year to allow deliveries of reagents/ chemicals to site and for waste sludges to be taken off site to an appropriate facility.
Chemical sulphide precipitation	The addition of sodium sulphide (Na_2S) sodium hydrosulphide (NaHS) to mine waters under controlled conditions can selectively target and remove dissolved metals as insoluble metal sulphides using pH adjustment as a control mechanism. Metals of value can potentially be recovered from the	As for HDS chemical precipitation systems, though less sludge is generated. A tank or vessel based chemical sulphide precipitation system would have a relatively small footprint compared to a VFP. This option will have better sustainability credentials	PAQUES have recommended the use of NaHS as a chemical reagent to precipitate the metals from solution and the use of their ASTRASAND© filtration system to remove the precipitated metals from suspension. PAQUES are able to design a system that reduces the size of the filtration tanks needed making them shorter and easier to fit into the surrounding landscape. The figure below illustrates the standard ASTRASAND© filtration system.	CAPEX: Costs for the ASTRASAND filter equipment is circa £80K. This cost does not include the price for installation or additional equipment such as dosing systems for which costs were not provided. No further information regarding the costs of dosing equipment and lifetime of the media was	The containers would require a relatively small foot print. It is plausible that the structures could be set into earthworks to reduce height impact and structures sympathetic to the site setting constructed; alternatively the structures could be housed within an existing barn or engineering

Remediation Option	Description of Applicability	Evaluation of Applicability	Description of Proposed actions	High Level Costing	Applicability for a Scheme in the Nent Valley
	sulphide sludges where practicable and economically feasible.	than HDS systems as less waste sludge will be generated.		provided by PAQUES to confirm the CAPEX costs. OPEX: Reagents: Dosing with NaHS would be required however PAQUES could not provide a quote without further testing Waste: Precipitated metals will be collected separate to the sand media. A yearly waste disposal cost is estimated at £10-£15K however this would need confirmation following additional testing. The sand media within the filter is estimated to cost £7000 upon replenishment. Filtration systems have been known to run for 10 years without media replacement if operated correctly. Operation: a general operational cost of £50-£60K p.a. is estimated to cover operation of the plant. Total Opex: >60K p.a.	shed structure. Good site access will be required at all times of year to allow deliveries of reagents/ chemicals to site and for waste sludges to be taken off site to an appropriate facility.
			Veolia recommend the use of their Actiflo© treatment process. The Actisand™ used in this process acts as a seed for flocculation and provides a surface area that enhances flocculation.	CAPEX: the equipment cost is approximately £275K with the estimated total build cost at £0.80-£1.1Million.	The containers would require a relatively small foot print and have been shown that they can be constructed to look like

Remediation Option	Description of Applicability	Evaluation of Applicability	Description of Proposed actions	High Level Costing	Applicability for a Scheme in the Nent Valley
			The system can be constructed into standard sized shipping containers and therefore limited space would be needed, minimizing the visual impact on the surroundings. The figure below shows a similar system installed by Veolia. 	OPEX: Reagents: 4kg of Actisand™ will be used a day with a cost of £500-£600/year. Polymer and coagulant dosing will also be required however quantities required would need to be confirmed with jar testing. Waste: The quantity of waste produced would need confirmation from additional testing. Operation: a general operational cost of £50-£60K p.a. is estimated to cover operation of the plant. Total OPEX: >£50-60k p.a.	cladded buildings which may not be suitable in the North Pennines Area of Outstanding Natural Beauty (NP AONB). However, it is plausible that the structures could be set into earthworks to reduce height impact and structures sympathetic to the site setting constructed; alternatively the structures could be housed within an existing barn or engineering shed structure. Good site access will be required at all times of year to allow deliveries of reagents/ chemicals to site and for waste sludges to be taken off site to an appropriate facility.
			GE recommends dosing the water with either Metclear MR2405 or Metclear MR2508 to precipitate metals from solution. This would run in combination with an ultrafiltration plant to remove precipitated metals brought into suspension during treatment. The figure below indicates the type of filtration system that could be used.	CAPEX cost is estimated at £0.75-£1 Million. It is noteworthy that GE Water offer an option to pay a monthly fee to operate and maintain the plant instead of purchasing the equipment and running the plant, estimated to cost ~£132K a year for a 10 year contract. Equivalent to a CAPEX of £1.32 m for 10 years.	The containers would require a relatively small foot print and have been shown that they can be constructed to look like cladded buildings which may not be suitable in the North Pennines Area of Outstanding Natural Beauty (NP AONB). However, it is plausible that the structures could be set into earthworks to reduce height impact and structures sympathetic to the site setting constructed; alternatively the structures could be housed within an

Remediation Option	Description of Applicability	Evaluation of Applicability	Description of Proposed actions	High Level Costing	Applicability for a Scheme in the Nent Valley
				PEX: eagents: costing of hemical dosing per year s estimated at £120K-185K p.a. Vaste: A yearly waste isposal cost is stimated at £10-£15K .a. . peration: a yearly perational cost of £50K s estimated for running he plant. Total OPEX: *C.* £180-250k p.a.	existing barn or engineering shed structure. Good site access will be required at all times of year to allow deliveries of reagents/ chemicals to site and for waste sludges to be taken off site to an appropriate facility.
Reverse osmosis	Reverse osmosis (RO) is a process that forces a fluid with high solute concentration, by applying a pressure in excess of the osmotic pressure, through a semi-permeable membrane to a region of low solute concentration.	The application of pressure in excess of the osmotic pressure requires active pumping. RO is suitable for the removal of dissolved constituents remaining in wastewater following other stages such as filtration and pH adjustment and other treatments.	Discussions with suppliers suggest that this method would not be applicable for Haggs discharge due to the large size of the system required and the suitability of the membranes.	Not applicable	Not applicable
Ion Exchange	Zeolites such as clinoptilolite are naturally occurring minerals comprising microporous arrangements of silica and alumina tetrahedra, which can be used as ion exchange media for the removal of Zn, Cu, Pb and Cd from mine waters.	Suitable for removal of dissolved metals. Metals that are in suspension as solids or have been precipitated will need to be removed via a settlement or filtration step. Competing ions, particularly those that will be preferentially removed, must be removed for effective targeted removal of Zn, Cd, Pb and Cu. This suits the Nentsberry Haggs mine	Discussions with Ion Exchange suppliers suggest that compared with other potential treatment options, Ion Exchange is costly and unlikely to be more effective than other options.	Not applicable	Not applicable

Remediation Option	Description of Applicability	Evaluation of Applicability	Description of Proposed actions	High Level Costing	Applicability for a Scheme in the Nent Valley
		waters which are low in Fe, Mn and Al which sorb in preference to Zn and Cd.			

3. Conclusions

A number of remedial technologies have been appraised in Table 2 based on the information provided by suppliers using data for the Haggs adit discharge. These technologies fall into three categories of treatment:

1. Sulphide precipitation using biogenically produced hydrogen sulphide (H_2S);
2. High Density Sludge (HDS)
3. Chemical sulphide precipitation

Reverse osmosis and ion exchange were not considered useful technologies following discussion with suppliers.

From the information supplied the following costs are broad indications of the likely capital (CAPEX) and operational (OPEX) costs for each of the categories of treatment described above:

1. Sulphide precipitation using biogenically produced hydrogen sulphide (H_2S);

   CAPEX: £0.9-1.2m

   OPEX: £57.5-81.5k per annum

2. High Density Sludge (HDS)

   CAPEX: £0.8-1.1m

   OPEX: £55-170k per annum

3. Chemical sulphide precipitation

   CAPEX: £0.8-1m

   OPEX: £>50-250k per annum

For these treatment technologies, the foot print is considerably smaller than would be required for a vertical flow pond passive mine water treatment system. However they have a greater vertical height and thus potential for visual impact.

Due to the use of pumps and control systems there may be a localised noise impact. The systems may have to be enclosed within an existing structure or new structure sympathetic to the site setting (NP AONB) or shielded with appropriate vegetative screening. It is plausible that earthworks would allow for the systems to be set below ground level to reduce the height of the visual impact and ease enclosure within a new building or shielding with landscape planting.

The schemes would require a constant supply of energy and resources and the removal of waste sludges by appropriately licensed contractors to suitable disposal facilities. There would therefore be more vehicle movements than a VFP would require (notwithstanding any vehicle movements which would be required for VFP compost bed replacement and to supply reagents for odour mitigation – if active chemical dosing is the chosen technology to deal with odour issues).This report should be updated following receipt of additional information from suppliers.

Any cost estimates contained within this report should be regarded as high level since they are based on indicative design concepts from the information provided. No trials have been undertaken nor have any of the suppliers visited the sites. The costs do not include supplying the mine water to the site or discharge infrastructure. Any significant earthworks or landscaping schemes my also incur additional significant costs. In conclusion, active mine water treatment technologies are available as potential treatment solutions for the Haggs mine water discharge. Whether the active treatment technologies provide a more suitable treatment approach to a passive VFP based system will depend on the relative importance of a number of criteria, including: CAPEX cost, OPEX cost, sustainability (energy, resource, waste), ease of operation, certainty of treatment, site footprint, visual impact, odour and ease of accessibility. Some of these criteria / preferences will be common across all candidate sites (e.g. CAPEX, OPEX, sustainability), whereas some may be highly dependent on the prospective site setting (e.g., visual impact, ease of access).

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