Natural Resources Wales

ABBEY CONSOLS REMEDIATION STUDY

Adit Discharge Treatment Feasibility Study Report

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CONFIDENTIAL

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WSP

Willow House
Brotherswood Court
Great Park Road
Bradley Stoke, Bristol
BS32 4QW

WSP.com

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CONTENTS

TABLES

APPENDICES

1 INTRODUCTION

1.1 BACKGROUND

Natural Resources Wales (NRW) commissioned WSP in April 2018 to deliver the Abbey Consols Metal Mine Surface Water Management System Design and Mine Water Treatment Feasibility Study. This report presents the mine water treatment feasibility study element of the wider project.

The historical mining site to the east of Pontrhydfendigaid was identified as the main source of heavy metal (in particular zinc) contamination of the Afon Teifi, causing the river to fail the Water Framework Directive (WFD) targets for approximately 40km downstream of the site.

The two main sources of heavy metal contamination at the site are the outflow of water from the underground mine workings, via a buried drainage adit, and the leaching of heavy metals from old spoil heaps. This report is focused on the feasibility of treating the adit discharge, with only occasional reference to the remediation of the spoil tips.

This report should be read in conjunction with the WSP Site Constraints and Opportunities Document (November 2018), which contains detailed descriptions of the site conditions, environmental constraints and the adit blow out risk assessment.

A ground investigation (GI) was undertaken in January 2019 to confirm ground conditions and pollutant linkages on site. The GI results will be presented in a separate Ground Investigation Interpretative Report but preliminary findings, relevant to this report, are discussed in the specific sections.

A laboratory treatability trial and a field trial form part of project scope, following the overall water treatment feasibility assessment, and will be used to optimise the selected treatment solution design.

1.2 FEASIBILITY STUDY OBJECTIVES AND SCOPE

The objective of the feasibility study was to identify a preferred water treatment solution aiming to reduce the metal loading (in particular zinc and cadmium) from the adit discharge and to assess the feasibility of implementing a treatment scheme on site in a cost-effective manner.

Based on available site information a wide range of treatment options was discussed in an Innovation Workshop (June 2018), with a short list of options then being assessed in the form of an options appraisal (WSP Treatment Options Appraisal Technical Note, December 2018). This led to a preferred option which was then evaluated in more detail and discussed within this report. Site constraints and high-level cost estimates were considered as part of the assessment.

The benefits of the proposed scheme were assessed to confirm treatment targets and to compare the expected benefits with estimated scheme costs (costs versus benefits considerations).

1.3 LIMITATIONS

This report is presented to NRW with respect to the Adit Discharge Treatment Feasibility Study for the Abbey Consols Remediation Study and may not be used or relied on by any other person or by the client in relation to any other matters not covered specifically by the scope of this Report.

Notwithstanding anything to the contrary contained in the report, WSP UK (WSP) is obliged to exercise reasonable skill, care and diligence in the performance of the services required by NRW, and WSP shall not be liable except to the extent that it has failed to exercise reasonable skill, care and diligence, and this report shall be read and construed accordingly.

This report has been prepared by WSP. No individual is personally liable in connection with the preparation of this report. By receiving this report and acting on it, the client or any other person accepts that no individual is personally liable whether in contract, tort, for breach of statutory duty or otherwise.

New information, changed practices or new legislation may necessitate revised interpretation of the report after the date of its submission.

2 SITE SETTING

2.1 SITE DESCRIPTION

Abbey Consols mine is situated in mid-Wales on the edge of the Cambrian Mountains, approximately 23km southeast of Aberystwyth and 1.5km east of the small village of Pontrhydfendigaid. The site location and site boundary are shown on Figure 1 in Appendix A.

The site is cut into the gently sloping land on the northern side of the Afon Teifi valley with a footprint of approximately 5.5 hectares. A steeper slope is observed to the north of the site where the ground rises from ~ 200mOD to ~ 240-250mOD and beyond. There is evidence of historical mine infrastructure, such as foundations, remaining at several locations on-site and to the north of the site.

The historical mining features can be grouped into three areas (Figure 1):

- area to the north of the site boundary which is underlain by the former mine workings and includes a number of former mine shafts and related mine infrastructure;
- an adit connecting the underground workings and the area around the adit entrance, which lie within the bounds of a former quarry;
- mine waste tips and mineral processing area which occupy most of the area within the site boundary;

To the north of the former processing area, a series of shafts and vents are located in a linear SW-NE orientation, following a mineralised fault zone. Only one of the shafts is still open at surface whilst the others have been partially and loosely infilled or have collapsed since mine closure.

The adit runs in a north/north-eastern direction and connects the mine workings to the north of the site with a buried adit entrance location to the north of the mine waste tips and mineral processing area. The adit was used both as an ore extraction point and to discharge pumped mine water. The buried adit entrance location has been estimated from historical maps and was targeted during the WSP ground investigation in January 2019 but the exact location and its condition are not yet confirmed. The adit still acts as the discharge route for water from the mine workings.

The adit was connected with the main processing area to the south of the current access road via a tramway. The former processing area has been covered with mine waste tips forming a significant part of the site. Spoil has been removed previously and may have been used during the construction of a race track that traverses the site. The spoil heaps with below ground structures, cover an area of ~1.5 hectares and together with the adit discharge, which flows in a ditch around the waste tips towards the Afon Teifi, act as the main source of groundwater and surface water pollution.

The main access to the site is via an access road from the farm yard to the west of the site. The access road has been extended in a loop across the waste tips forming part of the car race track.

The Afon Teifi defines the southern limit of the site boundary, flowing in a westerly direction.

Small wooded areas are present close to the river and to the northeast of the site.

2.2 ENVIRONMENTAL AND OTHER DESIGNATIONS

A detailed description of the environmental constraints is provided in WSP Site Constraints and Opportunities Document (November 2018). The site is located within a rural setting, surrounded by predominantly agricultural fields and a large area of mature woodland to the south and southeast of the site, with a smaller section of semi-ancient natural woodland to the north.

The Afon Teifi, at the southern boundary of the site, supports otters and is designated a Special Area of Conservation (SAC) and a Site of Special Scientific Interest (SSSI). Under the Water Framework Directive (WFD), the Afon Teifi is classified as 'Moderate' (overall waterbody status) with an aspiration to achieve 'Good' status by 2021. The sites considered for the proposed treatment works are outside the river's flood zone.

Three other SSSIs and a Special Protection Area (SPA) for birds are present within 2km of the site.

The site is within the Upland Ceredigion Landscape of Outstanding Special Historic Interest, and there are several cultural heritage and historic designations associated with the Strata Florida Abbey, 450m southeast of the site. The Abbey Consols mine is listed by the Royal Commission on the Ancient and Historic Monuments of Wales and has eleven recorded non-designated archaeological features.

2.3 MINING HISTORY

The mine, abandoned since the early twentieth century, exploited the ores galena and sphalerite, rich in lead, silver and zinc. Evidence suggests the area was originally mined by monks from the nearby Strata Florida Abbey. The oldest features in the linear series of shafts and vents that follows the mineralised fault zone are believed to be small scale workings to the eastern end close to Bron-y-berllan. A new phase of development in the 1840s drove in new shafts in the western end of the mine footprint. By the 1850s, extensions toward the east were ongoing and the deep adit had been driven horizontally into the hillside to cut the lode. At this point, new infrastructure was rapidly being installed to improve production. At the surface, construction of a new watercourse (leat) and wheelhouse provided power for drawing extracted material and pumping out groundwater. By the early 1860s the mine had produced 466 tonnes of lead concentrates and 845 troy ounces of silver among other commodities in a six-year period.

Over the 1870-1890s the mine changed hands frequently and production quietened with a last flurry of activity in the early 1900s; the last output from the mine is reported in 1913.

Appendix 4 of the WSP Site Constraints and Opportunities Document (November 2018) provides a more detailed description of the historical features on site.

2.4 GEOLOGY

The bedrock geology at regional scales (1:625 000) consists of a south dipping sequence of the Silurian age Llandovery Rocks comprising mudstones, siltstones and sandstones. On smaller scales (1:50 000), the Llandovery sequence in the Abbey Consols locality comprises the Devil's Bridge Formation (an interbedded mudstone and sandstone) and the Rhayader Mudstones Formation (mudstones). Regional folding and uplift occurred during the Caledonian orogeny and gave rise to the synclinal structure observed. The mineralisation occurred later, post Acadian orogeny during the Permian or post Permian and is recorded to be contained within a northeast - southwest trending fault to the north of the site, dipping southwards between 55 and 70 degrees. The bedrock is exposed in the small quarry on site.

Superficial deposits of glacial till and alluvium (clay, silt, sand and gravel) are present on site. Glacial till overlying bedrock is present across the site comprising predominantly fine sediments. As described in the BGS Site Visit Report (2012) and as confirmed by the 2019 GI, glacial till is also exposed at a small cliff next to the river in the south-western part of the site and was found to underlay the mine waste within the waste tips area. Alluvium overlays the till along the margins of the Afon Teifi within the floodplains. The alluvium is normally soft to firm with compressible silty clay, but can contain layers of silt, sand, peat and basal gravel. To the north of the site, at the steeper slopes, no drift cover is present, with a thin layer of topsoil overlaying weathered bedrock.

Mine waste tips cover most of the site area appearing as coarser material at the surface in the northern part of the site and finer material in the southern part (e.g. former slime pits). The quarry area to the north of the access road is generally filled with spoil material from the quarrying process.

2.5 HYDROGEOLOGY

Regionally, bedrock is expected to be of low hydraulic conductivity, i.e. with very limited ability to transmit groundwater (classed as Secondary B aquifer). The highest hydraulic conductivities are expected within the fault zone to the north of the site and within the weathered bedrock zone. Bedding plane seepages were observed at the quarry face during a site visit in May 2018 and in previous studies (BGS, 2012).

The extent of influence on groundwater dynamics as a result of the historical mine workings is difficult to quantify without groundwater level monitoring data. During the operational life of the mine, dewatering of the workings would have lowered groundwater in a localised area around the footprint of the mine due to the tightness of the formation and the low hydraulic conductivities. At the point of mine closure, groundwater levels would have rebounded and raised to the adit level.

Groundwater flow on site is dominated by the material properties and thicknesses of the drift deposits and the man-made impact at and around the mine waste tips. Preferential flow paths may exist within coarser drift material (in particular within the alluvium) and within the waste material.

The northern half of the waste tips are dominated by coarse material at the surface compared to fine waste material (tailings/former slime pits) dominating the southern half of the tips which results in significantly higher groundwater recharge rates in the northern parts and run-off and seepage dominating the southern part.

Substantial groundwater recharge is likely to originate from steep slope runoff in the northern part of the site, i.e. in the area where drift cover thickness increases approximately along the access road.

A marshy area at the north-western site boundary indicates shallow groundwater, perhaps associated with a natural spring line at the break in slope. A contribution of adit discharge to the shallow groundwater/springs in this area cannot be excluded at this point.

The 2019 GI included the installation of groundwater monitoring locations and subsequent groundwater monitoring. The main conclusions from the GI results are:

- Perched water tables are common in particular at the base of the waste on site but “true” groundwater levels were found to be within the till that is underlying the waste;
- Groundwater flow direction is in a south-westerly direction towards the Afon Teifi;
- Drainage ditches on site are generally interacting with perched water tables (receiving and feeding shallow groundwater) and are partially fed by runoff from the slopes to the north and discharge from the adit;
- The discharge from the pipe under the access road represents a mixture of adit discharge and groundwater/runoff from the slopes to the east. Parts of the adit discharge migrate via a

groundwater flow path into the waste tips and possibly towards the marshy area to the west of the site;
- A standpipe installed in close proximity to the expected adit entrance confirms much higher zinc concentrations in the adit discharge compared to previously measured concentrations in the discharge from the pipe under the road;
- Groundwater metal concentrations under the waste tips were found to be very high locally, indicating a vertical pathway in addition to the horizontal migration of leachate/seepages as observed at the surface.

2.6 HYDROLOGY

In addition to the adit discharge ditch there is another small stream running along the western boundary of the site. Both streams receive seepages or groundwater from the waste tips and both streams discharge into the Afon Teifi at the southern boundary of the site.

The Afon Teifi is a major river running through central and south Wales. Flood hydrographs from nearby gauging stations at Pontrhydfendigaid show the catchments to be flashy with short lag times and significant peak flows.

This region of Wales has a strongly maritime climate with high annual average rainfall totals between 1200-1400mm, caused by predominant south-westerly winds pushing moist air in to the higher elevations of the Cambrian Mountains.

2.7 SUMMARY OF SITE CONSTRAINTS

The site constraints are summarised in Figure 2 in Appendix A and their effect upon the proposed mine water treatment scheme is described below:

- Site topography provides little constraint, with the gentle slope from the quarry towards the river allowing gravity flow through the treatment system without excessive excavation depths or the need for pumping;
- Geology – the strength of the drift deposits limits the stable slope angles achievable, which affects the treatment system footprint and cost for vehicle access tracks;
- Groundwater is a potential constraint, requiring temporary or permanent lowering if too high relative to the works, leading to increased costs and pollution risk. The recorded groundwater level varies from about 0.5m below ground level near the road to over 4m south of the site, and so this may not arise;
- Requirements for adit mine water pressure management would constrain any works near to the adit portal, and may require further investigation and the lowering of mine water levels to reduce risks of blow out/sudden release of high volumes of polluted water (WSP Blow Out Potential Assessment, 2018);
- Archaeological remains provide some constraint on potential treatment works sites. This might increase construction costs by limiting working space and access routes, and would require an archaeological investigation prior to any unavoidable disturbance. There is an opportunity to improve protection of these remains with the remediation works;
- Several environmental/ecology constraints have been identified on site, the main concern for the likely water capture, transfer, treatment and discharge locations being the river (SSSI/otter) and potential pollution during construction. Opportunities for habitat creation could be included in combination with the site wide remediation;

- Utilities constraints comprise an overhead high voltage electricity cable along the southern edge of the spoil heaps which limits the treatment site location, especially as regards construction. The lack of other nearby utilities, such as potable water, provides another potential constraint.
- A public footpath (PRoW) runs parallel to the river to the south of the site. This may require a temporary diversion during construction of treatment works.
- Existing land use and access: the land owner operates a motor racing circuit past and around the spoil heaps which would constrain both temporary and permanent works, particularly regarding the safety of vehicles leaving the road and surface water runoff. Safe access will be required to operate the treatment system. All the land is currently owned by the local farmer.

3 ADIT DISCHARGE CHARACTERISTICS

3.1 FLOW

The 2019 GI confirmed that the discharge from the adit only partially finds its way to the discharge pipe under the access road (where flow rate has previously been measured) and the other part following a groundwater flow path into the waste tips and possibly into the marshy area to the west of the waste tips. No flow measurements are available to confirm the adit discharge flow rates and variation of flows (seasonal and in response to rainfall events). The mine water blow out potential assessment undertaken by WSP in 2018 suggests that a relatively low baseflow (<1l/s) would be expected but that there is uncertainty around runoff or shallow groundwater entering the mine workings via open/collapsed shafts to the north (i.e. direct discharge) which could substantially increase flows under wet weather conditions. Considering the uncertainties around the flows and flow pattern it was agreed with NRW to base the current assessments on a design flow of 1l/s with a sensitivity test considering an increase to 3l/s.

3.2 QUALITY

Prior to the 2019 GI the discharge from the pipe under the access road was understood to be representative of the adit discharge.

During the GI a monitoring standpipe was installed in a trial trench ~10m from the presumed position of the adit entrance to allow measurement of water pressure and water sampling for chemical analysis. Two rounds of water sampling and analysis were carried out and indicate dissolved zinc concentrations of ~16mg/l (~40µg/l of dissolved cadmium and ~200µg/l dissolved lead). The pH was found to be between 6.6 and 7, with a low electrical conductivity of 151-181µS/cm and total alkalinity (as $CaCO_3$) of 23.7 and 31.5mg/l. The test results from this standpipe are believed to approximately represent adit discharge chemistry.

4 TREATMENT OPTIONS

With the objective of identifying a suitable, cost effective solution for removing heavy metals (in particular zinc and cadmium) from the adit discharge WSP initially produced a long list of possible mine water treatment options which was discussed at an Innovation Workshop in June 2018. The objective of the workshop was to allow innovative ideas to be integrated into the options appraisal. The outcome of the workshop was a preference for the following three options to be considered:

1. Compost-based Vertical Flow Pond (VFP)
2. Phosphate treatment system
3. Vertical Flow Reactor (VFR) with chemical dosing

Two design flows were considered for each treatment option; the anticipated 1l/s from the adit, and a higher rate of 3l/s to test the sensitivity of the option to increased flow rate. Sizing of the treatment facilities was based on an assumed pre-treatment zinc concentration of 16.8mg/l (based on the previously measured final site discharge concentration).

Concept designs for each option were prepared and costed, and the risks and opportunities assessed. The findings were presented in a 'Treatment Options Appraisal – Technical Note' (Appendix B) and are summarised below. Layout sketches of each of the three options which were used for the costing purposes are provided in Figures 3-5 in Appendix A. The options appraisal focused on the treatment element only, i.e. costs for mine water capture, transfer and discharge are not included (being the same for all options).

The costs of each option were estimated at 2018 prices for flow rates of 1l/s and 3l/s, and the net present value calculated for a 25-year lifespan with 2% annual inflation and a 3.5% discount rate. Significant planned operational and maintenance costs vary for each option and are described in the following sections.

4.1 COMPOST-BASED VERTICAL FLOW POND (VFP)

The compost-based VFP aims to precipitate dissolved metals in the form of sulphides within an organic substrate in open ponds. A full-scale mine water treatment VFP has been operating at Force Crag in Cumbria since 2015, providing data on treatment efficiency and operational issues which informed this options study.

4.1.1 COSTS

The estimated Present Value (PV) costs for treating 1l/s and 3l/s over a 25-year life cycle are tabulated below. The compost is assumed to be saturated with absorbed metals after 10 years, at which time it would be removed for disposal and replaced with fresh compost. A disposal site 20 miles from Abbey Consols has been assumed, charging £300/t for the compost as hazardous waste on account of its heavy metal content. Disposal of the compost at the end of the 25 years life cycle is also included. Hydrogen sulphide is likely to be generated by the VFP and so indicative costs for odour control via hydrogen peroxide dosing has been included.

Table 4-1 – VFP estimated costs

Flow rate	1l/s	3l/s
CAPEX & OPEX	£443k	£588k
Odour control	£37k	£112k
Media disposal & replacement	£159k	£445k
TOTAL (life cycle PV)	**£639k**	**£1,145k**

4.1.2 RISKS

The following key risks have been identified:

- The VFP hasn't been tested on the mine water at Abbey Consols, which differs from that at Force Crag on which this option is based. There is therefore some uncertainty around its performance in achieving sufficient metal removal;
- Due to the low natural sulphate concentrations in the water addition of sulphate is likely to be required to raise the concentration in the mine water to enable the process to work (costs of sulphate dosing is not included in the current cost estimate but cost impacts are expected to be similar to the odour control dosing);
- Force Crag suffered from bacterial growth on top of the compost which reduced its permeability requiring remedial works. Although differing in water quality and location, Abbey Consols may suffer likewise;
- Potential for developing preferential flow paths that short-circuit the compost;
- Odour management may be more challenging than expected, and with uncertain costs, e.g. due to the volatility of hydrogen peroxide price and more substantial chemical storage/protection costs (i.e. a small building);
- Waste disposal options (and related costs) for the compost are uncertain and may change in the future (risk and opportunity). Dewatering and/or treatment of the compost waste may be required prior to disposal with potential impact on land take and costs;
- There will potentially be excavated material to be taken off site. If this material is contaminated, disposal costs could be high (i.e. geo-environmental issues affecting earthworks);
- Potential damage to the HDPE geomembrane during media removal would need to be accommodated in design or costly liner repairs considered; and
- The land take and earthworks costs for this option are dependent on the stable slope angle allowed by the ground conditions, a shallower angle giving greater area and cost.

4.1.3 OPPORTUNITIES

The following opportunities have been identified:

- The low hydraulic head requirement for this option could avoid the need for pumping, resulting in an entirely passive system (apart from sulphate-dosing and potential chemical dosing as part of odour control);

- Lessons learnt from the Force Crag site could enable selection of more effective media reducing the risks of performance issues;
- Innovative design of the VFP, e.g. by arranging the flow through the compost to run horizontally rather than vertically could result in reduction of footprint, reduced visual impact and easier odour control;
- Optimisation of the waste stream aiming to avoid landfill disposal or incineration, e.g. via soil improvement facilities, could result in significant cost savings and increased sustainability of the option.

4.2 PHOSPHATE TREATMENT SYSTEM

This phosphate treatment process is based upon the stabilisation of a wide range of metals by chemically binding them into low-solubility phosphate minerals. In addition, the presence of sulphate-reducing bacteria in anaerobic zones in the treatment beds results in the precipitation of metal sulphides. No operational examples of this system are available in the UK, and so this option was based upon the system used to treat acid mine discharge from the Success mine, draining into Ninemile Creek near Wallace, Idaho, USA since 2000.

4.2.1 COSTS

The estimated Present Value (PV) costs for treating 1l/s and 3l/s over 25 years are tabulated below. The fishbone based media is assumed to need replacing after 5 years, as at the Success mine. A disposal site 20 miles from Abbey Consols has been assumed, charging £300/t for the waste media as hazardous waste.

Table 4-2 – Phosphate treatment system – estimated costs

Flow rate	1l/s	3l/s
CAPEX & OPEX	£314k	£425k
Odour control	£37k	£112k
Media disposal & replacement	£173k	£518k
TOTAL (life cycle PV)	**£524k**	**£1,055k**

4.2.2 RISKS

The following key risks specific to this option have been identified:

- Current and future availability of suitable media is uncertain (media cost has not been confirmed by the supplier);
- Performance under site conditions is unconfirmed;
- The rate and effect of clogging of the media is uncertain;
- Discharge quality could be unacceptable (e.g. if phosphate gets mobilised) considering the sensitivity of the Afon Teifi;
- Generation of odour could be a problem depending on media type and site-specific conditions; and

- Risks related to ground conditions (excavation depth) or other environmental constraints for construction and maintenance.

4.2.3 OPPORTUNITIES

The following opportunities have been identified:

- Slope-sided channels would reduce construction costs, but would increase land take and might adversely affect treatment effectiveness and maintenance requirements;
- Increased treatment area could reduce the clogging risk but would cause an increase in initial earthworks and land take;
- Fishbone derived media could be replaced with other apatite sources which would mitigate the potential odour issues but would remove the sulphide precipitation element of the treatment. This would, however, require specific research into alternative media; and
- From the three options this is the only potentially fully passive system (if no odour risk from the media) and could be attractive for the low flow or temporary flow discharge component from the waste tips (residual seepage).

4.3 VERTICAL FLOW REACTOR (VFR) WITH CHEMICAL DOSING

This process involves dosing the mine water with ferric sulphate in the presence of limestone (to mitigate the resulting drop of pH) followed by a VFR, allowing the dissolved iron to precipitate and to co-precipitate zinc and other heavy metals which are then absorbed into a sludge layer on the surface of the VFR gravel bed.

4.3.1 COSTS

The estimated Present Value (PV) costs for treating 1l/s and 3l/s over 25 years are tabulated below. Desludging of the VFRs is assumed to be required every year, with the sludge dewatered on site before removal for disposal as hazardous waste at £300/t to a landfill site 20 miles away. The sludge disposal cost is sensitive to the dry solids (DS) content achievable on site before transport away, and so costs for a range of DS are provided. In addition, the chemical dosing would require regular replenishment, assumed to be two 1000 litre IBCs every four months. The limestone bed will gradually dissolve as well and require refilling, assumed to be needed every five years.

Table 4-3 – VFR estimated costs

Flow rate	1l/s				3l/s			
Sludge DS	10%	15%	20%	25%	10%	15%	20%	25%
CAPEX & OPEX	£383k	£383k	£383k	£383k	£570k	£570k	£570k	£570k
Ferric dosing & limestone	£65k	£65k	£65k	£65k	£194k	£194k	£194k	£194k
Sludge disposal	£157k	£108k	£85k	£71k	£442k	£299k	£227k	£185k
TOTAL (life cycle PV)	**£604k**	**£556k**	**£532k**	**£518k**	**£1,207k**	**£1,064k**	**£992k**	**£949k**

4.3.2 RISKS

The following key risks have been identified:

- The land take and earthworks costs for this option are dependent on the stable slope angle allowed by the ground conditions, a shallower angle giving greater area and cost;
- The OPEX cost is sensitive to the dry solids content of the precipitated metal sludge as it's removed from site. At 10% DS the annual desludging & disposal cost would be roughly double that at 25% (Cardiff University research currently suggests that 25% DS is achievable);
- Potential damage to the HDPE geomembrane during media removal would need to be accommodated in design or costly liner repairs considered; and
- Chemical storage and handling on site needs to be managed avoiding impacts to the environment and human health.

4.3.3 OPPORTUNITIES

The following opportunities have been identified:

- Dosing with both Ferrous Sulphate and Potassium Permanganate offers an interesting alternative with the two chemicals reducing/oxidising each other and removing the need for aeration. The VFRs could be replaced with smaller size sand filters. Manganese is expected to be more efficient in zinc removal compared to iron;
- Use of the available mine water head to power the dosing system, automatically compensating for flow variation without the need for flow measurement and avoiding the costs of providing an electricity supply. Such a system may need developing, but alternative off-grid dosing systems using wind & solar power with battery backup are commercially available. Alternatively, overdosing could be considered providing additional sorption potential within the precipitate to deal with peak flow scenarios;
- Sludge disposal from the VFR has been costed as a hazardous waste product. Research from Cardiff University suggests that non-hazardous waste classification is likely to be achievable. Outlets for this sludge as a raw material would reduce OPEX costs considerably; and
- Involvement of competent Welsh Water staff from the nearby water treatment site in the operation could reduce costs.

4.4 SUMMARY OF COSTS, RISKS AND OPPORTUNITIES

The costs, risks and opportunities for the three options considered are summarised in tables 4-4 and 4-5 below:

Table 4-4 – Summary of treatment options appraisal (costs)

Option	Flow Rate	Required Area (m^2)	CAPEX (£k)	OPEX (£k pa)	Life cycle costs Present Value £k	Sludge/media Volume (m^3)	Sludge/media Disposal (£k)
VFP	1l/s	1,600	319	6* +2†	639 (544)**	166	65 (media disposal) + 6 (new media) every 10 years
	3l/s	3,100	464	11* +5†	1,145 (877)**	464	182 (media disposal) + 16 (new media) every 10 years
Phosphate system	1l/s	230	192	6* +2†	524 (434)**	90	35 (media disposal) + 9 (new media) every 5 years
	3l/s	490	303	6* +5†	1,055 (783)**	270	106 (media disposal) + 27 (new media) every 5 years
VFR with chemical dosing	1l/s	770	263	9*	604 556 532 518 (481)**	20 @ 10% DS 13 @ 15% DS 9 @ 20% DS 7 @ 25% DS	7.2 (every year) 5.0 (every year) 3.9 (every year) 3.2 (every year)
	3l/s	1,500	451	14*	1,207 1,064 992 949 (838)**	60 @ 10% DS 38 @ 15% DS 28 @ 20% DS 21 @ 25% DS	20.3 (every year) 13.7 (every year) 10.4 (every year) 8.5 (every year)

Notes*:*

1. CAPEX excludes land purchase, connections to mains electricity and water (if required) and financing and decommissioning costs
2. CAPEX values include 20% contingency
3. Required area assumes a relatively flat site and excludes access roads
4. Present Value costs based upon 25-year life with 2% inflation and 3.5% discount rate

5. Dosing equipment assumed to last 25 years

* Excludes media replacement and waste disposal costs (included in PV)

** NPV value for low (£100/t) waste disposal cost

† Supply of hydrogen peroxide for odour control (included in PV)

Table 4-5 – Advantages and disadvantages of the individual options

Option	Advantages	Disadvantages
VFP	No telemetry needed Natural appearance	Large footprint increases cost. Large waste volume and waste type make OPEX sensitive to increased disposal costs. Likely to require sulphate dosing (not included in cost estimate). Potential operational issues (algae clogging). Odour control may be needed
Phosphate system	Small footprint No mains power needed No telemetry needed Fully passive (if no odour issues)	Uncertain media cost & availability. Treatment effectiveness not proven (in particular over time). Potential discharge quality issues (e.g. phosphate) - considering the sensitivity of the Teifi. Potential operational issues (clogging or creation of preferential flow paths within the media). Odour control may be needed if media derived from fishbones.
VFR with chemical dosing	Performance is mainly a function of chemical dosing hence more manageable risks compared to other options. Chemicals are commonly used in water treatment (Welsh Water site nearby). Additional benefit with raising sulphate levels if discharge to soakaway/floodplain (fixing diffuse metals as sulphides in groundwater). A number of design opportunities with the potential to reduce scheme costs (e.g. combination of	Power & chemical supply needed. Active treatment element requires operations to be managed by competent contractor (or NRW staff). Telemetry needed. Sludge disposal costs dependent on dry solids content; high DS may not be achievable by gravity drainage & evaporation alone.

Option	Advantages	Disadvantages
	$FeSO_4$ with $KMnO_4$ reducing the VFR to simple sand filters). Process reduces water content of the waste product increasing chance of re-use.	

4.5 SUMMARY OF OPTIONS APPRAISAL

The high-level costing of the three options indicate similar life cycle costs with the VFP likely to be the most expensive option and the phosphate system likely to be the cheapest option. Considering the risks, uncertainties and the opportunities associated with each of the options the VFR with the chemical dosing seems to offer the most robust solution offering better control over performance issues, has a lower risk of odour production and offers various opportunities related to design improvements, cost reductions and a better waste product. In particular, the possible combination of $FeSO_4$ and $KMnO_4$ dosing offers an interesting and innovative further development of this option.

The VFR with chemical dosing is therefore the preferred option. Laboratory treatability trials are recommended to collect additional design information and grow confidence in the achievable metal removal rates.

5 HIGH LEVEL DESIGN OF PREFERRED TREATMENT OPTION

5.1 WATER CAPTURE

Water from the old mine workings emerges from the adit whose entrance is currently buried under spoil material and may have partially collapsed. The ground investigation confirmed that the discharge pipe under the road is collecting a mixture of adit discharge, surface run-off and shallow groundwater from the east. Parts of the adit discharge are following groundwater flow paths under the waste tips on top of or within the glacial tills. It is therefore vital to improve the water capture to ensure that a future treatment scheme is able to treat all of the mine water and to do so efficiently by minimising the capture of additional unpolluted water.

An options appraisal for water capture from the adit has therefore been undertaken. The following options have been considered (Figure 6 in Appendix A):

1. Shallow interception drain at toe of quarry spoil
   A linear drain at the top of the glacial till would intercept the groundwater flow path from the adit and convey the intercepted water by pipe to the treatment works. The drain would be laid parallel to the road and beyond the quarry fill where the depth to the till is reduced. The distance from the adit allows a large lateral spread of the mine water, and thus a long drain is required to capture a sufficient percentage of the water.

2a. Deep interception drain within quarry spoil
   By moving the drain closer to the adit, the lateral spread of mine water, and thus the length of drain required, is reduced. This brings the drain within the area of made ground on the quarry floor, however, resulting in a deeper excavation (about 3m) to the drain level.

2b. Cut-off wall & drain within quarry spoil
   A variation of option 2a has an impermeable wall created across the likely adit flow pathway in place of the filter drain, and a single outlet pipe. This potentially reduces the excavation required but leaves uncertainty regarding how much of the mine water is captured and how much flows around the wall.

3a. Piped drain from buried adit portal
   This option requires the excavation of the adit entrance before sealing a drainage pipe into the mouth of the adit to ensure total capture of the adit flow, with the area reinstated to existing levels (i.e. all features remain below ground). A new manhole close to the adit entrance would provide limited access to the adit and also allow flow measurement and sampling of the outflow.

3b. Piped drain from exposed adit portal
   This variation of option 3a ensures total capture of the adit flow as before, but reinstates the adit portal and leaves it exposed for historical interest and environmental benefit. A catchpit, far enough inside the portal to prevent falling leaves, etc. from entering the flow, would capture the water before conveying it to the treatment system in a buried pipe.

Details of the proposed options and their advantages and disadvantages are provided in the options table in Appendix C.

The estimated construction cost for the water capture options are shown in Table 5-1:

Table 5-1 – Estimated costs for water capture options

Option	1	2a	2b	3a	3b
CAPEX (£k)	15	20	50	35	60

The main uncertainties of options 1, 2a and 2b are how much of the mine water would bypass the collection drain and how much surface water run-off and groundwater would be captured. This would risk untreated mine water reaching the river and the treatment works being oversized or hydraulically overloaded. This risk is less with options 2a and 2b, but at the expense of higher construction risk due to the greater depth and more uncertain ground conditions.

The main uncertainty of options 3a and 3b are the condition of the adit, and thus how much work would be required to stabilise the entrance (temporarily for option 3a and permanently for option 3b). £10k and £20k of the above figures have been assumed for work to the adit for 3a and 3b respectively.

Option 3a is considered to offer the greatest benefits in terms of capturing all the adit mine water and very little surface/groundwater, thus minimising the size of the treatment works, but without the risks and uncertainties involved with permanently reinstating the adit portal.

5.2 WATER TREATMENT

The preferred VFR process involves dosing the mine water with ferric sulphate in the presence of limestone (to mitigate the drop in pH) followed by a VFR, allowing the dissolved iron to precipitate and to co-precipitate and absorb zinc and other heavy metals.

This treatment option comprises the following elements:

1. A limestone gravel bed to increase the alkalinity of the adit mine water. This is proposed to be formed by adding an impermeable liner to the 10m length of ditch immediately downstream of the road culvert, with a downstream weir to form a pond, giving a surface area of about 45m^2 (actual size to be confirmed after the lab trials). This would be partially filled with about 3m^3 of limestone gravel through which the mine water would travel with an average retention time of 1-1½ hours.
2. A Ferric Sulphate dosing system comprising:
    a. Three 1m^3 IBC storage tanks for a 40% aqueous solution of $FeSO_4$. At an average dosing rate of 0.7 l/h for 1 l/s of mine water, each IBC would last for two months. Changeover would be manual during a routine maintenance visit, with two empty IBCs replaced by the chemical supplier every four months. Appropriate screening or enclosure of the IBCs would be provided to give an acceptable visual appearance.
    b. An enclosed, skid-mounted dosing system on a concrete slab next to the storage tanks. This would include duty/standby variable-speed electric dosing pumps, controlled by the mine water flow rate.

    c. A V-notch flow measurement weir with ultrasonic level sensor, feeding flow data to the dosing system.
    d. Dual-contained dosing lines in buried ducts to the dosing point.
    e. A dosing point upstream of an engineered hydraulic jump to ensure rapid mixing of the ferric sulphate with the mine water.
3. Two VFR ponds of rectangular trapezoidal shape, sized at 1.2 l/min/m^2 minimum plan area, but increased in size to provide enough sludge storage to allow desludging once per year. With side slopes at an angle of 1 in 2.5 (dependent upon local soils), each VFR pond would be about 235m^2 area at the top of the bank for 1 l/s flow rate, and 520m^2 for 3 l/s. Each VFR would comprise, from the base upwards:
    a. An impermeable geomembrane liner to contain the mine water, with a geotextile drainage layer beneath to prevent groundwater pressure lifting the liner;
    b. 500mm depth of limestone gravel (200mm of 6mm size overlying 300mm of 20mm) with perforated drainage pipes at the bottom to remove treated mine water and encourage vertical flow through the gravel;
    c. Up to 1000mm depth of mine water above the gravel; and
    d. 300mm freeboard at maximum water level.
4. An outlet sampling chamber to provide a safe facility to obtain treated water samples prior to discharge.

Flow through the treatment system would be by gravity, making use of the fall from the road towards the river.

5.3 WATER DISCHARGE

The discharge route of the treated water would depend in part upon the location and level of the treatment system.

The site wide Surface Water Management System (SWMS) will require improvements to the current drainage system and is likely to involve groundwater control. It will also generate clean runoff from capped areas. It is recommended to link the discharge solution of both elements which could involve:

- Discharge to ground (e.g. via soakaway trenches);
- Using existing drainage discharge routes; or
- Formation of a new outfall location to the river.

5.4 ASSUMPTIONS

Based on the previous VFR trial results, a minimum VFR treatment area of 50m^2 is required to treat 1l/s based on a VFR flow rate of 1.2 l/min/m^2, although this has been increased to provide sufficient sludge storage volume.

The proposed treatment location is to the south of the waste tips site, i.e. between it and the Afon Teifi floodplain. This site allows gravity flow from both the adit and capped spoil sources to and through the treatment system. There may be an opportunity to use land within the current waste tips for the treatment area if design is combined with the SWMS remediation element of the site.

Three potential access routes to the proposed treatment location have been identified:

1. via the existing farm access track leading off the western side of the 'racetrack' loop, resurfaced with granular material and extended along the southern side, outside of the boundary fence. Approximate length 190m. This route avoids constraints within the site, but the poorer ground south of the boundary is likely to lead to higher construction costs.
2. a shorter route from the nearest point of the 'racetrack' loop to the site. Approximate length 115m. This route crosses the site with its constraints, and also creates a new access off the racetrack with potential liabilities in its operation.
3. along the eastern boundary of the site from the existing east-west road. Approximate length 220m. This avoids the racetrack and spoil heaps entirely, but may still affect archaeological remains.

Each option would include a turning stub at the treatment site. For costing purposes option 1 has been used for the access route.

Two equal-sized VFRs are proposed to allow one to be taken offline for maintenance and desludging. Each VFR is assumed square in plan, with side slopes of 1 in 2.5 and set with the top of bank at ground level. All excavated material is assumed to be used elsewhere on site for landscaping, but, depending on the exact location, the VFRs could be partly raised above existing ground level with this material used for the embankments, thus reducing the volume of excavation required.

The overall footprint of the VFRs and access track within the fenced perimeter of the treatment site is estimated to be 770m^2 (for the 1l/s base case) with an additional 480m^2 of new access track.

Mine water discharging from the culvert under the road would flow through a limestone bed and then by gravity in a buried pipeline to the flow measurement weir and dosing point, just upstream of the VFR flow distribution chamber. Two V-notch outlet weirs in this chamber would divide the flow equally between the VFR ponds, with handstops to isolate either pond when required. An overflow weir in the chamber would divert excess inflow to the outlet pipe, and also provide a bypass whilst one or both VFRs are offline for maintenance.

The outlet from each VFR comprises an array of perforated drainage pipes at the base of the gravel, combined into a single flexible pipe in the outlet chamber. Raising or lowering of this flexible pipe allows the water level in the VFR to be controlled.

The precipitated metals are expected to form a sludge blanket on the surface of the gravel in the VFR. When this blanket occupies half the maximum depth of water in the VFR, the inlet would be shut and the outlet pipe lowered to drain the pond. The sludge would then be left in situ to dewater by gravity drainage and surface evaporation from an assumed initial 2% dry solids (DS) to 25% DS. Whilst one VFR is desludging, all the flow would be diverted into the other VFR. The VFRs would be sized to require desludging once per year, timed to take place during the summer to maximise the rate of dewatering and also to take advantage of the expected reduced summer flow rate to reduce the impact of one VFR being offline. Once the sludge had dewatered sufficiently, it would be removed from the surface by mechanical excavator and transported off site for disposal as hazardous waste. The VFR would then be returned to service and the process repeated for the second VFR.

The performance of the VFR with chemical dosing will be tested as part of a laboratory trial to improve estimates of required pH/alkalinity adjustments and chemical dosing (dosing product). Subsequently a field trial will be run to optimise performance and operational requirements.

5.5 PERMITS/CONSENTS REQUIREMENTS

The following permits and consents are likely to be required:

- A Habitats Regulations Assessment and discharge consent for the treated water discharge and any storm or emergency overflows that may be required
- Planning permission for construction and operation of the works.
- Consent to temporarily divert or close the public footpath during construction if required.
- Notice to carry out works near/within a SSSI & SAC (i.e. the Afon Teifi).
- Land drainage consent.
- Abstraction license.

5.6 TOTAL ESTIMATED COSTS OF PREFERRED OPTION

Assuming water capture option 3a and sludge dewatered to 15% dry solids, the estimated CAPEX and OPEX costs for the two flow rates considered are shown in Table 5-2:

Table 5-2 – Breakdown of estimated CAPEX and OPEX costs

Flow rate	1l/s	3l/s
CAPEX*	**£k**	**£k**
Water capture	35	35
Treatment works	258	446
Water disposal	10	10
Total CAPEX	**303**	**491**
OPEX – annual cost	**£k**	**£k**
General operation & maintenance	6	6
Ferric dosing & limestone	3	9
Sludge disposal @ 15%DS	5	14
Total OPEX	**14**	**29**
Total PV (25 year life cycle)**	**601**	**1,109**
Total PV (40 year life cycle)**	**730**	**1,374**

Notes:

*CAPEX excludes land purchase, connections to mains electricity and water (if required) and financing and decommissioning costs.

**The Present Value (PV) cost of the project has been calculated for two operational lives, 25 and 40 years, on the basis of an annual inflation rate of 2% and a 3.5% discount rate.

5.7 RISKS AND OPPORTUNITIES

The following key risks and opportunities have been identified:

- The proposed VFR size, and thus cost, is derived from its expected performance based upon other trials of the system, and so may change once the laboratory trial results on the actual mine water from Abbey Consols is available;
- The performance of the VFR during field trials may differ from that suggested by the lab trials, which could affect the OPEX costs and the environmental benefits obtained;
- The actual location and condition of the adit portal is not known, and thus the cost of exposing and stabilising it may be higher than assumed;
- The OPEX cost is sensitive to the dry solids content of the precipitated metal sludge that can be achieved on site; and
- There are a number of opportunities when combining the mine water treatment design, planning and construction with the SWMS element of the site remediation (e.g. on costs and programme, management of environmental risks and opportunities, management of performance risks and creation of a site water discharge point).

5.8 SUMMARY OF THE BENEFITS ASSESSMENT

An assessment of benefits of a mine water treatment scheme has been undertaken and is presented in a separate technical memo (Appendix D). This includes an assessment of typical metal loadings from the site affecting the Afon Teifi and how these are expected to change after site remediation. The benefits are assessed for the full site remediation (i.e. the combination of the mine water treatment and the SWMS) as site data does not allow a separate assessment of the two elements. This leads to the recommendation to integrate the two remediation elements as far as practical. The conclusions from the benefits assessment are:

The current impact of heavy metal pollution originating from the Abbey Consols site via the adit discharge and uncontrolled seepages from the waste tips and underlying groundwater has been assessed by comparing results from previous studies with the most recent site data (WSP ground investigation 2019). The results were found to be similar and confirm a substantial impact of the site discharges on the Afon Teifi. NRW had previously identified the site as the main reason for the river not meeting “Good” WFD status.

The main contaminants of concern from the site are zinc, cadmium and lead, with zinc concentrations in the Teifi exceeding the EQS for ~11km downstream of the site. Based upon the available NRW monitoring data, the following average metal loadings originating from the site have been estimated:

- 1,214kg/year dissolved zinc;
- 1.6kg/year dissolved cadmium; and
- 21.3kg/year dissolved lead.

Considering the zinc loading above and measured zinc concentrations next to the adit entrance (approximately 16mg/l) indicates that the 1l/s discharge rate treatment scenario (base case) is likely to be realistic (accounting for over 40% of the average loading contribution). 2l/s discharge from the adit would result in around 85% of the site zinc loading originating from the adit and the 3l/s scenario is probably overly conservative, at least under average conditions. Based on the current knowledge it is expected that more than half of the site metal loading is coming from waste tips.

The effect of a full site remediation has been simulated removing all or parts of these average metal loadings (i.e.100%, 70% and 50% removal rates) from the average downstream metal loadings of the river. Considering that removal rates are likely to be between 70 and 100%, a substantial improvement of the water quality (i.e. meeting EQS targets) of at least 4km downstream of the site is predicted. The following approx. 7.4km may show slight exceedances of the zinc EQS due to inputs from the Cwm Mawr and Esgair Mwyn mine sites.

Based on these assumed improvements of the Afon Teifi quality (full 11.4km stretch) a total present benefits value has been calculated using the Environment Agency’s NWEBS values (£2.7m to £3.7m depending on which discount rate is applied over the 40-year life cycle). The value with the standard discount rate applied (starting with 3.5% per year) is likely to be overly conservative as “willingness to pay” for a cleaner environment is expected to increase over the years rather than losing value. These values also do not include additional benefits which haven’t been monetised. In line with the Well-being of Future Generations (Wales) Act (2015) the remediation scheme intends to include additional benefits with focus on adding value to the local and wider communities.

Overall the study concludes that the estimated benefits of the Abbey Consols remediation scheme in combination with some remedial works at the nearby Cwm Mawr site exceed the costs of the proposed site wide remediation scheme (currently estimated at £1m to 1.5m) and some remedial work at the Cwm Mawr site (approx. £1.6m estimated remediation costs). More detailed assessments to quantify additional benefits are therefore not recommended at this stage.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

As part of the mine water treatment feasibility assessment, a number of potential treatment techniques have been considered for the adit discharge. Initially these were discussed in an Innovation workshop, which led to a shortlist of the following three options:

1. Compost-based Vertical Flow Pond (VFP)
2. Phosphate treatment system
3. Vertical Flow Reactor (VFR) with chemical dosing

High level sizing and layouts of these treatment solutions were developed to allow costing (CAPEX, OPEX and life cycle costs) based on a 1l/s discharge rate base case scenario and sensitivity analysis for a potentially higher discharge rate of 3l/s. Overall focus of the treatment solution is on zinc removal (and to some extent cadmium removal).

The life cycle costs for the three treatment options were found to be similar, but consideration of the risks and opportunities identified the VFR with chemical dosing as the preferred option. An option assessment was also undertaken for the mine water capture element as the adit discharge is currently not accessible. That means there is significant uncertainty around the discharge flow rates, variability of flow rates (i.e. seasonal variation and response to rainfall events) and mine water quality variability. The recommended option for the mine water capture includes the excavation and re-instatement of the buried adit entrance allowing water to be captured within the adit and then carried generally below ground towards the treatment area.

There is also uncertainty around the efficiency of the VFR solution in terms of metal removal rates. This requires laboratory and field trials to optimise the permanent treatment system.

The assessment of current impacts from the site on the Afon Teifi metal loadings suggest that on average 1,214kg/year of zinc, 1.6kg/year of cadmium and 21kg/year of lead are entering the river from the site. This includes metals originating from the adit discharge and mobilisation of metals from the waste tips.

The effect of a full site remediation has been simulated, removing 100%, 70% and 50% of the calculated average metal loadings from the site from the average downstream metal loadings of the river. Considering that removal rates are likely to be between 70 and 100%, a substantial improvement of the water quality (i.e. meeting EQS targets) of at least 4km downstream of the site is predicted. The following approx. 7.4km may show slight exceedances of the zinc EQS due to inputs from the Cwm Mawr and Esgair Mwyn mine sites.

Based on these assumed improvements of the Afon Teifi quality (full 11.4km stretch) a total present benefits value has been calculated using the Environment Agency's NWEBS values (£2.7m to £3.7m depending on which discount rate is applied over the 40-year life cycle), expected to exceed the estimated 40-year life-cycle costs for the overall site remediation scheme.

In line with the Well-being of Future Generations (Wales) Act the remediation scheme intends to include additional benefits with focus on adding value to the local and wider communities.

Overall, the study confirms feasibility and the importance of the adit discharge treatment element as part of the site wide remediation project.

6.2 RECOMMENDATIONS

It is recommended to incorporate the design of the field trial mine water treatment solution in the SWMS remediation design and to consider an oversizing of the field trial to a potential full size solution (or allow future expansion of the trial facilities). It should be aimed at using parts of the waste tips area (e.g. south-eastern part of the former processing area) to locate the treatment facilities to reduce land take from the adjacent fields and to optimise earthworks during overall site remediation. A discharge solution for the treated mine water should be incorporated into the site wide drainage and SWMS, e.g. by considering a single outfall to the river.

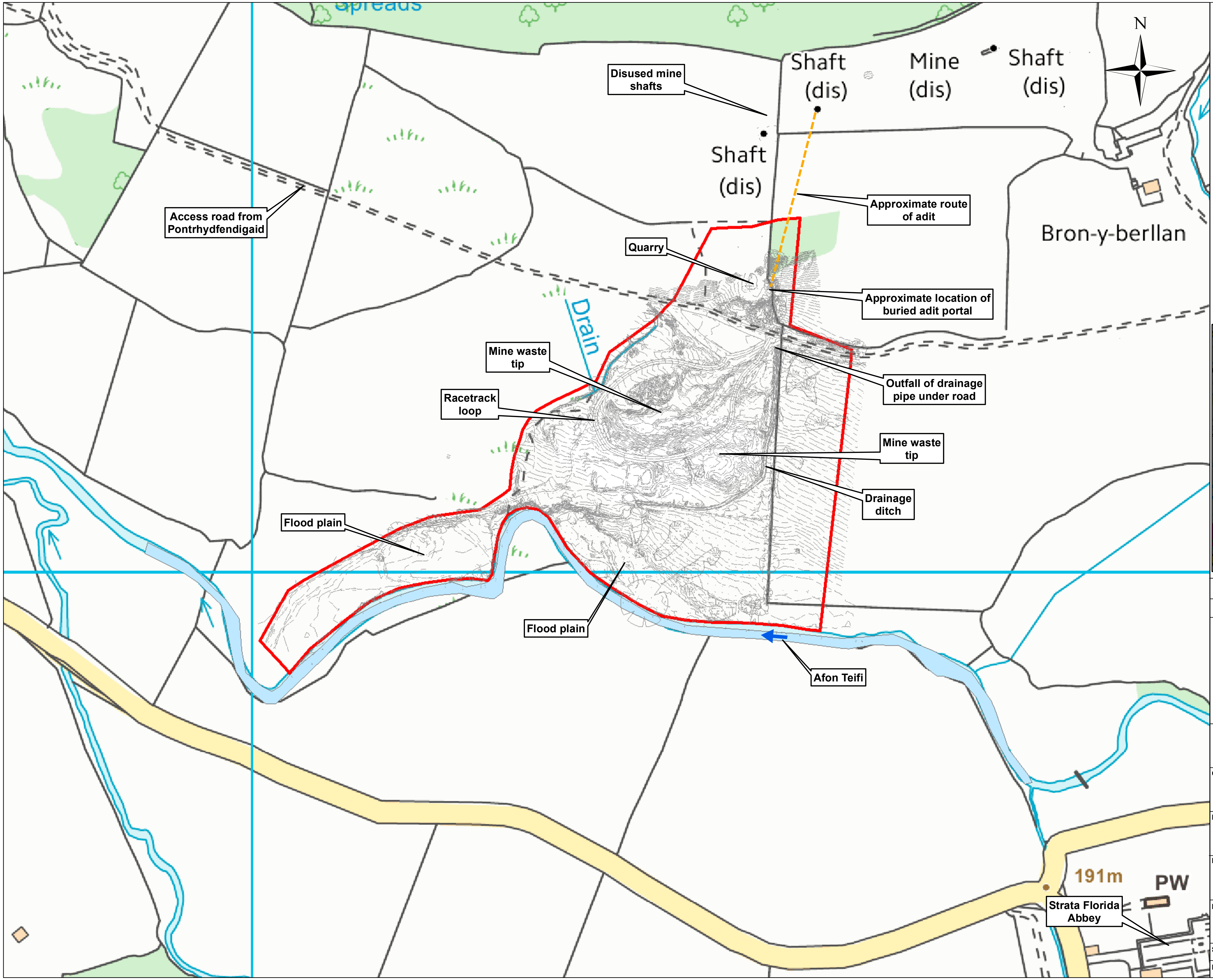
The main advantage of the VFR solution is that its performance (metal removal rates) is mainly controlled by the chemical dosing, i.e. the laboratory trial and the field trial will enable optimisation of the system. Designs of the onsite facilities should allow for flexibility in undertaking further testing, optimisation and research.

The recommended water capture option offers the opportunity to fully capture and measure flows from the adit and to control the water pressure in the mine, whilst also providing information on the state of the adit to inform potential future works to reinstate the adit portal. Implementation of a flow monitoring scheme during the field trial period will be important to establish the flow profile (e.g. response to rainfall events). Measures to improve safety around the open or collapsed mine workings to the north of the site could be incorporated in the remediation programme and could include drainage measures to minimise direct discharge of slope run-off into the mine workings, especially if discharge flow monitoring data indicate a substantial contribution of direct discharge during wet weather conditions.

In order to create a robust baseline data set it is recommended to collect more river quality data during the pre-remediation period (i.e. upstream and downstream of the site). This can later be used to demonstrate the efficiency of the overall remediation scheme.

Appendix A

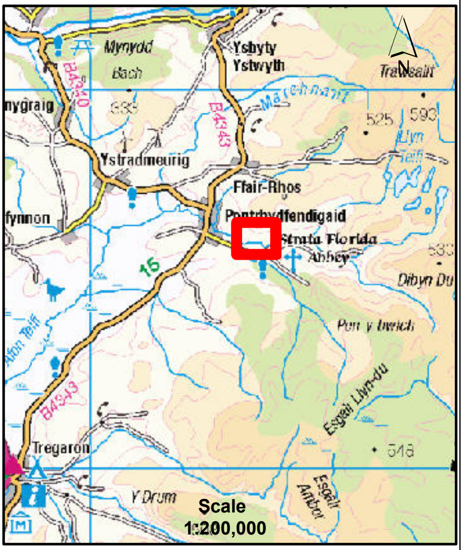
FIGURES



Key

🟥 Abbey Consols - Site Area

Overview Map



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A		DH 22/02/2019	GJ 22/02/2019	TE 22/02/2019
Ver	Amendments	Originated by and date	Checked by and date	Approved by and date

Client : Cyfoeth Naturiol Cymru Natural Resources Wales

Project : **Abbey Consols Metal Mine Remediation Project**

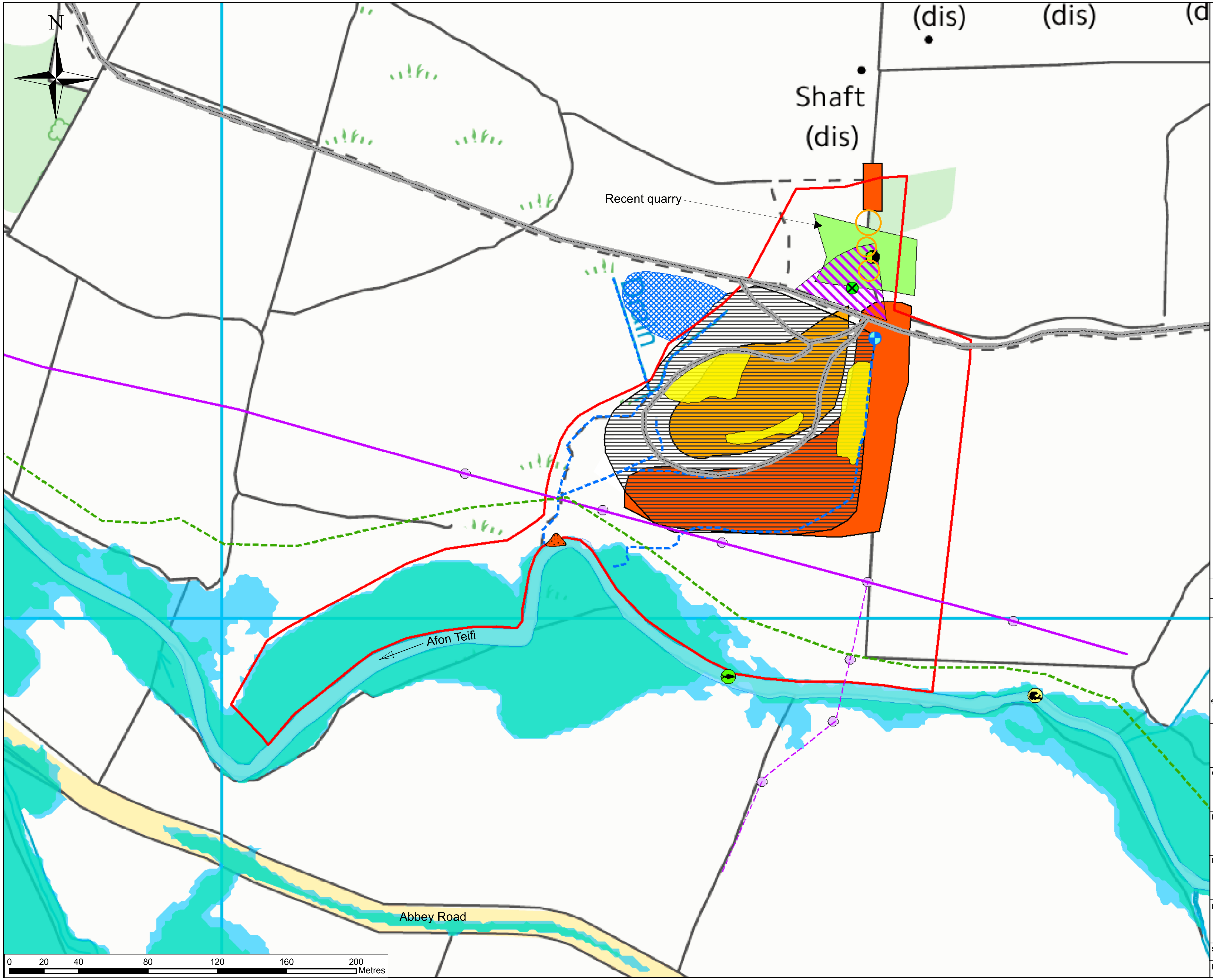
Drawing Title : **Site Location**

Drawing No : **Figure 01**

Scale @ A3 : **1:2,500**

Purpose : **Information**

Path: \\uk.wspgroup.com\central data\Projects\700418xx\70041881 - Abbey Consols mine water FS\02 SW Data\00 GIS Work\01 GIS\01 MXD\08 Feasibility report\Figure 01.mxd



KEY

- 🟥 Abbey Consols - Site Area
- ◐ Area of collapsed Adit entrance
- ⊕ Discharge point
- - - Stream/ditch
- - - Public Rights of Way
- - - Access road
- ▨ Area of uncertain flow conditions
- ▦ Marshy area
- ▤ Waste tips
- 🟨 Areas marked during lower plan survey 2016
- ○ Trees with potential bat roosts
- ▲ Inland river cliff to be protected
- ● Otter spraint confirming Otter presence in the area
- ⊗ Potential bat swarming and hibernation sites
- ● Protected Fish species
- 🟧 Area of high archaeological potential
- 🟩 Area of low archaeological potential
- 🟧 Area of medium archaeological potential
- 🟩 Flood Zone 3
- 🟦 Flood Zone 2
- ▢ River (Afon Teifi)
- — Overhead HV Line (11kV)
- - - Overhead LV Line (11kV)
- ○ Electric pole

Note:
Site is part of the Upland Ceredigion Landscape of Outstanding Special Historic Interest and Ystrad Fflur Historic Landscape Character (HLC).

-The majority of the Site is a Habitat of Principal Importance; and

- Nationally scare bryophyte and lichens are present on the site but accurate and up to date mapping of these species has not yet been conducted

Ver	Amendments	Originated by and date	Checked by and date	Approved by and date
A		IW 26/06/2018	GH/KB/TE/RG 26/06/2018	TE 26/06/2018

Client : Cyfoeth Naturiol Cymru Natural Resources Wales

Project : **Abbey Consols Metal Mine Remediation Project**

Drawing Title : **Summary Constraints Map**

Drawing No : **Figure 02**

Scale @ A3 : **1:2,000**

Purpose : **Information**

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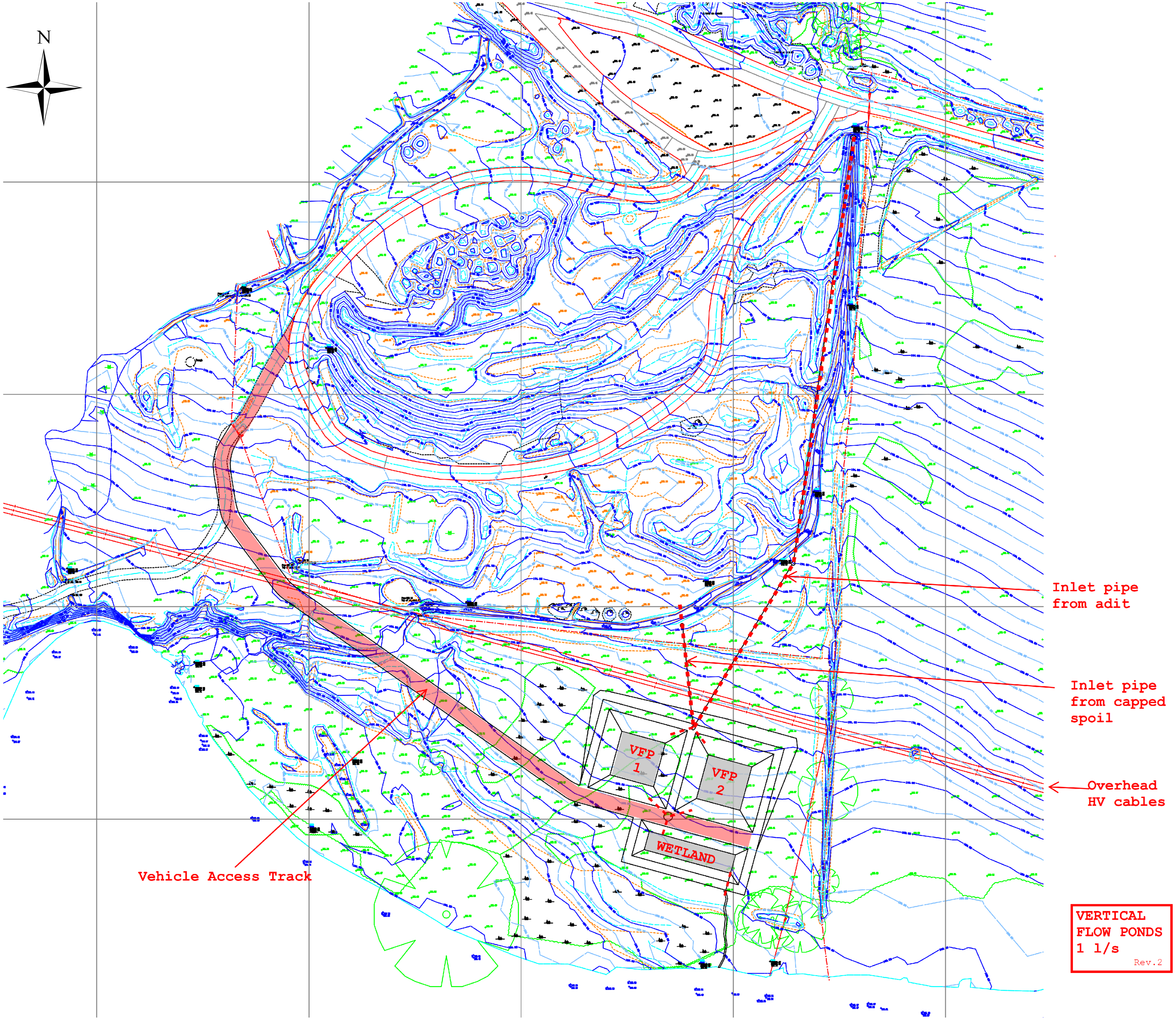


A		DH 22/02/2019	GJ 22/02/2019	TE 22/02/2019
Ver	Amendments	Originated by and date	Checked by and date	Approved by and date

Client : Cyfoeth Naturiol Cymru Natural Resources Wales

Project :
Abbey Consols Metal Mine
Remediation Project

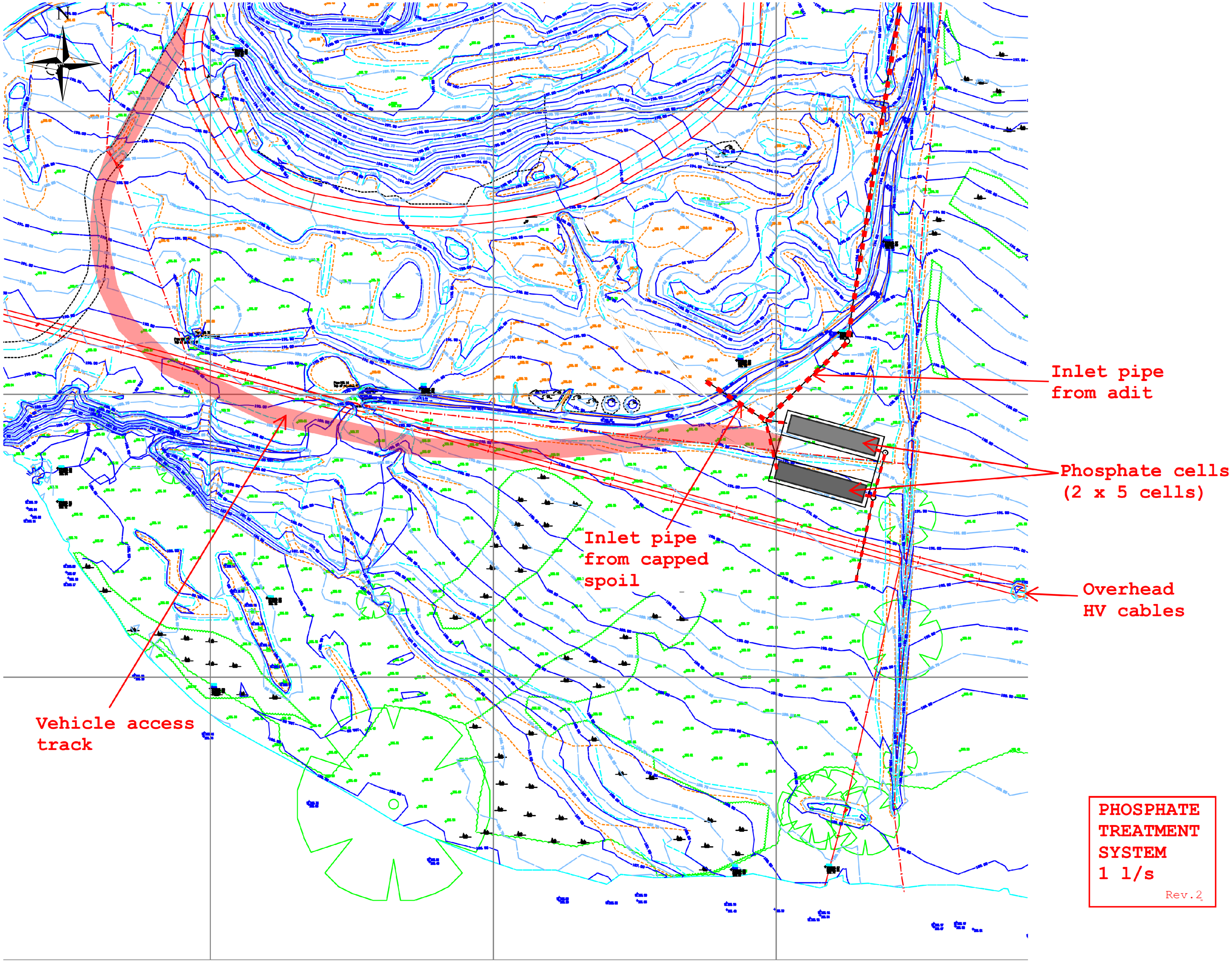
Drawing Title :
Compost-based Vertical
Flow Pond (VFP)

Drawing No : Figure 03

Scale @ A3 : NTS

Purpose : Information

Path: \\uk.wspgroup.com\central data\Projects\700418xx\70041881 - Abbey Consols mine water FS\02 SW Data\00 GIS Work\01 GIS\01 MXD\08 Feasibility report\Figure 03 option 1.mxd



PHOSPHATE TREATMENT SYSTEM 1 l/s

Rev.2

A		DH 22/02/2019	GJ 22/02/2019	TE 22/02/2019
Ver	Amendments	Originated by and date	Checked by and date	Approved by and date

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Client : Cyfoeth Naturiol Cymru Natural Resources Wales

Project : Abbey Consols Metal Mine Remediation Project

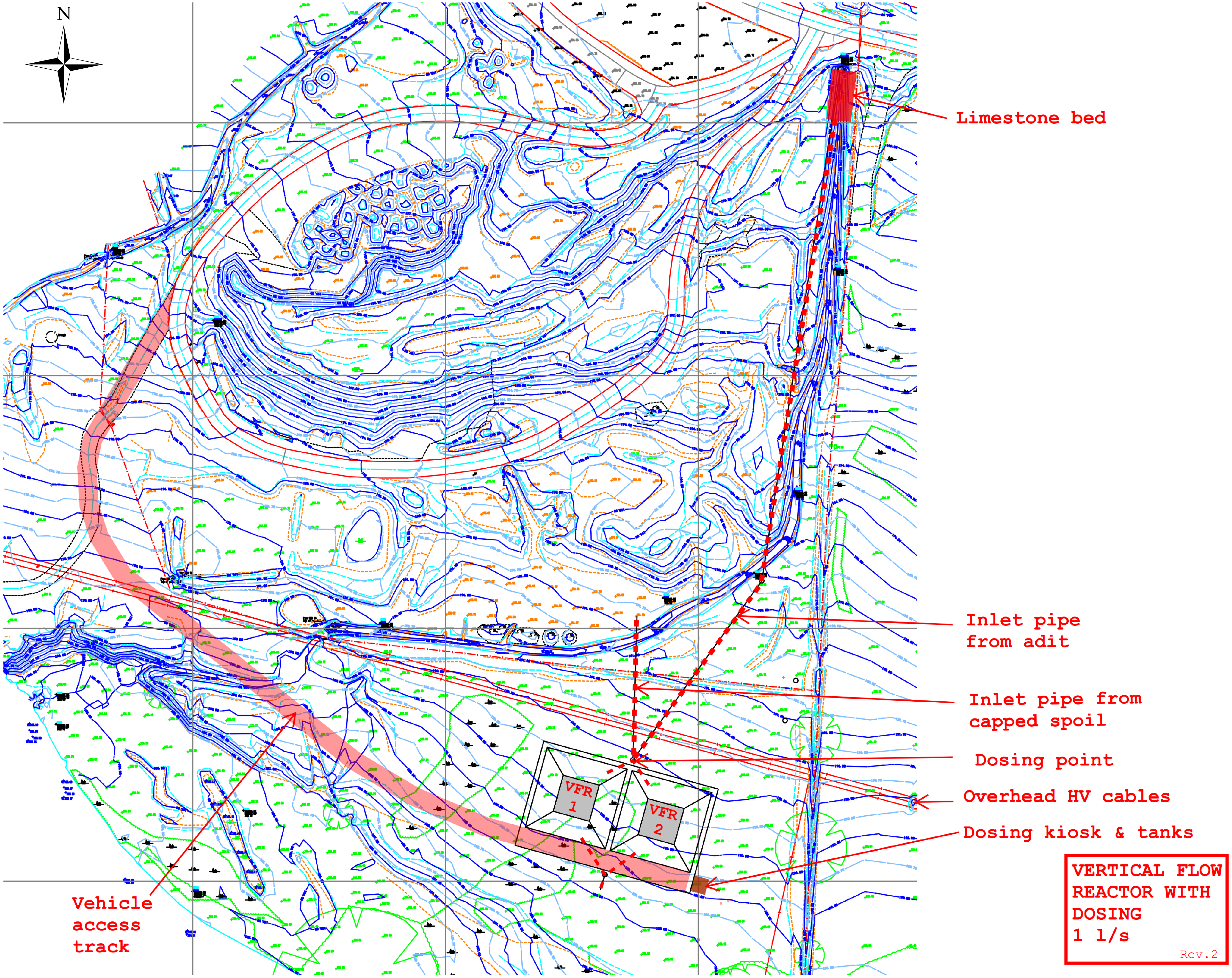
Drawing Title : Phosphate treatment system

Drawing No : Figure 04

Scale @ A3 : NTS

Purpose : Information

Path: \\uk.wspgroup.com\central data\Projects\700418xx\70041881 - Abbey Consols mine water FS\02 SW Data\00 GIS Work\01 GIS\01 MXD\08 Feasibility report\Figure 04 option 2.mxd



VERTICAL FLOW REACTOR WITH DOSING 1 l/s

Rev.2

A		DH 22/02/2019	GJ 22/02/2019	TE 22/02/2019
Ver	Amendments	Originated by and date	Checked by and date	Approved by and date

Client : Cyfoeth Naturiol Cymru Natural Resources Wales

Project : Abbey Consols Metal Mine Remediation Project

Drawing Title : Vertical Flow Reactor (VFR) with chemical dosing

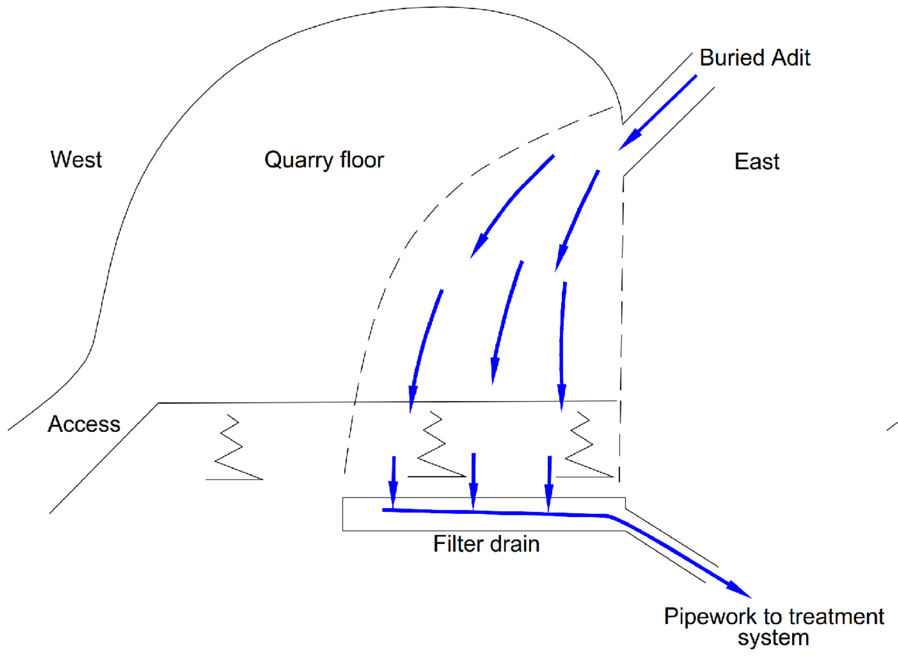
Drawing No : Figure 05

Scale @ A3 : NTS

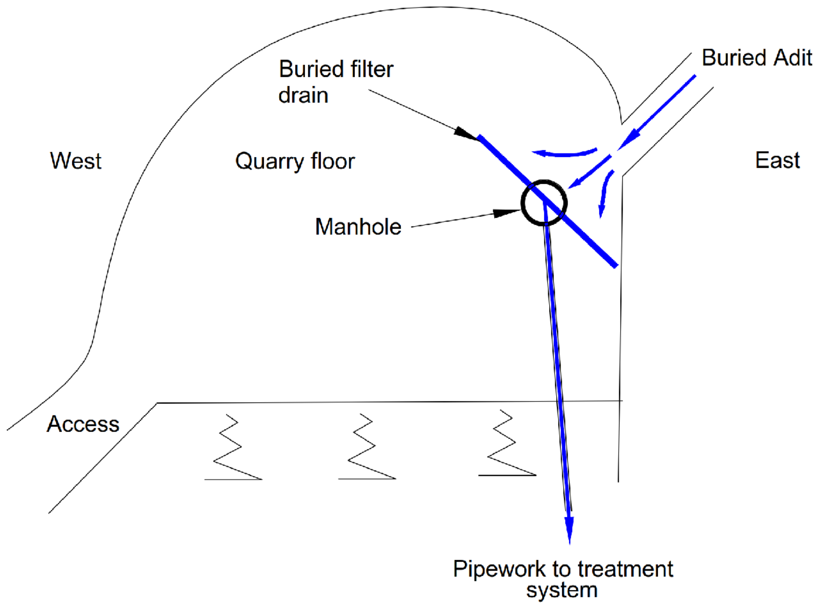
Purpose : Information

Path: \\uk.wspgroup.com\central data\Projects\700418xx\70041881 - Abbey Consols mine water FS\02 SW Data\00 GIS Work\01 GIS\01 MXD\08 Feasibility report\Figure 05 option 3.mxd

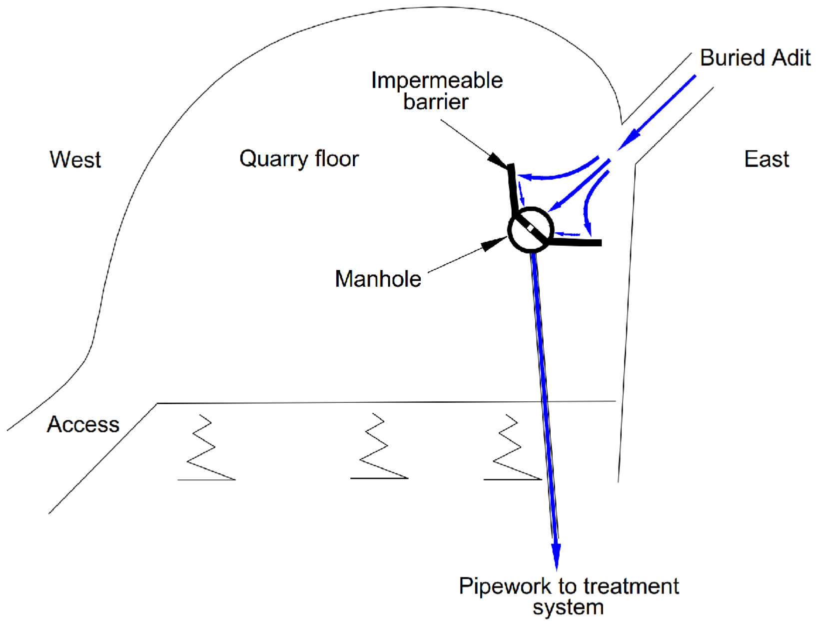
Option 1 Shallow interception drain at toe of quarry spoil



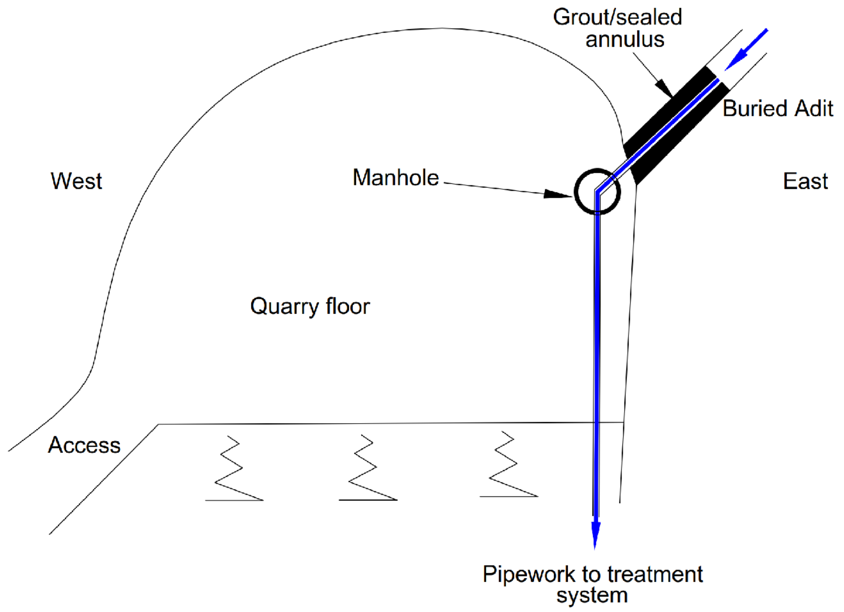
Option 2a Deep interception drain within quarry spoil



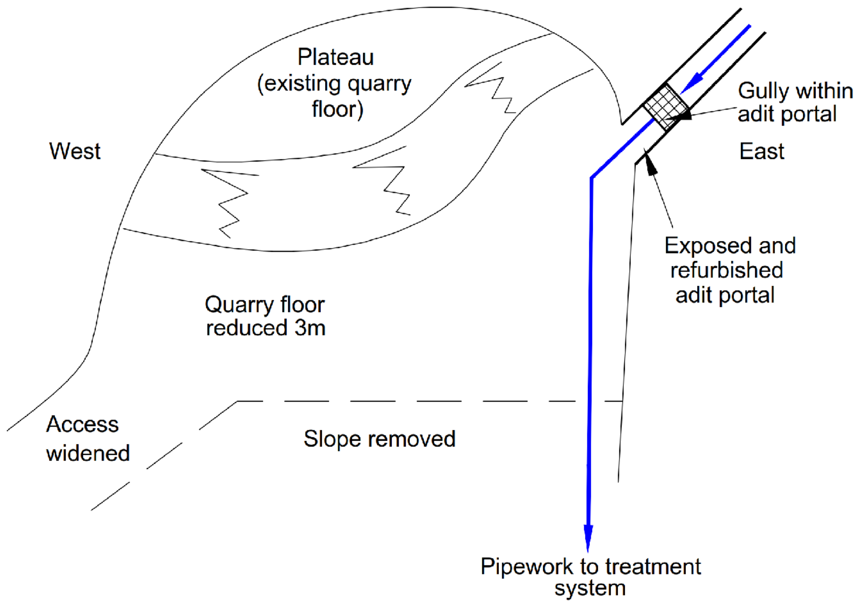
Option 2b Cut-off wall and drain quarry spoil



Option 3a Buried drain from adit portal



Option 3b Open drain from adit portal



A		DH 22/02/2019	GJ 22/02/2019	TE 22/02/2019
Ver	Amendments	Originated by and date	Checked by and date	Approved by and date

Client : Cyfoeth Naturiol Cymru Natural Resources Wales

Project : **Abbey Consols Metal Mine Remediation Project**

Drawing Title : **Adit discharge capture options**

Drawing No : **Figure 06**

Scale @ A3 : **NTS**

Purpose : **Information**

Path: \\uk.wspgroup.com\central data\Projects\700418xx\70041881 - Abbey Consols mine water FS\02 SW Data\00 GIS Work\01 GIS\01 MXD\08 Feasibility report\Figure 06 Adit options.mxd

Appendix B

TREATMENT OPTIONS TECHNICAL NOTE

CONFIDENTIAL

MEMO

TO: Tom Williams (Natural Resources Wales)

FROM: Thomas Eckhardt (WSP)

SUBJECT: **Abbey Consols – Treatment Options Appraisal - Technical Note (final version)**

DATE: **December 14, 2018**

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1. INTRODUCTION

This Mine Water Treatment Options Technical Note provides a summary of the high-level costing assessments for the identified three main treatment options:

- Compost-based Vertical Flow Pond (VFP);
- Phosphate treatment system; and
- Vertical Flow Reactor (VFR) with chemical dosing.

The document aims to provide all relevant information to support the decision on which treatment option(s) to take further for more detailed assessment as part of the feasibility study (i.e. preferred option selection). The technical overview is provided within the text and specific technical details and supporting documents are provided as attachments to this Memo. More detailed considerations and design of a selected preferred option will be required in the following stages of this feasibility study and as part of the following design stages.

2. SITE CONSTRAINTS AND OPPORTUNITIES

This document should be read in conjunction with the Constraints and Opportunities Document which provides information about specific site constraints, in particular issues around the mine water capture, specific environmental constraints (ecology, heritage, landscape, Public Right of Way, Teifi SSSI and flood zones), utilities connections and land ownership.

The mine water treatment will be designed to deal with the two principal sources of metal contamination, i.e. the discharge from the underground mine workings and residual leachate discharge from the waste tips after remediation (capping/reprofiling). The costs of the remedial actions related to the surface water management system for the waste tips are not considered in the assessments presented in this document.

Average zinc concentrations based on NRW monitoring data are at sample point 82988 (pipe under road, presumed raw mine water) total zinc of 7.59mg/l and dissolved zinc of 7.66mg/l, whereas sample point 82991 (final discharge to Teifi, mine water and surface runoff) has total zinc of 16.8mg/l and dissolved zinc of 16.6mg/l. It is therefore possible that a combination of treatment options will be recommended for treatment of the mine waters, for example treating the mine water discharge and the residual leachate from waste tips differently.

3. TREATMENT CRITERIA

There is no continuous flow and discharge quality data available for the site. Remediation activities such as capping, improved groundwater flow control and improved mine water capture and transfer will aim to reduce the discharge flow rates without increasing the metal concentrations in the discharges. For the purpose of this assessment stage it has been agreed with NRW to consider a total treatment design flow of 1l/s and to test sensitivity for increasing the flow to 3l/s. Flow monitoring will become essential as the project progresses to optimise the sizing of the scheme.

It was also agreed that focus of the treatment should be on maximising the removal of zinc (ideally below EQS) and, as a second objective, to achieve some cadmium removal. Site specific metal removal rates have not been determined for any of the three treatment options. Therefore, all three options would require laboratory and possibly field trials to confirm metal removal rates. For the assessment purposes an average zinc concentration of 16.8mg/l (NRW, discharge to Teifi concentration) prior to treatment has been assumed.

Metal loading assessments as part of the scheme benefits assessment are ongoing and will generate estimates of impacts on the Afon Teifi quality for a range of zinc removal rates. These loading assessments are not specific to the treatment methodology.

4. MINE WATER CAPTURE

For all treatment options it is currently considered that the mine water will be captured on the south side of the site access road where the piped culvert discharges into an open ditch. The inlet to this pipe is thought to be under the northern verge of the road, about 30m from the buried mouth of the adit. The flow path from the adit to the pipe is uncertain, so this pipe may not be capturing all of the flow emerging from the adit, and will also be taking surface water runoff from the hillside. It may therefore be necessary to excavate back to the adit mouth and lay a new pipe to ensure full capture of the mine water, with a new crossing under the road to separate it from surface water.

From the culvert a new buried pipe is proposed to take the mine water to the proposed treatment location at the south side of the site, leaving the ditch for surface water drainage. Outflow of remaining contaminated water from the capped spoil area would also be conveyed for treatment.

Discharge route costs (after treatment) have not been included in the assessments as they are likely to be similar for all three treatment options and discharge options would be dependent on the results of the proposed ground investigation.

5. COMPOST-BASED VERTICAL FLOW POND

5.1 TREATMENT PROCESS

Compost-based VFPs aim to precipitate dissolved metals in the form of sulphides within an organic substrate. The Coal Authority's Force Crag VFP project is the most advanced VFP scheme in the UK, and data and design information from that site have therefore been used to develop a potential scheme layout for the Abbey Consols site.

The principal treatment components are:

- A water-saturated organic material bed with an aggregate underdrain allowing vertical percolation of the mine water; and

- A wetland (post treatment) to re-oxygenate the water prior to discharge.

5.2 DESIGN AND OPERATIONS ASSUMPTIONS

A sketch showing an indicative layout of the treatment solution, used for high level costing purposes, is provided in Appendix A.

Based on the Force Crag mine water treatment scheme, the ponds are sized to provide a hydraulic residence time of 15 hours at the design flow rate of 1 l/s (at Force Crag it was 15-20 hours), which gives a total treatment volume of 135m^3 of compost at 40% porosity. The design thickness of compost is 500mm, giving a total treatment area of 270m^2. This volume is split between two equal-sized ponds for operational flexibility. The ponds are designed with sloping earth banks which reduces the thickness of compost at the perimeter, potentially reducing treatment effectiveness there. This reduced thickness at the perimeter is therefore excluded from the 135m^3 required, giving an actual total compost volume of 166m^3 with a total surface area of 399m^2 with assumed 1 in 2.5 side slopes.

To treat 3 l/s with the same parameters, 405m^3 (effective) volume of compost would be required (464m^3 total volume).

A preliminary location has been chosen between the southern boundary of the site and the Afon Teifi, on ground above the 0.1% river flood risk level. This location allows gravity flow of water from both the adit and capped area through the whole treatment system. The main constraints are overhead electricity cables and a footpath. The ground here slopes at about 1 in 20 towards the river.

Access to the proposed site is via the existing farm access track leading off the western side of the ‘racetrack’ loop. This would be resurfaced with granular material and extended along the southern side, outside of the boundary fence, to the proposed site. A turning stub would allow vehicles to drive forwards, in and out. If the capping design and archaeological constraints allow, a shorter access route is possible from the nearest point of the ‘racetrack’ loop, saving about 75m of new road.

The flow is divided amongst two equal-sized ponds to reduce the effect of one pond being offline for maintenance, etc. In such circumstances the effluent quality from the pond remaining in service would reduce, and so the acceptability of this would need to be agreed. Programming maintenance for when mine water outflow is low, to reduce effluent volume, or when the river flow is high, giving greater dilution of the lower quality effluent, would mitigate this issue to some extent. Proposed maintenance during operation can be qualified once flow monitoring confirms seasonality of mine water discharge.

For the baseline case of treating 1 l/s, two square ponds, each with a 10.6m x 10.6m base, would be required. A side slope of 1 in 2.5 has been assumed, giving dimensions of 19.1m x 19.1m at the top of the bank. If the actual site geology allows the slopes to be steeper, the overall pond area and excavation volume could be reduced. Excavated material is assumed to be re-used on site as fill material.

A 4m wide track for vehicles along one side of the VFPs would allow a medium-sized excavator to place compost into the VFPs, and later remove it for disposal

The ponds are assumed to be rectangular trapezoidal in shape, comprising, from the base upwards:

- An impermeable geomembrane liner to contain the mine water, with a geotextile drainage layer beneath to prevent groundwater pressure lifting the liner when the pond is empty (this could be omitted if the site geology is suitable).
- 200mm depth of limestone gravel containing perforated drainage pipes to remove treated mine water and encourage vertical flow through the compost.
- 500mm depth of compost, comprising 45% PAS100 compost, 45% wood chips and 10% municipal WWTW digested sludge as at Force Crag,
- 500mm depth of mine water,
- 500mm freeboard.

Contaminated water from the adit and the capped spoil heaps would flow under gravity in a new buried pipelines to a distribution chamber, where two V-notch weirs would divide the flow equally between the VFPs. Measurement of the water level in the chamber would allow the flow rate to be calculated (automatic level measurement and flow logging has not been specifically allowed for). A handstop at each weir would allow the downstream VFP to be isolated.

The outlet from each VFP comprises a drainage pipe network within a gravel base layer, emerging as a single flexible pipe in an outlet level-control chamber. The water level in the VFP would be controlled by raising or lowering the outlet pipe in this chamber. Careful design will be required to minimise turbulence leading to odour problems from the release of dissolved hydrogen sulphide.

The outflow from both VFPs flows by gravity in a buried pipe to a 1m deep planted wetland, sized at one third of the total compost pond area. This has been assumed to be rectangular trapezoidal in shape, with 1 in 2.5 side slopes as for the ponds. The water inlet and outlet would be designed to minimise turbulence and thus potential odour problems.

Although remote from habitation, the presence of the nationally important Strata Florida Abbey close by, a footpath crossing the site and the adjacent racetrack makes the reduction of odours necessary. Potential odour problems could be addressed by removing dissolved hydrogen sulphide downstream of the VFP by dosing with hydrogen peroxide. As a rough estimate, $0.5m^3$ per year of hydrogen peroxide would be required, which could be supplied in a $1m^3$ Intermediate Bulk Container (IBC) placed onto a flat slab with a small dosing pump in a GRP kiosk alongside. The IBC would be screened or enclosed within a building to suit its location. The dosing pump could be solar/wind/fuel cell powered with battery back-up, given the low dosing rate, thus avoiding the need for a mains power connection. The VFP outlet chambers would be a suitable dosing point, with a forebay at the wetland entry acting as a contact tank. Detailed studies of the mine water, treatment process, site location, etc. would be required to confirm details required to prevent any odour nuisance beyond the site boundary. Alternative solutions should be investigated as part of future design stages aiming to remove/reduce the chemical/active treatment element of the odour control. Preferably the hydrogen sulphide should be released (aerate flow) and then absorbed (e.g. via carbon filter).

An outlet sampling chamber would provide a safe facility to obtain treated water samples prior to discharge to the river via an open channel, as at present.

For removal of the compost the inflow would be isolated at the flow distribution chamber and the pond drained via the level control chamber. The compost could then be removed by hydraulic excavator from the adjacent track.

At this stage it is assumed that replacement of the compost will be required every 10 years requiring disposal to a hazardous landfill or incineration. We are aware of the Coal Authority's efforts in trying to address the waste issue for VFPs by optimising the disposal process. At this high-level stage of the study only the most common disposal routes are considered with detailed considerations to follow in later stages of the project, if this option is taken forward. Frequency of compost replacement may also be influenced by the performance of the compost bioreactor, e.g. from clogging risks. At this stage no onsite compost treatment/dewatering has been considered. Compost replacement and disposal requirements are considered key elements for further design stages.

5.3 RISKS AND OPPORTUNITIES

The following key risks have been identified:

- The VFP hasn't been tested on the mine water at Abbey Consols, which differs from that at Force Crag on which this option is based. There is therefore some uncertainty around its performance in achieving sufficient metal removal;
- Sulphate addition is likely to be required to raise the concentration in the mine water to enable the process to work (costs of sulphate dosing is not included in the current cost estimate but cost impacts are expected to be similar to the hydrogen peroxide dosing);
- Force Crag suffered from bacterial growth on top of the compost which reduced its permeability requiring remedial works. Although differing in water quality and location, Abbey Consols may suffer likewise;
- Potential for developing preferential flow paths that short-circuit the compost;
- Odour management may be more challenging than expected, and with uncertain costs, e.g. due to the volatility of hydrogen peroxide price and more substantial chemical storage/protection costs (i.e. a small building);
- Waste disposal options (and related costs) for the compost are uncertain and may change in the future (risk and opportunity). Dewatering and/or treatment of the compost waste may be required prior to disposal with potential impact on land take and costs;
- There will potentially be excavated material to be taken off site. If this material is contaminated, disposal costs could be high (i.e. geo-environmental issues affecting earthworks);
- Potential damage to the HDPE geomembrane during media removal would need to be accommodated in design or costly liner repairs considered; and

- The land take and earthworks costs for this option are dependent on the stable slope angle allowed by the ground conditions, a shallower angle giving greater area and cost.

The following opportunities have been identified:

- The low hydraulic head requirement for this option could avoid the need for pumping, resulting in an entirely passive system (apart from sulphate-dosing and potential chemical dosing as part of odour control). This would remove the need for a mains power supply at the site;
- Lessons learnt from the Force Crag site could enable to use better media reducing the risks of performance issues;
- Innovative design of the VFP, e.g. by arranging the flow through the compost to run horizontally rather than vertically could result in reduction of footprint, reduced visual impact and easier odour control;
- Optimisation of the waste stream aiming to avoid landfill disposal or incineration, e.g. via soil improvement facilities, could result in significant cost savings and increased sustainability of the option.

5.4 COSTING (INCLUDING ASSUMPTIONS)

Based on the design information and assumptions above, the following costs have been estimated (see Table 5.4.1 (capital) and 5.4.2 (operations) below). Costs are based on supplier information, previous project experience or professional judgement with further detail being provided in Appendix B.

Table 5.4.1 Estimated CAPEX for 1 l/s base case

Item	Estimated Cost (£k)	Comment
Earthworks for ponds	118	All excavated material assumed to be re-used on site.
Pipework & chambers	108	Mine water capture, distribution, drainage & disposal
Odour Control	17	Hydrogen peroxide dosing
Site works	76	Perimeter fence and access tracks
Total CAPEX	319	Estimated CAPEX for 3 l/s treatment: £464k

Table 5.4.2 Estimated OPEX for 1 l/s base case

Item	Estimated Cost (£k/year)	Comment
Inspection & maintenance	6	Annual cost for monthly routine check & minor maintenance, sampling and odour control maintenance
Odour control (consumables)	2	Supply of hydrogen peroxide
One-off Costs in Addition to Routine OPEX	**Estimated Cost (£k)**	**Comment**
Compost removal and disposal	65 (per removal event)	Disposal as contaminated waste to landfill 20 miles from site once every 10 years and at the end of lifecycle. Assuming waste disposal cost of £300/t plus excavation and haulage costs.
Compost refill	6	Once every 10 years

Whole Life Costs (NPV)

Whole Life Cycle costs were estimated based upon a 25 year life with only minor maintenance required to the site within this period. It is assumed that at years 10, 20 and 25, all of the compost would be removed for disposal. At this stage the NPV value considers the more expensive hazardous waste disposal route as disposal to a non-hazardous landfill and alternatives such as soil improvement facilities remain unconfirmed. For the latter option compost treatment prior to disposal may be essential or more frequent compost replacement may be required which would result in increased costs compared to the estimates for disposal to non-hazardous landfill presented in Table 6.4.2.

OPEX costs were assumed to rise at 2% per year and discounted at 3.5% to give the present value of the whole life cycle costs. Financing costs and decommissioning costs have not been included.

Estimated Net Present Value (NPV) for treating:	**1 l/s**	**3 l/s**
CAPEX & OPEX	£443k	£588k
Odour control	£ 37k	£112k
Compost disposal & replacement	£159k	£445k
TOTAL	**£639k**	**£1,145k**

If disposal of the compost waste to non-hazardous landfill became feasible (at approx. £100/t) the NPV value would drop to approx. £544k for 1 l/s or £877k for 3 l/s (considering the same number of removal events). This shows the sensitivity of this option to the currently unresolved waste disposal issue.

6. PHOSPHATE SYSTEM TREATMENT

6.1 TREATMENT PROCESS

This process is based upon the stabilization of a wide range of metals, especially Pb, U, Cd, Zn, Cu and Al, by chemically binding them into new, low-solubility, phosphate minerals. In addition, the presence of sulphate-reducing bacteria in anaerobic zones in the treatment beds results in the precipitation of metal sulphides.

6.2 DESIGN AND OPERATIONS ASSUMPTIONS

A sketch showing an indicative layout of the treatment solution, used for high level costing purposes, is provided in Appendix A.

The proposed design is based upon the 'Phosphate-Induced Metal Stabilization' system used to treat acid mine discharge from the Success mine, draining into Ninemile Creek near Wallace, Idaho, USA[1]. This system used a proprietary product derived from fish bones, 'Apatite II', as the active media, mixed with plastic filter media to improve the hydraulic properties.

The proposed treatment system for the adit discharge would comprise two 18m long x 2m wide x 2m deep rectangular-section channels, each sub-divided into five 2.5m long cells with cross walls and filled with 1.8m depth of 70% Apatite II/30% plastic filter media. Mine water would flow horizontally through the media, with a downstream weir formed by the dividing wall of each cell keeping the water surface just below the top of the media. The treated water emerging from both final cells would collect in a sampling chamber before discharge to the river via an open channel, as at present.

Operational experience from the Success mine showed a build-up in sediment within the media, resulting in reduced hydraulic conductivity and the formation of preferential flow paths leading to reduced treatment efficiency. To combat this, compressed air was injected into the media to break up and mix clumps of media. It is assumed that similar measures would be needed at Abbey Consols, with an operator using a portable air compressor and manual lance. The required frequency of this activity would be determined by operational experience, but for this report has been assumed to be every two weeks.

When the treatment potential of the media has been exhausted, it would need to be removed and replaced with fresh media. The old, contaminated media would be excavated with a hydraulic or vacuum excavator from the adjacent access track and disposed of to a hazardous-waste landfill. This has been assumed to be required every five years. Whilst media is being removed from one treatment stream, all flows would pass through the other stream. Replacing the media when mine water outflow is low, to reduce effluent volume, or when the river flow is high, giving greater dilution of the lower quality effluent, would minimise the impact on the river quality. The optimum time would be determined once flow monitoring confirms the seasonality of mine water discharge.

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[1] https://www.researchgate.net/publication/237378190_TREATMENT_OF_ACID_MINE_DRAINAGE_USING_FISHBONE_APATITE_IITM1

Anaerobic conditions within the treatment cells could create potential odour problems, and so covers and hydrogen peroxide dosing has been allowed for.

The proposed location for these treatment cells is in the southeast corner of the site, where it can receive gravity flows from both the adit drain and the capped spoil (assuming the capped spoil is kept saturated with a high water level to minimise oxidation of the mine waste).

Access to the proposed site is via the existing farm access track leading off the western side of the 'racetrack' loop. This would be resurfaced with granular material and extended along the southern side, outside of the boundary fence, to the proposed site. A turning stub would allow vehicles to drive forwards, in and out. If the capping design and archaeological constraints allow, a shorter access route is possible from the nearest point of the 'racetrack' loop, saving about 120m of new road.

6.3 RISKS AND OPPORTUNITIES

The following key risks specific to this option have been identified and should be considered in following design stages:

- Current and future availability of suitable media is uncertain (media cost has not been confirmed by the supplier);
- Performance under site conditions is unconfirmed;
- The rate and effect of clogging of the media is uncertain;
- Discharge quality could be unacceptable (e.g. if phosphate gets mobilised) considering the sensitivity of the Afon Teifi;
- Generation of odour could be a problem depending on media type and site specific conditions; and
- Risks related to ground conditions (excavation depth) or other environmental constraints for construction and maintenance.

The following additional opportunities may be considered for refinement of the design:

- Slope-sided channels would reduce construction costs, but would increase land take and might adversely affect treatment effectiveness and maintenance requirements;
- Increased treatment area could reduce the clogging risk but would cause an increase in initial earthworks and landtake;
- Fishbone derived media could be replaced with other apatite sources which would mitigate the potential odour issues but would remove the sulphide precipitation element of the treatment. This would, however, require specific research into alternative media; and
- From the three options this is the only potentially fully passive system (if no odour risk from the media) and could be attractive for the low flow or temporary flow discharge component from the waste tips (residual seepage).

6.4 COSTING (INCLUDING ASSUMPTIONS)

Based on the design information and assumptions above, the following costs have been estimated (Table 6.4.1 (capital) and 6.4.2 (operations) below). Costs are based on supplier information, previous project experience or professional judgement with further detail being provided in Appendix B.

Table 6.4.1 Estimated CAPEX for 1 l/s base case

Item	Estimated Cost (£k)	Comment
Earthworks and treatment cells	43	All excavated material assumed disposed of on site
Pipework & chambers	28	Mine water capture, distribution, drainage & disposal
Odour Control	34	Covers & hydrogen peroxide dosing
Site works	87	Perimeter fence and access tracks
Total CAPEX	**192**	**Estimated CAPEX for 3 l/s treatment: £303k**

Table 6.4.2 Estimated OPEX for 1 l/s base case

Item	Estimated Cost (£k pa)	Comment
Inspection & maintenance	6	Includes mixing media every two weeks to maintain flow rate and treatment efficiency
Odour control (consumables)	2	Supply of hydrogen peroxide
Total OPEX	**8**	**Estimated OPEX for 3 l/s treatment: £13k**

One-off Costs in Addition to Routine OPEX	Estimated Cost (£k)	Comment
Media disposal	35	Assumed every 5 years with £300/t landfill/incinerator charge
Media refill	9	Assumed once every 5 years
Total one-off OPEX	**44**	**Estimated one-off OPEX for 3 l/s treatment: £133k**

Whole Life Costs (NPV)

Whole Life Cycle costs were estimated based upon a 25 year life with replacement of the media every 5 years. OPEX costs were assumed to rise at 2% per year and discounted at 3.5% to give the present value of the whole life cycle costs. Financing costs and decommissioning costs have not been included.

Estimated Net Present Value (NPV) for treating:	**1 l/s**	**3 l/s**
CAPEX & OPEX	£314k	£425k
Odour control	£ 37k	£112k
Media disposal & replacement	£173k	£518k
TOTAL	**£524k**	**£1,055k**

If disposal of the treatment media waste to non-hazardous landfill became feasible (at approx. £100/t) the NPV value would drop to approx. £434k for 1 l/s or £783k for 3 l/s (considering the same number of removal events). This shows the sensitivity to the waste classification at disposal for this option.

7. VERTICAL FLOW REACTOR WITH CHEMICAL DOSING

7.1 TREATMENT PROCESS

This process involves dosing the mine water with ferric sulphate in the presence of limestone to mitigate drop of pH followed by a VFR allowing the dissolved iron to precipitate and to co-precipitate and absorb zinc and other heavy metals.

This treatment option comprises the following elements:

1. A limestone gravel bed to increase the alkalinity of the adit mine water. This would be formed by adding an impermeable liner to the 10m length of ditch immediately downstream of the road culvert and a downstream weir to form a pond. This would be partially filled with about $3m^3$ of limestone gravel through which the mine water would travel with an average retention time of 1-1.5 hours.

2. A Ferric Sulphate dosing system comprising:
    a. Three $1m^3$ IBC storage tanks for a 40% aqueous solution of $FeSO_4$. At an average dosing rate of 0.7 l/h for 1 l/s of mine water, each IBC would last for two months. Changeover would be manual during a routine maintenance visit, with two empty IBCs replaced by the chemical supplier every four months. Appropriate screening or enclosure of the IBCs would be provided to give an acceptable visual appearance.
    b. An enclosed, skid-mounted dosing system on a concrete slab next to the storage tanks. This would include duty/standby variable-speed electric dosing pumps, controlled by the mine water flow rate.
    c. A V-notch flow measurement weir with ultrasonic level sensor, feeding flow data to the dosing system.
    d. Dual-contained dosing lines in buried ducts to the dosing point.
    e. A dosing point upstream of an engineered hydraulic jump to ensure rapid mixing of the ferric sulphate with the mine water.

3. Two VFR ponds of rectangular trapezoidal shape, sized at $1.2\ l/min/m^2$ minimum plan area, but increased in size to provide enough sludge storage to allow desludging once per year. These would comprise, from the base upwards:
    a. An impermeable geomembrane liner to contain the mine water, with a geotextile drainage layer beneath to prevent groundwater pressure lifting the liner;
    b. 500mm depth of limestone gravel (200mm of 6mm size overlying 300mm of 20mm) with perforated drainage pipes at the bottom to remove treated mine water and encourage vertical flow through the gravel;
    c. Up to 1000mm depth of mine water above the gravel; and
    d. 300mm freeboard at maximum water level.

4. An outlet sampling chamber to provide a safe facility to obtain treated water samples prior to discharge to the river via an open channel, as at present.

7.2 DESIGN AND OPERATIONS ASSUMPTIONS

A sketch showing an indicative layout of the treatment solution, used for high level costing purposes, is provided in Appendix A.

Based on the previous VFR trial results a minimum VFR treatment area of 50m^2 is required to treat 1 l/s based on a VFR flow rate of 1.2 l/min/m^2, although this has been increased to provide sufficient sludge storage volume.

The proposed location is to the south of the mine workings site, between it and the Afon Teifi floodplain. This site allows gravity flow from both the adit and capped spoil sources to and through the treatment system.

Access to the proposed site is via the existing farm access track leading off the western side of the ‘racetrack’ loop. This would be resurfaced with granular material and extended along the southern side, outside of the boundary fence, to the proposed site. A turning stub would allow vehicles to drive forwards, in and out. If the capping design and archaeological constraints allow, a shorter access route is possible from the nearest point of the ‘racetrack’ loop, saving about 75m of new road.

Two equal-sized VFRs are proposed to allow one to be taken offline for maintenance and desludging. Each VFR is assumed square in plan, with side slopes of 1 in 2.5 and set with the top of bank at ground level. All excavated material is assumed to be used elsewhere on site for landscaping, but, if suitability confirmed by the ground investigation, the VFRs could be partly raised above existing ground level with this material used for the embankments, thus reducing the volume of excavation required.

The overall footprint of the VFRs and access track within the fenced perimeter is estimated to be 770m^2 (for the 1 l/s base case) with an additional 480m^2 of new access track.

Mine water discharging from the culvert under the road would flow through a limestone bed and then by gravity in a buried pipeline to the flow measurement weir and dosing point, just upstream of the VFR flow distribution chamber. Two V-notch outlet weirs in this chamber would divide the flow equally between the VFR ponds, with handstops to isolate either pond when required.

The outlet from each VFR comprises an array of perforated drainage pipes at the base of the gravel, combined into a single flexible pipe in the outlet chamber. Raising or lowering of this flexible pipe allows the water level in the VFR to be controlled.

The precipitated metals are expected to form a sludge blanket on the surface of the gravel in the VFR. When this blanket occupies half the maximum depth of water in the VFR, the inlet would be shut and the outlet pipe lowered to drain the pond. The sludge would then be left in situ to dewater by gravity drainage and surface evaporation from an assumed initial 2% dry solids (DS) to 25% DS. Whilst one VFR is desludging, all the flow would be diverted into the other VFR. The VFRs would be sized to require desludging once per year, timed to take place during the summer to maximise the rate of dewatering and also to take advantage of the expected reduced summer flow rate to reduce the impact of one VFR being offline. Once the sludge had dewatered sufficiently, it would be removed from the surface by mechanical excavator and transported off site for disposal as hazardous waste. The VFR would then be returned to service and the process repeated for the second VFR.

7.3 RISKS AND OPPORTUNITIES

The following key risks have been identified:

- The land take and earthworks costs for this option are dependent on the stable slope angle allowed by the ground conditions, a shallower angle giving greater area and cost;
- The OPEX cost is sensitive to the dry solids content of the precipitated metal sludge as it's removed from site. At 10% DS the annual desludging & disposal cost would be roughly double that at 25% (Cardiff University research currently suggests that 25% DS is achievable);
- Potential damage to the HDPE geomembrane during media removal would need to be accommodated in design or costly liner repairs considered; and
- Chemical storage and handling on site needs to be managed avoiding impacts to the environment and human health.

The following opportunities have been identified:

- Dosing with both Ferrous Sulphate and Potassium Permanganate offers an interesting alternative with the two chemicals reducing/oxidising each other and removing the need for aeration. The VFRs could be replaced with smaller size sand filters. Manganese is expected to be more efficient in zinc removal compared to iron;
- Use of the head available to the mine water to power the dosing system, automatically compensating for flow variation without the need for flow measurement and avoiding the costs of providing an electricity supply. Such a system may need developing, but alternative off-grid dosing systems using wind & solar power with battery backup are commercially available. Alternatively overdosing could be considered providing additional sorption potential within the precipitate to deal with peak flow scenarios;
- Sludge disposal from the VFR has been costed as a hazardous waste product. Research from Cardiff University suggests that non-hazardous waste classification is likely to be achievable. Outlets for this sludge as a raw material would reduce OPEX costs considerably; and
- Involvement of competent Welsh Water staff from the nearby treatment site in the operation could reduce costs.

7.4 COSTING (INCLUDING ASSUMPTIONS)

Based on the design information and assumptions above, the following costs have been estimated [Table 7.4.1 (capital) and 7.4.2 (operations) below]. Costs are based on supplier information, previous project experience or professional judgement with further detail being provided in Appendix B.

Table 7.4.1 Estimated CAPEX for 1 l/s base case

Item	Estimated Cost (£k)	Comment
Earthworks for VFRs	53	All excavated material assumed re-used on site
Pipework & chambers	58	Mine water capture, distribution, drainage & disposal
Dosing system	80	Flow-controlled electric dosing pumps, incl. storage and elec. supply
Site works	72	Perimeter fence and access track from tarmac road
Total CAPEX	**263**	**Estimated CAPEX for 3 l/s treatment: £451k**

Table 7.4.2 Estimated OPEX for 1 l/s base case

Item	Estimated Cost (£k/year)	Comment
Inspection & maintenance	6	Annual cost for monthly routine check & minor maintenance, sampling and chemical dosing maintenance
Chemical resupply	2.7	Supply of Ferric Sulphate (2m^3 every 4 months)
Metals removal from VFR and disposal at:		Transportation and disposal as contaminated waste to hazardous landfill 20 miles from site. Assumed waste disposal cost of £300/t plus haulage.
10% dry solids	7.2	Sludge dewatering assumed to be by gravity drainage and evaporation in VFR taken off-line.
15% dry solids	5.0	
20% dry solids	3.9	
25% dry solids	3.2	
Total OPEX		**Estimated OPEX for 3 l/s treatment:**
10% dry solids	15.9	34.5
15% dry solids	13.7	27.9
20% dry solids	12.6	24.6
25% dry solids	12.0	22.7

One-off Costs in Addition to Routine OPEX	Estimated Cost (£k)	Comment
Limestone replenishment	1	Every 5 years

Whole Life Costs (NPV)

Whole Life Cycle costs were estimated based upon a 25-year life with replenishment of ferric sulphate every 4 months, limestone every 5 years and desludging every year. Sludge disposal costs are given for a range of dry solids content to show the sensitivity to the degree to which the sludge can be dewatered prior to disposal. OPEX costs were assumed to rise at 2% per year and discounted at 3.5% to give the present value of the whole life cycle costs. Financing costs and decommissioning costs have not been included.

Table 7.4.3 Estimated Net Present Value (NPV) based on dry solids

Flow rate	**1 l/s**				**3 l/s**			
Sludge DS	**10%**	**15%**	**20%**	**25%**	**10%**	**15%**	**20%**	**25%**
CAPEX & OPEX	£383k	£383k	£383k	£383k	£570k	£570k	£570k	£570k
Ferric dosing & limestone	£65k	£65k	£65k	£65k	£194k	£194k	£194k	£194k
Sludge disposal	£157k	£108k	£85k	£71k	£442k	£299k	£227k	£185k
TOTAL	**£604k**	**£556k**	**£532k**	**£518k**	**£1,207k**	**£1,064k**	**£992k**	**£949k**

8. OPTIONS APPRAISAL

Details of the options appraisal are summarised in the table on the following page (Table 8.1).

Table 8.1: Options appraisal summary

Option	Flow Rate	Required Area (m^2)	CAPEX (£k)	OPEX (£k pa)	Net Present Value £k	Sludge/media Volume (m^3)	Sludge/media Disposal (£k)	Advantages	Disadvantages
VFP	1 l/s	1,600	319	6* +2†	639 (544)**	166	65 media disposal + 6 new media every 10 years	No mains power needed No telemetry needed Natural appearance	Large footprint increases cost. Large waste volume and waste type make OPEX sensitive to increased disposal costs. Likely to require sulphate dosing (not included in cost estimate). Potential operational issues (algae clogging). Odour control may be needed
	3 l/s	3,100	464	11* +5†	1,145 (877)**	464	182 media disposal + 16 new media every 10 years		
Phosphate system	1 l/s	230	192	6* +2†	524 (434)**	90	35 media disposal + 9 new media every 5 years	Small footprint No mains power needed No telemetry needed Fully passive (if no odour issues)	Uncertain media cost & availability. Treatment effectiveness not proven (in particular over time). Potential discharge quality issues (e.g. phosphate) - considering the sensitivity of the Teifi. Potential operational issues (clogging or creation of preferential flowpaths within the media). Odour control may be needed if media derived from fishbones.
	3 l/s	490	303	6* +5†	1,055 (783)**	270	106 media disposal + 27 new media every 5 years		
VFR with chemical dosing	1 l/s	770	263	9*	604 556 532 518 (481)**	20 @ 10% DS 13 @ 15% DS 9 @ 20% DS 7 @ 25% DS	7.2 every year 5.0 every year 3.9 every year 3.2 every year	Performance is mainly a function of chemical dosing hence more manageable risks compared to other options. Chemicals are commonly used in water treatment (Welsh Water site nearby).	Power & chemical supply needed. Active treatment element requires operations to be managed by competent contractor (or NRW staff). Telemetry needed.
	3 l/s	1,500	451	14*	1,207 1,064 992	60 @ 10% DS 38 @ 15% DS 28 @ 20% DS	20.3 every year 13.7 every year 10.4 every year		

Option	Flow Rate	Required Area (m^2)	CAPEX (£k)	OPEX (£k pa)	Net Present Value £k	Sludge/media Volume (m^3)	Sludge/media Disposal (£k)	Advantages	Disadvantages
					949 (838)**	21 @ 25% DS	8.5 every year	Additional benefit with raising sulphate levels if discharge to soakaway/floodplain (fixing diffuse metals as sulphides in groundwater). A number of design opportunities with the potential to reduce scheme costs (e.g. combination of $FeSO_4$ with $KMnO_4$ reducing the VFR to simple sand filters). Process reduces water content of the waste product increasing chance of re-use.	Sludge disposal costs dependent on dry solids content; high DS may not be achievable by gravity drainage & evaporation alone.

Notes*:*

1. CAPEX excludes land purchase, connections to mains electricity and water (if required) and financing and decommissioning costs
2. CAPEX values include 20% contingency
3. Required area assumes a relatively flat site and excludes access roads
4. Net Present Value based upon 25 year life with 2% inflation and 3.5% discount rate
5. Dosing equipment assumed to last 25 years

* Excludes media replacement and waste disposal costs (included in NPV)
** NPV value for low (£100/t) waste disposal cost
† Supply of hydrogen peroxide for odour control (included in NPV)

9. SUMMARY AND RECOMMENDATIONS

The high-level costing of the three options indicate similar life cycle costs with the VFP option likely to be the most expensive option and the Phosphate system option likely to be the cheapest option. Considering the risks, uncertainties and the opportunities associated with each of the options the VFR option with the chemical dosing seems to offer the most robust solution offering better control over performance issues, has a lower risk of odour production and offers various opportunities related to design improvements, cost reductions and a better waste product. In particular the possible combination of $FeSO_4$ and $KMnO_4$ dosing seems to offer an interesting and innovative further development of this option.

Laboratory tests (mainly jar tests) should be undertaken using Abbey Consols mine water to:

- establish the optimum iron dosing rate for zinc removal;
- test the impacts on pH from $FeSO_4$ dosing (ferrous versus ferric iron) and required presence of limestone (a column test may be required to test $FeSO_4$ dosing into limestone versus passing mine water through limestone and $FeSO_4$ dosing afterwards);
- confirm required residence times for iron precipitation;
- as the three items above but considering combined $FeSO_4$ and $KMnO_4$ dosing, including tests at various mixing ratios; and
- test sludge dewaterability and consolidation

Investigation of disposal options for the sludge and/or media should be undertaken to aid selection of the most cost-effective overall system.

Further research into available apatite products maybe worthwhile, followed by laboratory trials (column tests) as a Phosphate system could be ideal to supplement a VFR system to deal with variable low flow discharges from the waste tips.

T. Eckhardt

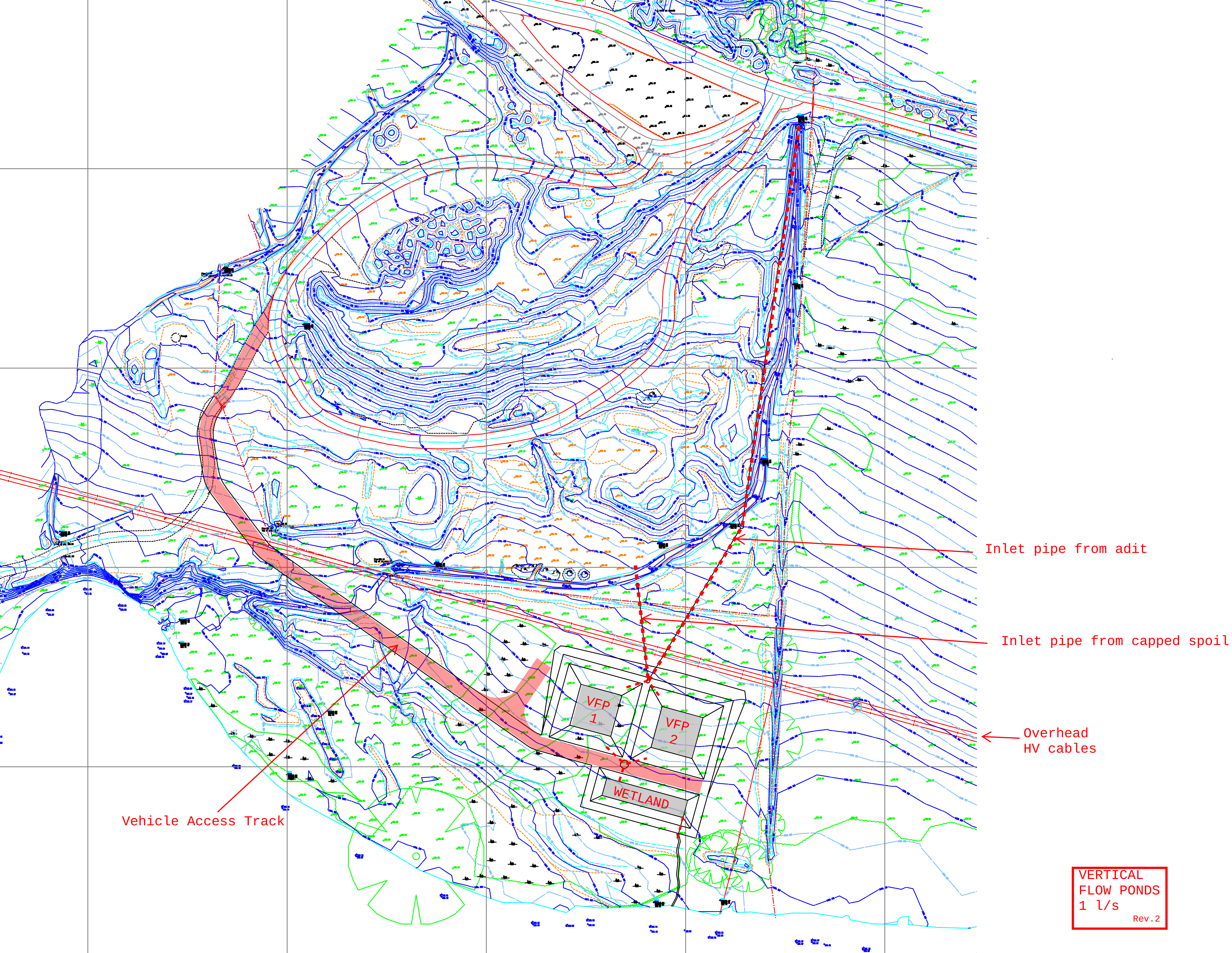
Thomas Eckhardt
Principal Hydrogeologist and Project Manager (WSP)

Enclosures:

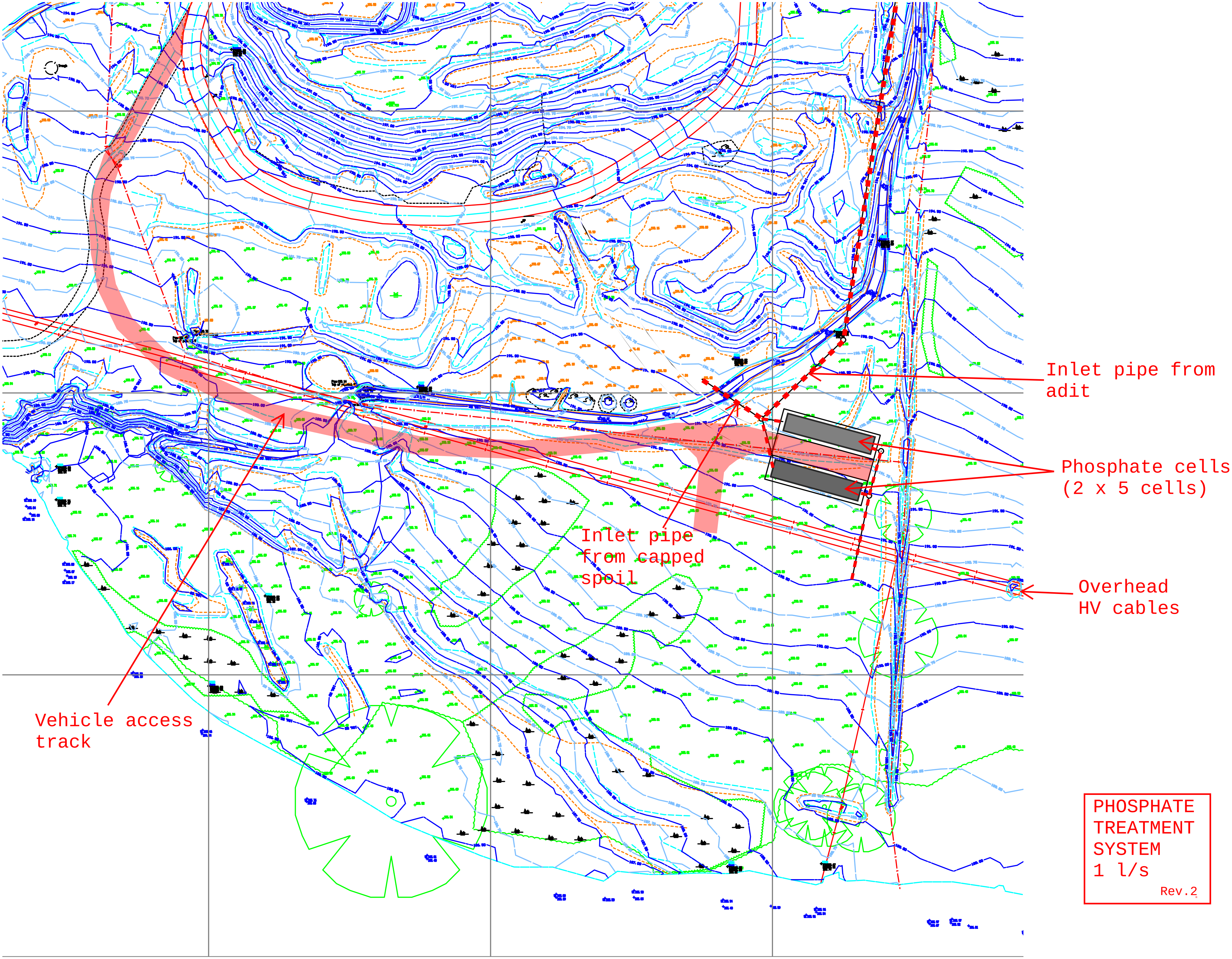
APPENDIX A: LAYOUT SKETCHES

APPENDIX B: COSTING DETAILS FOR THE 3 OPTIONS (EXCEL FILE)

APPENDIX A – LAYOUT SKETCHES

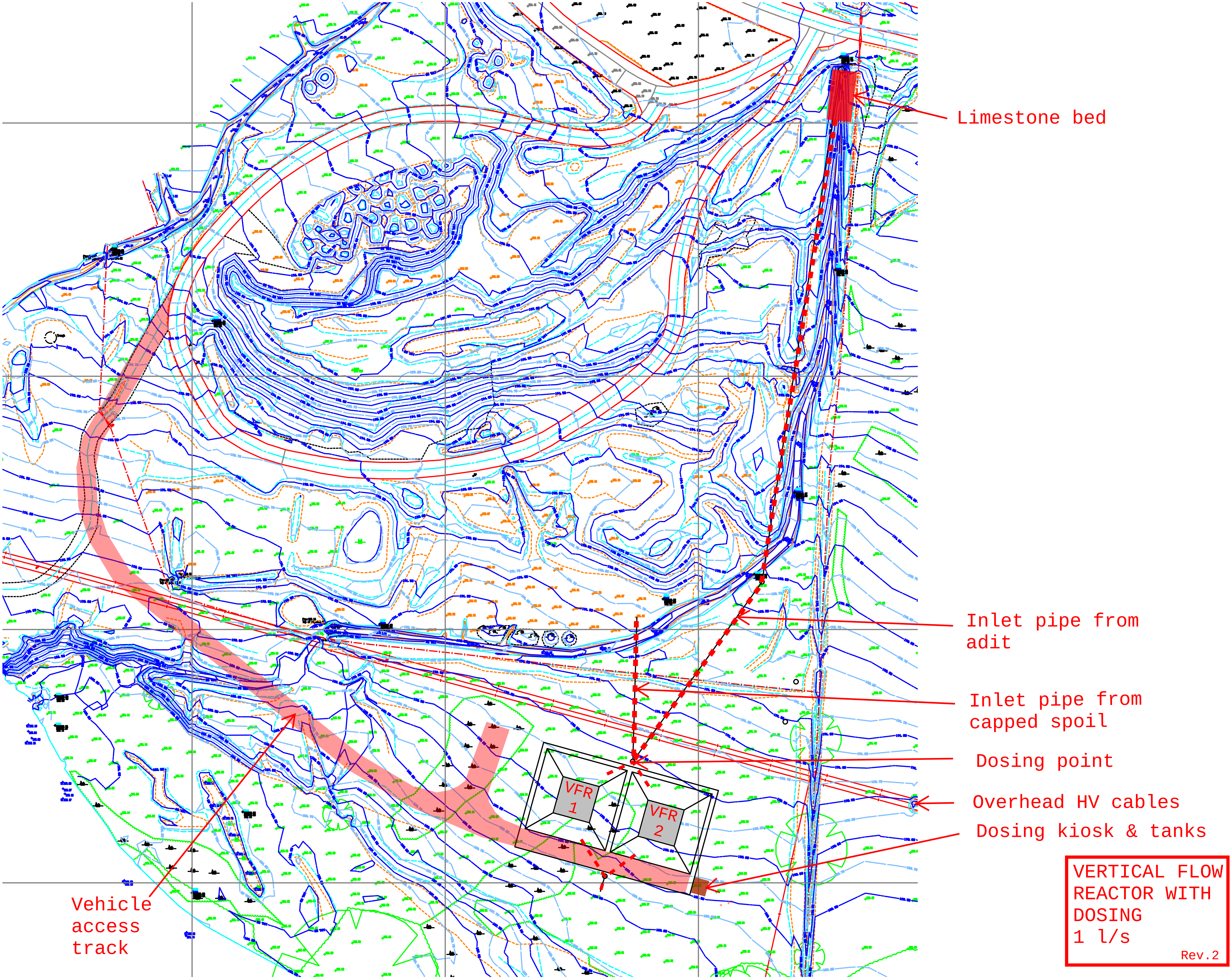


VERTICAL
FLOW PONDS
1 l/s
Rev.2



PHOSPHATE
TREATMENT
SYSTEM
1 l/s

Rev.2



VERTICAL FLOW
REACTOR WITH
DOSING
1 l/s
Rev.2

APPENDIX B: COSTING DETAILS FOR THE 3 OPTIONS (EXCEL FILE)

Appendix C

ADIT DISCHARGE CAPTURE OPTIONS APPRAISAL

*BMS : **Project Delivery***

T492b: Calculation Continuation Sheet

Project No.	**70041881**	**Project Name**	**Abbey Consols Mine Water Treatment**
Date	**03/04/2019**	**Calculation No**	
Client	**National Resources Wales**	**Page No**	1

Section C: Calculation	**ABBEY CONSOLS - WATER CAPTURE OPTIONS**	
Ref		**Rev**

Option No.	Option Name	Description	Advantages / Opportunities	Disadvantages / Risks	Estimated Cost £k
1	Quarry Spoil Toe Drainage	Adit water capture, downgradient of adit portal using filter drain at toe of quarry backfill. Aims to intercept adit waters seeping at the quarry backfill/till interface and carrying them to a low level sump.	Cheapest / simplest solution	Loss of adit waters to underlying strata between adit portal and collection system.	15
			Long term farmer access unaffected.	Infiltrating rainwater and groundwater captured as well as adit water, resulting in increased treatment volumes.	
			No large or deep excavations required	May not capture full lateral extent of adit water.	
			No blow out risk		
			Tree line habitat unaffected		
2a	Interception Drainage Arc / Cordon	Adit water capture downgradient of adit portal using filter drain to manhole in quarry plateau area. Collected water piped to treatment area by gravity. Capture area reinstated as existing.	Not required to clear out adit blockages.	Excavation closer to adit portal increases blow out risk - portal location and adit water pressure required to assess risk.	20
			Relatively simple solution	Temporary works excavation - stability risks	
			Drain on quarry floor minimises loss of adit water to underlying strata.	Lack of control over adit water pressure	
			Long term farmer access maintained	Rainwater captured as well as adit water, resulting in increased treatment volumes.	
			Tree line habitat unaffected.	Confined space working if access into manhole required for maintenance of pipelines.	
			Rainwater/groundwater capture reduced.		
2b	Vertical Barrier System - Flow Control	Adit water captured downgradient of adit portal using vertical barrier system to direct water to low level sump in quarry plateau area. Captured water piped to treatment area under gravity. Capture area reinstated as existing.	Not required to clear out adit blockages.	Localised excavation for sump still required - closer to adit portal so increased blow out risk.	50
			If sheet piled, significant reduction in volume of excavation required	Lack of control over adit water pressure	
			Barrier keyed in to bedrock to minimise loss of adit water to underlying strata	Potential for adit water to move laterally bypassing vertical barrier.	
			Long term farmer access maintained	Rainwater captured as well as adit water, resulting in increased treatment volumes.	
			Tree line habitat unaffected	Noise & vibration (if sheet-piled) could adversely affect people and wildlife.	
			Rainwater/groundwater capture reduced.	Vibration (if sheet-piled) might destabilise the adit and quarry slopes.	
				Bentonite slurry wall would need trench excavation - side wall stability potential	
3a	Direct Adit connection - Full reinstatement with limited maintenance access	Temporary excavation to expose adit portal and clearance of adit debris. Installation of a piped connection within the adit portal and grouting of annulus around pipe with a foam grout or similar. Manhole provided for pipe maintenance and adit reburied as existing. Captured water piped to treatment area under gravity.	Direct connection to adit. 100% adit water capture and full control over adit water pressure.	Blow out risk in exposing portal. May need to drill into adit to relieve water pressure, releasing unknown quantity of water requiring treatment.	35
			No infiltration contribution across quarry to adit water capture volumes	Temporary works excavation - stability risks	
			Treatment area fully reinstated to quarry level on completion (current status)	Structural survey and clearance of portal debris required - short term stability considerations	
				Sealing annulus around pipe-work / portal connection. Potential for grout loss	
				Confined space working if access into manhole required for maintenance of pipelines.	
				May affect tree line habitat.	
3b	Direct adit connection - Fully open configuration with portal refurbishment	Fully excavate adit portal, battering slopes back to safe angles of repose around the portal. Re-establish portal frame and fit grillage to prevent entry. Low level sump with grill to collect adit water and pipe to treatment area by gravity.	Direct connection to adit. 100% adit water capture and full control over adit water pressure.	Blow out risk in exposing and renovating portal. May need to drill into adit to relieve water pressure, releasing unknown quantity of water requiring treatment.	60
			No infiltration contribution across quarry to adit water capture volumes	Structural survey and clearance of portal debris required - short & long term stability considerations	
			Generation of a surplus spoil for re-use in capping area.	Significant excavation and generation of spoil for disposal.	
			Ecological habitat creation / mitigation (portal area - bats)	Long term security H&S liability - adit access	
			Heritage benefit to local interest groups, mining enthusiasts, etc.	Farm access to adjacent field (east) removed	
			PROW feature on the mine walk could be generated	Potential for disturbance to tree line habitat (habitat loss potential)	

Appendix D

BENEFIT ASSESSMENT

MEMO

TO	Tom Williams	**FROM**	Thomas Eckhardt
DATE	**04 June 2020**	**CONFIDENTIALITY**	**Confidential**
SUBJECT	**Abbey Consols Discharge Treatment – Benefits Assessment (Final Version)**		

INTRODUCTION

This Technical Memo is prepared as part of the Abbey Consols Adit Discharge Treatment Feasibility Study, aiming to determine monetary and other benefits from the proposed treatment of the discharge from the historical metal mine.

The methodology is as follows:

- quantify current mass loadings of the main contaminants from the site into the Afon Teifi;
- estimate the potential mass removal rates associated with proposed remediation works (this is by necessity very approximate and has been undertaken as a sensitivity analysis);
- assess the implications for Teifi water quality in the context of Water Framework Directive (WFD) targets if the remediation is undertaken;
- using National Water Environment Benefit Survey (NWEBS) values to determine the potential monetary benefits of the water quality improvements; and
- describe additional remediation benefits which cannot easily be assigned a monetary value.

In 2012 the Environment Agency undertook a detailed study of mine water impacts on the Afon Teifi catchment (WFD Abandoned Mines Project: Afon Teifi catchment, 2012) driven by the failure to achieve 'Good' Water Framework Directive (WFD) status at various monitoring locations. That work is summarised briefly in this report. It is not the purpose of this study to update or duplicate that work.

There have also been a number of other studies undertaken on the site since the 1990s. The purpose of our reviews in this document is to assess the metal loadings arising from the Abbey Consols site as estimated in previous studies to select a suitable data set as a baseline for predicting water quality improvements after site remediation.

Detailed site descriptions and evaluations of mine water treatment options are discussed in the main body of the Adit Discharge Treatment Feasibility Study Report. The adit, with its currently buried entrance, is believed to be the only discharge point of mine water collected within the underground mine workings to the north of the site. Part of the mine water discharges via a pipe under the access road, forming a ditch running around the waste tips towards the Afon Teifi. Another part of the adit discharge was found to follow a groundwater pathway contributing to groundwater and surface water pollution on site. The waste tips on site form another major source of heavy metal pollution and are part of the wider site remediation programme.

Since the discharge from the underground adit flows into and interacts with the water from waste tips and the mine water from waste tips flows into the adit discharge ditch, it is not possible to characterise the mine water from the adit and from the tips separately. This is an exercise that previous studies have attempted by assuming that the discharge from the pipe under the access road represents water from the adit and that all other water comes from the waste tips. The 2019 ground investigation results generated evidence that this was an invalid assumption.

The conclusions of this loadings and benefits assessment affect the outcome of the feasibility assessment and will need to be considered during the subsequent design stages.

AFON TEIFI WATER FRAMEWORK DIRECTIVE STATUS

The 2015 WFD classification identified the Afon Teifi headwaters (containing Abbey Consols) and the three downstream water bodies as having an overall status of 'Moderate'. The main reason for failing to achieve 'Good' status was the Annex 8 failures for zinc, with Abbey Consols identified as the primary source. The four impacted water bodies are (see also Figure 1 in Appendix A):

1. GB110062043540 Teifi headwaters to confluence with Meurig
2. GB110062043501 Teifi confluence with Meurig to confluence with Brennig
3. GB110062043566 Teifi Afon Brennig to Afon Dulas; and
4. GB110062043565 Teifi Afon Dulas to Afon Clettwr

Based on the 2015 WFD classification the Afon Teifi achieves 'Good' overall waterbody status at its confluence with the Afon Clettwr near Llanfihangel-ar-arth (Waterbody ID GB110062043564) ~70km downstream of Abbey Consols. However, due to the WFD's 'one out all out' methodology and the location of classification points within water bodies, the actual length impacted by Abbey Consols is less than 70km. The water quality modelling tool SIMCAT has previously been used to estimate the length of river being impacted (Williams, 2010; EA, 2012), resulting in a figure of ~40km.

In 2016, following the implementation of bioavailable EQS, NRW used the Metals Bioavailability Assessment Tool (MBAT) to calculate the bioavailable concentrations of zinc in the Teifi and redefined the WFD status of the water bodies in 2018. This resulted in only water bodies GB110062043540 (Teifi headwaters to confluence with Meurig) and GB110062043501 (Teifi confluence with Meurig to confluence with Brennig) being classed as 'Moderate' and the following water body GB110062043566 (Teifi Afon Brennig to Afon Dulas) achieving overall 'Good' status. In addition to the impact from the Abbey Consols site (main source) two other historical mines (Cwm Mawr and Esgair Mwyn) affect the water quality of the two 'Moderate' surface water bodies. The following table (Table 1) summarises the reasons for not achieving 'Good' WFD status for these two water bodies.

Table 1: 'Moderate' water body failure details from 2018 interim classification

WATER BODY	OVERALL STATUS	ECOLOGY STATUS	REASON FOR FAILURE	CHEMICAL STATUS	REASON FOR FAILURE
GB110062043540	Moderate	Moderate	Zinc, pH	Good	n/a
GB110062043501	Moderate	Moderate	Zinc, invertebrates	Fail	Cadmium

The classification of each individual water body is strongly influenced by the location of the reference surface water monitoring point. The most relevant NRW locations for surface water monitoring within the upper Teifi catchment are the following (also shown on Figure 1): Teifi below Strata Florida WTW (83011), Teifi 250m d/s Abbey Consols discharge (82992), Teifi 20m u/s Pontrhydfendigaid STW (83001), Teifi at Old Railway Bridge (34407), Teifi at Pont Eynon Tregaron (34403), Teifi at Pont Llanio (32482) and Teifi at Pont Gogoyan (34561).

Considering that when using the bioavailable metal concentrations, the Teifi mean zinc concentration at monitoring point 34403 (Teifi at Pont Eynon Tregaron), 12.7km downstream of Abbey Consols, is below the EQS means that the impact from the Abbey Consols site causing the failure of achieving 'Good' status is limited to a distance of approx. 11.4km (based on interpolation using monitoring locations 34407 and 34403 - see details in loading calculation sections later on in this memo). This does not mean that the pollution from the Abbey Consols site is not affecting the water quality further downstream, as demonstrated in later sections of this memo. Maximum bioavailable zinc concentrations at monitoring point 34403 exceed the EQS and the site contributes a considerable zinc load at further downstream monitoring points. Even if this is not relevant for the WFD status assessment, it still represents a minor impact, i.e. a site remediation would contribute to the stabilisation or increased robustness of the surface water quality many kilometres downstream, as indicated by the earlier studies.

PREVIOUS CALCULATIONS OF METALS LOADINGS FROM THE ABBEY CONSOLS SITE

A number of previous investigations have attempted to estimate the metals loadings from Abbey Consols mine site. The findings from the WSP 2019 ground investigation suggest that direct measurement of surface water flows from site would potentially under-estimate the metals loadings due to the complex hydrological and hydrogeological setting, therefore, where possible, loadings calculated based on measurements of water quality in the Teifi upstream and downstream of the site have been obtained from previous studies. Where this is not possible, loadings estimated from direct surface water measurements have been compiled.

Table 2 summarises loading estimates from the previous studies and separates out those measured by differences in Teifi water quality from those estimated by direct measurement of surface waters.

Table 2: Summary site loading calculations from previous studies

INVESTIGATION	(KG/YEAR)			
	Zn	Cd	Pb	Cu
Based on Teifi u/s and d/s measurements				
SRK (1997) Modelled Q50	1381	-	111	42
Excal (1999) Table 9B data - March 1999 samples	1045		38	
Atkins (2010) Calculated from Figures in Annex D- February 2010 samples	1949	3.6	105	
Parker MSc (2014)	1329	3.0	45	25.7
Based on Abbey Consols site surface water measurements				
Environment Agency (2012) 5 year average 2007-2012	2168	1.3	156	5.9
Parker MSc (2014)	1780	0.6	86	4.8
AECOM (2016) February 2015 sample	401	1.1	24	0.2

With the exception of the AECOM data, these results show good agreement with a factor of two or three between the zinc, cadmium and lead results and approximately nine between the copper results. Copper is not of particular concern at Abbey Consols.

There is no obvious difference between the magnitude of the estimates based on upstream and downstream measurements and those based on measurements of surface water on the Abbey Consols site.

The AECOM results appear anomalously low compared to all other estimates. This is likely because the results are based on a single sample taken on a day of relatively low flows, with limited run-off from the spoil tips.

For the metals of concern, the total estimates by whatever approach are in very good agreement over a long time period.

ABBEY CONSOLS METALS LOADINGS CALCULATED BASED ON WSP (2019) DATA

The detailed interpretations of the 2019 ground investigation (GI) results will be presented in a GI Interpretative report. For the purpose of this technical memo the total dissolved zinc, cadmium and lead contributions from the site to the Afon Teifi loadings were calculated based on the measured upstream and downstream river concentrations. Two rounds of water sampling were undertaken (29/1/2019 and 25/2/2019). The site conditions during the first monitoring round were very wet, with the second round being much drier. To allow the calculation of metal loadings NRW provided modelled river flow data for the sampling dates derived from the Low Flows Enterprise surface water flow model for the Afon Teifi (produced for NRW: *This data has been produced by Low Flows Enterprise with the permission of Wallingford Hydrosolutions Limited. Unauthorised reproduction infringes copyright.*). The loading results are presented in Table 3.

Table 3: Site discharge loadings based on 2019 GI data

SAMPLING ROUND		(KG/YR)		
	Flow (m^3/s)	Zn	Cd	Pb
29 January 2019	1.24 upstream and 1.30 downstream	2466	4.5	148
25 February 2019	0.29 upstream and 0.30 downstream	203	0.04	-1

These figures indicate a high variability of the metal discharges from the site depending on flow conditions (in this case higher flows in the river coincide with higher concentrations in the river water). The February 2019 zinc loading from the site is only about 8% of the zinc loading released during wet weather as measured on 29th January 2019. The calculated loadings are at the extreme ends of the range of loadings derived in previous studies (summarised in Table 2 in the section above).

VARIABILITY OF METALS LOADINGS WITH FLOW RATE

There has not been much work on this aspect of the metal release rate from site. Information from previous reports is as follows:

- The SRK (1997) report was based on a constant mass loading from site diluted in different flow rates in the river.

- The Excal (1999) report plots average monthly river water quality data through the year (it is not clear which year or whether the figures are composite for several years). The figures show a range of approximately a factor of two between summer zinc concentrations which are lower and winter concentrations which are higher. This suggests a strong correlation between the amount of water coming into contact with the waste and the mass loading rate of zinc. Similar data for lead show no discernible pattern, but the lead data shows a peak in the early autumn suggesting a rewetting effect following the summer.

- The Environment Agency (2012) modelling appears to have used annual variability of flows and water quality to predict the average metals concentrations for comparison with the EQS, so that the relationship between metal concentrations and flow rates has been included in the predictions.

- Parker (2014) found that there was a general inverse relationship between metals concentrations measured on site and flow rates for all sampling points combined. The data fit was generally poor, but also the data included site flows within the tips and from the adit as well as main river flows. Such a correlation would be expected in this case as the river samples would generally be expected to have lower metals concentrations than the values on site. This data cannot be used for interpretation in this form.

- Parker (2014) also found that during a high flow event in summer the concentrations increased. This again may indicate the rewetting effect which is reflected in the Excal data.

The Excal data suggests a strong positive correlation between the mass loading from site and the Afon Teifi flow rate, with much higher mass loadings in winter than summer.

To gain further insight on this issue we have assessed the Teifi flows and dissolved zinc concentrations downstream of the site (82992 compared to 83011) where we have flow and water quality data on the same date. The difference between upstream and downstream loadings from the period 2009-2012 is plotted against the downstream flow rate on Figure 2 below. The plot shows three types of behaviour:

- low flows where the loading from site is very low – interpreted as summer dry conditions where there is not much mobilisation of metals from site;

- medium flows where the loading is almost directly proportional to the river flow, where river concentrations are similar – under these conditions the zinc loading migrating from site is approximately proportional to the flow of water from or through the site – the more water the more zinc; and

- high flow conditions where there is a limitation on the zinc loading from site and more clean water passing through the site contributes to dilution.

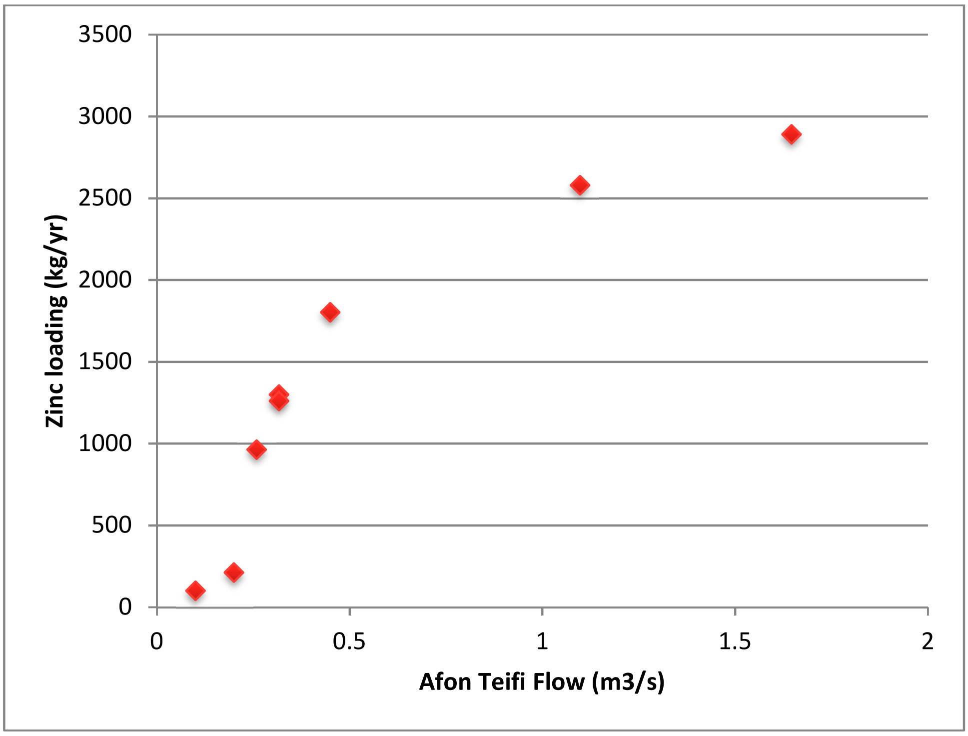


Figure 2: Zinc loadings from the site versus Teifi flow rates (2009-2012 EA data)

Zinc loadings described in the previous section using the January and February 2019 ground investigation data fit well into the Figure 2 chart confirming the considerations above.

IMPLICATIONS FOR REMEDIATION

The WSP (2019) conceptual site model differs from those of previous workers due to the significant new information obtained from the site investigation in the following important respects:

- We now know that a significant proportion of the adit discharge flows through the waste.
- We also know that the waste is, in the main, above the saturated groundwater zone.

The proposed remediation will be to separate the adit discharge water from the waste and to hydraulically isolate the waste through capping and drainage. The loadings assessments suggest that minimising the water flow through the site has the potential to significantly reduce the heavy metal mobilisation towards the Teifi.

An important factor in determining the effectiveness of hydraulic isolation is the risk that the metal sulphide minerals continue to react at a similar rate after remediation and metals are released from the waste at a similar rate even after hydraulic isolation works. This could occur because small amounts of water come into contact with the waste and leach very high concentrations of metals. This type of process could make the remediation works ineffective.

The information from the site investigation suggests that we have an opportunity to make the waste much drier by removing the adit water. Since the waste generally sits above the water table, capping could be very effective at keeping the waste dry.

There is still significant uncertainty, however, about how effective the adit water treatment will be and the effectiveness of hydraulic isolation works.

SIMULATION OF IMPACTS FROM SITE REMEDIATION ON RIVER QUALITY

Reviews of the previous studies and the most recent data indicate no substantial change in metal loading over at least the last 25 years, i.e. loadings vary within a similar range. The most comprehensive available data set for the assessments in this section are the EA/NRW river monitoring data from the 7 monitoring stations along the Teifi (Figure 1) for the period 2008-2018. Considering the variability of the metal loadings only average conditions were considered in this section to predict the impact from site remediation. This is in line with the EQS being for comparison with average concentrations. The following process was followed for the assessment:

- Mean flows provided by NRW from the Low Flows Enterprise surface water model together with average dissolved zinc, cadmium and lead concentrations (measured by NRW) were used to calculate average zinc, cadmium and lead loadings per monitoring point;
- The difference between the average zinc, cadmium and lead loadings between the Teifi Strata Florida monitoring location (upstream of the site) and Teifi 250m downstream of the Abbey Consols discharge monitoring location (i.e. 1,214kg/year zinc, 1.6kg/year cadmium and 21.3kg/year lead) were calculated and considered the total average load coming from the site. These loadings are within the ranges discussed earlier in this report (Tables 2 and 3);

- Subsequently, the metal loading from the site has been removed from all calculated average loadings of the downstream monitoring locations allowing the calculation of a predicted average concentration per monitoring location. Site metal removal rates of 100%, 70% and 50% were simulated to reflect the uncertainty associated with the remediation works;

- The predicted average zinc and lead concentrations were then assessed for bioavailability using the WFD M-BAT and WFD Pb screening tool (https://www.wfduk.org/resources/rivers-lakes-metal-bioavailability-assessment-tool-m-bat) and were ultimately compared with the established EQS (Table 3).

The EQS for zinc, cadmium and lead, as defined under the WFD for freshwater water bodies, are:

- Dissolved zinc (bioavailable): 13.4µg/l
- Dissolved lead (bioavailable): 1.2µg/l
- Dissolved cadmium: 0.08µg/l

Detailed outputs of the loading calculation spreadsheets are provided in Appendix B and the results are summarised in Table 4 and 5 below.

Table 1: Calculated loadings based on 2008-2018 NRW monitoring data (all dissolved concentrations)

STATION ID	STATION NAME	MEAN FLOW (M^3/S)*	AVERAGE ZINC CONCENTRATION (µG/L)	AVERAGE ZINC LOAD (KG/YEAR)	AVERAGE CADMIUM CONCENTRATION (µG/L)	AVERAGE CADMIUM LOAD (KG/YEAR)	AVERAGE LEAD CONCENTRATION (µG/L)	AVERAGE LEAD LOAD (KG/YEAR)
83011	Teifi below Strata Florida WTW	0.83	4.85	127	0.08	2.09	1.56	40.8
82992	Teifi 250m d/s Abbey Consols discharge	0.84	50.67	1341	0.14	3.70	2.35	62.2
83001	Teifi 20m u/s Pontrhydfendigaid STW	1.48	45.32	2120	0.08	3.74	1.13	52.8
34407	Teifi at Old Railway Bridge	2.16	45.71	3116	0.09	6.14	2.95	201.1
34403	Teifi at Pont Eynon Tregaron	4.10	22.19	2872	0.05	6.47	2.33	301.5
32482	Teifi at Pont Llanio	5.94	16.04	3006	0.08	14.99	1.97	369.2
34561	Teifi at Pont Gogoyan	7.03	12.80	2836	not recorded	-	not recorded	-

**Provided by NRW. This data has been produced by Low Flows Enterprise with the permission of Wallingford Hydrosolutions Limited. Unauthorised reproduction infringes copyright.*

The calculated zinc loadings in Table 4 show some unexpected variations at the downstream monitoring locations. Rather than indicating zinc precipitation/sorption, decreasing loadings are probably due to the quality of the data sets (i.e. number/conditions of sampling events and accuracy of flow estimates). It would be expected that zinc loadings downstream of monitoring point 34403 increase slightly or remain approximately constant. For cadmium, the average loading results seem to be more consistent with some impact from using detection limits in the calculations. For lead, the main input is from Esgair Mwyn mine via the Afon Meurig, downstream of Abbey Consols. Remediation works at Abbey Consols are therefore unlikely to significantly improve the lead loading. Bioavailable lead concentrations in the Afon Teifi, however, do not exceed the EQS and therefore lead concentrations and loadings are not discussed further in this document.

Table 5 and 6 summarise predicted impacts of the proposed site remediation on the river concentrations considering bioavailable zinc concentrations and cadmium concentrations in comparison with the relevant EQS. This assumes a range of loading reductions from the site discharges.

Table 5: Predicted average bioavailable zinc concentrations with 100%, 70% and 50% reduction of zinc loading from the Abbey Consols site. 0% removal means average baseline conditions.

Monitoring location	**Distance from site in km**	**Zinc concentrations (baseline/ 0% removal) in µg/l**	**Predicted zinc concentrations (50% removal) in µg/l**	**Predicted zinc concentrations (70% removal) in µg/l**	**Predicted zinc concentrations (100% removal) in µg/l**
EQS		13.4	13.4	13.4	13.4
Teifi below Strata Florida WTW	0.8 upstream	3.29	3.29	3.29	3.29
Teifi 250m d/s Abbey Consols discharge	0.25	**36.74**	**20.11**	**13.46**	3.48
Teifi 20m u/s Pontrhydfendigaid STW	1.9	**28.06**	**20.02**	**16.81**	11.99
Teifi at Old Railway Bridge	4.3	**28.22**	**22.72**	**20.53**	**17.23**
Teifi at Pont Eynon Tregaron	12.7	10.21	8.06	7.19	5.9
Teifi at Pont Llanio	22.5	7.87	6.28	5.64	4.7
Teifi at Pont Gogoyan	26.3	6.17	4.85	4.32	3.53

Table 6: Predicted average cadmium concentrations with 100%, 70% and 50% reduction of cadmium loading from the Abbey Consols site. 0% removal means average baseline conditions.

Monitoring location	**Distance from site in km**	**Cadmium concentrations (baseline/ 0% removal) in µg/l**	**Predicted cadmium concentrations (50% removal) in µg/l**	**Predicted cadmium concentrations (70% removal) in µg/l**	**Predicted cadmium concentrations (100% removal) in µg/l**
EQS		0.08	0.08	0.08	0.08
Teifi below Strata Florida WTW	0.8 upstream	0.08	0.08	0.08	0.08
Teifi 250m d/s Abbey Consols discharge	0.25	**0.14**	**0.11**	**0.10**	0.08
Teifi 20m u/s Pontrhydfendigaid. STW	1.9	0.08	0.06	0.06	0.05
Teifi at Old Railway Bridge	4.3	**0.09**	0.08	0.07	0.07
Teifi at Pont Eynon Tregaron	12.7	0.05	0.04	0.04	0.04
Teifi at Pont Llanio	22.5	0.08	0.08	0.07	0.07
Teifi at Pont Gogoyan	26.3	Not recorded	-	-	-

A 100% zinc and cadmium removal from site discharges is unlikely to be achievable due to diffuse sources, elevated background concentrations and any practical mine water treatment system unlikely to fully remove all zinc, but a reduction of the metal loading by >70% seems to be a realistic target with an efficient surface water management system for the waste tips in place. The reduction of metal loadings from the site observed during the 2019 GI water monitoring rounds (to less than 10% under dry conditions) suggests that loading reduction can potentially get close to the 100% but how close will be dependent on the efficiency of the adit discharge treatment and adit discharge flow rates.

However, the results in Tables 5 and 6 show that considering a zinc and cadmium loading reduction from the site of >70%, it can be expected to take water body GB110062043540 to compliance for zinc or very close to compliance. It has also significant benefits to the downstream water body and monitoring points, e.g. it is predicted to remove the cadmium failure (WFD chemical status) for water body GB110062043501. Zinc levels in GB110062043501 are still predicted to fail due to the inputs from the Cwm Mawr and Esgair Mwyn mines, but average concentrations get much closer to the EQS, suggesting that a minor reduction of zinc loadings from one of these sources may be sufficient to achieve ‘Good’ WFD status. A reduction of river sections with ‘Moderate’ WFD status at the downstream end of water body GB110062043501 is also predicted to be achieved due to the predicted reduction of zinc concentrations (i.e. over the 8.4km section between NRW monitoring point Teifi at Pont Eynon Tregaron and monitoring point Teifi at Old Railway Bridge). The additional river kilometres predicted to achieve compliance for zinc is between 2.4km and 5.6km (considering 70% and 100% loading reductions from Abbey Consols and linear extrapolation of concentrations between the two monitoring points). Further downstream water bodies also see a reduction in zinc levels, but average concentrations were already found to be below EQS under current conditions.

With the reduction of zinc loadings from either (or both) Cwm Mawr and Esgair Mwyn mines in addition to the remediation of the Abbey Consols site, ‘Good’ WFD status should be achievable for both currently failing water bodies, which would result in approximately 11.4km of SSSI/SAC protected river section being improved from ‘Moderate’ to ‘Good’

The following should be noted:

- The river flow data have a degree of uncertainty as mainly based on modelling results and not real site measurements, e.g. minor exceedances indicated for the 70% loading reduction scenario could in reality still result in compliance; and

- The simulations are based on average data, but with the proposed site remediation benefits would be more significant during prolonged wet periods or storm events (removing peak concentrations from the data set). After remediation, loading from site should only marginally increase during such conditions and the dilution effect in river should dominate (i.e. the opposite to current observations, see 2019 GI monitoring results). During dry conditions site discharges (and treatment requirements) should become less. Overall this could result in an underestimate of the beneficial impact of the remediation using the average calculation approach above.

MONETARY VALUE AND SOFT BENEFITS

Monetary Value

The monetary value of the expected benefits of the proposed remediation were calculated following the Environment Agency guidance: “Water Appraisal Guidance; Assessing Costs and Benefits for River Basin

Management Planning", May 2013; using the National Water Environment Benefit Survey (NWEBS) values updated in 2012. The NWEBS study estimated the "willingness to pay" for improvement of the water environment. The original survey was undertaken in 2007 and involved over 1500 people across the UK. The survey results were translated into NWEBS values for improving the WFD Quality Status of the major rivers/catchments (e.g. step change from Moderate to Good status). The original NWEBS values were updated in 2012 (Environment Agency summary of the Metcalfe et al review 2012, "Updating the National Water Environment Benefit Survey values: summary of the peer review") and provide low, central and high NWEBS values for step changes for the individual river system. The six, equally weighted, NWEBS ecosystem components are:

- Fish;
- Other animals such as invertebrates;
- Plant communities;
- The clarity of water;
- The condition of the river channel and flow of water; and
- The safety of the water for recreational contact.

To establish the monetary value of the Abbey Consols site remediation the following process was followed (including Stage 1 Valuation of the EA guidance). The details of the calculations are provided in Appendix B.

- Select low, central and high NWEBS values assuming change of WFD status from 'Moderate' to 'Good' considering values for South West Wales (in absence of values for the Afon Teifi);
- Adjust 2012 NWEBS values to 2020 values for inflation (2.36% average/year 2012-2018 Office for National Statistics composite price index);
- Establish NWEBS values for a 40-year scheme life cycle (2020-2059, applying a 3.5% discount rate in line with HM Treasury Green Book guidance). The discount rate is the same as assumed for the water treatment life cycle cost estimate. Different to the cost estimates inflation and a likely increase in willingness to pay over the life cycle period are not considered in the standard calculations, therefore sensitivity of the results has been tested applying the lower Health discount rates (also indicated in the HM Treasury Green Book guidance);
- In line with the guidance apply the benefits to the six NWEBS components. Table 4.2 of the EA guidance document indicates that reduction of zinc levels should create benefits in particular to fish, other animals such as invertebrates and plant communities. It is assumed that the contribution of the six NWEBS components to the total NWEBS values are equal (i.e. each component represents 1/6 of the total NWEBS value);

- The sum of the individual benefits components represents the total benefits value over the life cycle allowing comparison with the estimated remediation costs.

Table 7 below provides the selected NWEBS values and their adjustments to 2020 prices (inflation adjusted) and Table 8 the breakdown of the assumed significant improvements (km sections of the Afon Teifi).

Table 7: Selected NWEBS values

NWEBS VALUES FOR SOUTH WEST WALES (ANNUAL PER KM)	LOW	CENTRAL	HIGH
WFD status changed from Moderate to Good (2012)	£11,600	£14,200	£16,800
2020 inflation adjusted values (2.36% per year 2012-2020)	£13,980	£17,113	£20,247

Table 8: NWEBS ecosystem components with expected significant change

NWEBS ECOSYSTEM COMPONENTS WITH SELECTED NWEBS VALUE; IMPROVEMENT IN KM	LOW	CENTRAL	HIGH
Fish	n/a	n/a	4km
Other animals such as invertebrates	n/a	n/a	4km
Plant communities	n/a	n/a	4km
The clarity of water	n/a	n/a	1km
The condition of the river channel and flow of water	n/a	n/a	1km
The safety of the water for recreational contact	n/a	n/a	1km

With the Teifi being designated as a SAC/SSSI the high NWEBS value has been selected. An immediate improvement to clarity of water, river channel condition and safety of the water for recreational contact elements can be expected for the river section adjacent to the site (considering the poor current conditions). A 1km section has been considered for that.

The distance of river section which improves from ‘Moderate’ WFD status to ‘Good’ status as a result of the reduced metal loadings is more difficult to estimate. In the previous section of this memo a status change for 2.4km to 5.6km at the downstream end of water body GB110062043501 and a likely status change directly downstream of the Abbey Consols site have been predicted. For the NWEBS value calculations a stretch of 4km has been assumed combining the improvements to these two surface water sections. That is likely to be a very conservative approach to establish the money value of the Abbey Consols site remediation with regards to WFD status improvements. In reality, a significant improvement of the water quality for a much longer section of the river is predicted, just not necessarily achieving the required step change (‘Moderate’ to ‘Good’ status change).

Based on these inputs into the EA Guidance Stage 1 Valuation a total present benefit value for a 40-year life cycle period of **£1,081,474** has been calculated. This does not include benefits which we were unable to monetise (see following section) and is based on the standard discount rate. The risk of the remediation scheme not achieving a substantial improvement of the Afon Teifi water quality is considered Low (<20%).

The benefits value is highly sensitive to the discount rate applied to the NWEBS values over the life cycle period. Applying the lower Health discount rate (which starts with 1.5% per year), the total present benefit value increases to **£1,499,276**.

Considering the potential to achieve 'Good' WFD status for the entire length of the currently failing Afon Teifi sections (approx.11.4km) but probably requiring some loading reductions also from the other two mines, the total present benefit value would increase to **£2,667,073** (with the standard discount rate applied). Using the lower discount rate the calculated present benefit value was calculated at **£3,703,222**. The latter value is considered more realistic taking into account that the "willingness to pay" for an improved water environment is increasing over time (rather than losing value).

These benefit values compare to estimated 40-year life cycle costs (NPV) of the mine water capture and treatment system of £730k (1l/s scenario) and £1,374k (3l/s scenario). It should be noted that these costs are based on a chemical dosing system and related waste disposal requirements (which the following design stages will aim to minimise), but the values do not include construction costs for the earthworks/capping and drainage for the Surface Water Management System. Overall full remediation costs are currently estimated at £1m to £1.5m.

Based on high-level estimates of proposed remediation works at the Cwm Mawr mine site (approx. £1.6m in total) it is considered realistic to assume that with successful remediation schemes at both Abbey Consols and Cwm Mawr that the full 11.4km stretch of the Teifi could be improved to 'Good' WFD status. The combined remediation costs are similar to the lower estimated present benefit value and clearly below the higher value. Based on these estimations, which exclude non-quantified benefits, the remediation works are expected to be cost-effective.

Non-quantified Benefits

In line with the Well-being of Future Generations (Wales) Act (2015) a number of opportunities have been identified during the project aiming to create additional benefits with focus on the local community, overall educational benefits and environmental benefits. The Abbey Consols site offers a wealth of opportunities related to the local mining history (heritage protection and education), biodiversity and the tourist attraction at Strata Florida Abbey but, with the proposed treatment system, also includes opportunities for treatment technology development and innovation with the potential to act as an example for other historical mining sites in Wales and elsewhere in the UK and abroad. The following table summarises a number of assets and initiatives which will benefit from the proposed remediation programme. Detailed stakeholder liaison and consultation will be undertaken at the following design stages to maximise the benefits and to develop additional benefits, where feasible.

Table 8: Additional benefits/opportunities

FEATURE	CURRENT IMPACTS/RISKS	REMEDIATION BENEFIT	BENEFICIARY
Overall uncontrolled status of the site	a. Uncontrolled mine water release via groundwater and surface water pathways b. Uncontrolled mine water pressure behind adit blockage c. Erosion of waste particles with transport towards the Afon Teifi d. Onsite habitats and mining heritage features are unprotected e. Overall site Health and Safety (e.g. slope stability, exposure to contaminated seepage/adit discharge)	Transfer the site into a controlled status which allows capture, measurement and flow regulation of the adit discharge, mitigates migration of waste particles, minimises contact between contaminant sources and the water environment (breaking pollutant linkages), protects onsite environmental and heritage features and provides a safer environment for the farming activities and public access (Public Rights of Way).	Farm (landowner), site visitors, local environment
Biodiversity & Ecosystems	a. Within proximity to six designated sites comprising 1 SAC, 4 SSSI and 1 SPA, with most significant impact on Afon Teifi SAC (within 10m of the site), designated for the presence of protected species. b. Mine waste and contaminated groundwater and surface water offer suitable conditions for specific lower plants, but uncontrolled site conditions offer no long term protection.	Opportunity to secure long term protection of particular habitats and increasing biodiversity onsite and offsite reducing exposure to toxic metals in soils and water environment. Opportunities to implement habitat improvement measures (e.g. bats, invertebrates, birds). Regeneration of parts or all of the waste tip areas. Opportunity to improve conditions for bryophytes and lichens on site.	Ecology on and off site (local community and visitors)
Cultural heritage (including architectural and archaeological aspects	a. Buried or partially buried historical mine features (former processing area) on site are unprotected or partially protected by spoil material b. Site is visible/partially visible from the remains and visitor centre at Strata Florida	Opportunity to improve protection of heritage features or increasing visibility of such features to the public (e.g. creation of information points).	Heritage protection and education (wider public)

FEATURE	CURRENT IMPACTS/RISKS	REMEDIATION BENEFIT	BENEFICIARY
Tourism	a. High archaeological/heritage potential of the site currently unused. The site is also within a designated Upland Ceredigion Landscape of Outstanding Special Historic Interest and Ystrad Fflur Historic Landscape Character (HLC). b. Limited use of Public Rights Of Way (affected by contaminated seepages from the waste tips and adit discharge ditch).	Opportunity to improve historic landscape character as part of the remediation process. Opportunity to increase attractiveness of PRoW, e.g. by minimising exposure to contamination and creation of addition visitor points. Opportunities to connect with the “Elan Links: People, Nature and Water Scheme”, or other trails, including a Miner’s Trail at Bwlch Nant Yr Arian Visitor Centre. Opportunity to extend the information centre at Strata Florida.	Heritage, local community, visitors
Land	Site contamination and related seepages affect land value	Site remediation increases land value as a result of: • Reduced site contamination, improved visual impact, • opportunity to create value from the historical coach house complex (e.g. self-catering visitor stay), • as a result of the mine water monitoring remediation scheme could potentially be extended to the open/collapsed mining features to the north of the site increasing site safety.	Landowner

FEATURE	CURRENT IMPACTS/RISKS	REMEDIATION BENEFIT	BENEFICIARY
Research and Innovation	Site has previously been used for research projects on mine water treatment innovations but limited accessibility to the adit discharge and limited site monitoring facilities limit flexibility on research programmes	Proposed mine water treatment solution includes a large scale site trial to develop a new, innovative treatment solution in collaboration with Cardiff University. This site potentially becomes part of a substantial national research programme increasing the visibility of the area and creating specialist know-how with relevance for numerous other sites in Wales and elsewhere.	Research, future generations and Welsh businesses.

CONCLUSIONS

The current impact of heavy metal pollution originating from the Abbey Consols site via the adit discharge and uncontrolled seepages from the waste tips and underlying groundwater has been assessed, comparing results from previous studies with the most recent site data (WSP ground investigation 2019). The results were found to be similar and confirm a substantial impact of the site discharges on the Afon Teifi. NRW had previously identified the site as the main reason for the river not meeting ‘Good’ WFD status.

The main contaminants of concern on-site are zinc, cadmium and lead, with zinc concentrations in the Teifi exceeding the EQS for ~11km downstream of the site. Based on the available NRW monitoring data the following average metal loadings originating from the site have been estimated:

- 1,214kg/year dissolved zinc;
- 1.6kg/year dissolved cadmium; and
- 21.3kg/year dissolved lead.

The effect of a full site remediation has been simulated removing all or parts of these average metal loadings (i.e.100%, 70% and 50% removal rates) from the average downstream metal loadings of the river. Considering that removal rates are likely to be between 70 and 100%, a substantial improvement of the water quality (i.e. meeting EQS targets) of at least 4km downstream of the site is predicted. The following approx. 7km may show slight exceedances of the zinc EQS due to inputs from the Cwm Mawr and Esgair Mwyn mine sites.

Based on these assumed improvements of the Afon Teifi quality (full 11.4km stretch) a total present benefits value has been calculated using the Environment Agency’s NWEBS values (£2.7m to £3.7m depending on which discount rate is applied over the 40-year life cycle). The value with the standard discount rate applied (starting with 3.5% per year) is likely to be overly conservative as “willingness to pay” for a cleaner environment is expected to increase over the years rather than losing value. These values also do not include additional benefits which haven’t been monetised. In line with the Well-being of Future Generations (Wales)

Act (2015) the remediation scheme intends to include additional benefits with focus on adding value to the local and wider communities.

Overall the study concludes that the estimated benefits of the Abbey Consols remediation scheme in combination with some remedial works at the nearby Cwm Mawr site exceed the costs of the proposed site wide remediation scheme (currently estimated at £1m to 1.5m) and some remedial work at the Cwm Mawr site (approx. £1.6m estimated remediation costs). More detailed assessments to quantify additional benefits are therefore not recommended at this stage.

REFERENCES

Metal Mines Amelioration Study – Abbey Consols Site Study (SRK, 1997)

Metal Mine Study - Abbey Consols (Excal, 1999)

Abbey Consols mine monitoring data and review (Atkins, 2010)

A SIMCAT model to assess the impact of abandoned metal mines on the Afon Teifi, Wales (Williams, 2010)

WFD abandoned mines project – Afon Teifi (EA/NRW, 2012)

An Investigation to identify and apportion sources of metal pollution at Abbey Consols mine, Ceredigion (Parker, 2014)

Abbey Consols Options Appraisal (AECOM, 2016)

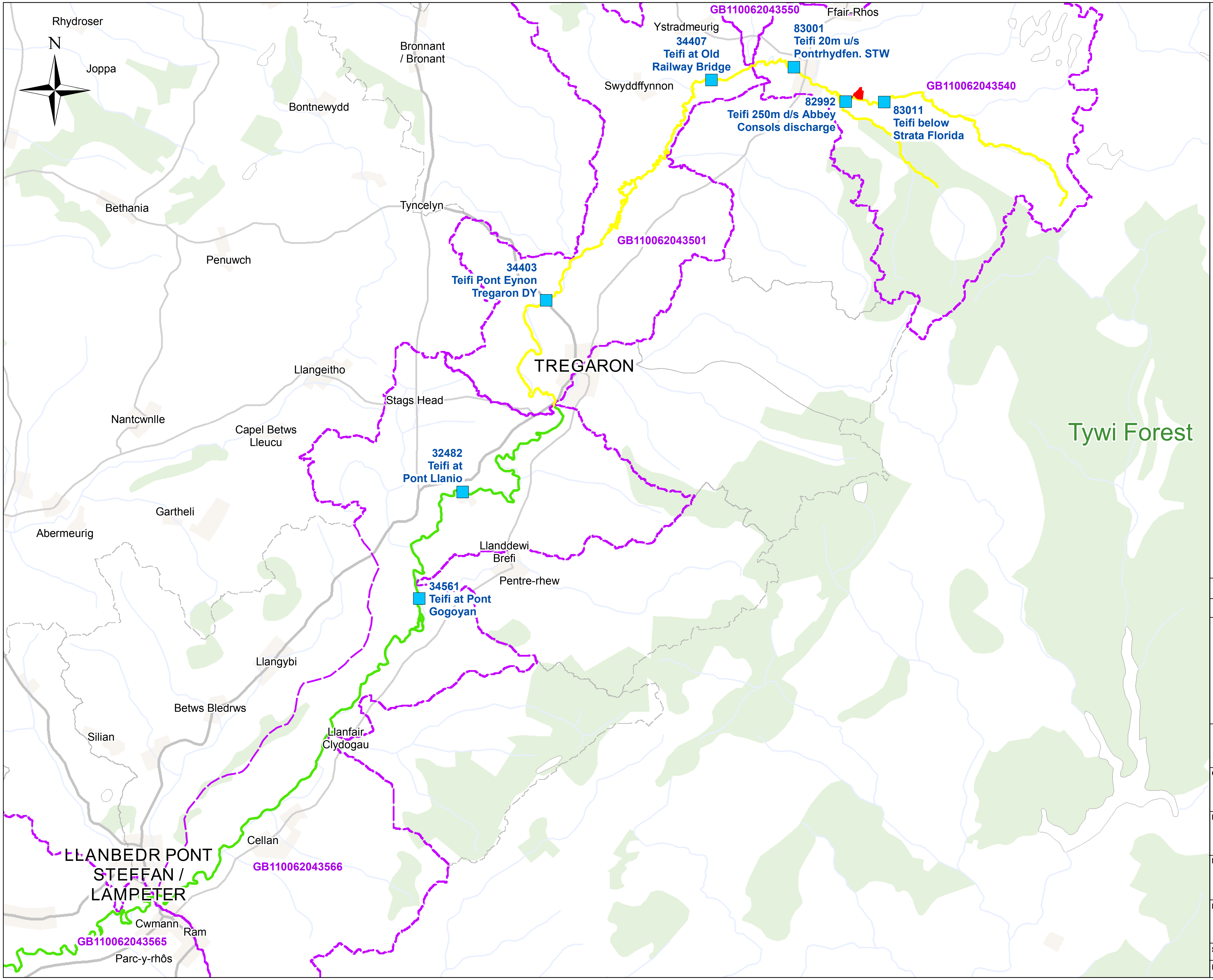
The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015

Water Appraisal Guidance; Assessing Costs and Benefits for River Basin Management Planning, Environment Agency 2013

Updating the National Water Environment Benefit Survey values: summary of the peer review; Environment Agency summary of the Metcalfe et al review 2012

APPENDIX A FIGURE

Figure 1 WFD water bodies and monitoring locations



Key

🟦 Monitoring Station

🟥 Abbey Consols - Site Area

▭ Teifi Catchments

Water Body Status

— Good quality

— Moderate quality

0 0.5 1 2 Km

A		DH 27/08/2019	GJ 27/08/2019	TE 27/08/2019
Ver	Amendments	Originated by and date	Checked by and date	Approved by and date

Client :

Project :
Abbey Consols Metal Mine Remediation and Benefits Assessment Report

Drawing Title :
WFD water bodies and monitoring locations

Drawing No :
Figure 01

Scale @ A3 : **1:80,000**

Purpose : **Draft**

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APPENDIX B CALCULATIONS

Loading and concentration predictions
M-BAT Zn results
M-BAT Pb results
Predicted Teifi concentrations (bioavailable)
NWEBS breakdown

TREATMENT	% LOAD REDUCTION
	100%

STATION ID	STATION NAME	FLOW (m3/s)	LOAD (mg/s)	REDUCED LOAD (mg/s)	CONCENTRATION (ug/L)	LOAD (mg/s)	REDUCED LOAD (mg/s)	CONCENTRATION (ug/L)	LOAD (mg/s)	REDUCED LOAD (mg/s)	CONCENTRATION (ug/L)
				Zn (filtered)			Cd (filtered)			Pb (filtered)	
83011	R. TEIFI BELOW STRATA FLORIDA	0.83	4.026	4.026	4.850	0.066	0.066	0.080	1.295	1.295	1.560
82992	TEIFI 250M D/S ABBEY CONSOLS DISCHARGE	0.84	42.515	4.026	4.798	0.117	0.066	0.079	1.972	1.295	1.543
83001	TEIFI 20M U/S PONTRHYDFEN.STW	1.48	67.210	28.720	19.366	0.119	0.068	0.046	1.676	0.999	0.674
34407	TEIFI:AT OLD RAILWAY BRIDGE	2.16	98.821	60.332	27.905	0.195	0.144	0.066	6.378	5.701	2.637
34403	TEIFI : PONT EYNON TREGARON DY	4.10	91.062	52.573	12.813	0.205	0.154	0.038	9.560	8.883	2.165
32482	TEIFI AT PONT LLANIO	5.94	95.310	56.821	9.563	0.475	0.424	0.071	11.706	11.029	1.856
34561	TEIFI AT PONT GOGOYAN	7.03	89.940	51.451	7.323						

TREATMENT	% LOAD REDUCTION
	70%

STATION ID	STATION NAME	FLOW (m3/s)	LOAD (mg/s)	REDUCED LOAD (mg/s)	CONCENTRATION (ug/L)	LOAD (mg/s)	REDUCED LOAD (mg/s)	CONCENTRATION (ug/L)	LOAD (mg/s)	REDUCED LOAD (mg/s)	CONCENTRATION (ug/L)
				Zn (filtered)			Cd (filtered)			Pb (filtered)	
83011	R. TEIFI BELOW STRATA FLORIDA	0.83	4.026	4.026	4.850	0.066	0.066	0.080	1.295	1.295	1.560
82992	TEIFI 250M D/S ABBEY CONSOLS DISCHARGE	0.84	42.515	15.572	18.560	0.117	0.082	0.097	1.972	1.498	1.785
83001	TEIFI 20M U/S PONTRHYDFEN.STW	1.48	67.210	40.267	27.152	0.119	0.083	0.056	1.676	1.202	0.811
34407	TEIFI:AT OLD RAILWAY BRIDGE	2.16	98.821	71.878	33.246	0.195	0.159	0.073	6.378	5.904	2.731
34403	TEIFI : PONT EYNON TREGARON DY	4.10	91.062	64.120	15.627	0.205	0.169	0.041	9.560	9.086	2.215
32482	TEIFI AT PONT LLANIO	5.94	95.310	68.367	11.506	0.475	0.440	0.074	11.706	11.232	1.890
34561	TEIFI AT PONT GOGOYAN	7.03	89.940	62.997	8.966						

TREATMENT	% LOAD REDUCTION
	50%

STATION ID	STATION NAME	FLOW (m3/s)	LOAD (mg/s)	REDUCED LOAD (mg/s)	CONCENTRATION (ug/L)	LOAD (mg/s)	REDUCED LOAD (mg/s)	CONCENTRATION (ug/L)	LOAD (mg/s)	REDUCED LOAD (mg/s)	CONCENTRATION (ug/L)
				Zn (filtered)			Cd (filtered)			Pb (filtered)	
83011	R. TEIFI BELOW STRATA FLORIDA	0.83	4.026	4.026	4.850	0.066	4.026	4.850	1.295	1.295	1.560
82992	TEIFI 250M D/S ABBEY CONSOLS DISCHARGE	0.84	42.515	23.270	27.735	0.117	0.092	0.110	1.972	1.633	1.947
83001	TEIFI 20M U/S PONTRHYDFEN.STW	1.48	67.210	47.965	32.343	0.119	0.093	0.063	1.676	1.337	0.902
34407	TEIFI:AT OLD RAILWAY BRIDGE	2.16	98.821	79.576	36.807	0.195	0.169	0.078	6.378	6.039	2.793
34403	TEIFI : PONT EYNON TREGARON DY	4.10	91.062	71.817	17.504	0.205	0.180	0.044	9.560	9.222	2.248
32482	TEIFI AT PONT LLANIO	5.94	95.310	76.065	12.801	0.475	0.450	0.076	11.706	11.367	1.913
34561	TEIFI AT PONT GOGOYAN	7.03	89.940	70.695	10.062						

ID	Location	Waterbody	Date	Measured Cu Concentration (dissolved) (μg l^{-1})	Measured Zn Concentration (dissolved) (μg l^{-1})	Measured Mn Concentration (dissolved) (μg l^{-1})	Measured Ni Concentration (dissolved) (μg l^{-1})	pH	DOC	Ca	Site-specific PNEC Dissolved Copper (μg l^{-1})	BioF	Bioavailable Copper Concentration (μg l^{-1})	Risk Characterisation Ratio	Site-specific PNEC Dissolved Zinc (μg l^{-1})	BioF	Bioavailable Zinc Concentration (μg l^{-1})	Risk Characterisation Ratio	Site-specific PNEC Dissolved Manganese (μg l^{-1})	BioF	Bioavailable Manganese Concentration (μg l^{-1})	Risk Characterisation Ratio
1	R. TEIFI BELOW STRATA FLORIDA 100%redScenario				4.85			7.07	3.5	1.8	13.84	0.07			16.08	0.68	3.29	0.30	123.00	1.00		
2	TEIFI 250M D/S ABBEY CONSOLS DISCHARGE 100%redScenario				4.797973778			6.86	3.4	1.8	11.67	0.09			15.03	0.73	3.48	0.32	123.00	1.00		
3	TEIFI 20M U/S PONTRHYDFEN.STW 100%redScenario				19.36642819			6.95	4	2.7	14.76	0.07			17.61	0.62	11.99	1.10	186.79	0.66		
4	TEIFI:AT OLD RAILWAY BRIDGE 100%redScenario				27.90543432			7.07	3.8	3.8	15.07	0.07			17.65	0.62	17.23	1.58	267.05	0.46		
5	TEIFI : PONT EYNON TREGARON DY 100%redScenario				12.81326712			7.05	5.3	6.1	21.03	0.05			23.69	0.46	5.90	0.54	357.81	0.34		
6	TEIFI AT PONT LLANIO 100%redScenario				9.56252659			7.05	4.9	5.9	19.40	0.05			22.22	0.49	4.69	0.43	379.71	0.32		
7	TEIFI AT PONT GOGOYAN 100%redScenario				7.322897666			7.06	5	5.7	19.91	0.05			22.60	0.48	3.53	0.32	367.90	0.33		
8	TEIFI 250M D/S ABBEY CONSOLS DISCHARGE 70%redScenario				18.56048164			6.86	3.4	1.8	11.67	0.09			15.03	0.73	13.46	1.23	123.00	1.00		
9	TEIFI 20M U/S PONTRHYDFEN.STW 70%redScenario				27.15249973			6.95	4	2.7	14.76	0.07			17.61	0.62	16.81	1.54	186.79	0.66		
10	TEIFI:AT OLD RAILWAY BRIDGE 70%redScenario				33.24620402			7.07	3.8	3.8	15.07	0.07			17.65	0.62	20.53	1.88	267.05	0.46		
11	TEIFI : PONT EYNON TREGARON DY 70%redScenario				15.62748699			7.05	5.3	6.1	21.03	0.05			23.69	0.46	7.19	0.66	357.81	0.34		
12	TEIFI AT PONT LLANIO 70%redScenario				11.50576861			7.05	4.9	5.9	19.40	0.05			22.22	0.49	5.64	0.52	379.71	0.32		
13	TEIFI AT PONT GOGOYAN 70%redScenario				8.966328366			7.06	5	5.7	19.91	0.05			22.60	0.48	4.32	0.40	367.90	0.33		
14	TEIFI 250M D/S ABBEY CONSOLS DISCHARGE 50%redScenario				27.73548689			6.86	3.4	1.8	11.67	0.09			15.03	0.73	20.11	1.85	123.00	1.00		
15	TEIFI 20M U/S PONTRHYDFEN.STW 50%redScenario				32.34321409			6.95	4	2.7	14.76	0.07			17.61	0.62	20.02	1.84	186.79	0.66		
16	TEIFI:AT OLD RAILWAY BRIDGE 50%redScenario				36.80671716			7.07	3.8	3.8	15.07	0.07			17.65	0.62	22.72	2.08	267.05	0.46		
17	TEIFI : PONT EYNON TREGARON DY 50%redScenario				17.50363356			7.05	5.3	6.1	21.03	0.05			23.69	0.46	8.06	0.74	357.81	0.34		
18	TEIFI AT PONT LLANIO 50%redScenario				12.8012633			7.05	4.9	5.9	19.40	0.05			22.22	0.49	6.28	0.58	379.71	0.32		
19	TEIFI AT PONT GOGOYAN 50%redScenario				10.06194883			7.06	5	5.7	19.91	0.05			22.60	0.48	4.85	0.45	367.90	0.33		

INPUT DATA						RESULTS (Pb)			
ID	Location	Waterbody	Date	Measured Pb Concentration (dissolved) (µg l^{-1})	DOC	Site Specific PNEC Dissolved Pb (µg l^{-1})	BioF	Available Pb (µg l^{-1})	Risk Characterisation Ratio
1	R. TEIFI BELOW STRATA FLORIDA			1.56	3.50	4.20	0.29	0.45	0.37
2	TEIFI 250M D/S ABBEY CONSOLS DIS			1.54	3.40	4.08	0.29	0.45	0.38
3	TEIFI 20M U/S PONTRHYDFEN.STW 1			0.67	4.00	4.80	0.25	0.17	0.14
4	TEIFI:AT OLD RAILWAY BRIDGE 100%			2.64	3.80	4.56	0.26	0.69	0.58
5	TEIFI : PONT EYNON TREGARON DY			2.17	5.30	6.36	0.19	0.41	0.34
6	TEIFI AT PONT LLANIO 100%redScena			1.86	4.90	5.88	0.20	0.38	0.32
7	TEIFI 250M D/S ABBEY CONSOLS DIS			1.79	3.40	4.08	0.29	0.53	0.44
8	TEIFI 20M U/S PONTRHYDFEN.STW 7			0.81	4.00	4.80	0.25	0.20	0.17
9	TEIFI:AT OLD RAILWAY BRIDGE 70%r			2.73	3.80	4.56	0.26	0.72	0.60
10	TEIFI : PONT EYNON TREGARON DY			2.21	5.30	6.36	0.19	0.42	0.35
11	TEIFI AT PONT LLANIO 70%redScenari			1.89	4.90	5.88	0.20	0.39	0.32
12	TEIFI 250M D/S ABBEY CONSOLS DIS			1.95	3.40	4.08	0.29	0.57	0.48
13	TEIFI 20M U/S PONTRHYDFEN.STW 5			0.90	4.00	4.80	0.25	0.23	0.19
14	TEIFI:AT OLD RAILWAY BRIDGE 50%r			2.79	3.80	4.56	0.26	0.74	0.61
15	TEIFI : PONT EYNON TREGARON DY			2.25	5.30	6.36	0.19	0.42	0.35
16	TEIFI AT PONT LLANIO 50%redScenari			1.91	4.90	5.88	0.20	0.39	0.33

Conversion of predicted concentrations in bioavailable concentrations (inputs for M-BAT)

All values are average concentrations **M-BAT parameters**

100% site load reduction	Zn	Zn bio	Cd	Pb	Pb bio	pH	Ca mg/l	DOC mg/l
R. TEIFI BELOW STRATA FLORIDA	4.850	3.288	0.080	1.560	0.446	7.07	1.8	3.5
TEIFI 250M D/S ABBEY CONSOLS DISCHARGE	4.798	3.479	0.079	1.543	0.454	6.86	1.8	3.4
TEIFI 20M U/S PONTRHYDFEN.STW	19.366	11.989	0.046	0.674	0.168	6.95	2.7	4
TEIFI:AT OLD RAILWAY BRIDGE	27.905	17.229	0.066	2.637	0.694	7.07	3.8	3.8
TEIFI : PONT EYNON TREGARON DY	12.813	5.897	0.038	2.165	0.408	7.05	6.1	5.3
TEIFI AT PONT LLANIO	9.563	4.690	0.071	1.856	0.379	7.05	5.9	4.9
TEIFI AT PONT GOGOYAN	7.323	3.532	NR	NR	NR	7.06	5.7	5

70% site load reduction	Zn	Zn bio	Cd	Pb	Pb bio	pH	Ca mg/l	DOC mg/l
R. TEIFI BELOW STRATA FLORIDA	4.850	3.288	0.080	1.560	0.446	7.07	1.8	3.5
TEIFI 250M D/S ABBEY CONSOLS DISCHARGE	18.560	13.459	0.097	1.785	0.525	6.86	1.8	3.4
TEIFI 20M U/S PONTRHYDFEN.STW	27.152	16.809	0.056	0.811	0.203	6.95	2.7	4
TEIFI:AT OLD RAILWAY BRIDGE	33.246	20.526	0.073	2.731	0.719	7.07	3.8	3.8
TEIFI : PONT EYNON TREGARON DY	15.627	7.192	0.041	2.215	0.418	7.05	6.1	5.3
TEIFI AT PONT LLANIO	11.506	5.643	0.074	1.890	0.386	7.05	5.9	4.9
TEIFI AT PONT GOGOYAN	8.966	4.324	NR	NR	NR	7.06	5.7	5

50% site load reduction	Zn	Zn bio	Cd	Pb	Pb bio	pH	Ca mg/l	DOC mg/l
R. TEIFI BELOW STRATA FLORIDA	4.850	3.288	0.080	1.560	0.446	7.07	1.8	3.5
TEIFI 250M D/S ABBEY CONSOLS DISCHARGE	27.735	20.112	0.110	1.947	0.573	6.86	1.8	3.4
TEIFI 20M U/S PONTRHYDFEN.STW	32.343	20.022	0.063	0.902	0.225	6.95	2.7	4
TEIFI:AT OLD RAILWAY BRIDGE	36.807	22.724	0.078	2.793	0.735	7.07	3.8	3.8
TEIFI : PONT EYNON TREGARON DY	17.504	8.055	0.044	2.248	0.424	7.05	6.1	5.3
TEIFI AT PONT LLANIO	12.801	6.278	0.076	1.913	0.390	7.05	5.9	4.9
TEIFI AT PONT GOGOYAN	10.062	4.853	NR	NR	NR	7.06	5.7	5

NWEBS values breakdown

Inflation adjustment

Year	low	central	high	
2012	£11,600	£14,200	£16,800	Pre-constrcution
2013	£11,874	£14,535	£17,196	
2014	£12,154	£14,878	£17,602	
2015	£12,441	£15,229	£18,018	
2016	£12,734	£15,589	£18,443	
2017	£13,035	£15,957	£18,878	
2018	£13,343	£16,333	£19,324	
2019	£13,657	£16,719	£19,780	
2020	£13,980	£17,113	£20,247	

Discount rate adjustment (Green Book)*

Year	Standard Discount Rate	Discount Factor	NWEBS Value High (adjusted)	Health Discount Rate	Discount Factor	NWEBS Value High (adjusted)
2020		1	£20,247		1	£20,247
2021	3.500%	0.9662	£19,562	1.500%	0.9852	£19,947
2022	3.500%	0.9335	£18,900	1.500%	0.9707	£19,653
2023	3.500%	0.9019	£18,261	1.500%	0.9563	£19,362
2024	3.500%	0.8714	£17,644	1.500%	0.9422	£19,076
2025	3.500%	0.8420	£17,047	1.500%	0.9283	£18,794
2026	3.500%	0.8135	£16,471	1.500%	0.9145	£18,516
2027	3.500%	0.7860	£15,914	1.500%	0.9010	£18,243
2028	3.500%	0.7594	£15,375	1.500%	0.8877	£17,973
2029	3.500%	0.7337	£14,856	1.500%	0.8746	£17,707
2030	3.500%	0.7089	£14,353	1.500%	0.8617	£17,446
2031	3.500%	0.6849	£13,868	1.500%	0.8489	£17,188
2032	3.500%	0.6618	£13,399	1.500%	0.8364	£16,934
2033	3.500%	0.6394	£12,946	1.500%	0.8240	£16,684
2034	3.500%	0.6178	£12,508	1.500%	0.8118	£16,437
2035	3.500%	0.5969	£12,085	1.500%	0.7999	£16,194
2036	3.500%	0.5767	£11,676	1.500%	0.7880	£15,955
2037	3.500%	0.5572	£11,281	1.500%	0.7764	£15,719
2038	3.500%	0.5384	£10,900	1.500%	0.7649	£15,487
2039	3.500%	0.5202	£10,531	1.500%	0.7536	£15,258
2040	3.500%	0.5026	£10,175	1.500%	0.7425	£15,032
2041	3.500%	0.4856	£9,831	1.500%	0.7315	£14,810
2042	3.500%	0.4692	£9,499	1.500%	0.7207	£14,591
2043	3.500%	0.4533	£9,177	1.500%	0.7100	£14,376
2044	3.500%	0.4380	£8,867	1.500%	0.6995	£14,163
2045	3.500%	0.4231	£8,567	1.500%	0.6892	£13,954
2046	3.500%	0.4088	£8,278	1.500%	0.6790	£13,748
2047	3.500%	0.3950	£7,998	1.500%	0.6690	£13,545
2048	3.500%	0.3817	£7,727	1.500%	0.6591	£13,345
2049	3.500%	0.3687	£7,466	1.500%	0.6494	£13,147
2050	3.500%	0.3563	£7,213	1.500%	0.6398	£12,953
2051	3.000%	0.3459	£7,003	1.286%	0.6316	£12,789
2052	3.000%	0.3358	£6,799	1.286%	0.6236	£12,626
2053	3.000%	0.3260	£6,601	1.286%	0.6157	£12,466
2054	3.000%	0.3165	£6,409	1.286%	0.6079	£12,308
2055	3.000%	0.3073	£6,222	1.286%	0.6002	£12,151
2056	3.000%	0.2984	£6,041	1.286%	0.5926	£11,997
2057	3.000%	0.2897	£5,865	1.286%	0.5850	£11,845
2058	3.000%	0.2812	£5,694	1.286%	0.5776	£11,695
2059	3.000%	0.2731	£5,528	1.286%	0.5703	£11,546
2060	3.000%	0.2651	£5,367	1.286%	0.5630	£11,400

* https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

High discount rate scenario

4km status change

NWEBS values over life cycle per NWEBS element assuming equal contribution to total NWEBS value (3.5% discount rate)

Year	Fish	Other animals such as invertebrates	Plant communities	The clarity of water	The condition of the river channel and flow of water	The safety of the water for recreational contact
2020	0	0	0	3,374	3,374	3,374
2021	13,041	13,041	13,041	3,260	3,260	3,260
2022	12,600	12,600	12,600	3,150	3,150	3,150
2023	12,174	12,174	12,174	3,044	3,044	3,044
2024	11,762	11,762	11,762	2,941	2,941	2,941
2025	11,365	11,365	11,365	2,841	2,841	2,841
2026	10,980	10,980	10,980	2,745	2,745	2,745
2027	10,609	10,609	10,609	2,652	2,652	2,652
2028	10,250	10,250	10,250	2,563	2,563	2,563
2029	9,904	9,904	9,904	2,476	2,476	2,476
2030	9,569	9,569	9,569	2,392	2,392	2,392
2031	9,245	9,245	9,245	2,311	2,311	2,311
2032	8,933	8,933	8,933	2,233	2,233	2,233
2033	8,630	8,630	8,630	2,158	2,158	2,158
2034	8,339	8,339	8,339	2,085	2,085	2,085
2035	8,057	8,057	8,057	2,014	2,014	2,014
2036	7,784	7,784	7,784	1,946	1,946	1,946
2037	7,521	7,521	7,521	1,880	1,880	1,880
2038	7,267	7,267	7,267	1,817	1,817	1,817
2039	7,021	7,021	7,021	1,755	1,755	1,755
2040	6,783	6,783	6,783	1,696	1,696	1,696
2041	6,554	6,554	6,554	1,639	1,639	1,639
2042	6,332	6,332	6,332	1,583	1,583	1,583
2043	6,118	6,118	6,118	1,530	1,530	1,530
2044	5,911	5,911	5,911	1,478	1,478	1,478
2045	5,712	5,712	5,712	1,428	1,428	1,428
2046	5,518	5,518	5,518	1,380	1,380	1,380
2047	5,332	5,332	5,332	1,333	1,333	1,333
2048	5,151	5,151	5,151	1,288	1,288	1,288
2049	4,977	4,977	4,977	1,244	1,244	1,244
2050	4,809	4,809	4,809	1,202	1,202	1,202
2051	4,669	4,669	4,669	1,167	1,167	1,167
2052	4,533	4,533	4,533	1,133	1,133	1,133
2053	4,401	4,401	4,401	1,100	1,100	1,100
2054	4,273	4,273	4,273	1,068	1,068	1,068
2055	4,148	4,148	4,148	1,037	1,037	1,037
2056	4,027	4,027	4,027	1,007	1,007	1,007
2057	3,910	3,910	3,910	978	978	978
2058	3,796	3,796	3,796	949	949	949
2059	3,686	3,686	3,686	921	921	921
	285,694	**285,694**	**285,694**	**74,798**	**74,798**	**74,798**
					Sum	**£1,081,474.07**

11.4km status change

NWEBS values over life cycle per NWEBS element assuming equal contribution to total NWEBS value (3.5% discount rate)

Year	Fish	Other animals such as invertebrates	Plant communities	The clarity of water	The condition of the river channel and flow of water	The safety of the water for recreational contact
2020	0	0	0	3,374	3,374	3,374
2021	37,168	37,168	37,168	3,260	3,260	3,260
2022	35,911	35,911	35,911	3,150	3,150	3,150
2023	34,696	34,696	34,696	3,044	3,044	3,044
2024	33,523	33,523	33,523	2,941	2,941	2,941
2025	32,389	32,389	32,389	2,841	2,841	2,841
2026	31,294	31,294	31,294	2,745	2,745	2,745
2027	30,236	30,236	30,236	2,652	2,652	2,652
2028	29,213	29,213	29,213	2,563	2,563	2,563
2029	28,226	28,226	28,226	2,476	2,476	2,476
2030	27,271	27,271	27,271	2,392	2,392	2,392
2031	26,349	26,349	26,349	2,311	2,311	2,311
2032	25,458	25,458	25,458	2,233	2,233	2,233
2033	24,597	24,597	24,597	2,158	2,158	2,158
2034	23,765	23,765	23,765	2,085	2,085	2,085
2035	22,961	22,961	22,961	2,014	2,014	2,014
2036	22,185	22,185	22,185	1,946	1,946	1,946
2037	21,435	21,435	21,435	1,880	1,880	1,880
2038	20,710	20,710	20,710	1,817	1,817	1,817
2039	20,010	20,010	20,010	1,755	1,755	1,755
2040	19,333	19,333	19,333	1,696	1,696	1,696
2041	18,679	18,679	18,679	1,639	1,639	1,639
2042	18,048	18,048	18,048	1,583	1,583	1,583
2043	17,437	17,437	17,437	1,530	1,530	1,530
2044	16,848	16,848	16,848	1,478	1,478	1,478
2045	16,278	16,278	16,278	1,428	1,428	1,428
2046	15,727	15,727	15,727	1,380	1,380	1,380
2047	15,196	15,196	15,196	1,333	1,333	1,333
2048	14,682	14,682	14,682	1,288	1,288	1,288
2049	14,185	14,185	14,185	1,244	1,244	1,244
2050	13,705	13,705	13,705	1,202	1,202	1,202
2051	13,306	13,306	13,306	1,167	1,167	1,167
2052	12,919	12,919	12,919	1,133	1,133	1,133
2053	12,542	12,542	12,542	1,100	1,100	1,100
2054	12,177	12,177	12,177	1,068	1,068	1,068
2055	11,822	11,822	11,822	1,037	1,037	1,037
2056	11,478	11,478	11,478	1,007	1,007	1,007
2057	11,144	11,144	11,144	978	978	978
2058	10,819	10,819	10,819	949	949	949
2059	10,504	10,504	10,504	921	921	921
	814,227	**814,227**	**814,227**	**74,798**	**74,798**	**74,798**
					Sum	**£2,667,073.24**

Lower discount rate scenario

4km status change

NWEBS values over life cycle per NWEBS element assuming equal contribution to total NWEBS value (1.5% discount rate)

Year	Fish	Other animals such as invertebrates	Plant communities	The clarity of water	The condition of the river channel and flow of water	The safety of the water for recreational contact
2020	0	0	0	3,374	3,374	3,374
2021	13,298	13,298	13,298	3,325	3,325	3,325

2022	13,102	13,102	13,102	3,275	3,275	3,275
2023	12,908	12,908	12,908	3,227	3,227	3,227
2024	12,717	12,717	12,717	3,179	3,179	3,179
2025	12,529	12,529	12,529	3,132	3,132	3,132
2026	12,344	12,344	12,344	3,086	3,086	3,086
2027	12,162	12,162	12,162	3,040	3,040	3,040
2028	11,982	11,982	11,982	2,996	2,996	2,996
2029	11,805	11,805	11,805	2,951	2,951	2,951
2030	11,631	11,631	11,631	2,908	2,908	2,908
2031	11,459	11,459	11,459	2,865	2,865	2,865
2032	11,289	11,289	11,289	2,822	2,822	2,822
2033	11,122	11,122	11,122	2,781	2,781	2,781
2034	10,958	10,958	10,958	2,740	2,740	2,740
2035	10,796	10,796	10,796	2,699	2,699	2,699
2036	10,637	10,637	10,637	2,659	2,659	2,659
2037	10,479	10,479	10,479	2,620	2,620	2,620
2038	10,325	10,325	10,325	2,581	2,581	2,581
2039	10,172	10,172	10,172	2,543	2,543	2,543
2040	10,022	10,022	10,022	2,505	2,505	2,505
2041	9,874	9,874	9,874	2,468	2,468	2,468
2042	9,728	9,728	9,728	2,432	2,432	2,432
2043	9,584	9,584	9,584	2,396	2,396	2,396
2044	9,442	9,442	9,442	2,361	2,361	2,361
2045	9,303	9,303	9,303	2,326	2,326	2,326
2046	9,165	9,165	9,165	2,291	2,291	2,291
2047	9,030	9,030	9,030	2,257	2,257	2,257
2048	8,896	8,896	8,896	2,224	2,224	2,224
2049	8,765	8,765	8,765	2,191	2,191	2,191
2050	8,635	8,635	8,635	2,159	2,159	2,159
2051	8,526	8,526	8,526	2,131	2,131	2,131
2052	8,417	8,417	8,417	2,104	2,104	2,104
2053	8,311	8,311	8,311	2,078	2,078	2,078
2054	8,205	8,205	8,205	2,051	2,051	2,051
2055	8,101	8,101	8,101	2,025	2,025	2,025
2056	7,998	7,998	7,998	2,000	2,000	2,000
2057	7,897	7,897	7,897	1,974	1,974	1,974
2058	7,796	7,796	7,796	1,949	1,949	1,949
2059	7,697	7,697	7,697	1,924	1,924	1,924
	397,107	**397,107**	**397,107**	**102,651**	**102,651**	**102,651**
					Sum	**£1,499,276.37**

11.4km status change

NWEBS values over life cycle per NWEBS element assuming equal contribution to total NWEBS value (1.5% discount rate)

Year	**Fish**	**Other animals such as invertebrates**	**Plant communities**	**The clarity of water**	**The condition of the river channel and flow of water**	**The safety of the water for recreational contact**
2020	0	0	0	3,374	3,374	3,374
2021	37,900	37,900	37,900	3,325	3,325	3,325
2022	37,340	37,340	37,340	3,275	3,275	3,275
2023	36,788	36,788	36,788	3,227	3,227	3,227
2024	36,244	36,244	36,244	3,179	3,179	3,179
2025	35,709	35,709	35,709	3,132	3,132	3,132
2026	35,181	35,181	35,181	3,086	3,086	3,086
2027	34,661	34,661	34,661	3,040	3,040	3,040
2028	34,149	34,149	34,149	2,996	2,996	2,996
2029	33,644	33,644	33,644	2,951	2,951	2,951

2030	33,147	33,147	33,147	2,908	2,908	2,908
2031	32,657	32,657	32,657	2,865	2,865	2,865
2032	32,175	32,175	32,175	2,822	2,822	2,822
2033	31,699	31,699	31,699	2,781	2,781	2,781
2034	31,231	31,231	31,231	2,740	2,740	2,740
2035	30,769	30,769	30,769	2,699	2,699	2,699
2036	30,314	30,314	30,314	2,659	2,659	2,659
2037	29,866	29,866	29,866	2,620	2,620	2,620
2038	29,425	29,425	29,425	2,581	2,581	2,581
2039	28,990	28,990	28,990	2,543	2,543	2,543
2040	28,562	28,562	28,562	2,505	2,505	2,505
2041	28,140	28,140	28,140	2,468	2,468	2,468
2042	27,724	27,724	27,724	2,432	2,432	2,432
2043	27,314	27,314	27,314	2,396	2,396	2,396
2044	26,910	26,910	26,910	2,361	2,361	2,361
2045	26,513	26,513	26,513	2,326	2,326	2,326
2046	26,121	26,121	26,121	2,291	2,291	2,291
2047	25,735	25,735	25,735	2,257	2,257	2,257
2048	25,355	25,355	25,355	2,224	2,224	2,224
2049	24,980	24,980	24,980	2,191	2,191	2,191
2050	24,611	24,611	24,611	2,159	2,159	2,159
2051	24,298	24,298	24,298	2,131	2,131	2,131
2052	23,990	23,990	23,990	2,104	2,104	2,104
2053	23,685	23,685	23,685	2,078	2,078	2,078
2054	23,385	23,385	23,385	2,051	2,051	2,051
2055	23,088	23,088	23,088	2,025	2,025	2,025
2056	22,795	22,795	22,795	2,000	2,000	2,000
2057	22,505	22,505	22,505	1,974	1,974	1,974
2058	22,220	22,220	22,220	1,949	1,949	1,949
2059	21,938	21,938	21,938	1,924	1,924	1,924
	1,131,756	**1,131,756**	**1,131,756**	**102,651**	**102,651**	**102,651**
					Sum	**£3,703,222.95**

Willow House
Brotherswood Court
Great Park Road
Bradley Stoke, Bristol
BS32 4QW

wsp.com