THE UNIVERSITY OF HULL

# Framework for Remediation of Rivers Impacted by Legacy Metal Mine Pollution

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by

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## Abstract

Seven percent of surface waters in England and Wales are impacted by pollution from abandoned non-ferrous metal mines. It is estimated that there are about five thousand five hundred of these. There is no legal liability to any party attached to abandoned metal mines in the UK if they ceased operation before 1999. Preventing pollution from entering river catchments from these sources can be expensive and public funds are limited in extent. These enduring sources of pollution are a significant impediment to compliance with the legislative requirements, such as the European Water Framework Directive. This thesis develops a framework for integrating pre-existing tools and methodologies to address this environmental problem: Environmental Impact Assessment (EIA), Life Cycle Impact Assessment (LCIA) and Payments for Ecosystem Services (PES). By fully quantifying the economic, social and environmental impacts of abandoned mine discharges and the net benefits of potential management interventions over different scales, it is proposed that the framework can provide a sustainable way forward for identifying appropriate cost-effective remedial interventions, identify sources of funding for remediation to take place through PES, while at the same time being sensitive to stakeholder concerns. To determine the effectiveness of this framework two phases of research have been undertaken. The first was a series of interviews with a range of key stakeholders with relevant knowledge and expertise, targeting key concerns and conflicts that arise in managing legacy pollution. The second was to apply the framework to a specific mine-impacted catchment to determine the effectiveness of the framework and an optimal solution for that site. Key findings of stakeholder interviews revealed the general positive attitude towards PES-schemes also discrepancies in knowledge between different sectors. Industrial representatives emphasised the likely need for regulation to initiate such processes. The potentially important role of stewardship and conservation organisations as “ethical brokers” for such schemes was highlighted, given their expertise at communicating and managing a range of stakeholder opinions. The application of the framework to the Hebden Beck catchment in North Yorkshire found that multiple small scale passive remediation at affected locations would be an optimal solution. The full costs of such systems are outweighed by the potential ecosystem service benefits of metal removal from upland

streams.  Fundamental to the acceptability and sustainability of the remedial solution was the requirement for habitat offsetting to be incorporated into the proposed works.

## Acknowledgements

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## List of acronyms

- **I** Industry
- **GA** Government Agencies
- **SICSO** Special Interest/Conservation/Stewardship Organisations
- **ES** Ecosystem Services
- **PES** Payment for Ecosystem Services
- **AONB** Area of Outstanding National Beauty
- **WFD** Water Framework Directive
- **LCA** Life Cycle Assessment
- **LCIA** Life Cycle Impact Assessment
- **SLCA** Social Life Cycle Assessment
- **LCC** Life Cycle Costing
- **LCSA** Life Cycle Sustainability Assessment
- **DLCA** Dynamic Life Cycle Assessment
- **EA** Environment Agency
- **RBD** River Basin District
- **RBC** River Basin Catchment
- **RBMP** River Basement Management Plans
- **UKWIR** UK Water Industry Research Group
- **EQS** Environmental Quality Standards
- **WTP** Willingness to Pay
- **TEEB** The Economics of Ecosystems and Biodiversity
- **EIA** Environmental Impact Assessment
- **SEA** Strategic Environmental Assessment
- **SETAC** Society for Environmental Toxicology and Chemistry
- **TEV** Total Economic Value
- **DALY** Disability Adjusted Life Year
- **RBC** River Basin Catchments
- **WHO** World Health Organisation
- **UN** United Nations
- **EU** European Union
- **UKWIR** UK Water Industry Research Organisation

- **EUJRC** European Union Joint Research Council
- **ONS** Office for National Statistics
- **PV** Present Value
- **UFL** Ultra Fine Limestone
- **MPC** Monetary Policy Committee
- **GDP** Gross Domestic Product
- **STEAM** Scarborough Tourist Economic Activity Monitor
- **NWEBV** National Water Environment Benefit Values
- **WISE** Water Information Systems for Europe
- **SSSI** Sites of Special Scientific Interest
- **JNCC** Joint Nature Conservation Committee
- **UK NEA** UK National Ecosystem Assessment
- **HFO** Hydrous Ferrous Oxide
- **UU** United Utilities
- **SETAC** Society of Environmental Toxicology and Chemistry
- **UNEP** United Nations Environmental Protection
- **ILCD** International-Reference Life Cycle Data-System
- **ANOB** Area of Outstanding Natural Beauty
- **ISO** International Standards Organisation
- **EPLCA** European Platform on Life Cycle Assessment
- **ILCA** Integrated Life Assessment Methodology
- **DAS** Disbursed Alkali Substrate
- **NFOL** Natural Fe-Oxidizing Lagoon
- **AMD** Acid Mine Drainage
- **IPCC** Intergovernmental Panel on Climate Change

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# Chapter One Introduction

## 1.1 Abandoned Mines and the Water Environment

Metals are naturally occurring elements in the Earth's crust and are released into river catchments through natural environmental processes such as erosion and weathering. Extraction of metals has the effect of accelerating mineral weathering rates and redistributing metals from ore bodies. This can lead to elevated instream water and sediment metal concentrations to the point where they can become toxic, consequently impeding the functioning of the ecosystems of which they are part (Batty et al., 2010, Jarvis and Mayes, 2012). In England and Wales there are an estimated 5500 metal mines, although the number is probably much greater than this (Potter et al., 2012, Mayes et al., 2010, Mayes et al., 2009). These sites are shown in Figure 1.1. Extraction of metals can be tracked back to the Bronze Age in the UK (Craddock, 1995, Farley, 2012) making it difficult to determine what levels of these metals would occur within the environment if it were not for this form of human activity. It was not until the late 18th and early 19th century when the volume of metal ore extraction and processing increase to fulfil the requirements of the Industrial Revolution that the negative impacts on human health became apparent (Batty et al., 2010). Mine sites, including non-operational sites, still contribute significantly to the levels of zinc (Zn), copper (Cu) cadmium (Cd) and lead (Pb) in their immediate vicinity and hence to the global flux of metals. The oxidative dissolution of metal-bearing minerals, notably the sulphide ores in which most common metals are found such as pyrite ($FeS_2$), sphalerite (ZnS) and galena (PbS), is the key mechanism by which mining accelerates mineral weathering (Mayes et al., 2009a, Nordstrom, 2011). As such, metal mine discharges provide a long-lived and significant pressure on the quality of many rivers.

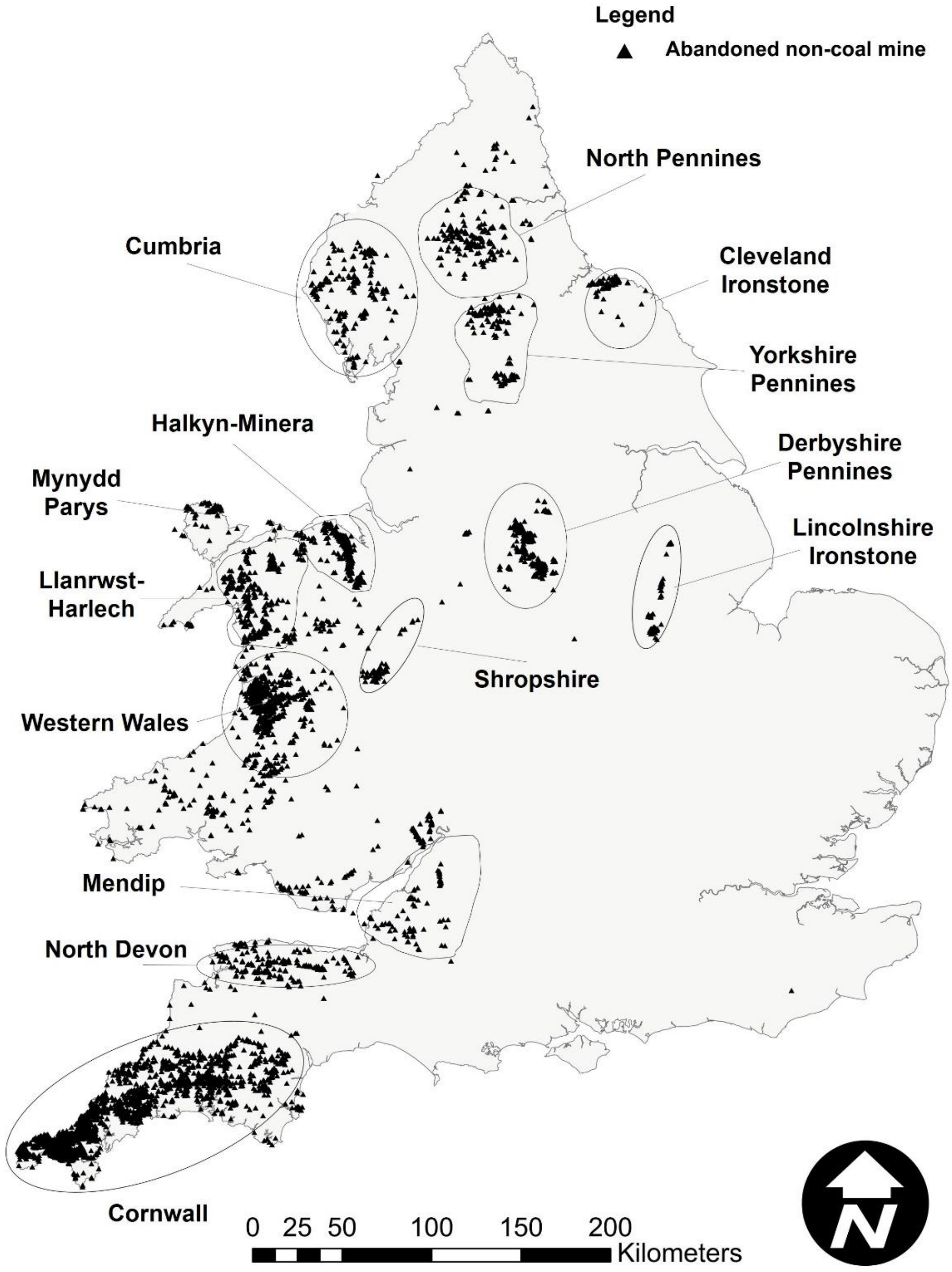


Figure 1.1: The distribution of abandoned non-coal mining ore fields across England and Wales

The European Union has created specific targets for Member States to protect and restore aquatic ecosystems and is a requirement of article 4 (1) of the Water Framework

Directive (WFD) (2000/60/EC) (European Parliament, 2000). The comprehensive nature of the WFD specifies that member states have to consider the environmental, economic and social ramifications of any actions taken to achieve this improvement, hence ensuring that sustainable water resource management is achieved. A significant contribution to why the UK fails to meet these targets is metal pollution from abandoned metal mine sites (Jarvis and Mayes, 2012). While modern mining is typically regulated by the polluter pays principle both in the UK and overseas, historic mining was not subject to such legislative control. It was only after 1999 in the UK, that a legislative loophole was closed which ensures mining operations are responsible for any polluting emissions to any environmental compartment in perpetuity, (European Commission, 2008, UK Government, 1998). Thus, prior to 1999, which covers the overwhelming majority of UK metal mining operations, any metal mine operator could close extractive operations and not have any liability for polluting discharges that arise from the site (Environment Agency, 2008). As such, efforts to achieve the good chemical and ecological status demanded of the WFD in mine-impacted catchments fall on the public purse. Other European Union legislation such as the Habitats Directive (European Parliament, 1992) and the Environmental Liabilities Directive (European Parliament, 2004) concerned with areas of environmental damage. The Environmental Liabilities Directive does not apply to any impacts covered by Article 4(7) of the WFD (European Parliament, 2000). It is the impact that discharges from abandoned metal mines have on the UK's ability to meet good chemical and ecological status as required by the WFD that is the focus of this research.

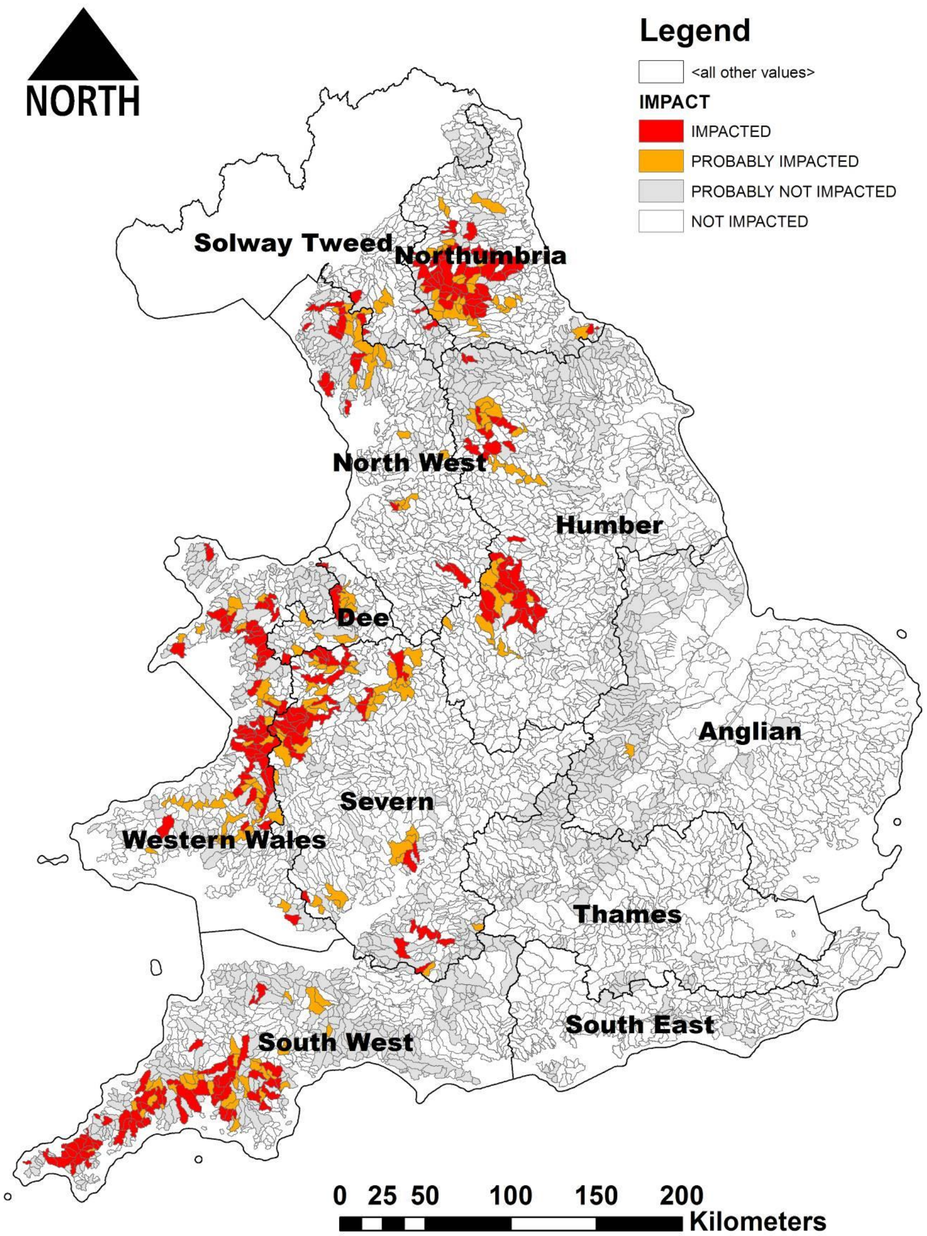


Figure 1.2: The distribution of impact categories of water bodies across England and Wales (Mayes et al., 2009b)

A concerted effort has been made by the Environment Agency (EA) to quantify the extent and level of this problem in recent years (Environment Agency, 2012b, Potter et al., 2012, Mayes et al., 2009b, Mayes et al., 2010, Jarvis and Mayes, 2012) to help support remediation planning (Figure 1.2). Despite this progress in both consolidating databases on the impacts of mining pollution that help prioritise sites for remediation, and in giving responsibility to the Coal Authority for operational remediation of priority mine sites, there remain some considerable obstacles that need to be overcome for effective management of legacy mine pollutants. These issues concern:

**Funding** – the monies committed so far by DEFRA have incorporated R&D funds (Mayes et al., 2009b) for assessing the extent of metal mine pollution, developing methodologies for prioritising sources, and developing tools for remediation. In addition, the first full-scale metal mine remediation scheme as part of recent WFD funding has been completed at Force Crag Mine in Cumbria (Jarvis et al., 2014a). The £10 million over the current WFD cycle is not insubstantial, but when compared with the estimated £370 million that was recently forwarded by Jarvis and Mayes (2012) as a ten year estimate of funding required to address 20 of the most acutely polluting sites, there is a major disparity. It is clear that central government funding alone cannot be relied upon to fund mine remediation in its entirety.

**Environmental assessments** – one of the key areas of research focus in recent years surrounding metal mining has been the development of robust tools for determining the provenance of instream metal sources in mined catchments. Given the large number of potential sources of metals in a river basin (e.g. mine discharges, spoil heaps, roads, atmospheric deposition, active industry), the basis for any remedial intervention at abandoned mine sites needs to be well-justified. Various researchers have therefore developed and trialled methods for source apportionment (Mayes et al., 2008, Gozzard et al., 2011), but there remain some crucial uncertainties about the extent of impact of metal-rich discharges. These include improvements in quantifying the ecological impacts of metal-rich discharges, particularly in systems that may have become acclimated to such conditions over time. Other researchers are also questioning the validity of Environmental Quality Standards (EQS), the regulatory thresholds set for assessing compliance with various directives, given the variation in bulk water chemistry across streams of England and Wales (Merrington and Alloway, 1994, Balistrieri et al., 2012, Whelan, 2014, Woznicki et al., 2015, Donnachie et al., 2014, Merrington and Van Sprang, 2014)

**Remedial technologies** – the most common pollutants encountered at abandoned metal mine sites in England and Wales are zinc, cadmium, lead and copper. These elements provide particular challenges for removal – notably zinc and cadmium, given their environmental mobility (Langmuir, 1997). Traditional approaches to metal removal from wastewaters, such as lime dosing, require ongoing inputs of reagents and energy so are not deemed best-suited to remote, abandoned sites (Jarvis and Mayes, 2012). *Passive remediation* technologies (i.e. those that rely on natural energy gradients and infrequent, albeit continued maintenance) have yet to be demonstrated at full scale for the range of discharge types present in the UK. As such, a range of researchers (and central government remedial funds) have been directed towards developing and trialling lower cost passive technologies (Gandy and Jarvis, 2012, Jarvis et al., 2014b). There is however a dearth of information on the full life cycle costs and environmental benefits of such remedial schemes over their operational lives.

**Stakeholder engagement -** there is a wide range of stakeholders with interests in abandoned mine sites, notably centring on the conservation value of both natural and built environment features. Some of these abandoned and closed mining sites are of historic significance and are designated scheduled monuments (English Heritage, 2013) additionally increased levels of metal output have contributed to unique metallophyte communities developing in some areas which are now designated Sites of Special Scientific Interest (SSSI; (Lucassen et al., 2009, Whiting et al., 2004a)). In addition to this the sites are often located in difficult and remote areas which has impacts upon the type of remediation that can be practically deployed. These factors will impact on the decisions about the type of remediation chosen, in what manner to preserve sites of conservation importance, and have implications for how to achieve good chemical and ecological status for the impacted water body. These different dynamics introduce a diverse range of potential stakeholders in any project who would wish to contribute to the conversation about the measures being considered to address these sources of pollution. As such, robust frameworks for effectively engaging with a range of catchment-scale stakeholders is key as part of any remedial planning at abandoned mine sites.

This range of issues therefore encompasses fundamental science research (e.g. on metal-biota relationships in mine-affected systems), practical engineering considerations in terms of technologies that can be deployed, and frameworks for stakeholder engagement in remedial planning. Improved frameworks for managing legacy pollutants need to be sensitive and responsive to advances in scientific understanding (for example if EQS values were revised after new insights into toxicological thresholds were provided

(Gandhi et al., 2010, Verdonck et al., 2014)) and advances in remedial technologies that could be applied to such problem sites.

## 1.2 Payments for Ecosystem Services: Could Remediation Pay for Itself?

The direct and indirect direct contributions that ecosystems make to human well-being are known as ecosystem services (ES) (Kumar, 2012). Payment for Ecosystem Services (PES) schemes are an approach applied internationally (Ruckelshaus et al., 2013, Hejnowicz et al., 2014, Ingram et al., 2014, Kumar et al., 2014) for remunerating those who implement environmentally beneficial management practices. This ensures that the physical environment they are responsible for is capable of sustaining strong and resilient ecosystem services, by the beneficiaries of those services. This approach is an economic arrangement between two or more parties where ecological goals are delivered through the intervention and interests of the stakeholders involved in the scheme, either through changing management practices or restoration/remediation of damaged environments (Kumar, 2012). As this approach develops and matures its application to resolve environmental problems to restore and improve ecosystem services has become more accepted by governments as a possible solution to funding environmental projects to improve and restore habitats which are under threat (Van Hecken and Bastiaensen, 2010, Greiner and Stanley, 2013, Kroeger, 2013). In the UK, guidance on how to manage and implement these types of schemes has been published (Smith, 2013) and a number of case studies and pilot projects undertaken (see Table 2.1) but as yet its consistent application has yet to be fully integrated into operational environmental policy. A new framework has been developed as shown in Figure 1.3 which seeks to demonstrate a workable way in which action taken to resolve environmental issues can be of benefit, have a tangible positive impact at multiple scales and be self-funding.

The starting point for the development of this framework was how to fund the remediation of abandoned non-coal mine sites. To assess whether it was it would be economically viable to do so with existing remediation technologies. The four issues outlined in Section 1.1; funding, environmental assessment, remediation technologies and stakeholder engagement, are captured by the proposed new framework.

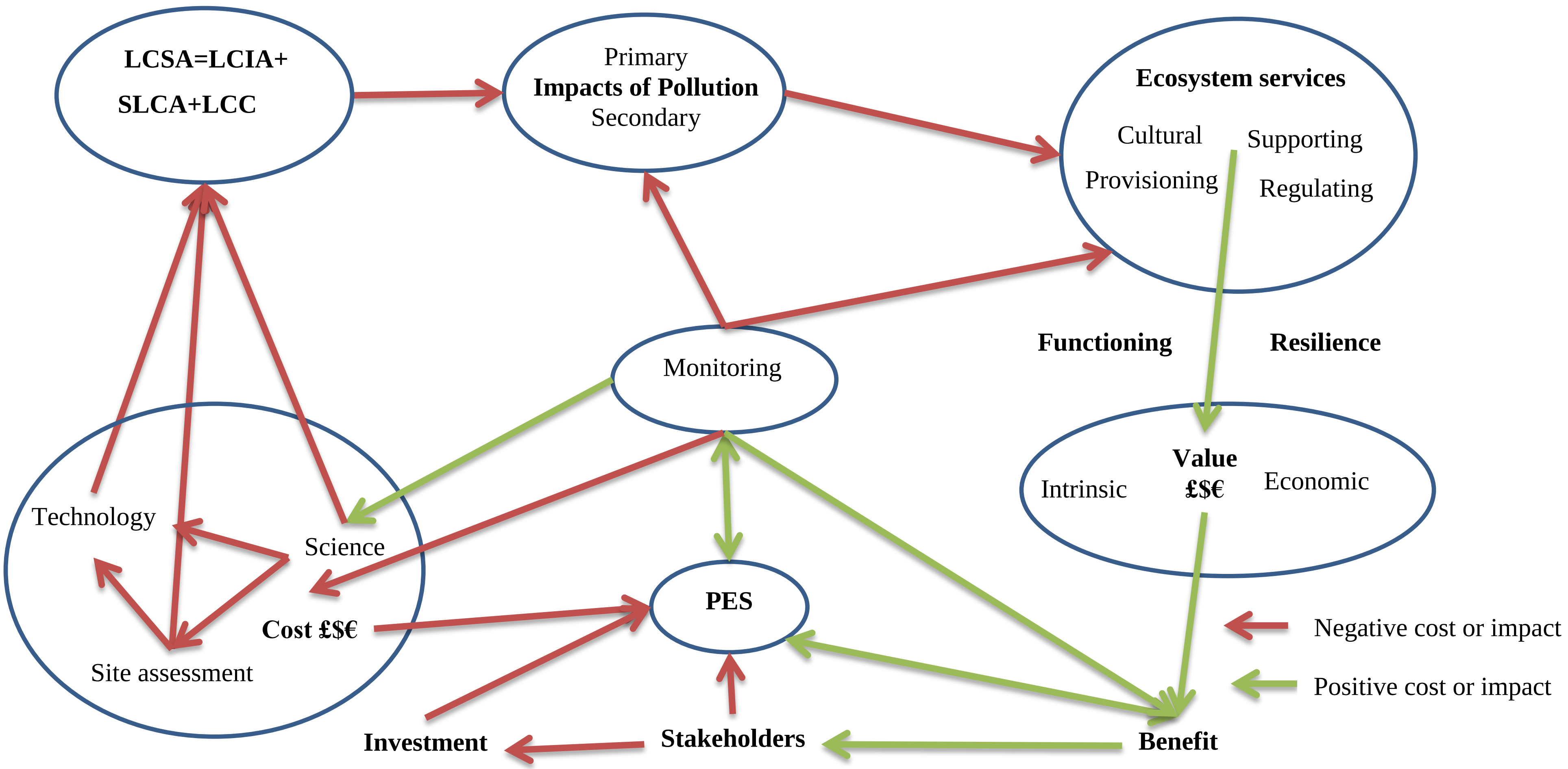


Figure 1.3: Overview of the proposed research framework, authors own.

## 1.3 Project Aims

The overall aim of the thesis is to develop trial and critically assess this new framework, Figure 1.3, for managing and implementing treatment of polluting abandoned mine discharges.

This innovative framework integrates Environmental Impact Assessment (EIA), Life Cycle Impact Assessment (LCA) and Payments for Ecosystem Services (PES) of remedial systems to resolve the different elements of legacy mine pollution. This integrated approach allows a systematic, robust and sustainable solution to be brought to bear to address this environmentally damaging issue.

The framework has been designed to be flexible enough to be applied different causes of environmental pollution where there are options for remedial interventions to reduce the cause of this contamination; additionally it is envisaged that it is adaptable enough to be applicable globally. Legacy mine pollution is a common issue in many other nations and similar difficulties arise in sourcing funding for remedial intervention elsewhere (Younger et al., 2002).

The successful implementation of this framework depends upon it achieving five fundamental objectives:

- Determine whether remediation can take place (i.e. assess environmental impacts of discharges and treatment feasibility)
- Enable successful communication and management of the issues and concerns of the stakeholders at the site being considered for remediation
- Successfully address the pollution issues at the site being remediated
- Demonstrate whether or not a net environmental benefit will be achieved over the lifetime of the remediation scheme over multiple scales (local, regional, national and global)
- Provide a model to ensure that funding is secured to enable the remediation to go ahead and continue for as long as it is necessary (or at least over the predicted operational lifetime of the remediation options selected)

## 1.4 Thesis Structure

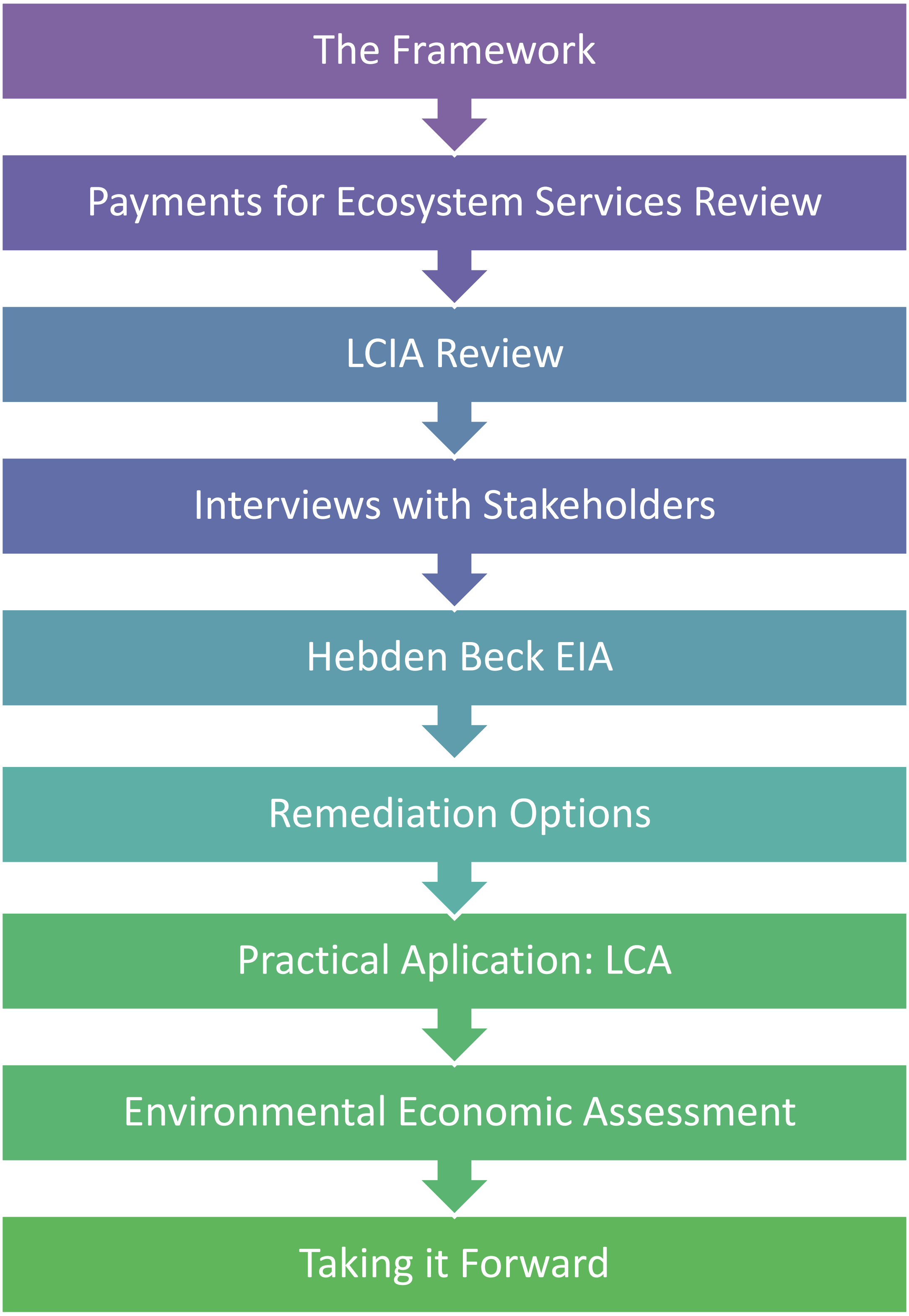


Figure 1.4: Outline of thesis structure

The environmental management framework presented in this thesis integrates several environmental assessment and classification approaches bringing them together to create a systematic approach to addressing legacy pollution being released into the environment;

- Environmental Assessment
- Environmental impact assessment (EIA)
- Life cycle sustainability assessment (LCSA)
- Payments for ecosystem services (PES)

These approaches are brought together using the ecosystem service concept and linking services over different geographical and temporal scales recognising the interrelatedness and complexity of these systems. Chapter Two reviews the philosophy behind some of these approaches, their limitations and their growing application in the UK and elsewhere. Chapter Three reviews Life Cycle Integrated Assessment (LCA) methodology and summaries it applications. These chapters set the scene for applying such processes to abandoned mine pollution in the UK.

Beyond these three concepts is the importance of learning lessons from effective communication with and between stakeholders in complex environmental management problems is key to the thesis. Stakeholder input is crucial to modern water regulation (e.g. WFD), PES approaches and has been a key issue in many attempts at mine site remediation given the varied (and sometimes conflicting) stakeholder interests that can be apparent (Mayes et al., 2009b). Chapter Four provides a detailed assessment of the stakeholder context with regards to the application of the new environmental management framework to abandoned mine pollution. A series of interviews across a broad range of relevant stakeholders have been undertaken which critically assesses their experiences and attitudes towards PES, mine remediation and new management approaches to deal with legacy pollutants.

The subsequent chapters of the thesis then apply the framework to a specific case study catchment; Hebden Beck; a typical mine polluted stream in North Yorkshire, UK. This process begins with Environmental Assessment (Chapter Five) on the nature of the pollution impacts from the abandoned mine sites in this water body. Once the impacts are identified and the need for remedial intervention is apparent, a range of technologies across the spectrum of engineering complexity are detailed and evaluated (Chapter Six).

Chapter Seven then assessed the Life Cycle Costs (LCC) of these interventions using standard EU methodologies. The economic environmental benefits of remediation are then evaluated using current methodologies and those of the Environment Agency, which permits a comparative assessment of the value of remedial intervention versus the current *status quo* (Chapter Eight). The thesis concludes with Chapter Nine, which critically assesses the framework applied and discusses options for taking the framework forward in practice.

## 1.5 The Framework – Underlying Philosophy and Evolution

The following section of this introductory chapter provides a brief background to the evolution of the management framework tested in subsequent chapters and the philosophy behind it. The four stages of the framework once a problem has been identified are as follows;

- Environmental Assessment
- Life Cycle Sustainability Assessment
- Payments for Ecosystem Services
- Ongoing Monitoring and Data Collection Over the Lifetime of the Intervention

### 1.5.1 Flexibility

A key aspect of this framework is its adaptability to different situations and the ability to take advantage of the latest models, techniques and research.  It is a process with defined steps guiding the process which addresses the issue of stakeholders becoming bogged down and side tracked by individual issues presenting a process in a wider interconnected context.

The objective of the framework proposed is to achieve a balance between the specificity of individual projects and the generality of the process which can be applied to a range of different problems. Allied to this, the framework seeks to give defined actions which can be easily applied and their results understood so that projects move forward and issues are resolved. It is recognised that negotiation and communication is vital to this process but it is envisaged that if all priorities are judged with the same set of criteria and tools, that stakeholders will be more receptive to considering how and where their particular priorities fit within the wider context and perhaps receptive to alternative solutions beyond their own area and concerns.

It is fundamental that the assessment and judgements made are based upon sound and robust methodologies and science which are acceptable to and trusted by the stakeholders. This is a strength of this framework as Life Cycle Analysis (LCA) and Life Cycle Integrated Assessment (LCIA) are widely accepted and trusted methodologies (European Commission, 2013, UNLCI et al., 2013) when applied transparently. The move towards LCSA (3.4) seeks to capture the triple bottom line of sustainability, Figure 1.5.

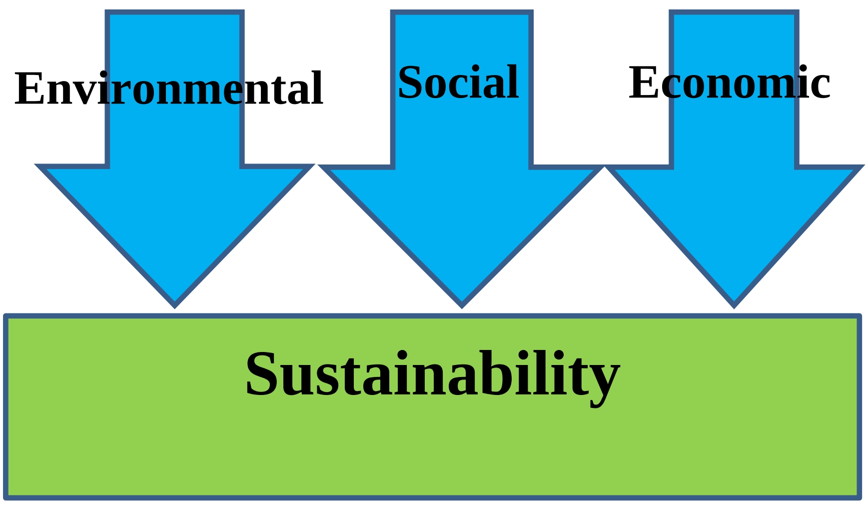


Figure 1.5: The triple bottom line of sustainability

Integrating PES and its sister approach The Economics of Ecosystems and Biodiversity (TEEB) which takes an ES approach, with the process of environmental assessment and formal EIA, which is part of some planning practices around the world (Zhuang et al., 2011, Brooks, 2009, Morris and Therivel, 2009), is the principal behind this research framework. All have underlying strengths and weaknesses, however fundamental to each is the attempt to quantify or explain the consequences of specific human actions in the three areas of sustainability.

The use of these standard methods can also take into account different temporal and geographical scales as well as considerations of interconnectivity of different systems (Young, 1997, Hornberger et al., 2009, Gozzard et al., 2011, Defra et al., 2014, Everard et al., 2014, Hüesker and Moss, 2015).

A specific strength of the framework which comes from the conditionality (Section 2.10) aspect of PES schemes is the ability to feed back into wider knowledge about the effectiveness of specific remediation schemes once they have been deployed. The framework then becomes iterative, as monitoring over the lifetime of the remediation takes place. This is a necessary part of ensuring that the contract has been met by the individual parties involved; monitoring of the outcomes of remediation is part of the process. This information can be made available to the wider research community, and other interested parties, access to this information may even be negotiated to be part of payment in kind if it is deemed to be commercially sensitive, contributing to improving research and development in a specific area. The possibilities for use of the data collected during all the phases of the framework mean that this contribution to research and understanding is of benefit in itself and will contribute to understanding different systematic processes and develop the effectiveness of the framework of the whole as well as the individual elements involved in specific schemes.

### 1.5.2 Should Action be Taken?

Once it has been established that there is an environmental issue (e.g. a water quality chemical or biological failure at a compliance point) is the point at which the framework can start to be applied. However the existence of an environmental issue does not inevitably mean that it is necessary, appropriate or desirable to take action (Holl and Aide, 2011, Speldewinde et al., 2015). Figure 1.6 illustrates the first steps in the framework; a basic decision support process to establish if a specific site or issue is impacting on ecosystem services. The reasons behind taking action may be legislative, or as a result of intolerance of the levels of damage that is being done to the local or wider environment as a result of the issue identified due to social, political and or economic pressures or some combination of the above reasons. In the case of legacy mine pollution the motivation to resolve an issue which people locally have been living with for decades or more is to comply with the WFD requirements of water bodies meeting good ecological and chemical status by 2015 (European Commission and WISE, 2014). The River Basin Management Plans (RBMP) that have been implemented in the UK is requiring strategies to be developed for managing river systems at the catchment level as well as the local scale. This feeds into the approach adopted here by considering rivers at many different scales and integrating social, economic, political as well environmental considerations when managing them (Benson et al., 2014, Reyjol et al., 2014, Vlachopoulou et al., 2014, Bouleau and Pont, 2015, Hüesker and Moss, 2015, Defra et al., 2014, UK government, 2014).

This framework seeks to strengthen those drivers to action, should action be deemed appropriate, by reinforcing the reasons to act and making it possible to do so. This is important as a clause in the WFD enables no action to be taken if it is deemed to be too costly or burdensome and so “unreasonable” to expect the government to act.

To evaluate the potential suitability of remediation in individual cases, we need to identify:

- The key pollutant sources at a catchment scale
- The length of river that can be remediated through investment in treatment at a site
- The potential benefits in terms of environmental services and quality improvements that would accrue from such investment and
- The costs (both monetary and environmental) of installing and managing treatment systems (e.g. in terms of maintenance, handling and disposal of metal-rich solids etc.)

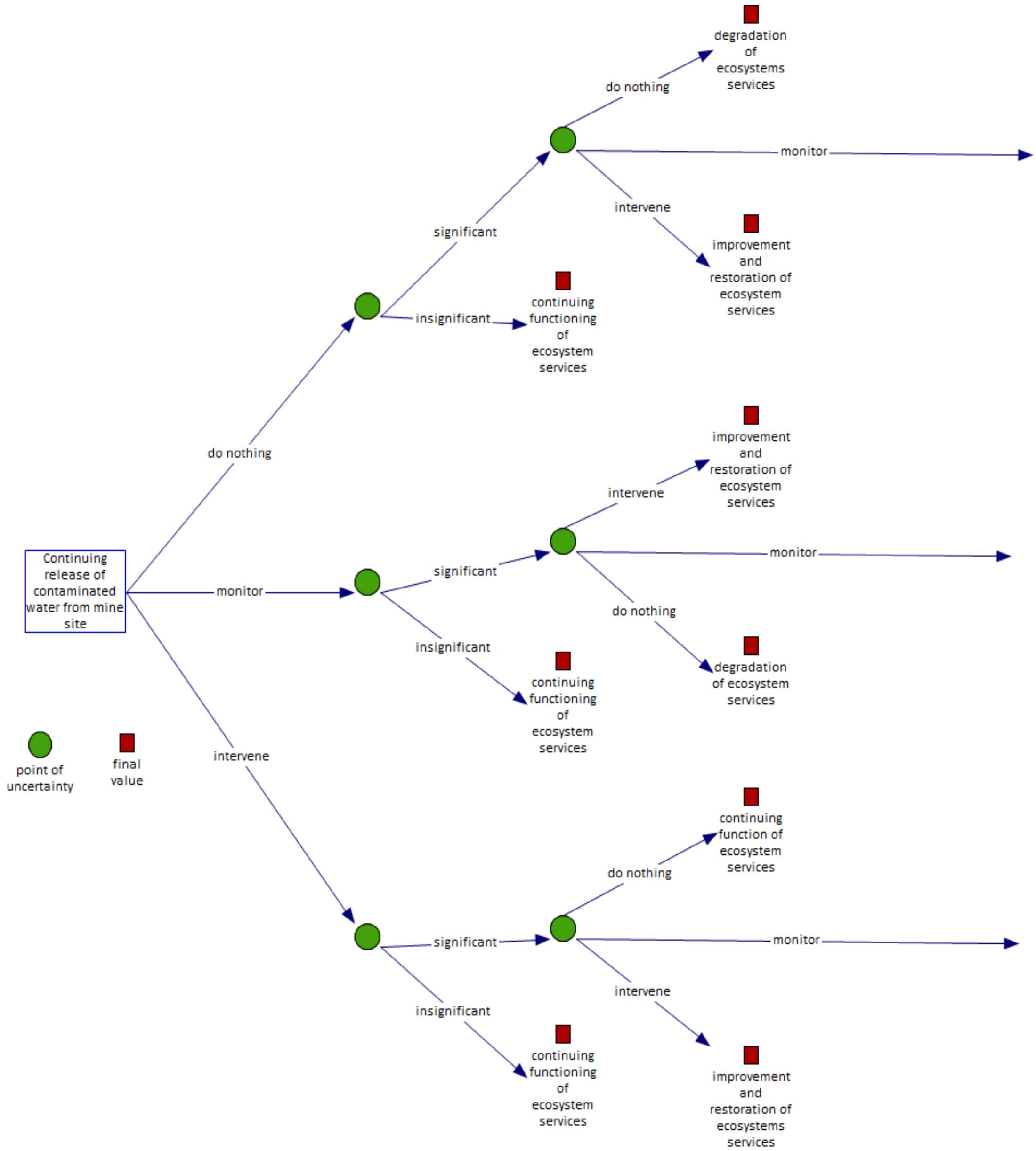


Figure 1.6: Decision support process showing outcomes (represented by the red square, final value), based upon monitoring of a water body for example that undertaken by the Environment Agency and the probable impacts on ecosystem services depending upon levels of pollution (significant or insignificant), what action is taken (intervene, continue to monitor or do nothing)

This framework, Figure 1.3, would potentially remove some of the difficulties implementing remediation projects particularly in the case of legacy mine pollution (Mayes et al., 2009b). It will also enable a determination to be made about whether action should be taken not simply based upon local interests around a contaminated site but also taking into account the burden that the remediation action itself takes upon the wider environment at multiple scales (e.g. from water body to basin scale).

Specifically for historic mine sites in the UK, the EA and other authors have identified, prioritised and ranked the known sites (Mayes et al., 2009b, Jarvis and Mayes, 2012, Pauget et al., 2013, Sawyer et al., 2014, Environment Agency, 2012b, Potter et al., 2012, Environment Agency, 2013). It is important and fundamental tenet of the framework that sites should be remediated not a purely for the sake of it but because action will make a real difference that can be demonstrated (Figure 1.7). Modelling tools and techniques using available data such as that collected by the EA on levels of metals in water and the source of these to determine where action needs to be taken and whether action will have a significant impact on improving all the time as understanding of the ways in which these pollutants behave when released into riverine systems.

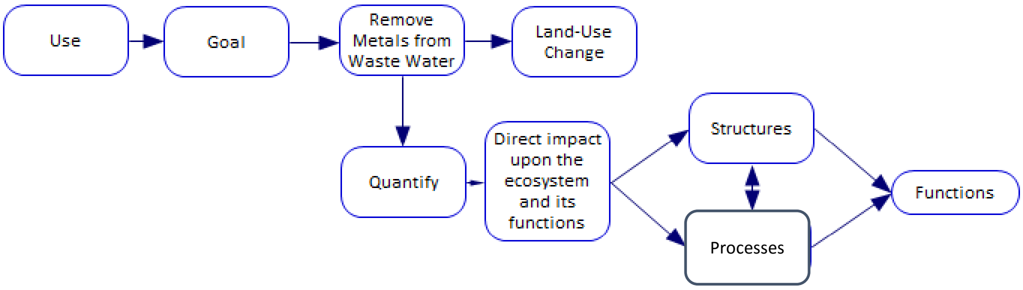


Figure 1.7: What changes when metals enter rivers?

When designing a PES scheme associated with a contaminated site it is often in response to local risk, or the primary impacts. By using LCIA to determine the secondary impacts or the wider impacts associated with the production, deployment, use and disposal of different methods of remediation it is possible to determine whether the secondary impacts outweigh the benefits derived from remediating a contaminated site. Through this approach comparisons can be made with alternative methods of remediation to assess which would be most effective locally while also assessing the secondary impacts to determine which method has the lowest impact globally when balanced against benefits achieved by remediating the site and hence protecting local habitat.

### 1.5.3 **Identifying Stakeholders**

The identification of ecosystem services that are currently been affected by the metal mine pollution via the environmental assessment process will enable keys stakeholders to be identified. An assessment of where value of these services is and how potential stakeholders value these services is also integral to the initial phase of the framework, before a more detailed breakdown is conducted. Figure 1.8 illustrates the total economic value (TEV) of ecosystem services, which is the utilitarian value, or the value to humanity.  This comprises elements illustrated in the bright green boxes shown in Figure 1.8. The different constituent parts are illustrated of ecosystem services. In the case of metal mine pollution those identified for the interviews conducted (Chapter Four) represent a good cross-section of institutions (Industry, Government and Special Interest and Stewardship Organisations) with an interest in addressing this issue.

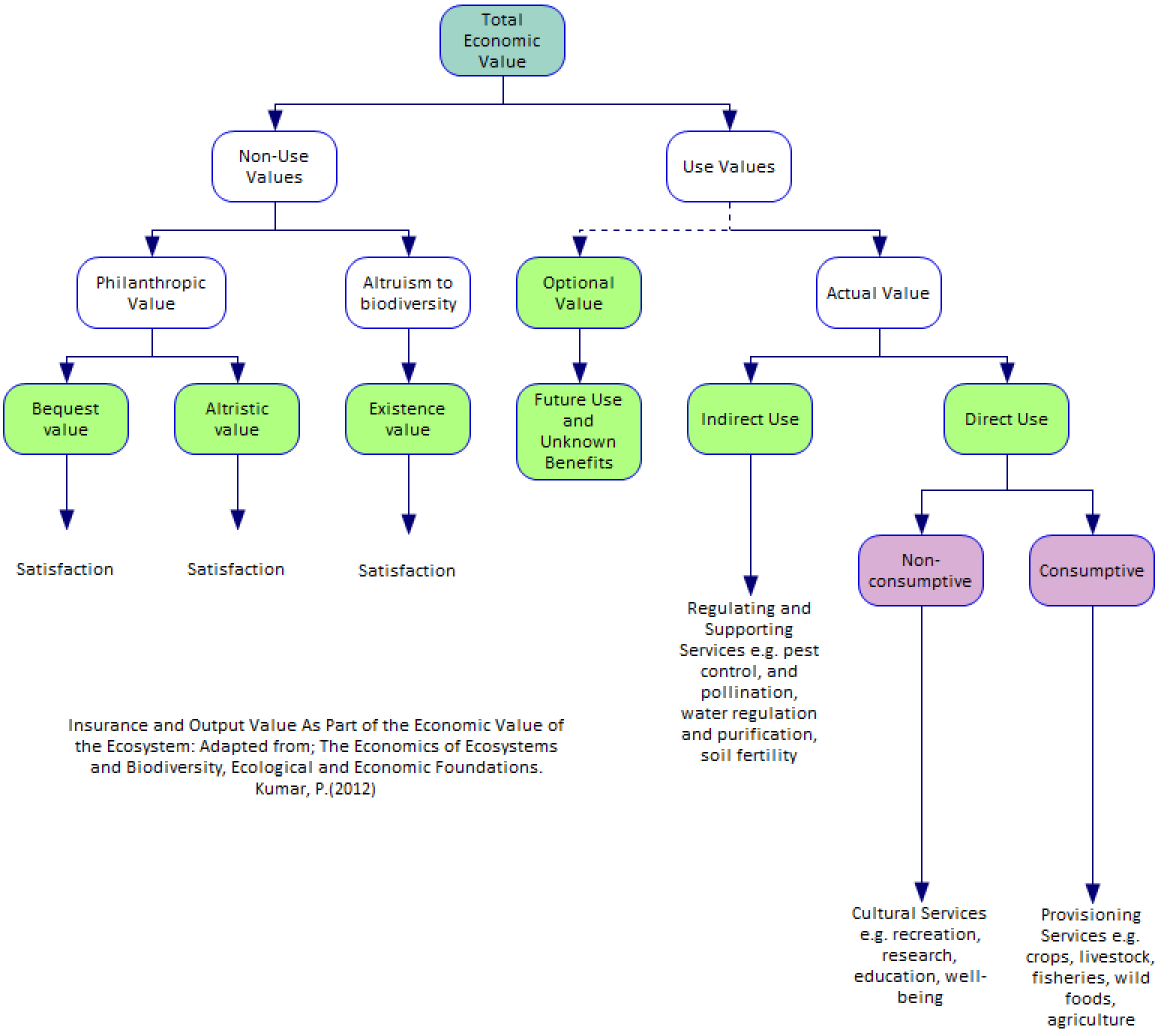


Figure 1.8: Total economic value of ecosystem services (Kumar, 2012).  Total economic value is comprised of the constituent parts which go to make up the total utilitarian value of ecosystem services, as illustrated by the bright green boxes.

The value of these services to the organisation or society and their willingness to invest in such a scheme will impart an economic value to the ES identified and ultimately form part of the economic investment. Regulations also impact upon the identification of stakeholders those who are affected by these regulations may be required to take certain actions which would be fulfilled by the proposed project for metal remediation.  The cost of compliance with these regulations may be reduced if upstream decontamination is taking place (in minimising potable water treatment costs for example), give a quantifiable value to reducing the levels of metal that they are exposed to. Additionally there is also the benefit of avoiding fines for non-compliance with EU directives (Bradford, 2014) which should be a key driver to action.

### 1.5.4 Negotiation and Implementation

When stakeholders have been identified and contacted and the process is underway, one of the key issues identified is negotiation between different parties with conflicting interests or a misunderstanding or mismatch of knowledge or priorities. The use of objective and transparent methodologies in the framework should ensure that the implementation and the ultimate goal of delivering site remediation (if it proves to be of overall environmental benefit) should not get bogged down in objections and “circular talking” (Chapter Four). Enabling sensible negotiation and all stakeholders to feel that their point of view has had a fair and balanced hearing and that the ultimate judgements made are reasonable is fundamental to the defined four stage process.

The PES effect provides a “default valuation for the ecosystem services” as the stakeholders involved will impart a value to the services received by how much they are willing to invest in the project, “their willingness to pay” (WTP). This will be part of the process but as can be seen in the economic section of the case study (Chapter Eight) there are also quantifiable benefit that are derived from taking action which deliver value to potential stakeholders. WTP can be used to inform a cost benefit assessment and LCA when assessing the potential for internalising environmental costs associated with specific human activities which are all too frequently externalised by business (TRUCOST Plc, 2013).

### 1.5.5 But is it Ethical?

There is often a feeling of unease about paying for nature some commentators finding it unethical others recognising a vague feeling of discomfort associated with the idea of putting a monetary value on the natural environment (Gowdy et al., 2012, Davidson, 2013, Jax et al., 2013, Abson et al., 2014, Daily, 1997, Costanza et al., 1998, Salles, 2011, Conniff, 2012, Dearden, 2013, Dogaru, 2014, Monbiot, 2014). Chapter Nine assesses the argument about the rights and wrongs; the fear that the market may distort nature and the tyranny of unforeseen consequences which should be guarded against.

Additionally there are problems associated with fairness and the non-excludable nature of ecosystem services and who should pay are all issues which are complex and difficult to resolve satisfactorily. Not ignoring these issues but accepting their existence and being aware of their implications for this framework, a pragmatic view has been taken. Funding to rectify environmental damage has to come from somewhere and this approach demonstrates that there is an economic benefit to resolving these environmental problems providing a way to access resources and funded from a range of different organisations. This can balance different vested interests against one another so market distortions and power relationships between different stakeholders are kept in check; particularly in allowing concerns to be voiced as part during the negotiations.

## 1.6 Summary

The framework presented in this thesis aims to offer a pragmatic way forward to assess and fund the wider benefits of solving some anthropogenic pollution issue; where no party can be identified who is legally liable for the costs incurred. It takes into account different stakeholders vested interests and seeks to use their concerns and priorities to move forward and solve environmental problems. A primary example being the historic metal mine sites in the UK, this is a problem with a potential solution but no source of funding available to implement a solution. The framework presented is a clearly defined process with enough flexibility to take advantage of the latest developments in science and technology and deliver objective answers and assessments of the impacts both positive and negative of taking action to resolve an environmental issue. Fundamental to this framework is; the potential contribution that its successful implementation can make to data available for research and the ability to recognise that it may not always be of benefit to take remedial action.

# Chapter Two Literature Review: Payment for Ecosystem Services (PES)

## 2.1 Introduction

*"the whole of the human economy is driven by the goods and services provided by ecosystems and natural resources"* (Edward-Jones et al., 2011)

The premise of Payment for Ecosystem Services (PES) is that the biophysical aspects of ecosystems provide direct benefits to humans and some of these benefits can have an economic value associated with them. This economic value should be received by the provider of that service as a compensation for maintaining and managing that natural resource. For a transaction to take place there needs to be a provider who supplies the service, a buyer who receives a service or services and a defined service/services which can be purchased. In the case of PES, an intermediary is also necessary to identify potential buyers and sellers of ecosystem services and to facilitate interactions between parties (Smith, 2013).

## 2.2 Definition of Ecosystem Services

Ecosystem services can be defined as the contribution which ecosystems make to human well-being either directly or indirectly (Godoy et al., 1993, Kumar, 2012). They occur as a result of ecosystem functioning, which is the result of the configuration of ecosystem structure and processes (Figure 2.1), the healthier the ecosystem the higher quality the ecosystem service. Quantity does not necessarily mean quality, as different systems of food production aptly illustrates. For example, a high crop yield as a result of intensive monoculture cropping provides an ecosystem service, food production, classified under provisioning (Figure 2.2). It is likely that limited benefits derived from the other ecosystem services would be supplied compared to a mixed, less intensively farmed agricultural area with greater habitat diversity. Nor can monoculture agriculture be said to fulfil the criteria of ecological sustainability which requires the ecosystem to be productive over time and maintain the provision of a range of ecosystem services, due to its resilience and diversity (Farley, 2012, Farley et al., 2014a). Indeed it has been argued that too automatically link biodiversity to ecosystem services is a false assumption as different ecosystem services and the biodiversity of an area may come into direct conflict, particularly when a pure market mechanism is at work (Jax et al., 2013). When the ecosystems approach is linked to biodiversity particularly the 12 principles adopted by the Convention on Biodiversity (Figure 2.4) and the systematic and interrelated nature of ecosystem services is understood and applied to the concept then ecosystem services are a powerful tool with which to improve the interactions between humanity and the wider natural world within which we live (Everard, 2013).

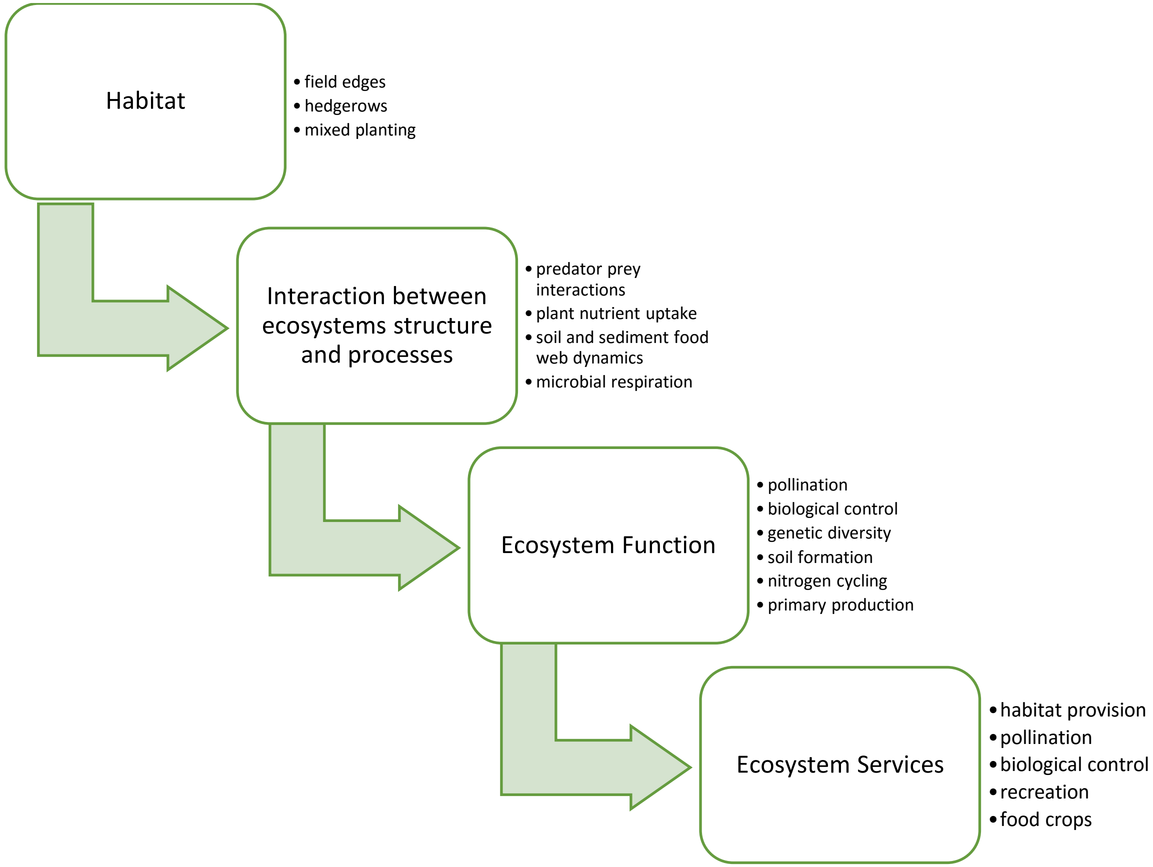


Figure 2.1: Pathway from habitat to ecosystem services using the example of an increased width of arable field margins adapted from UK National Ecosystems Assessment (Mace et al., 2011)

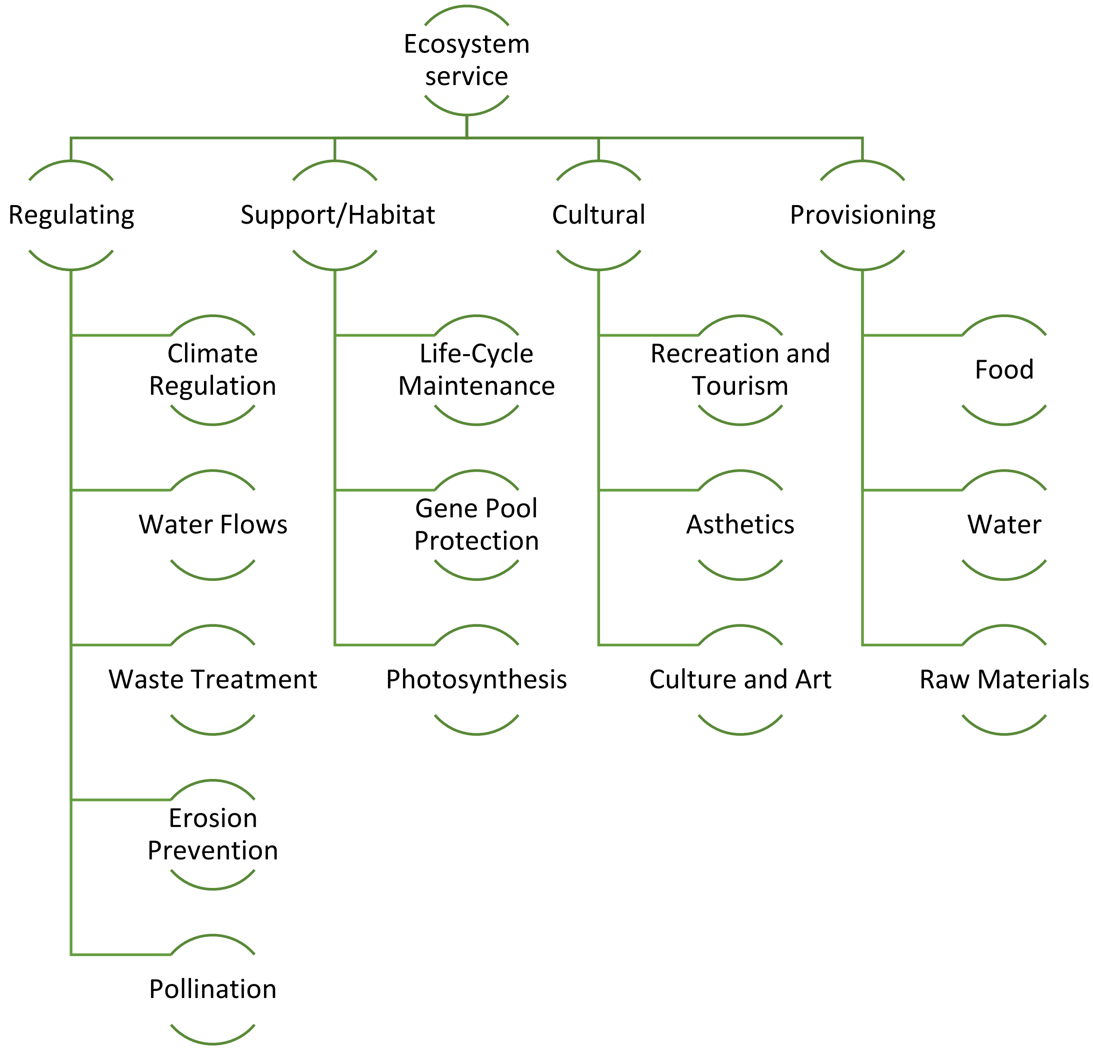


Figure 2.2: Ecosystem services classification, based upon UK national ecosystem services assessment and TEEB frameworks with examples of specific services (Mace et al., 2011, Kumar, 2012)

## 2.3 Development of PES Frameworks

The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) undertaken by the UN recognised the requirement to place an economic value upon ecosystem services (Costanza et al., 1997) and endeavoured to assess the consequences, for human well-being, of ecosystem change. This report definitively linked the dependence of humanity upon the services that ecosystems provide. The Stern review (Stern, 2007) further developed this process by placing an economic value on ecosystem services and sought to resolve the way in which environmental consequences are externalised by human processes of production and exchange with the potential economic cost of this behaviour. A neoclassical economic approach is often used in the development of many PES schemes (Wynne-Jones, 2012), but not all. Placing ecology in a market framework makes some ecologists feel that their work is viewed with greater respect (Wynne-Jones, 2012).

There are two aspects to putting a price on nature, the economic value of the services that nature provides as undertaken by the UK NEA (Bateman et al., 2014) and the intrinsic value of nature itself, which cannot be limited purely to a monetary value. Placing a monetary value on nature and human experience of nature, is sometimes viewed as intangible can be contentious. There is an ongoing debate associated both with the assessment of ecosystem services and their monetisation. This is reflected in the abundance of recent publications on this topic in the academic literature (Pirard and Lapeyre, 2014). As the term ecosystem services has entered the mainstream it is also being debated in the wider media particularly with regards to placing economic value upon intangible assets (Conniff, 2012, Dearden, 2013). Some of the participants in this research expressed a view that placing a monetary value on natural assets was uncomfortable for them (Chapter Four).

There are hundreds of PES like schemes currently being implemented around the globe based on market principles (Balmford et al., 2011, Campbell and Brown, 2012, Davidson, 2012, Díaz et al., 2012, Estoque and Murayama, 2012, Fisher et al., 2010, Larondelle and Haase, 2012, Powlson et al., 2011, Smith et al., Zander and Straton, 2010, European Union, 2008, TEEB, 2012), examples of which can be seen in the UK (Table 2.1) and around the world (Table 2.2 ). PES is perceived by some as one tool which can create a set of circumstances in which desired ecosystem services are produced through the maintenance and improvement of the natural environment, in order to enhance human well-being (Kroeger, 2013). The organisation for economic development (OECD) recognises the role that PES schemes can play in environmental social justice contributing to more environmentally beneficial ways of deprived communities generating an income and has researched the number of PES schemes currently running around the world (OECD, 2010).

Table 2.1 : Examples of a range of PES schemes and pilot PES schemes within the UK, format adapted from (Smith, 2013) with additional examples.

| **PES and Pilot PES schemes in the UK** | **Buyers** | **Sellers** | **Intermediaries** | **Transaction** |
|---|---|---|---|---|
| Pilot on flood regulation in Hull.<br>Local Scale<br>Country park scale and street scale.<br>Semi successful, scope of the project changed and ultimately there was only limited implementation (MacGillivray, 2013). | Hull City Council<br>Yorkshire Water Services<br>Amenities users<br>Local community organisations | Hull City Council<br>Individual householders | Green city initiatives<br>Environment Agency | Many to one scheme.<br>Encourage individuals and park managers to change and update individual infrastructure to prevent surface flooding. E.g. water permeable surfaces replacing concrete. Planting grass verges, creation affordable sports pictures, paying homeowners to install flood friendly features to their homes, to encourage rapid absorption of surface water and also its collection in water, butts etc. |
| The feasibility of the nitrogen PES schemes in Poole Harbour catchment.<br>Local/Regional/Catchment Scale<br>Found to be unfeasible due to political and ideological considerations although the approach was deemed to be one that should be pursued. Issues were also raised around compliance with statutory (RSPB, 2013) | County councils (planning authority)<br>RSPB<br>The Wildlife Trust<br>Natural England<br>Environment Agency | Farmers<br>Landowners<br>Wessex water | National Farmers Union<br>Natural England | Many to many.<br>Encouraging land management practices to promote the reduction of nitrogen entering the River system.<br>Improvement to wildlife and water quality. |
| The Fowey River Improvement Auction.<br>Local/Regional/ Catchment Scale<br>A useful approach to take although there were some unforeseen consequences in the competitive bidding process and the bundling of services.<br>There was limited interest from potential buyers due to a perception that the environmental benefits would be negligible for their business (Day and Couldrick, 2013). | West Country rivers trust beneficiaries from improvement of water quality e.g. Business, South West water | Farmers<br>Landowners | West Country Rivers Trust | Multiple sellers<br>Multiple Buyers<br>Identify changes in farming practices as that would produce a reduction in water pollution access to sources of funding through bidding for capital investment into the farm.<br>Selling improvements to potential investors.<br>The farmers would have ongoing obligations in line with PES schemes. (No funding is available for any statutory obligations that is not fulfilling) |
| Pumlumon Project.<br>Local/Regional/Catchment/ National | Landowners<br>Farmers | Water Companies<br>Environment Agency | Welsh Government<br>Pumlumon Project | Many to many<br>Wide range of changes to land management |

| | | | | |
|---|---|---|---|---|
| (Wales/England)<br>Successful PES scheme running in Wales currently being and way for 6 years.<br>Has proved the concept of PES schemes delivering a wide range of ecosystem services. Access to funding from different organisations such the natural lottery Heritage fund. Has demonstrated a tangible improvement in levels of carbon sequestration and also added value to sheep and cattle production (Alison Millward Associates, 2014). | | Wildlife Conservation Organisations (e.g. Osprey project) | | practices. Habitat restoration, tree planting farming practices etc. |
| West Country Angling Passport<br>Local<br>South West England<br>successful PES scheme (West Country Rivers Trust, 2014) | Anglers | Farmers and landowners | West Country Wildlife Trust | Landowners improve fishing beats through capital investment in infrastructure including fencing encompassing. Access to fishing is purchased by tokens which are redeemed by landowners. |
| English Woodland Grant Scheme (EWGS)<br>Individual schemes operate at a local level/international (carbon savings)<br>This Scheme has now closed but other forms of grants are now available, but this scheme proves the concept’s success (Forestry Commission, 2014). | UK Government (rural development programme) | Woodland owners | Forestry Commission | The goal of this scheme is to sustain and increase public benefits through maintaining would then and creating new woodlands. 6 separate types of grants are available Woodland owners to access. |
| Environmental stewardship (ELS and HLS)<br>Local<br>Successful Scheme<br>(Natural England, 2012). | UK Government (Defra) | Farmers and landowners | Natural England | Agri-environmental scheme administered by natural England since 2005. Agricultural landowners and managers are paid for maintaining and providing ecosystem services. |
| The Sustainable Catchment Management Plan (SCaMP)<br>Local/Regional/Catchment scale/International Carbon Savings<br>Successful and on-going (United Utilities, 2014) | United Utilities (UU) | Tenant farmers on UU land | UU and RSPB | SCaMP takes a partnership approach to improving rural water quality and addressing poor SSSI conditions. The view incentivises tenant farmers to improve land management delivery ecosystem services. |

Table 2.2 :International PES schemes evaluated (Hejnowicz et al., 2014)

| **A summary of selected articles; their geographical focus, the PES schemes investigated and their scale of operation**. | | |
|---|---|---|
| **Geographical location** | **No. of studies** | **PES programme and scale: Local (L), Regional (R), National (N)** |
| Costa Rica | 16 | PSA (N) Pagos por servicios ambientales |
| Mexico | 7 | PSAH (N) Payments for hydrological environmental services<br>PSA-CABSAd (N) PES programme for carbon sequestration and biodiversity conservation<br>Fidecoagua (L) |
| Ecuador | 4 | Pimampiro (L)<br>PROFAFOR (R) Programmea Face de Forestaciûn del Ecuador<br>SocioBosque (L) |
| Nicaragua | 4 | RISEMPf (L) Regional Integrated Silvopastoral Ecosystem Management Project – operates transnationally but in each area at a local level.<br>PPSA-H (L)<Proyecto de Pagos Por Servicios Ambientales Hidricos<br>San Pedro del Norte – PASOLAC (L) Programma para la Agricultura Sostenible en Laderas da América Central – operates transnationally but in each area at a local level. |
| Bolivia | 2 | Los Negros (L)<br>NKMCAPi (L) Noel Kempff Mercado Climate Action Project |
| Columbia | 1 | RISEMP (L) |
| Honduras | 1 | Jesus de Otoro – PASOLAC (L) |
| Brazil | 1 | Bolsa Floresta (L) |
| Madagascar | 2 | Durrel Conservation Trust PES Scheme (L) |
| Mozambique | 1 | Carbon Livelihoods Project |
| Kenya | 1 | WKIEMP (R) Western Kenya Integrated Ecosystem Management Project |
| Cambodia | 1 | Payments for wildlife friendly products, community-based ecotourism, bird nest scheme (L) |
| China | 5 | SLCPk (N) Sloping Land Conversion Programme<br>NFP (N) National Forest Programme |

There are many different definitions of what a true PES program is; a basic principle upon which all PES schemes rely on is that of conditionality; that payments are only exchanged if certain goals are achieved (Kroeger, 2013, Wynne-Jones, 2012, Davidson, 2012, Lockie, 2013, Smith, 2013). These goals need not be purely quantitative but may also be qualitative aspects which are valued by the community in which their PES scheme operates. Additionally goals may be changed and developed throughout the operation of a PES scheme. Stakeholders may enter the scheme as they recognise services they may wish to encourage, and hence purchase, which they value as being potentially provided by ecosystem management practices.

(Muradian et al., 2010) has argued, that traditionally PES have been based upon Coasean[1] economics and that being the case in order for a PES scheme to be genuine it is required that it meets three conditions;

1. The link between the ecosystem service and the type of land management been advanced must be clear
2. Any stakeholder in pes scheme must be able to end the contractual relationship as it is a voluntary agreement which has been entered into
3. Monitoring of the service provided must be undertaken in order to determine that the contract is being fulfilled

The issue is associated with defining PES schemes have been have been outlined in detail in the literature (Engel et al., 2008). Muradian et al. (2010) argues PES schemes cannot be truly Coasean or meet the three criteria outlined above because; they rely upon community cooperation, often occur as a requirement of externally imposed standards, such as the European Water Framework Directive and therefore cannot be a voluntary market transaction, the environmental service is not always fully defined, and a causal link has not always established between the land management practice and the environmental service being purchased (Muradian et al., 2010).

An alternative definition of PES is forwarded by (Muradian et al., 2010) as;

*“a transfer of resources between social actors, which aims to create incentives to align individual and/or collective land use decisions with the social interest in the management of natural resources”*

This definition encapsulates the majority of PES schemes that are accepted as being genuine, as opposed to the more rigid criteria imposed by the “Coasean Approach” to PES, which excludes many of the implicit purpose of PES schemes, such as social

[1] The Coase theorem states that though the creation of a voluntary market where there are clearly defined property rights and zero transaction costs, bargaining between parties compensating for harm done and rewarding the other for benefits received solves the problem of externality without government intervention provided that there are zero transaction costs and no wealth effects which may prevent equity between the parties (FARLEY, J. 2012. Ecosystem services: The economics debate. *Ecosystem Services,* 1**,** 40-49, MURADIAN, R., CORBERA, E., PASCUAL, U., KOSOY, N. & MAY, P. H. 2010. Reconciling theory and practice: An alternative conceptual framework for understanding payments for environmental services. *Ecological Economics,* 69**,** 1202-1208.).

justice and poverty alleviation. It is this definition that will be used for the purposes of this research.

This approach has evolved in parallel with the TEEB and is an integral part of PES, which has come about as a result of the recognition that current practices of economic growth and development are unsustainable for the planet, and that habitats and species diversity are contracting at an unprecedented rate (Bellard et al., 2012, Pachauri and Reisinger, 2007), and the existence of mankind. The timeline for its development resulting in its acceptance by government and intergovernmental organisations can be mapped from the end of the last century via the issues raised in academic literature and intergovernmental and NGO (Figure 2.3).

These publications have helped establish the paradigm that there are specific services that can be delivered by ecosystems that have a specific quantifiable economic value. Hence the maintenance and delivery of these services becomes economically viable in order to derive the human benefits delivered by these services which have an economic value. By implication this requires the presentation of the functioning and resilience of all ecosystems even where services to not necessarily have an explicit economic value in order to maintain the overall health and supply of ecosystem services.


Figure 2.3: Timeline of significant publications for the development of TEEB (Heywood, 1995, Pachauri and Reisinger, 2007, European Union, 2008, Stern, 2007, Millennium Ecosystem Assessment, 2005, Costanza et al., 1997, Daily, 1997, TRUCOST Plc, 2013, Edens and Hein, 2013, Stiglitz et al., 2009, Häyhä and Franzese, 2014, Abson et al., 2014)

The debate is very much on going and continuing research into how effective PES schemes are delivering their stated goals and how this can be improved into the future. It has recently proposed that there are 4 areas within PES that needed to be consistently part of any framework that applies the PES approach for ecosystem management; 1) to make the process deliberative, 2) develop institutional mechanisms, 3) spend time establishing trust within communities and ensure that there is equitable relationships between buyers and sellers, and 4) ensure ecosystem services are creditable and ethical (Kumar et al., 2014).

How these issues are dealt with by the framework being proposed in this research is discussed in the conclusion Chapter Nine.

## 2.4 **The PES Frame Work**

On the surface PES appears to be an pragmatic approach to contributing to the preservation of the global natural environment in order to benefit humanity and maintain the environmental services upon which human well-being depends. In a UK context the Defra “Payments for Ecosystem Services: A Best Practice Guide” (Smith, 2013) outlines the circumstance where the PES approach may be applicable;

1. The service is required by and is financially valuable to one or more parties
2. The ecosystem service is not currently supplied or is under threat
3. The ecosystem service can be supplied by implementing specific land management practices
4. The implementer of these practices can be clearly identified and the delivery of the service monitored

The UK government commissioned the UK National Ecosystem Assessment (UK NEA), an appraisal of the UK’s natural environment and habitats. This evaluated the contribution that the natural environment makes to the UK’s continuing well-being, economically and socially, (Brown et al., 2011). An ecosystems approach was adopted by the UK NEA, (UK National Ecosystems Assessment, 2014, Brown et al., 2011) using the principles out-lined in Figure 2.4. This method is; multidisciplinary; recognises the interrelationship between land management practices and the natural environment, and that people are part of natural systems.

The UK NEA involved a wide range of stakeholders to gain a comprehensive understanding of the ecosystem services that the UK relies upon. An objective of the UK NEA was to determine how the natural environment has changed over time and how it will continue to change in the future (Brown et al., 2011). The continuation of this type of research, into the interplay between human action and habitat, enables a link to be seen between the natural environment and its financial contribution to human production and exchange systems as well as other aspects of humanities well-being. The UKNEA comprised of the initial assessment that was undertaken between 2009 and 2011 and the follow-on phase (UK National Ecosystems Assessment, 2014). This follow-on phase allows an assessment be made of the rate of destruction of ecosystem services and also how successful any measures to preserve and improve the services are (UK National Ecosystems Assessment, 2014).

**The 12 Principles of the Convention on Biodiversity Ecosystems Approach**

1) The objectives of management of land, water and living resources are matter of societal choices
2) Management should be decentralised the lowest appropriate level
3) Ecosystems managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems
4) Recognising potential gains from management, there is usually a need to understand and manage the ecosystems in an economic context
5) Conservation of ecosystem structure and functioning, in order to maintain ecosystems services, should be a priority target of the ecosystems approach
6) Ecosystems must be managed within the limits of their functioning
7) The ecosystems approach should be undertaken in the appropriate spatial and temporal scales
8) Recognising the varying temporal scales unlike effects that characterise ecosystem processes, objectives for ecosystems management should be set for the long term
9) Management must recognise that change is inevitable
10) Ecosystems approach should see the appropriate balance between and integration of conservation and use of biological diversity
11) Ecosystems approach should consider all forms of relevant information, including scientific and indigenous local knowledge, innovations and practices
12) The ecosystems approach should involve all relevant sectors of society and scientific disciplines

Figure 2.4: Twelve principles of the CBD ecosystems approach (www.cbd.int/ecosystem/principles.shtml)

The framework developed for PES by TEEB (Figure 2.5) has been further refined by the UK NEA. This illustrates the way in which the general principle of linking an environmental service with an economic value can be achieved.

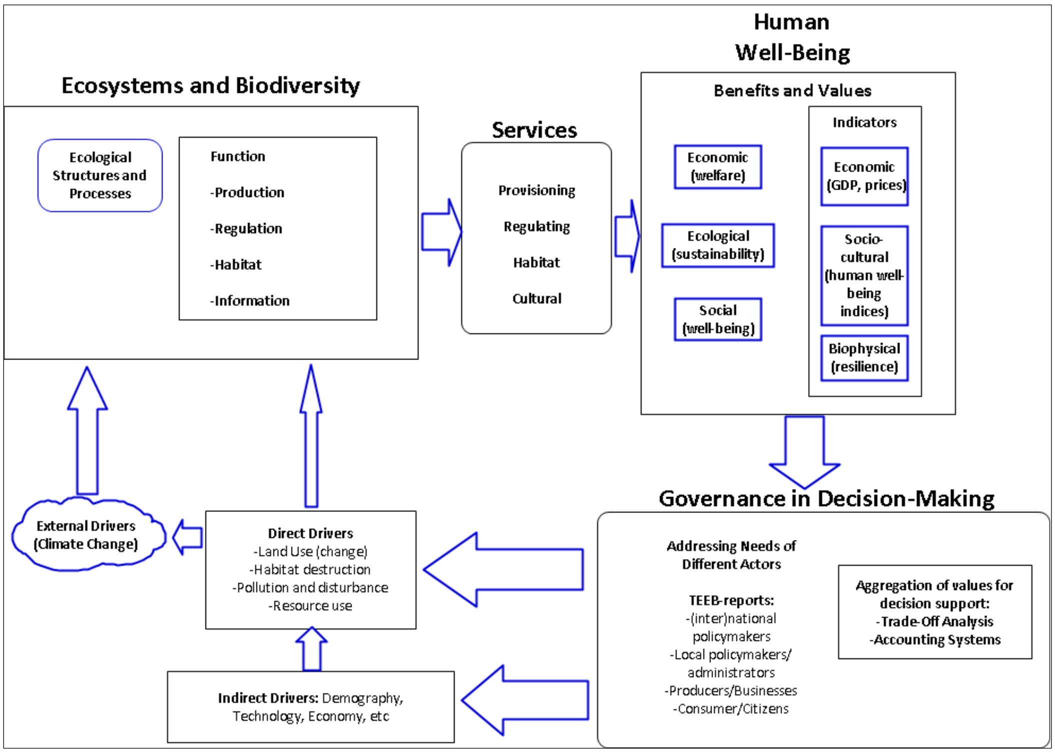


Figure 2.5: Adapted from TEEB conceptual framework for linking ecosystems and human well-being (Kumar, 2012)

The quantification and the complex interactions between ecosystem services is not straightforward and this is clearly brought out in the concerns expressed by the participants in this research (Chapter Four). Particularly when trying to relate it to groups of stakeholders who are participating in a PES scheme. Expressing the benefits at different scales is a complex process and often PES schemes only operate at a single scale rather than the multiple scales that they have the potential for. This results in, potential services not being captured or taken into consideration in some locally focused projects. This was particularly well illustrated in research on three UK based projects. showing how the schemes were very much driven by individuals managers.(Everard et al., 2014).The projects focused on the specific local, and possibly regional, goals unless there were specific statutory obligations or interests that they were required to fulfil which related to a more global or long-term ecosystem service, for example climate regulation by reducing $CO_2$ emissions (Everard et al., 2014).

## 2.5 Value of Ecosystem Services

Taking the first point from section 2.4 (1, The service is required by and is financially valuable to one or more parties); it is not always clear that a service is required or that it is value to an identifiable consumer. The quantification of certain ecosystem services is based upon counterfactuals[2] it is often difficult to express the value of the service that is not currently in existence and how this will potentially improve and benefit humanity. Furthermore, demonstrating that it is financially detrimental not to supply/maintain/improve a particular ecosystem service that is currently lacking or under threat presents an additional challenge. Equally for a service that is not explicitly visible, potential loss is not quantified as an economic impact. This is largely because many of the environmental impacts that human production and exchange systems have are perceived as external to the process. This is a problem that is tackled by Stern (2007) who quantifies the economic cost of not acting to tackle the consequences of climate change (Stern, 2007) and is further addressed by Balmford et al. (2011) who emphasise difficulties in constructing a framework to estimate costs and benefits economically which are generated from the definition of alternate counterfactual scenarios as illustrated in Figure 2.6. The framework that Balmford et al. (2011) construct simplifies the conditions using only two alternative scenarios (sustainable versus business as usual). In the real world, this would be a much more complex and environmental managers may be faced with a spectrum of management alternatives. This situation highlights the need for intermediaries and academic research to identify potential risks to human well-being before these risks are realised and mitigate them by incentivising the maintenance of habitat which supply these vital services.

[2] Counterfactuals are a "what if " conditional statement the first clause of which expresses something contrary to fact www.oxforddictionaries.com/definition/english/counterfactual

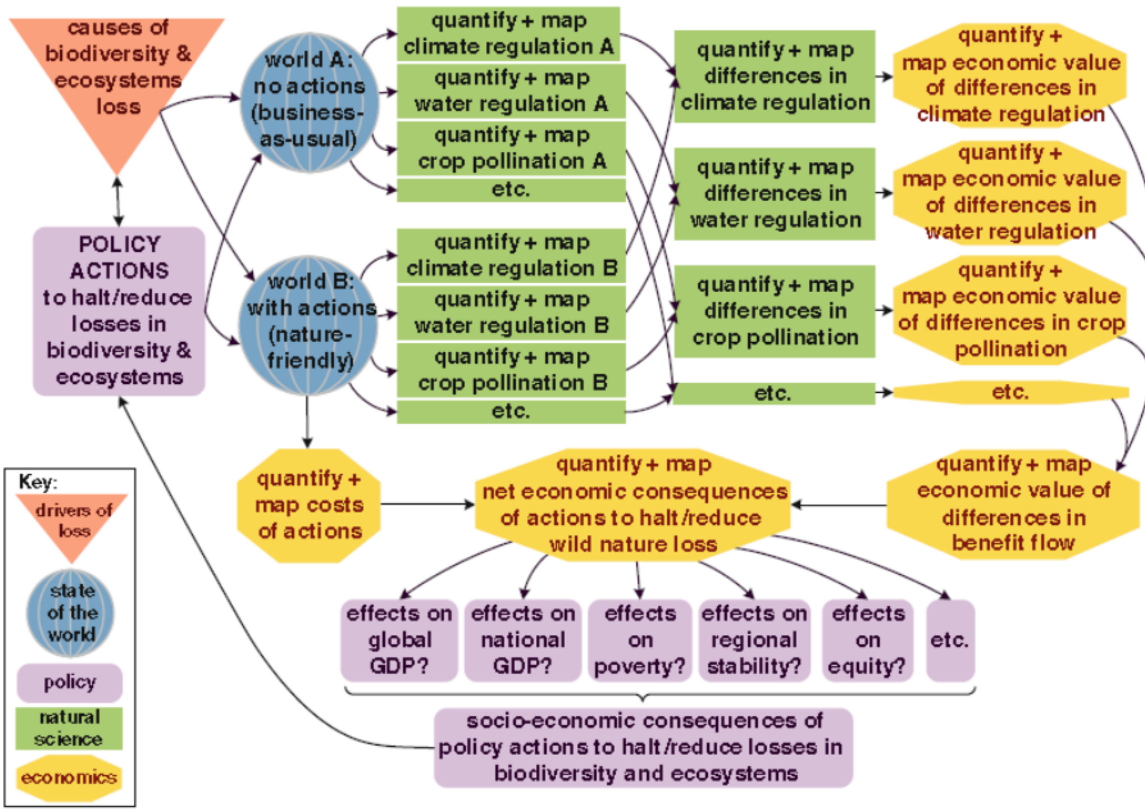


Figure 2.6: A framework for assessing economic consequences of losing biodiversity and ecosystems (Balmford et al., 2011)

Once the threats to ecosystem services have been identified and potential management practices to mitigate damage chosen; for PES to operate successfully there needs to be a willingness to pay (WTP) for that particular service and the management practices required in order to facilitate it. The nature of some ecosystem services make it difficult to explain that there can be a financial cost involved in maintaining and supplying some service and that this cost has to be borne, or potentially that service will be degraded or lost. As Farley (2012) points out, most ecosystem services cannot be stored and hence cannot be treated as a stock of raw materials. However they are often treated in this way, as was the case in the Millennium Ecosystem Assessment (2005). Ecosystem services are produced over time and result from a healthy ecosystem; ecosystems are not turned into the service. The service occurs in a way which fluctuates depending upon the different elements which contribute to its functioning and is not controllable by society but by natural processes and different configurations of the ecosystem structure which contribute to its healthy functioning (Farley, 2012). Accesses to some benefits are non-excludable[3], such as climate regulation or reduction in pollution levels. Therefore,

[3] No one can be prevented from receiving the service

despite these benefits accruing from some potential management intervention, a fair payment for these services could only come from a collective institution which represents all beneficiaries. In many cases there is no institution which represents all those who benefit and which can purchase the services. An individual/business/group may not perceive the requirement to contribute monetary towards the maintenance of an ecosystem service if its maintenance and functioning is been purchased by another beneficiary. This can present political problems, a government department purchasing an ecosystem service using public money will have to clearly articulate to the electorate the justification and value in such purchase. Members of the public are stakeholders in this process and can have an impact upon projects via the planning process and campaigns, either in a positive or negative way. Therefore methods of determining the opinions and values of the public are required; this can be done through questionnaire and interviews as well as stated vs revealed preference experiments (Greiner and Stanley, 2013, Lockie, 2013, Robards et al., 2011, Robinson et al., 2012). These issues were raised by participants in the research for this project (Chapter Four). An economic value needs to be placed upon the service that is acceptable to all those involved in the transaction, it also needs to be acceptable to wider stakeholders, such as members of the public, a range of methods for doing this are illustrated below (see Table 2.3).

Table 2.3: Economic valuation methods for ecosystem services (Bateman et al., 2011b)

| Valuation method | Value types | Methods overview | Common types of application | Examples of ecosystem services valued | Example Studies |
|---|---|---|---|---|---|
| **Adjustment market prices** | Use | Market prices adjusted for distortions: taxes, subsidies and non-competitive practices | Food, forest products, research and development benefits | Crops, livestock, multipurpose woodland | (Godoy et al., 1993, Bateman and Jones, 2003) |
| **Production function methods** | Use | Estimation of production function is to isolate the effects of ecosystem service as inputs to the production process | Environmental impacts on it, make activities and livelihoods, including damage costs avoided due to ecologically regulatory and habitat functions | Maintenance of beneficial species; maintenance of arable land and agricultural productivity, support for aquaculture, prevention of damage from erosion and siltation, groundwater recharge, drainage and irrigation, storm protection, flood mitigation | (Ellis and Fisher, 1987, Barbier, 2007) |
| **Damage cost avoided** | Use | Calculates the cost which are avoided by not allowing ecosystem services to degrade | Storm damage, supplies of clean water, climate change | Drainage and natural irrigation; storm protection; flood mitigation | (Kim and Dixon, 1986, Badola and Hussain, 2005) |
| **Averting behaviour** | Use | Examination of expenditures to avoid damage | Environmental impacts on human health | Pollution-control and detoxification | (Rosado et al., 2000) |
| **Revealed preference methods** | Use | Examines the expenditure made an ecosystems related goods e.g. travel costs, property prices | Recreation, environmental impacts on residential property and human health | Maintenance of beneficial species; productive ecosystems and biodiversity; storm protection; flood mitigation; air quality; peace and quiet; workplace risk | (Bockstael and McConnell, 2006, Daubert and Brennan, 2007) |
| **Stated preference methods** | Using and non-use | Use surveys to ask individuals to make choices between different levels of environmental goods different prices to reveal their willingness to pay for those goods | Recreation; environmental quality; impacts on human health; conservation benefit | Water quality; species conservation; flood prevention; air quality; peace and quiet. | (RC et al., 2003, W et al., 1994, Adamewicz et al., 1994, Bateman and Jones, 2003, Hime et al., 2009) |

Bateman (2011) has developed a route map (Figure 2.7) which can be used to value a single ecosystem service; this inevitably becomes more complex when multiple services are being considered. When used in conjunction with the framework outlined by Balmford et al. (2011) this is a useful tool in assessing alternative impacts in terms of financial consequences. Given financial valuation is a key requirement of best practice guidelines published by Defra (Smith, 2013) and robust techniques for quantifying these are essential.

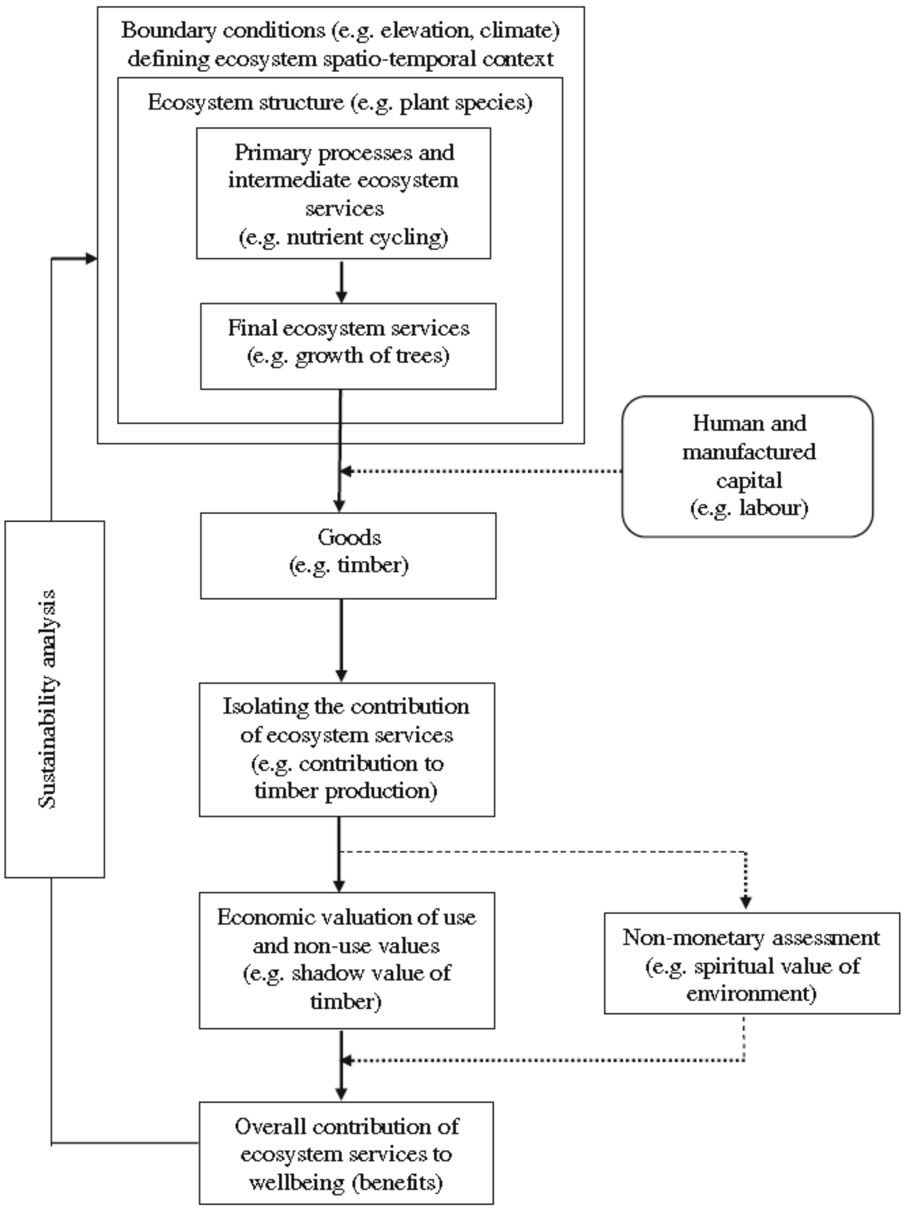


Figure 2.7: Phases of a joint ecosystem assessment and economic analysis for a single scenario (examples given in parentheses). Notes Solid lines indicate relations which always apply while dotted lines indicate relations that may or may not apply, as determined on a case by case basis (Bateman et al., 2011b)

### 2.5.1 **Regulating Services**

This is a very diverse group of services and the definition as outlined by the 2005 Millennium Assessment is: The benefits obtained from the regulation of ecosystem processes, (Millennium Ecosystem Assessment, 2005, Smith et al., 2011) examples of which include;

1. Climate Regulation
    a. Global e.g. providing sinks for greenhouse gases (oceans, forest, peat formation, etc.)
    b. Local e.g. macro and micro climates due to physical conditions as a result of deforestation, planting, land management, etc.
2. Hazard Regulation
3. Disease and Pest Regulation
4. Pollination Regulation
5. Noise Regulation
6. Air Quality Regulation
7. Water Quality Regulation
8. Soil Quality Regulation

Regulating services are particularly difficult to place an economic value on and are non-excludable; an example of which is climate change. This particular service provides a good example of the arguments which Farley (2012) outlines regarding sustainability, economics and ecosystem services. Three central debates are: First that of strong versus weak sustainability this is that there are some ecosystem services which are replaceable and without which humans cannot exist on the planet. The second is that ecological thresholds exist, which once past will cause a feedback loop to start into which ecosystems will flip into alternative states which are less beneficial to human well-being. Meadows (2009) cautions that it is impossible to tell how close to these thresholds we currently are (Meadows, 2009). The third debate centres on whether or not there are limits imposed upon economic production due to ecosystem services either by the loss of the critical ecosystem service or the requirement to conserve enough ecosystem structure to sustain economic production.

Organisations such as the UN and some government clearly see a requirement to pay for management practices to maintain ecosystem services whereas others do not (Pachauri and Reisinger, 2007, Munang et al., 2013, Rohr et al., 2013, Dietz, 2014, Ding and Nunes, 2014, European Union, 2008, TEEB, 2010, TRUCOST Plc, 2013). This generates problems associated with fairness, power, influence and economic competition, illustrated by the complexities of international negations between nations to place limits on global greenhouse gas emission. The willingness to pay and who should pay and who does pay is influenced by politics and differing priorities between, Developed nations, Developing nations, the BRIC nations (Brazil, Russia, India and China) and the Global North versus the Global South as well as other national and international groupings.

These debates impact strongly upon the value which is placed upon an ecosystem service provided that the parties involved reach consensus about the requirements for the ecosystem service and its importance for human well-being. This is where economics, the environment, society and politics can come into conflict in trying to determine how best to maintain ecosystem services for the benefit of humankind and how and who should pay for these services. The need for intermediaries to managed negations between parties is fundamental to PES schemes to objectively balance differing priorities and manage conflicts between parties (Smith, 2013, Schomers et al., 2015, Wunder, 2005, Wynne-Jones, 2012).

A more discreet regulating service which can be delivered from a land management practice to a customer (or customers) could be that of water quality regulation. For example the practice of using reed beds in order to clean up water so reducing the requirement of a water company to remove certain pollutants can be valued very directly as the use of reed beds as a form of land management can directly reduce the costs of water treatment for a water company therefore an economic value may be arrived at to the satisfaction of the land management practice and a water company. By taking into account the management costs of implementing and maintaining the service and the economic benefit derived by the water company of reduced treatment costs, an economic value can be arrived at. This is arguably a more straightforward situation in which PES schemes are more effective. Reverse auctions (Table 2.1), place a value on services by service providers bidding to supply a service to those that require the services and will pay for them. For reverse auctions to operate an intermediary is required to facilitate the process and identify buyers and sellers (Day and Couldrick, 2013) In the interviews conducted for this research this approach was also mentioned by interviewees (Chapter Four). The upstream thinking project (South West Water Limited, 2010) and catchment-based approach does try to foster these sorts of relationships between land management practices and those who directly benefit, an example of this sort of approach as is SCaMP (Table 2.1) (United Utilities, 2014). However this does not sell ecosystem service that operate over larger geographic scales or over longer time horizons, resulting in the multi-benefit and multiple scale nature of certain solutions being missed by a more focused approach (Everard and McInnes, 2013).

### 2.5.2 **Provisioning Services**

The relationship between ecosystem and provisioning services is the most visible of all the ecosystem services (Edward-Jones et al., 2011).

One of the most obvious provisioning services is food, which can be obtained from ecosystems in a number of ways; terrestrial agriculture, marine agriculture, "wild" food (hunting/collecting) and landscape management, e.g. deer, pheasant. Other provisioning services include;

1. Timber and forest products
2. Peat
3. Genetic resources
4. Ornamental resources
5. Water
6. Fuel

The values placed on the provisioning services appears to be direct and transparent. If resources are scarce, for example if there is a poor wheat harvest, then the price increases and if there is a good wheat harvest prices decrease. The intervention of the futures market can distort this process and again placing an economic value on an ecosystem service becomes more nuanced (De Groot et al., 2012, Gowdy et al., 2012). Governments, through policy intervention and subsidies, try to influence land management practices, food production, imports and exports and environmental impacts. This can influence prices and distort markets for provisioning services such as food. Prioritising different ecosystem services over others effects the value and the willingness to pay for certain provisioning services (Ring et al., 2010, Brondizio et al., 2012, Gowdy et al., 2012, Kumar et al., 2012, Ding and Nunes, 2014). Genetic diversity may for example lose out to ornamental resources such as cloned bedding plants for gardens (Gowdy et al., 2012). As with the all ecosystem services there are trade-offs between different priorities when trying to maximise one service above another. Balancing the requirement of different ecosystem service within a PES project to maintain the overall functioning of an ecosystem is an important aspect of the role played by the intermediaries (Smith, 2013) and is an aspect of the intermediaries role mentioned by an interviewee in Chapter Four.

### 2.5.3 **Supporting/Habitat Services**

Supporting services are closely linked to regulating services and are often more closely linked with the idea of ecological sustainability; ecosystems being diverse, resilient and productive. Supporting services are non-excludable so in valuing them and trying to internalise management costs to maintain their healthy functioning to the benefit of humanity is difficult. The main supporting/habitat services are

1. Soil formation
2. Nutrient cycling
3. The water cycle
4. Primary production

This particular set of ecosystem services are fundamental to all the other services as they are the basic building blocks of our environment. This makes them particularly difficult to quantify and integrate into a system such as PES. Certain types of management practices can improve and be seen to improve a specific aspect of supporting services under a defined set of circumstances. This improvement can be quantified and monitored and hence and an economic value attributed to a specific management practice. For example, improving nutrient cycling through crop rotation techniques, planting nitrogen-fixing leguminous plants as an alternative to chemical fertiliser additions (Gowdy et al., 2012, Knowler and Bradshaw, 2007, Feliciano et al., 2014).

### 2.5.4 **Cultural Services**

Examples of important ecosystem cultural services within the UK have been identified by the UK NEA these have been broadly classified into the categories below (Church et al., 2011)

1. Tourism/leisure/recreation
2. Heritage
3. Education/ecological knowledge

The value of the services need to be quantified to number of different scales, to determine of whom they will be of value to and who will derive direct a financial benefit from them. This will enable the identification of parties who will potentially be prepared to contribute financially to the PES scheme (Schaafsma et al., 2012, Jørgensen et al., 2013, Kopmann and Rehdanz, 2013, Van Houtven et al., 2014, Winthrop, 2014) . The willingness to pay for cultural services can be seen in terms of number of visitors to a National Park. Their willingness to pay is expressed in terms of their willingness to expend time and effort and money in travelling to an area and their expenditure in the area. This quantification is difficult and there is some resistance to placing an economic value on services that are seen as intrinsic (Winthrop, 2014, Davidson, 2013, Kopmann and Rehdanz, 2013).

Research and education and the metrics for quantifying the value that these services contribute to a national and local economy is undertaken in the UK by the Office for National Statistics (ONS). Their contribution to GDP is an accepted and acknowledged part of national budgets.

## 2.6 **Identifying Ecosystem Services**

The second key tenet of the Defra PES Best Practice document (Smith, 2013) (ecosystem service not currently supplied or is under threat) requires an assessment of the specific site / system which is being considered;

1. Which ecosystem services are currently supplied
2. Are these services under threat through current management practices
3. Has it historically supplied any other ecosystem services
4. Is it appropriate/desirable to restore these ecosystem services

It is not always desirable to restore sites to a previous state (Speldewinde et al., 2015), an objective assessment of the current state of the area needs to be undertaken. In case of a degraded or polluted site it is important to understand which ecosystem services are being impacted and asses the current level of the environmental impacts and what harm is being done, both socially and economically, by not restoring the site. Equally, it is important to take account of any positive impacts of the current state of the site for example some SSSI sites have developed as the direct result of high levels of certain metals associated with pollution in creating unique ecosystems (Allen Valleys Landscape Partnership, 2010a). When considering a site in order to protect/improve ecosystem services it is not always a matter of recreating a historic state but rather assessing the potential to deliver maximum benefit the through the implementation of land management practices in order to mitigate current harm or improve and increase the number of ecosystem services that the site can potentially delivery.

## 2.7 **Application of PES Methods to Assessment of Remediation of Abandoned Mine Sites**

The purpose of this research is to balance the impact of remediating abandoned mine sites with the benefits that would be derived from doing so. It is not always beneficial to restore a site and methods of determining whether or not to do so have been are available in the literature (Holl and Aide, 2011, Lemming et al., 2012). Holl and Aide's (2011) methodology focuses upon whether or not to actively restore an ecosystem by assessing the site, the framework put forward is outlined below (see Figure 2.8) The active intervention is where action is taken to change the site for example prevent pollution from entering a water course, to facilitate the restoration of the ecosystem. The passive approach is to do nothing and let the site respond to the source of pollution without intervention.

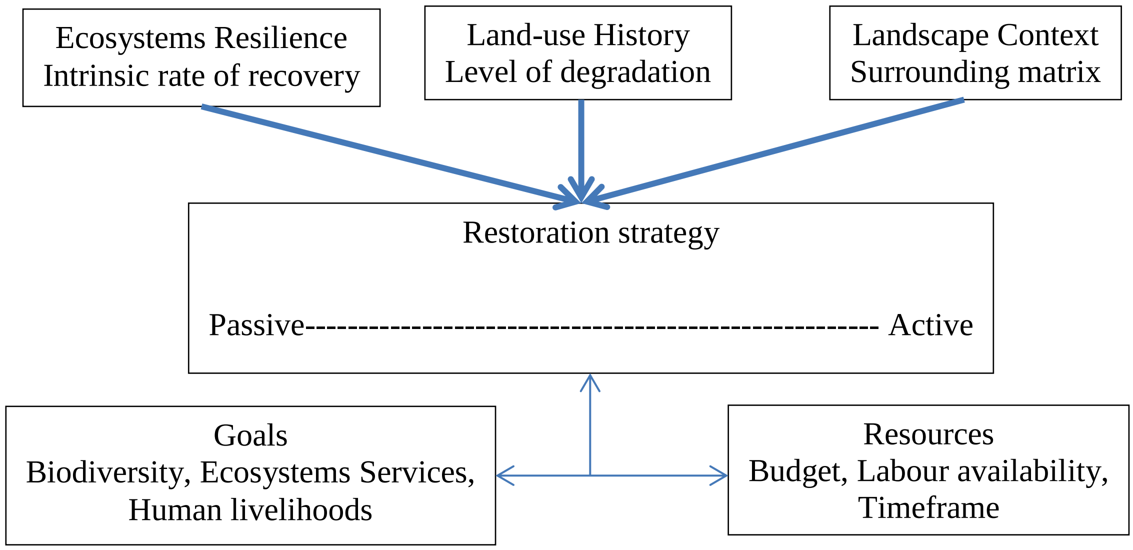


Figure 2.8: Factors to be considered when planning ecosystem restoration (Holl and Aide, 2011)

A scoping exercise to determine the current state of the site and the harm that is being done and the potential for remediation is only the first step in determining the overall environmental benefits to be derived from undertaking a PES scheme. The remediation of a site usually occurs because the immediate local risk to the environment (Holl and Aide, 2011). This approach is most suitable for using PES schemes where a clear relationship needs to be visible between those supplying the service and the parties paying for it. To widen the geographic temporal impacts which is the purpose of this research, an broader environmental assessment of the impacts using a LCIA (Chapter Three) approach to identify the best method of remediation is useful (Lemming et al., 2012). This may not necessarily deliver the best result for the parties involved in a PES scheme. The most globally beneficial method of remediation may not deliver as many local benefits as an alternative method of remediation. For example an active method of metal removal from wastewater may locally deliver the best results, but of the impact of the production, deployment, use and decommissioning of this may have secondary impacts which are greater than the local benefits derived. However LCIA analysis does not tend to take into account the cultural benefits associated with a PES scheme but focuses upon a narrower range of environmental impact categories such as those outlined in Table 2.4. To arrive at a single number (functional unit) which can be then normalised to determine the overall impact which can be used to compare alternative options. social (S)LCA (Chapter Three) does seek to quantify and assess the social impacts that processes have however culture is not explicitly included (Pizzirani et al., 2014). As life cycle analysis and modelling techniques developed more and more aspects of the impacts that different activities and processes have are sought to be captured. LCSA (Chapter Three and Section 3.2) seeks to combine the 3 aspects of sustainability; environmental, social and economic, by bringing together LCIA, SLCA and cost benefit analysis (CBA) (Heijungs et al., 2013, Holma et al., 2013, Jorgensen et al., 2013a, Wood and Hertwich, 2013, Zamagni et al., 2013, Hoogmartens et al., 2014). This move towards sustainability as a key determinant of human activity is also reflected in the literature elsewhere using sustainability with PES methodology (Abson et al., 2014). Bringing together LCSA with PES schemes enables different aspects and nuances to be captured within a broader research framework (1.5, Chapter Two, Chapter Three Chapter Five).

In the context of the PES this means that the value of the benefits derived and who is contributing financially to gain the benefits becomes a moral and ethical question. Balancing the benefits derived locally against wider impacts globally. Due to the difficulty of quantifying certain benefits in economic terms, which becomes more difficult the further removed from the PES project in time and space, it can be argued that PES schemes should be required to undertake a broader analysis placing all PES schemes in a global context to determine potential impacts on environmental services beyond the scope of local projects.

Table 2.4: Examples of Primary and Secondary Impact Categories for Life Cycle Analysis (Lemming et al., 2012)

| Life Cycle Analysis Impact category | Primary impact | Secondary impact |
|---|---|---|
| Global warming | No | Yes |
| Ozone formation | No | Yes |
| Acidification | No | Yes |
| Terrestrial eutrophication | No | Yes |
| Aquatic eutrophication | No | Yes |
| Respiratory inorganic | No | Yes |
| Eco-toxicology | No | Yes |
| Human toxicology (non-cancer) | Yes | Yes |
| Human toxicology (cancer) | Yes | Yes |

## 2.8 **Delivering Ecosystem Services**

The third point (Section 2.4) of the Defra Best Practice Guidelines (Smith, 2013) states that the ecosystem service can be supplied by implemented specific land management practices. This requires that the practice being implemented is identified and quantified in order to help to determine the value of the services being provided so that appropriate remuneration can be agreed upon. For example, the upfront cost incurred of putting in a new management system and any continuing maintenance costs. It is important that when implementing a PES scheme there is sufficient information about the management techniques to have the high degree of certainty that they have the potential to deliver sufficient benefit to justify the investment in the scheme. There are often high levels of uncertainty around the relationships between the ecosystem services delivered and the land use and management strategies that are being implemented which underpins many PES schemes (Muradian et al., 2010). In the alternative framework proposed by (Muradian et al., 2010), considerations, strategic decisions and trade-offs by various stakeholders involved in the PES scheme can be made in order to manage the underlying uncertainty that is the result of a lack of knowledge about the complex relationship between land-use and ecosystem services. As pointed out in much of the literature (Fisher et al., 2010, Greiner and Stanley, 2013, Van Hecken and Bastiaensen, 2010, Lockie, 2013, Kroeger, 2013, Wynne-Jones, 2012, Farley, 2012), PES schemes are about much more than direct purchasing of a service, but involve complex relationships between a range of stakeholders, which involves trust between different actors. This so that the balance of benefits derived, is positive, not only locally but at a range of different geographical and temporal scales and worth the investment made. Intermediaries are fundamental in ensuring that as far as practice this is the case though there role as objective facilitator and ethical broker (Baron et al., 2002, Bianchi et al., 2015, Farley and Costanza, 2010, Greiner and Stanley, 2013, Martín-López et al., 2012, Wunder, 2015)

Where a specific land management practice or intervention is implemented, set parameters can be monitored helping to untangle the relationship between the specific practice and the wider ecosystem. This should be taken advantage of in order to determine the ecosystem services provided. This is also a potential cultural benefit derived from a PES scheme, contributing to human knowledge and promoting research which may have additional applications and lead to developmental different areas that may have an economic value.

## 2.9 **Identifying the Supplier**

The final criterion laid down by Defra (Section 2.4); that the implementer of the practices can be identified and the delivery of the service monitored, is not always straight forward. Identifying the supplier of a service may involve; determining ownership of the land from where the service originates and whom is implementing the management practice on that land which delivers the ecosystem service or services. There may be multiple landowners or management practices, which may be being implemented by a group or an individual (Veldman and Putz, 2011, Killeen and Portela, 2012). These are the issues, raised by numerous authors (Farley, 2012, Muradian et al., 2010, Fisher et al., 2010, Greiner and Stanley, 2013, Van Hecken and Bastiaensen, 2010), are complex politically and morally. In the UK context it is often straightforward to identify the parties or individuals involved in delivering ecosystem service by their actions, such as land management or remediation techniques (Wynne-Jones, 2012, Brown et al., 2011, Mace et al., 2011, Defra et al., 2012).

Depending upon where a land management practice or deployment of a remediation technology lies in the benefits rights of property rights matrix below (Figure 2.9) will help to determine the potential remuneration that a landowner/tenant/custodian can negotiate within a PES scheme.

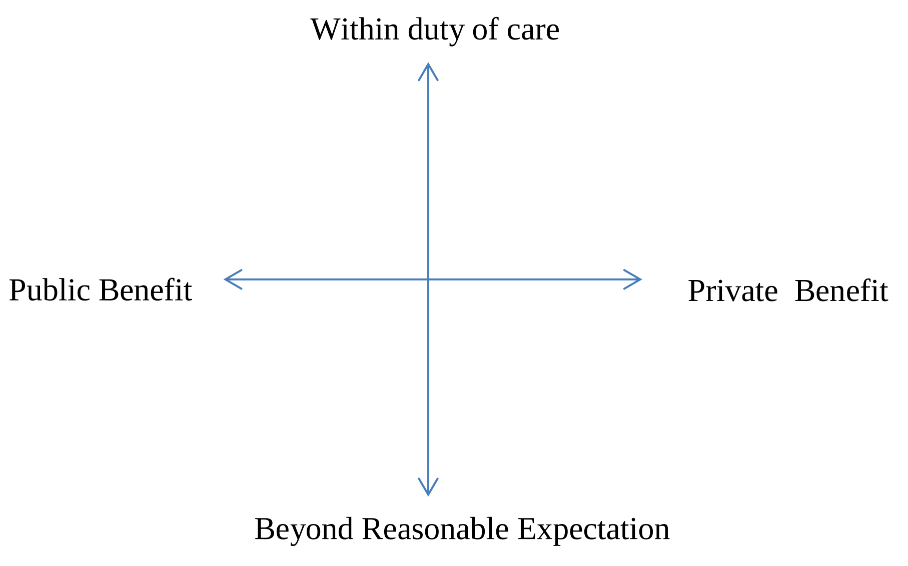


Figure 2.9:The benefits rights and property rights matrix (Lockie, 2013)

This matrix recognises that there are certain requirements placed on a land owner/manager often prescribed by legislation or accepted practices for which additional remuneration should not be expected. Those practices for which additional payment may be derived within a PES scheme should fall within the bottom half of the matrix.

## 2.10 **Conditionality**

A key aspect of PES schemes is conditionality (Kroeger, 2013); that is that the ecosystem services being delivered and meeting the agreed upon criteria. This can only be determined through monitoring if a specific out-come has been agreed upon between the buyers seller and intermediaries. Unless it is a straightforward and directly quantifiable parameter that is being delivered e.g. the reduction of levels of potentially toxic metals in a water course, it can be very difficult to determine. Also there may be problems with implementing continuous and appropriate monitoring of the agreed upon criteria either through lack of knowledge about interactions between ecosystems and land management practices or because it is prohibitively expensive to implement appropriate monitoring practices (Kroeger, 2013, Muradian et al., 2010).

Proxy indicators as well as direct measurement of key parameters may be used to determine whether or not agreed upon criteria have been met and are being delivered. It is however very difficult to determine whether or not certain ecosystem services are being delivered and more research is needed into a complex relationships between ecosystem services in the way in which land is managed by humanity. It has been highlighted that there are particular difficulties associated with PES schemes in monitoring biodiversity in order to determine whether the conditionality is had been met (Sommerville et al., 2011). The challenges associated with what indicators required monitoring, how these indicators will monitored and how the payments are to be differentiated especially with relationship to trends over time are complex (Sommerville et al., 2011). It is proposed that without monitoring it is argued improvement in service provision will be impaired as there will be no motivation for behavioural change from land managers if the payments are seen as stochastic, careful indicators selection is needed to prevent the costs of monitoring to being prohibitive.

In addition, subjective criteria such as the cultural services may be even more difficult to determine if the agreed upon criteria are being achieved. However the use of proxies such as house prices do give a quantifiable indication of the value being placed upon the improvement derived from the implementation of PES scheme in a local area (Clark et al., 2012). Additional difficulties with quantifying the value of some ecosystem services are associated with the time lag between implementation of remediation or land management practices and the resultant delivery of the ecosystem service. The location or diffuse nature of the benefit derived may make it difficult to determine whether or not the desired outcome has been achieved. Another problem is that of regulating services which often are decided because of what they prevent from happening, for example on prevention of flooding, making it difficult to quantify the monetary value of an event not occurring. For example predicting what the cost would have been had the ecosystem service not been correctly functioning? Insurance companies' methodologies for determining risk of events occurring can be useful ways to determine the value of these particular types of regulating services (Baumgärtner and Strunz, 2014).

In practice PES schemes conditionality may be linked to the intervention rather than an agreed upon out-come. So that payment is dependent on specific agreed management practices, action being taken or remediation technique being deployed (OECD, 2010, Smith, 2013). The monitoring becomes ensuring that the agreed upon strategy is taking place, which is simpler to check and enforce.

These problems show the importance of trust and strong relationships between different stakeholders to avoid conflicts and for PES schemes to successfully function. This again illustrates the importance of intermediary's role acting as facilitator in these complex interactions between buyers and sellers. The agreements may take the form of regulatory frameworks, and national or international policy, the European carbon trading scheme being such an example. This in theory enables PES schemes to operate at the local, regional, national and international levels and develop relationships between the public sector, private sector, commercial companies and NGOs as well as private individuals and large organisations. It also highlights the requirement for those monitoring the delivery of the ecosystem service are trusted by the stakeholders involved and also that you have sufficient power in order to determine whether or not payment should be received by the identified service provider (Kumar et al., 2012).

## 2.11 The Site Specific Nature of PES Schemes

Although the overall framework for PES schemes is generic (Smith, 2013, Mace et al., 2011), when PES schemes are implemented in practice, a determination of the particular circumstances and an understanding of the specific site and the specific outcomes that are desired is needed. It is therefore vitally important that a very detailed scoping exercise is undertaken before determining how appropriate using a PES scheme would be to encourage the use of more environmentally beneficial practices in order to improve overall well-being for humanity (Smith, 2013).

Therefore any PES scheme needs to be site-specific and carefully designed, based upon the most reliable and accurate knowledge available about a particular environment and area from a range of independent sources as well as the stakeholders involved. Appropriate monitoring techniques and practices need to be used as well as a degree of trust between stakeholders in order for PES schemes to function and for the maximum range of benefits to be derived from them.

Specific PES scheme determines who the stakeholders will be and hence who the principle actor in the market will be. In the in case study used here Chapter Five) it is the land owner upon which the remediation technology will be located who will be the seller, the potential buyer are those with a vested interest in the improvement of the water quality of the catchment, example the Environment Agency, anglers, commercial fish farm and water companies.

## 2.12 **Conclusions**

PES schemes offer a way forward to fund the rectification of certain types of environmental problems; where an intervention can be made in the form of a specific action or practice to improve or restore an ecosystem service or services. This methodological approach is fundamental to the framework presented in this thesis (Figure 1.3), for the funding and delivery of remediating specific abandoned metal mine sites. There are problems associated PES schemes which are directly addressed by the framework. Specifically two of the areas highlighted by (Kumar et al., 2014) of developing institutional mechanisms and developing equitable relationships between buyers and sellers and creditable use of ecosystem services.

The full range of different geographic and temporal scale ecosystem services need to be systematically included in the list of benefits presented to stakeholders. This is something that this framework seeks to do. How to communicate effectively to stakeholders specifically buyers and investors in a remediation scheme depends upon the individuals involved, this is something that should be part of the role of effective intermediaries. Legislation and policy tools can act as drivers towards the inclusion of different scales and connectivity of ecosystem services beyond just those delivered locally to address the specific problem. Though consistently including these aspects in PES as part of the proposed framework (Figure 1.3) it is hoped to generate a paradigm shift which will act as a driver to inclusion and consideration of wider and benefits which can be override local considerations.

# Chapter Three Literature Review and Methodological Justification: Life Cycle Impact Assessment

## 3.1 Introduction

The integration of Payments for Ecosystem Services (PES) approaches, which can provide a framework for quantifying the environmental benefits of remediation at abandoned mine sites (see Chapter Two), with Life Cycle Impact assessment (LCIA) is a fundamental component of this research. LCIA of the proposed remediation systems adopted at abandoned mine sites supplies the information about the economic and environmental costs which result from the decontamination of an abandoned, polluting mine site. Life cycle sustainability assessment (LCSA) which comprises of social life cycle assessment (SLCA), life cycle impact assessment (LCIA) and life cycle costing LCC (Wood and Hertwich, 2013, Valdivia et al., 2012, Zamagni et al., 2013), is a useful tool to expand the traditional LCA taking it beyond purely quantifying environmental impacts of a product or service. These methodologies can quantify the benefits and harms of remediation technologies when assessing alternative strategies for contaminated site mitigation (Lemming et al., 2010b, Lemming et al., 2012, Gallagher et al., 2013, Holland, 2011). The development of a coherent framework within which to determine the best option for site remediation in physically and chemically complex situations, often with a range of stakeholders, is an attempt to reconcile and address the various trade-offs that result from such complex situations. In this way the environmental benefits derived from remediating a site are balanced against the impact that actually producing and deploying the remediation technology incurs. Through objectifying the quantifiable impacts that site remediation will be predicted to have and determining the overall benefits, this will enable individual stakeholders to understand to what extent objectives are most likely to be achieved and how these different objectives are weighed against one another. This chapter provides a review of recent developments in the field of LCIA and provides the methodological justification for the approaches adopted in Chapter Seven.

## 3.2 The Development of LCIA

Attempts have been made to include culture in LCSAs (Pizzirani et al., 2014), even going so far as to claim that culture needs to be included as the fourth aspect of sustainability (social, economic, environmental plus culture) (Pizzirani et al., 2014). Culture informs values and values inform culture, therefore the choices made about the selection of impact categories and negotiations between different groups of stakeholders to determine priorities, reflect the culture of the differing sectors involved in the remediation, in addition to the local and national culture where the technology is to operate. The values of the stakeholders are reflected in the decisions and choices they make when implementing this proposed framework. This is a strength of the framework (Figure 3.1) proposed as it enables negotiation and consensus to be reached by identifying common interests and priorities between different sectors (Section 4.3.1). Cultural services are increasingly being recognised as of value and their need for inclusion in accounting for the costs of environmental degradation is becoming more widely acknowledged and their contribution to human well-being, (Section 2.5.4).

LCIA has become a widely standardised and recognised methodology (ISO, 2006a, European Commission et al., 2010b, European Commission et al., 2010a, European Commission et al., 2011, Valdivia et al., 2012) with which to assess options' environmental sustainability and compare alternative strategies with one another. LCIA can be applied to a broad range of technologies and activities including:

- Waste management technologies and strategies
- Product manufacture and production techniques
- Remediation technologies

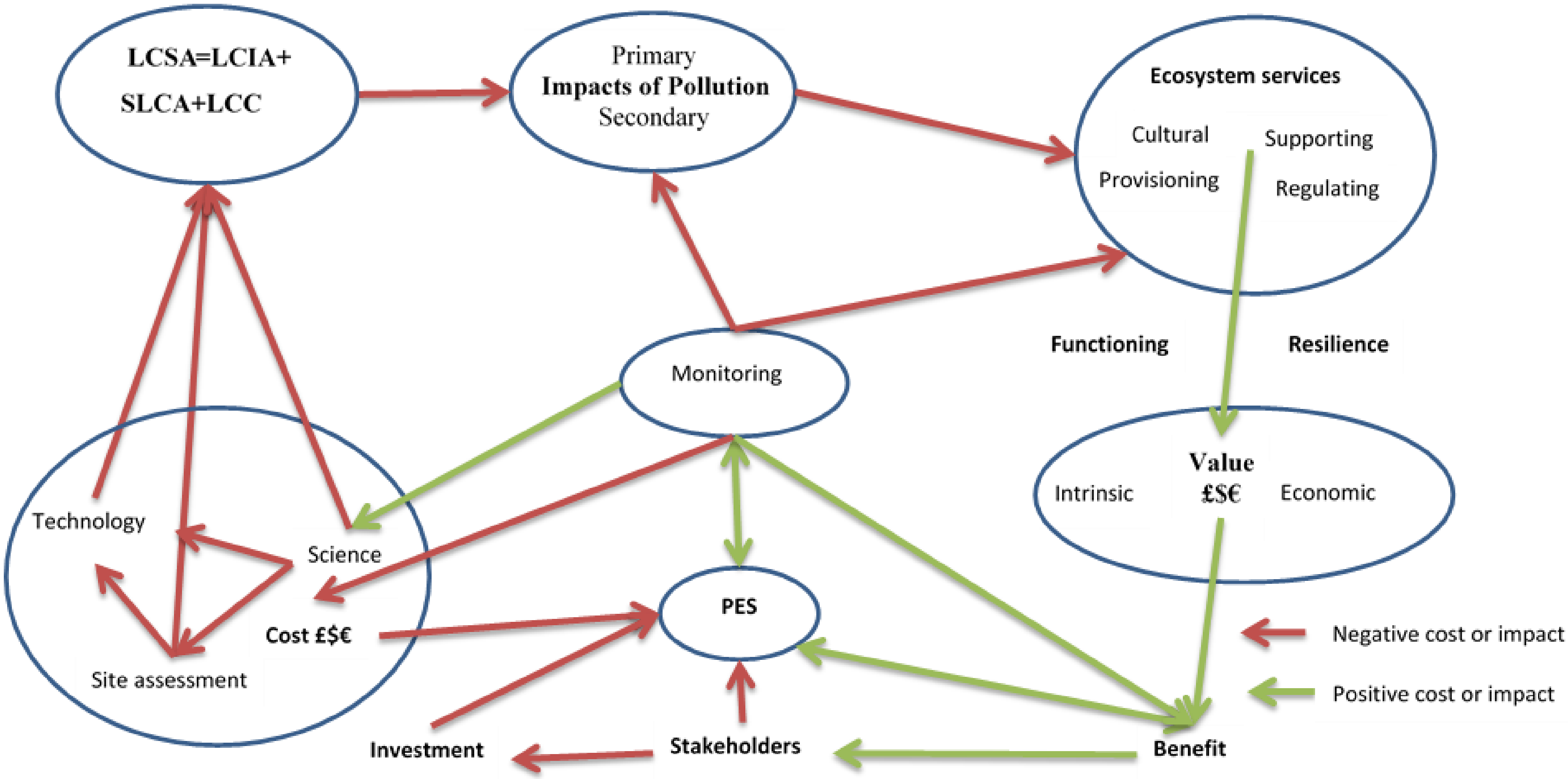


Figure 3.1: Overview of research framework, author's own

The European Commission Joint Research Centre (JRC) on LCA has produced a number of handbooks to standardise LCIA practices across the European Union (European Commission et al., 2010b, European Commission et al., 2011). These standardised methodologies attempt to create a framework within which to rigorously quantify the impact that these activities have upon the broader environment within a defined range of impact categories which can either be point or end point impacts, (Section3.3.2), (European Commission et al., 2010a). Metals in particular have been recognised by the LCA, Society of Environmental Toxicology and Chemistry (SETAC) and United Nations Environmental Protection (UNEP) communities as significance in LCIA due to their well-documented toxicity to both ecosystems and humans. Metal characteristics vary depending upon the environment into which they are released. This affects speciation, and bioavailability, thus their degree of impact making metals a challenging aspect of any LCIA. Different models and methodologies, which include metals, have been developed for the purpose of LCIA with a range of impact categories utilising different Characterisation Factors (CF) (Section 3.3.1). A number of different studies have been carried out comparing different methodologies to identify which approaches are most suitable for different impact categories and contexts (Bare, 2010, Cucurachi et al., 2014, Dong and Ng, 2014, European Commission et al., 2011, Hauschild et al., 2013, Hoof et al., 2013, Jolliet et al., 2014a, Koellner et al., 2013b, Owsianiak et al., 2014, Pizzol et al., 2011a, Pizzol et al., 2011c, Weidema, 2014). In particular the study undertaken by Hauschild et al (2013) has sought to identify the most accurate methodology and practice for modelling characterisation in LCIA and highlights the lack of guidance in the ISO 1404 4 standards and the handbooks produced by the European Union when selecting suitable models (Hauschild et al., 2013). It was acknowledge that there is much work needed in this area and organisations such as the Life Cycle Initiative (UNLCI) (UNLCI et al., 2013), the European Platform on Life Cycle Assessment Commission Joint Research Council (European Commission, 2013) and SETAC LCA group are constantly working on creating standard methodologies for life cycle thinking in all its different permutations (Owsianiak et al., 2014, Jolliet et al., 2014b). This reflects the dynamic nature of life cycle approaches and demonstrates the way in which application of this framework will actively contribute to the development and refinement of life cycle approaches. Monitoring the outcomes of an agreed upon intervention as part of PES schemes to ensure that the conditions of the PES scheme are being met (e.g. falling instream metal loads and biological improvements) can be used to contribute to the development of

LCSA methodologies by contribution data to open access databases and improving datasets, with accurate information about the performance of specific intervention strategies. This in itself could be viewed as a cultural ecosystem service of research and the added benefits that accrue from improve knowledge and understanding.

### 3.2.1 Stages and Structure of LCIA

LCA can be broken down into 4 key stages these are outlined by the ISO standard 14044 (ISO, 2006a, ISO, 2006b);

- Defining the goal and scope of the study including setting a functional unit
- Life cycle inventory analysis
- Life-cycle impact assessment which involves determining the associated impacts with the inputs and help for those identified in the inventory analysis
- Interpretation of the results

It is this framework in conjunction with the guidelines outlined by the European commission (European Commission et al., 2010a) that will be followed in order to conduct the LCIA aspect of this research project.

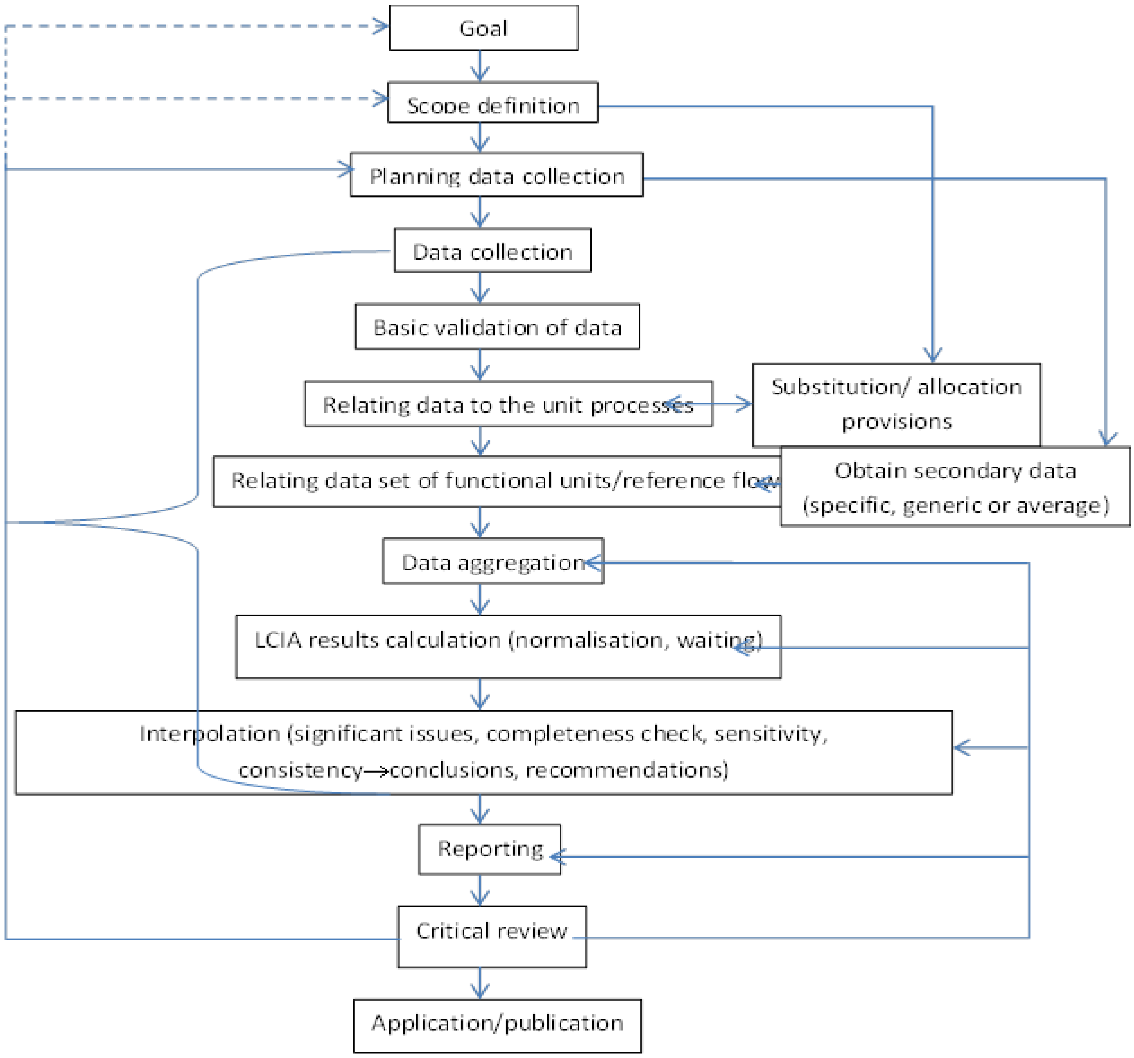


Figure 3.2: Iterative process for LCIA (European Commission et al., 2010b)

Figure 3.2 shows the generic iterative process for LCIAs studies, proposed by (European Commission et al., 2010a). As can be seen in diagram the LCIA process requires continuous reassessment at each stage to assess the robustness of the study; whether the goal of the study is being met, whether the chosen method and model used is appropriate and the validity and rigour of the data being used. This iterative process is valuable as it gives the LCIA the flexibility and an ability to adapt to unforeseen practical problems with data availability/validity and selection and use of the most appropriate models available. Figure 3.2 illustrates the different phases of an LCA which have been applied to the Hebden Beck case study (Chapter Six and Chapter Seven); the quantification of the impacts that the different remediation approaches would have were they to be deployed, for a comparative assessment of the different approaches. This establishes a quantitative benchmark for the minimum benefit required from each of the remediation techniques being assessed to achieve a positive overall benefit from site remediation. The benefit of the remediation has to be greater than the impacts of the Production deployment and use of the remediation approach decided upon.

### 3.2.2 **Goal Definition**

The General Guide for Life Cycle Assessment-Detailed Guidance International-Reference Life Cycle Data System (ILCD) Handbook (European Commission et al., 2010a) outlines 6 stages of goal definition;

1. Intended applications
2. (1) method, (2) assumptions and (3) impact limitations
3. Reason for carrying out the study and decision context
4. Target audience
5. Comparisons intended to be disclosed to the public
6. Commissioners of the study and other influential actors

Of the six points outlined above it is the 2nd point; methods, assumptions and impact limitations which will be covered below. The other points have been discussed and the ethos behind the research explained in other sections of this thesis (Section 1.3 and Chapter Nine).

### 3.2.3 **Functional Unit**

The functional unit is a product, or service quantified and defined for performance and/or comparison by the LCA. For the remediation of contaminated sites the functional unit is based upon the requirements to remove contaminants (or their availability) to a level where negative environmental impacts would not be expected, such as below regulatory quality standards (Sparrevik et al., 2011, Lemming et al., 2012, Diamond et al., 1999). In a review of life cycle assessment of remediation technologies it has been concluded that basing the functional unit on the treated volume of water or soil is a valid approach (Lemming et al., 2010a). This enables different remediation approaches to be compared for the requirement of a specific site for reduction of the contaminants. The functional unit used by recent studies comparing active and passive acid mine drainage treatment technologies (Hengen et al., 2014) normalised of all the scenarios to a functional unit of 1 kg of acidity neutralised per day, at the actual site the situation was 700 mg/L acidity fed at 2.2 9L/s. Such units are commonly used in design criteria of such treatment systems by environmental engineers (e.g. Piramid Consortium, 2003).

### 3.2.4 **Inventory Analysis (Data Collection)**

Data collection and use is one of the fundamental sources of uncertainty in all LCA studies. Often there are gaps in the required data, and in order to reduce these gaps and minimise the uncertainties constantly reviewing and revisiting the different stages of the LCA can be useful (European Commission et al., 2010b). Where there is large degree of uncertainty due to missing data or unverified data, this can be highlighted. The model's sensitivity to these uncertainties can be assessed. Areas of high sensitivity, once identified can be focused on for accuracy of information. Sensitivity analysis is be used to determine which pieces of information have the most effect on the final results thus which are most important to get accurate and which have a lesser degree of influence (Guo and Murphy, 2012).

## 3.3 **Life Cycle Impact Assessment**

Determination or characterisation of the life-cycle impact assessment results is a mandatory aspect of the ISO standard for LCA studies (ISO, 2006a, ISO, 2006b). There are a range of different models with which to determine the impacts caused by each inventory emission, both at the midpoint and an endpoint level. The midpoint is somewhere between emission and the severity of the damage being modelled (the endpoint), ideally an indicator along the impact pathway for which a common mechanism exists for the substances being modelled within that specific impact category. (Hauschild et al., 2013, Finnveden et al., 2009). A universally accepted method deterring impacts to the midpoint or endpoint this has yet to be agreed. The ISO 1404 4 standard states that "the impact categories, category indicators and characterisation models should be internationally accepted" The UNEP-SETAC life cycle initiative (Jolliet et al., 2004) and also more recently, the study conducted by (Hauschild et al., 2013) assessed which assess the current models available for characterisation of life cycle impacts to determine the most appropriate model for specific impact categories not taken into endpoint and a midpoint level. It was found that the most rigorous models were those that modelled the impacts to the midpoint level (Hauschild et al., 2013).

Indeed the choices made within LCIA such as time horizon, where to set the boundaries and which impact categories to include are unavoidable and these choices are predominantly value choices (Schryver et al., 2013). Transparency and a consistent approach throughout the whole framework is necessary in order to fully analysed the environmental problems and how these relate to the other impacts being assessed consistency. This is so that an assessment is as accurate as possible of the difference that can potentially be made by this sort of environmental intervention. The purpose of the LCIA is to assess whether a real and positive change will occur as a result of remediation of a specific site and which intervention is most probable to achieve it

### 3.3.1 **Characterisation Factors/Comparative Toxicity Potential**

Characterisation factors (CF) which are also known as comparative toxicity potential (CTP) are a key element in determining the impact of a substance being emitted into the environment. CFs are used to determine the magnitude of the impact that a specific substance has when emitted into a specific compartment; air, water, soil (Pizzol et al., 2011a, Pizzol et al., 2011c, van Zelm et al., 2013), per unit mass released. CFs are determined from fate factors (FF in days) and effect factor (EF). The fate factor is a quantification of the potential distribution and accumulation of the pollutant, metal, into a specific compartment (air and water or soil) it is often expressed in terms of an increase in concentration in a specific compartment per kilogram emitted (Pizzol et al., 2011b). Fate factors can be calculated by using 3 stage procedure;

1. Reference values for the model parameters relating to the environmental conditions
2. Output of contaminant into a specific compartment
3. Dividing the models output (e.g. The concentration in the specific compartment) by its input (contaminated emitted into the specific compartment)

These 3 stages will all the strongly affected by the specific site that is being assessed, alternatively in some LCIA models generic data is used, this clearly will influence the results obtained from the LCIA used.

It is important to determine as accurately as possible the different habitats in which the metals are being emitted to in order to understand the way in which different environmental conditions will potentially impact upon the effectiveness of remediation of contaminated water produced from abandoned mine sites. An additional influence upon the model results is the geomorphology of the system and the way in which the contaminant is distributed along the catchment, this can have a large impact upon the calculated CF values (Lundie et al., 2007). This is result of geomorphological processes such as spiralling; burial and resuspension of contaminated material as the energy environment of the system varies changing the levels of metal in the water column (Lundie et al., 2007, Macklin et al., 2006, Miller, 1997, Nordstrom, 2011). As the level of pollution entering the compartment is reduced and clean sediment buries contaminated sediment over time this should become less of an issue but cannot be entirely discounted (Bucher et al., 2005, Förstner et al., 2004)

A criticism of generic CF factors that have been developed without reference to spatial and temporal information is that this can lead to errors in the results for LCIA characterisation (Gandhi et al., 2011). Careful selection of the methodology and modelling framework using appropriate CF which incorporate rigorous spatial and temporal information can help to improve the accuracy of results. Work undertaken by (Dong et al., 2014) has built upon precursor work (Gandhi, 2012) to improve the CF/CTP for specific metal was released into the fresh water environment.

$$CTP_{i,s} = FF_{i,s}.BF_s.EF_s$$

Equation 1: General Framework for Calculation of Characterisation Factors/Comparative Toxicity Potential

Where $CTP_{i,s}$ (d $m^3$ $kg^{-1}$) is the eco-toxicity potential of substance s emitted into compartment i, $FF_{i,s}$ (d) is the fate factor, $BF_s$ (dimensionless ) is the bioavailability factor and $EF_s$ ( $m^3$ $kg^{-1}$ ) is the effect factor. Each of these 3 elements can be calculated separately and the methodology used to do so are important for determining the final results for the impact categories. How each of these elements is calculated is an area of ongoing research and debate. The need for realistic calculations for each of these parameters is vital which takes into account the different elements that affect the impacts that these metals have. The metal industry is particularly concerned about the environmental release factors upon which EU legislation is based (Verdonck et al., 2014) (See Chapter Four).

The decisions taken about the fate factors and the different influences upon their determination will strongly influence the results of the research (Rowley et al., 2012). It is vital that this research is rigorous and the decisions taken and the approach adopted can be set within the most appropriate framework in order to determine the potential for metal decontamination and hence restoration of ecosystem services. The different influences upon the model within this research will be related to specific sites taking into account the different ecology of the areas which will include the habitat type, geology and average precipitation all of which have a strong influence upon determining the fate factors (Dong et al., 2014). The sensitivity of the model to these different influences will determine their importance in the overall results.

The effect factors (EF) quantify the toxicological stress that a specific pollutant has upon the target species and how it varies with expenditure levels. The eco-toxicological effect of a specific pollutant is determined in general by laboratory studies. Usually a specific target species is exposed to a pollutant under controlled conditions and the stress can be quantified in terms of the mortality rate at a population level of that specific target species (Henderson et al., 2011, Jolliet et al., 2003). These differing concentrations can be expressed in different ways; sub lethal Effect Concentration (EC) which can be expressed in the level to which a pollutant will affect 50% or 5% of the population ($EC_{50,}$ $EC_5$) or the No Observed Effect Concentration (NOEC). NOEC data is chronic and often extrapolated from the acute ($EC_{50}$ and $EC_5$) data, this sort of data is more appropriate for modelling overtime however it is not as widely available as the acute data (Pizzol et al., 2011b). The effect factor is calculated as the impact upon a specific species that results from the increased exposure to a metal that is released into the environment and it is known as the "potentially affected fraction of species" (PAF). However the data available on CFs for metals is much more limited than is available for organic pollutants and there is a need for more research into CFs for metal (Pizzol et al., 2011b, Pizzol et al., 2011c).

The use and development of models and software such as WHAM, the biotic ligand model (BLM) or the free ion activity model (FIAM) enables a more detailed and specific calculations of CF to estimate metals speciation and toxicity is an important element in quantifying accurately impact categories in LCIA taking into account geographical variation (Huijbregts et al., 2003, Lautier et al., 2010, Roy et al., 2014).Temporal impacts also have a bearing on the impact of metals the environment and also needs accounting in LCIA (Lebailly et al., 2014). Whether the impact of the metal is calculated to occur immediately upon release, at some point in the future or integrated into an infinite time horizon, or over a predefined period, for example the lifetime of a remediation technology will significantly affect the results. Thus dynamic life cycle assessment (DLCA) aims to address this problem (Beloin-Saint-Pierre et al., 2014, Collet et al., 2014, Lebailly et al., 2014). This can be achieved through using time horizon dependent CFs in order to reconcile the time boundary of the system and the time horizon for the impact of a specific substance (Lebailly et al., 2014). This is a fast evolving field and still much work is needed in order to refine its application.

Both these points about inclusion of spatial and temporal scales for remediation of mine impacted rivers have been reinforced (Hornberger et al., 2009). Hornberger et al's (2009) study monitored a remediated mine waste site over 19 year period of a 200 km segment of the river catchment in Montana USA. It was found that there was a strong temporal correlation between consecutive downstream monitoring sites; there was variability in the strength of spatial connectivity from site to site. In as such, simple decay curves for metal concentration downstream of inputs are unlikely to accurately define the nuanced variability in metal availability in mine impacted systems. Such long-term, large scale studies are vital to inform the development of models for dynamic (D)LCA. Additionally the monitoring overlarge spatial areas contribute to the improvement of the geographical element of CF/ CTP.

This is an area in which the framework proposed will contribute greatly, as for a successful PES scheme to go forward monitoring of the results of the remediation technology applied is fundamental and thus will contribute to this area modelling impacts realistically over different timescales and geographies.

### 3.3.2 **Impact Categories**

The impact that a substance has is represented by an impact score and the impacts are dived into different areas of impact as can be seen in Figure 3.3 and Table 2.4. The midpoint and endpoint categories reflect different aspects of the impacts being modelled, midpoint results demonstrate the physical and environmental impacts, while the endpoint categories indicate the resulting societal impacts that these environmental impacts have (Goedkoop et al., 2009). It is not always the case that the LCIA study will automatically model to the endpoint categories. There are several reasons why this may be the case; purpose of the study, relevance of impact category, who the study is aimed at and the levels of uncertainty. The characterisation models perform the transformation from the direct impacts to the midpoint level and further to the endpoint level this will be further explained in Chapter Seven. Generally midpoint indicators have a higher level of certainty than endpoint indicators (European Commission et al., 2010a, Hauschild et al., 2013) and the meaning of endpoint level indicators (Figure 3.3 and Table 2.4) tend to be more easily communicable to non-expert stakeholders (Dahlbo et al., 2013).

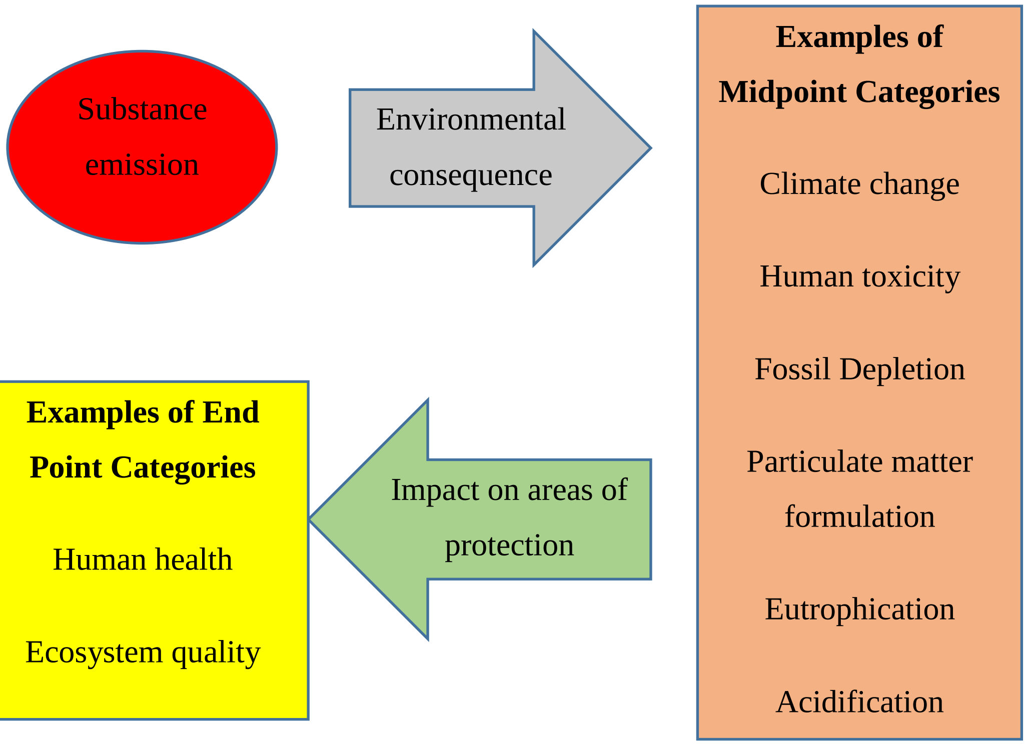


Figure 3.3: Relationship between midpoint and end point categories

Appropriate categories are selected depending upon the goal and scope and functional units of the LCA being undertaken. Midpoint categories are the processes and functions of ecosystem and a result of characterisation factors (CF) (see Section, 3.3.1)

The characteristics of endpoint categories have similar characteristics as ecosystem services which are also defined as end points (Brown et al., 2011, Smith, 2013). End point impact categories relate to the mid-point categories and are an attribute or an aspect of the environment and their selection is associated with the specific goal and scope or objectives that relate to the purpose of the LCIA study, examples include; human health or resource protection (European Commission, 2013, European Commission et al., 2011, European Commission et al., 2010b). As with all studies of this nature the selection of the impact categories being assessed whether they are endpoint or midpoint and what is being measured are based upon the practitioners judgement and knowledge. The justification for the selection of impact categories should be explicit and these choices should be based upon scientific research, the requirements of the study and current policy and legislation within the UK and EU. In the context of this research some on the influences on the impact categories selection include; the Water Framework Directive (Directive 2000/60/EC ),a catchment-based approach to water resources, other LCIA in the literature and needs identified by the UK National Ecosystems Assessment (Brown et al., 2011). It has been argued by Kontogianni et al (2010) that there is an "endpoint problem". That ecological endpoints need to concentrate on aspects of nature which are related to human well-being linking quantitative changes in selected scientifically valid aspects of nature with measurable variability in human well-being (e.g. upland restoration could minimise flood risk in a downstream town). This is needed to demonstrate the positive implications of ecosystem services' maintenance and improvement for society. The purpose of this is to communicate with policymakers and wider society "a solid conceptual translation of ecosystem realities into welfare related to social effects"(Kontogianni et al., 2010)

### 3.3.3 **Monetary Valuation**

Monetisation of social and biophysical impacts that pollutants have on the environment is an area of expanding interest. It is recognised that these impacts affect the global economic system and have cost implications for individuals, societies, government, and businesses at economic scales from local to multinational (TRUCOST Plc, 2013, European Union, 2008, TEEB, 2010, De Groot et al., 2012, Stern, 2007, Balmford et al., 2011, Dietz, 2014). Within LCA assessment of the TEV (Figure 1.8) of nonmarket goods, such as biodiversity or human well-being, has sought to be integrated within the wider LCSA context (Wood and Hertwich, 2013, Zamagni et al., 2013, Hoogmartens et al., 2014, Moxnes, 2014). A number of LCA methodologies include monetisation as one of their metric outputs and deploy a number of different valuation methods (Pizzol et al., 2014). This is a useful method to communicate the meaning of impact categories to stakeholders as quantifying them in terms of their monetary impact is meaningful to most stakeholders.

Money can be used to apply a weighting to impact categories enabling direct comparisons to be made between systems and approaches (Pizzol et al., 2014).

Integrating LCIA and LCSA into PES is something that is beginning to be explored in current research (Page et al., 2015, Arbault et al., 2014, Baxter and Mayes, 2014, Baxter and Mayes, 2013). Integrating ecosystem services into life cycle analysis methodologies is another area of active research being developed particularly by SETAC (Zhang et al., 2010, Koellner et al., 2013a)

Monetisation of TEVs inevitably involves value judgements and weighting as well as decisions about at what point over time horizon the costs are incurred (Baveye et al., 2013, Ahlroth, 2014). These are fundamental to the ultimate economic balance and impact that is determined using LCIA methodology and converting impact categories into monetary values.

### 3.3.4 **Reviewing LCIA Outputs**

The LCA process is an iterative one, and throughout the different stages the results obtained should be critically assessed in terms of the efficacy of the data and the transparency effectiveness of the models used. If it is found that a particularly dataset is not rigorous enough or a particular model does not provide realistic results, based upon known information about the sites, then this can be revisited and alternative and more precise data used or a more appropriate model selected. Assumptions should be robustly argued and justified based upon the literature, experimental data and other assorted sources of data which can be validated. The critical review of the results obtained from the LCIA can be made available to the stakeholders and scrutinised by them. Their comments and opinions are highly valuable and part of the iterative aspect of the framework (Figure 3.1). Informing the decisions about whether or not to invest in the PES scheme as well is which remediation approach comes closest to the filling individual stakeholders' requirements. Using the results and the different impact categories decisions can be made about possible alterations to remediation strategies such as the inclusion of possible biodiversity offsetting e.g. the creation of metallophyte the habitat within the remediation strategy (Whiting et al., 2004a, Lucassen et al., 2009). This critical review process is fundamental to ensuring that the results are understood by stakeholders and are successfully communicated to the range of expert and non-expert stakeholders.

## 3.4 Life Cycle Sustainability Assessment

LCSA is an expansion of traditional LCA and seeks to capture all the aspects of sustainability (Figure 1.5), social, economic, and environmental (Dewulf et al., 2015, Gemechu et al., 2015, Guinee et al., 2011, Heijungs et al., 2013, Keller et al., 2015, Parent et al., 2013, Sala et al., 2013, Sonnemann et al., 2015, Valdivia et al., 2012).

**LCSA = LCIA + LCC + SLCA**

Bringing together the three aspects of sustainability using LCA methodology is an ongoing process in which organisations such as the United Nations Life Cycle Initiative and SETAC are involved (Jolliet et al., 2014a, UNLCI et al., 2013). This is important because to understand whether a process or service is sustainable inclusion of all these aspects is necessary (Abson et al., 2014, Bachmann, 2013, Bakar et al., 2015, Cinelli et al., 2013, Curran, 2013).

Of the three aspects of sustainability, the impact categories for SLCA which seeks to capture and quantify the social aspects of a service or production system, is arguably the least developed and standardised (Dreyer et al., 2006, Martínez-Blanco et al., 2015, Parent et al., 2013). Selection of appropriate metrics for SLCA can be a highly problematic, impact categories including levels of noise, numbers of days missed from work; due to illness, accidents and strike action and land-use for leisure, and national parks, have been used as impact categories (Koellner et al., 2013b, Rack et al., 2013, Valdivia et al., 2012). Work is continuing on the selection of appropriate impact categories for inclusion in SLCA methodologies (Valdivia et al., 2012, UNLCI et al., 2013). This is also a fundamental part of the WFD (Azzellino et al., 2013, Benson et al., 2014, Bouleau and Pont, 2015, Koundouri et al., 2015). This includes cultural impacts although again this is an aspect that is difficult to capture in the LCSA methodology (Pizzirani et al., 2014). The other two aspects, LCIA (see section 3.2) and LCC (Chapter Eight) have more standardised impact categories and methodologies (European Commission et al., 2010b, Heijungs et al., 2013, Hoogmartens et al., 2014). This holistic approach is fundamental to the WFD (European Commission and WISE, 2014) and LCSA presents itself as a useful tool for the assessment and deployment and management strategies for the purpose of water bodies achieving good chemical and ecological status as required by the WFD or still for filling sustainability requirements.

## 3.5 Conclusions

LCIA is a useful tool to evaluate and compare different remediation options for the purpose of determining the balance of benefits of taking action to remediate historic point source of metal mine pollution. It is constantly evolving to take account of the latest research and has the ability to take into account relevant policy and legislation developments when selecting impact categories LCIA should be relevant, appropriate and meet the needs of the individual assessments being made. Any assumptions should be justified and applied transparently; it should be made explicit what decisions have been taken regarding modelling and software selection. Transparency is central to LAC good practice, the data used should be the most accurate available and its source identified, LCIA is only is good as the data and model used. The expansion of LCA methodology to LCSA capturing all elements of sustainability is a useful development, particularly in the context of this research framework. Which seeks to quantify the overall balance of benefits, environmentally, socially and economically. LCIA is a fundamental part of this research framework and is a useful and robust approach to take when assessing and comparing the different remediation approaches propose

# Chapter Four  Who Pays for Mine Pollution? Stakeholder Attitudes to Payments for Ecosystem Service Schemes for Legacy Mine Pollution

## 4.1 Introduction

The purpose of this section of the research is to find out about the experiences and attitudes of a cross-section of stakeholders towards non-coal mine site remediation and PES schemes. The aim of the interviews was to interrogate and explore differences and similarities in attitudes and perceptions between sectors and roles (e.g. environmental managers, policy makers and practitioners). In particular, insights towards potential roadblocks to implementing this proposed framework were sought as well as their own experiences of overcoming potential difficulties. A secondary objective was to assess whether these stakeholders saw a need (and benefit) for PES frameworks to be applied to remediation of legacy mine sites. This information can be utilised to interrogate the proposed PES framework. The framework processes was explained to the interviewees as in Figure 4.1.

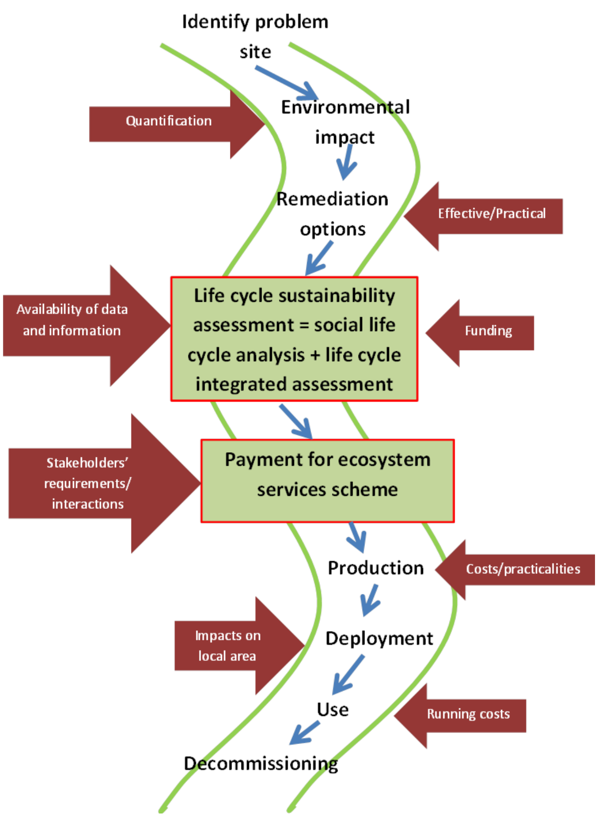


Figure 4.1: Framework pathway presented to interviewees

## 4.2 Methodology

Stakeholders were selected from three areas; industry (I), government agencies (GA) and special interest/conservation/stewardship organisations (SICSO). In addition to being drawn from these groups their geographical location was taken into account. For example, organisations, located in areas which contains a significant number of abandoned non-metal mine sites were selected over areas of the country without such a legacy. In this initial phase of the research, thirty-eight organisations were contacted by e-mail, which contained information outlining the research and requesting their participation by being interviewed, a questionnaire was also attached (see 0). Of these, twelve organisations agreed to be interviewed, of these ten interviews took place over the phone and two were face-to-face. Eleven of the interviews were recorded after first seeking permission to do so, a single participant refused permission and only brief notes were taken. All participants were guaranteed individual anonymity, only their organisational sector will be identifiable. Permission to directly quote individuals was sought; some individuals also gave their permission for these comments to be attributed to them. Some of the organisations approached, while not agreeing to an interview, provided e-mail comments in response, which have been taken into account to inform the findings and conclusions drawn (two responses of this type from the industry sector).

Those organisations classified as Industry (I) were drawn from UK water companies and the metal prospecting and mining sector. Organisations classified as Government Agencies (GA) have been defined as those bodies which statutory powers and to implement the legal requirements of legislation and policy. The number of interviews was limited to two from the GA (Table 4.1).sector and is not representative of the all GAs. They did have some in-sight into attitudes different from their own in other government departments and agencies The main purposed of the interviews was to obtain experiences and attitudes from individual working in different organisations rather than a representative sample across a whole sector. That Individuals from different GAs may have different attitudes, is important to be aware of. Special interest/conservation/ stewardship organisations (SICSO) are groups with no statutory powers, but with specific interests and goals which are impacted on by pollution from these abandoned non-coal mines sites.

Table 4.1: Interviews by sector

| Sector | Industry | SICSO | GA |
|---|---|---|---|
| Number of Interviewees | 5 | 5 | 2 |

The structure of the interview and the information elicited depend very much on the individual being interviewed. All the interviews initially started with a brief explanation wider context of this research and a brief outline and explanation of the framework that has been developed. Next the individual's knowledge and understanding of ES and familiarity and awareness of PES schemes was established. The interviews were not heavily structured although seven key areas of interest were always covered:

- Does their organisation perceive there to be a problem with legacy non-coal mining pollution
- Views on the concept of paying to maintain the natural environment and ecosystem services
    - Organisational and personal attitudes
    - Organisational and personal perceptions
- What they see their organisation's role being within the framework
- Roadblocks to action
- What is needed?

The interview transcripts were transcribed and analysed. From this analysis the key points have been distilled: similarities and differences between different organisations and sectors have been highlighted and are presented and discussed in the rest of this chapter. It is difficult to generalise about individual sectors by extrapolating from the responses from the interviewees. However for the purposes of this chapter and based upon the commonalities within the three sectors that were revealed, it has been assumed that the attitudes and level of knowledge shown are a reasonable representation of the individual sectors. As potential interviewees were only contacted after ensuring that their role within the company was relevant to this research and then the interviewees who responded self-selected as a result of having additional interest and or expert knowledge in an area or areas covered by the proposed framework. Then the individuals represented in this research, by dint of this two phase selection, are those with the greatest interest, knowledge, experience and understanding in some aspect of the framework.

## 4.3 Results

### 4.3.1 General Summary of Knowledge

The prevailing pattern observed from their interviews was, the general level of knowledge about ecosystem services (ES) varied greatly both between and within sectors. Everybody interviewed had heard of ES and Payments for Ecosystem Services (PES) schemes, although their individual interpretations of these concepts varied greatly, though all could be said to be a valid interpretation of the concepts. The sector with the greatest knowledge about ecosystem services and experiences of payments for ecosystem services schemes was the SICSO sector. GA and industry had arguably less knowledge and experience of ES and PES although all interviewees from these two sectors were aware of at least one specific PES scheme which related to their own particular areas of interest.

This finding could be the result of both industry and GA propensity to operate with specific targets and purposes to fulfil. They have tended to maximise their efforts towards these specific goals, giving them a narrow field of vision. The UK government's encouragement of PES schemes as evidenced by Defra active involvement in PES pilot projects[4] and its publication of the Payment of Ecosystem Service: Best Practice Guide (Smith, 2013) would suggest that government agencies would be expected to be as equally as well-informed as the SICSO sector. This was not the case for those individuals, interviewed in this research, who were selected based upon their interest in the specific problem of abandoned metal mining site pollution. This may highlight the problem of lack of awareness of what is available and potentially useful, which was evident in all three sectors.  It was particularly striking when one subject from the, SICSO sector, who was actively involved in putting together a report on a future PES scheme, when asked about the Defra best practice guidelines (Smith, 2013) did not even know of their existence.

The SICSO sector's overall greater experience of PES schemes and hence the ES concept resulted from the recognition that these types of schemes are one method of achieving the results that they seek. Generally these organisations, which have no statutory powers or commercial imperatives tend to be more used to negotiating with a

[4] https://www.gov.uk/ecosystems-services

number of different organisations and hence having to take into account needs and motivations different from their own and in order to achieve their own goal. These organisations also were motivated by a broader in remit, for example a healthy river ecosystem, they tended to recognise that even if their specific goal was to increase the number of newts in a river reach there was the implicit understanding that in order to achieve this a holistic view of the whole ecosystem needed to be taken into account. This was not universally the case some specialist groups had a very narrow focus, concentrated only on achieving their own conservation goal.

There was a diversity of opinions and knowledge within all three sectors, however general trends could be detected both within and between sectors (Table 4.2). Within sectors motivations and constraints were shared between the different organisations, attitudes towards these constraints depended very much on the individual. Most interviewees had a positive attitude towards protecting the environment and using ES as a way to do this. All felt the ES were not clearly defined and it was a confused concept that was difficult to communicate to stakeholders without an inherent interest in the environment. The use of the framework to harmonize all the different aspects and monetize them was accepted by all interviewees as a useful tool in order to communicate succinctly and immediately with decision-makers who possessed the power to release funds (Table 4.2).

Table 4.2: Summary of motivations, constraints and suggested drivers to act on an environmental problem, from all interviewees.

| Sector | Current motivations | Constraints | Suggested new drivers/requirements |
|---|---|---|---|
| **Industry (I)** | legal requirements<br>cost savings<br>EU/government policy<br>philanthropy (ethical business model)<br>benefits derived<br>public image<br>regulatory organisations<br>media<br>knowledge (data) | cost<br>shareholders<br>time<br>understanding<br>ineffective<br>customers<br>regulatory organisations<br>communication<br>culpability/liability<br>conflicting interests<br>media | policy<br>legislation<br>public education<br>knowledge<br>knowledgeable broker<br>consistent framework<br>funding |
| **Government agencies (GA)** | legal requirements<br>EU/government policy/priorities<br>targets<br>efficiency<br>public outrage/lobbying<br>media | lack of funding (government cuts, austerity)<br>communication<br>public image<br>understanding<br>knowledge<br>government policy/priorities<br>mistrust/suspicion<br>time<br>media | policy<br>legislation<br>public education<br>trust<br>consistent framework<br>ethical broker |
| **Special interest/ conservation /stewardship organisations (SICSO)** | organisational ethos<br>wildlife/environment/ conservation/specific interest<br>legal requirements<br>public campaigns<br>membership pressures/need/wishes<br>research<br>grants and funding<br>public campaigns<br>media | cost<br>funding<br>knowledge<br>lack of networks<br>time<br>conflict<br>priorities<br>administration<br>land use | policy<br>legislation<br>public education<br>consistent framework<br>improved contacts<br>conversations |

### 4.3.2 **Industry**

The majority of the interviewees from industry had the words "environmental manager" included in their job title. This epithet was one that seems to be reflected in the attitudes of the individuals interviewed, they all expressed a desire to protect and care for the wider environment, indeed, they all expressed some frustration in the limitations placed upon them by the working practices and requirements of the organisation for which they worked. The "end of pipe solution" and the "bolted to the end" failsafe option were mentioned with some frustration, as these are the accepted solutions to a contaminant removal that the environmental managers thought could be achieved with alternative, more catchment-based, approaches (Corominas et al., 2013, UK Government, 2003, United Utilities, 2014). One respondent explicitly said that the directors were very risk averse and resistant to alternative because of the involvement of pension funds and they did not want shareholders to hear, as that was where there investment came from, this despite the push from Europe and the UK government for more catchment-based approach as specified in the European WFD (Vlachopoulou et al., 2014, Benson et al., 2014, European Commission and WISE, 2014).

Every interviewee from this sector talked about regulations and how they impacted upon their organisation. There was a definite implication that, particularly with the water industry, they are being pulled in several directions at once. Having to satisfy requirements of various regulators, inspectorates as well as their customers. Sometimes these things come into conflict, and that as water companies, they are neither one thing nor the other. For example one interviewee said.

*"It's not a straight business choice in the sort of competitive environment that applies with other industry; we almost operate as a sort of arm of government of implementation of environmental policy" while at the same time " access to funding for environmental projects is contingent almost entirely on being able to demonstrate to our regulator that this is something for which our customers should pay."*

Another comment was about the fact that they had more than a single regulator, one for the customers, one for drinking water quality and environmental regulation as well. The water companies are highly aware of the perception of the public, their customers:

*"all water company investment must be shown to be supported by customers."*

Despite this government still seem to be using water companies as a tool to deliver environmental goals.

*"I think the way that things had been set up at the moment it is much easier to target the water company to sort it rather than to tax certain products or do it in another way."*

Another comment was;

*"we are a bit like a sort of useful tool on the end of a long stick government uses to prod things around."*

Surprisingly, however the environmental regulation or the use of the water companies to try to implement the Water Framework Directive (WFD) and improve the environment did not seem to be resented. In fact, legal requirements of regulations were welcomed as a way to achieve wider environmental improvements which would impact upon their own ability to deliver drinking water, fulfilling quality regulations. For example one comment was

*"you need that formal regulation so that you can go to Ofwat and say well we have to have the money to do this because it's a statutory requirement. And to be honest that's the only way… You need some sort of legal framework to be able to do it. So it's difficult."*

Another aspect of the regulation desired was so that they could go to their own directors and shareholders and change the way in which things are done justifying the change as it has become a statutory requirement. For example,

*"so they, the directors, want, if you've got like 2 options ..... One of them is guaranteed and the other one is well we should do some catchment management, which works most of the time, even though that might be more cost-effective, they, the directors, always go for the guaranteed control measure."*

In direct contradiction to this, the same interviewee mentioned how everything had to go through costing and be put through an affordability test and cost benefit analysis. The timescales were seen as a definite problem as well.

*"What we're trying to argue with our board is... It's about creating resilience within the system and that will help if we can really understand our catchment and target the real*

*problem areas which will help in the future, protecting our sources and safeguarding them putting in resilience and protection against residual pesticides and chemicals that we are not even aware of yet."*

There is a definite move towards a catchment-based approach (Allan, 2012, Ofwat, 2011, Yorkshirewater Services Ltd, 2014, Yorkshirewater, 2014) from the water companies; this is predominantly driven being by regulation such as the WFD. All of the interviewees were aware of environmental projects and pilot scale schemes being undertaken by other water companies as well as the measures and schemes been implemented by their own company. Most of these pilot scale projects and investigation were being implemented incrementally. A key driver which was identified was when something became the water companies' problem. For example a pollutant being present which could only be removed by using land management practices rather than the standard bolt on solution at the treatment works which engineers, it was mentioned, are more comfortable with. Metaldehyde being a case in point,

*"the reason we are looking at catchment management now it's because of things we can't remove like the Metaldehyde, which potentially we could using reverse osmosis, but it's incredibly expensive."*

The water companies do have to take environmental responsibilities seriously due to the national environmental programme which is a statutory program for the water industry and also includes a statement about the water companies' social obligations (Ofwat, 2014a). Some water companies are landowners others are not, and they take their responsibility to land management requirements very seriously (South West Water Limited, 2010). One company, giving an example of SSSI sites;

*"We operate a number of SSSI sites of strategic interests and those are at threat status for nutrient quality, so the issues we would want to address is twofold one is, the actual regulatory obligations to which used nutrient levels to meet targets and the framework directive for SSSI sites."*

Another manager felt that their ownership of large tracks of land was very useful to enable them to control inputs into the water so that they did not have to remove them at a later point.

*"We are very, very fortunate because for underground resources we own an awful lot of the catchment, and… we own forest… and we don't allow any chemical use because it's not grazed. It's very rigid what goes on there. So we don't have any water quality problems. We just pull the water out and add a bit of chlorine."*

This demonstrates that although there is a propensity towards bolt-on solutions within the water industry. The water companies do use land management practices where they can to control what is put on the land. Again pilot projects were mentioned in particular "upstream thinking" which is the land management practice, in a number of different water company catchments throughout the UK (Ofwat, 2011, South West Water Limited, 2010) There was strong recognition that:

*"every single catchment is different. What works in one doesn't work in another."*

Also, there is a wide degree of variability in the resources and assets that are available to the water companies and what they can do with these assets.

*"We are obviously put under pressure not to increase prices."*

One company was even considering buying a whole catchment to prevent inputs as it was recognised as the most cost effective measure but it was also acknowledged that this would have an impact on food production. This highlights the potential conflict between ES, where one stakeholder is interested in maximising a specific ES, which comes into conflict with the ecosystems ability to deliver a different ES.

The interviewees from the water companies could all see the possibilities for PES schemes within this context, however, felt that it would be difficult concept to sell within the current paradigms.

*"Because, you know all of our training tells us that, our knowledge, it's obvious, but to engineers, it's not, as they'd much rather put a bolt on to a treatment plant which is much more comfortable for them, so it's all about trying to get it into a language which they are comfortable with."*

In addition to the requirement for all measures to be costed, pass the affordability test, placed within a business plan and withstand the scepticism of shareholders who are concerned that they may be

*"…taking on everybody else's problem."*

Another big issue for this sector is the problems of exclusion of people from the benefit, and fairness. This was particularly the case of the water companies who were worried about being able to justify being involved in a scheme which could be spun in such a way that could potentially be seen as unfair.

*"Should water customers pay for farmers not to pollute their drinking water? If you are a farmer who is really not polluting would you miss out on this payment? Is it fair? Would customers think it's fair?"*

Although these questions are not directly relevant to the problem of metal mine pollution they do speak to the principle that the polluter should pay and the concept of responsibility. Additionally, exclusion from benefits would also be an issue and whether water companies should be paying for certain benefits even if they are a side effect of a specific benefit that the water companies are paying for.

*"The biggest single blocker to PES schemes is that the benefits are very, very diffuse … Working out who is receiving the benefit and therefore who should pay for it becomes so nebulous"*

A significant problem identified was being able to communicate the concept of ES.

*"Nobody has at the moment even the most rudimentary understanding of what ecosystems are and therefore the notion of paying for them becomes fantastically difficult."*

This negative attitude about people's willingness to pay was quite pervasive throughout the water companies, which is understandable possibly as a result of the attacks made upon them by politicians and media about the cost of water and the profits that the water companies are making (The Environment Food and Rural Affairs Committee, 2013). All the respondents from this sector did feel that public education and media preoccupations could have the potential to make people more willing to pay for these sorts of things though their water bill. One manager expressed frustrations,

*"…biodiversity is fundamental. We are simply a part of biodiversity ourselves as species and trying to explain to someone that actually means it's worth the exchange*

*rate that we use for currency as a species. There is an enormous gap there and I think it will probably be at least, at least, a generation before it is starting to be bridged properly."*

When the example was given about the issues surrounding honeybees and how the UK public had rallied round with this issue (in reference to BBC website article (Black, 2010, BBC, 2013a)). The response was,

*"...yes, there is a gradual growing awareness that something like that might be of value."*

And in general the importance of public awareness and education not only about biodiversity and the natural environment but also about how the water companies operate within the wider community was seen as of vital importance and felt would be of great use to their companies to help with the public perception of water companies and their

*"...unfair profiteering."*

Indeed, they felt it was this attitude which prevented them from acting in a more environmentally beneficial way and being involved in schemes such as PES as this was not

*"...the water companies' role".*

Partnership working is an initiative, mentioned by some managers, water companies are being encouraged to take part in. An example of this was given

*"...to deal with the Flood Waters Act, within our area there are twenty-one local authorities and three people at our company to deal with this flood waters act. So if they attended all the local authority meeting this would be a full-time job in itself".*

These requirements were often seen as getting in the way of the water company ability to fulfil its fundamental role of supplying clean and safe drinking water. Additionally, the partnership schemes were seen to be very difficult to manage as

*"…there is a massive mismatch between the water companies' knowledge and skills and the expertise and expectations of the partnership organisations especially if they are enthusiastic volunteers"*

It was also acknowledged that some partners may possess knowledge, skills and expertise that the water company did not have. The biggest problem with this partnership working was identified to be the

*"…disproportionate amount of time required by liaison with potential partners".*

Liaison with different organisations and groups which was supposed to be part of involvement in PES schemes was perceived to have 3 main problems by the interviewees from the water companies:

- Mismatch between skills, knowledge and expertly between the water companies and the partner organisations.
- The large burden on time and resources.
- Managing expectations of potential partners, they may have an unrealistic idea of what can be achieved.

All of which was felt would compromise the everyday purpose of water companies. When it was suggested that a rigorous and clear process, such as the framework being proposed, could be used to ameliorate some of these issues, it was agreed that it would be helpful to have a clear framework to follow and hence manage the process.

Respondents from all the three sectors mentioned the principle of "polluter pays", as previously mentioned, there is no legally liable party for mine sites closed before 1999. Despite this, it was felt that those who had benefited from historic metal mining should contribute to its cleaning up. One anecdote, that a government minister from the previous administration had given a speech in which he claimed that the moral responsibility for remediating abandoned non-ferrous mine sites lay with the UK government and "UK plc" because the Industrial Revolution from which the country is the whole benefited was built on them. More directly the metal industry itself may be seen as a source of funding for remediating these sites. This industry has declined significantly in terms of active nonferrous metal mine operations within the UK. An expert from the nonferrous metal industry stated that

*"I don't think that there's been a commercially viable lead and zinc mining in the UK for 50 or 60 years, probably 100+ years, because there are other mine bodies which was so much richer and bigger and your economies of scale come in."*

The interviewee identified the large metal recycling sector,

*"but none of those people would pick up and identify with the historic mine pollution"*

and would have no incentive to act unless they were legally liable to do so. In addition to that the metals processing sector in the UK and Europe is

*"10 or 11% less competitive compared with industries outside Europe. Nobody will buy from Europe in the UK, for example, we had three aluminium refineries, two of which have closed down due to energy supply[5] issues, not economics. So the metal industry generally is not making big margins."*

Minco plc is currently conducting exploratory drilling in the North Pennines to assess potential zinc and lead deposits below previously historically exploited seams (Minco plc, 2003-2014) Which suggests that there may be some scope for a commercially viable mine were the deposits to be significant enough; currently the closest deposit being exploited is zinc in Ireland, which is approximately 2 to 3% of the global deposits. So the bottom line of the metals industry's attitude towards contributing to legacy nonferrous mine pollution:

*"…my initial response would be that they wouldn't be very interested at all, simply because the margins are pretty tight.",*

this was given the caveat that:

*"…some companies are more interested than others and some companies are doing the remediation, because they literally do not have any choice because of their legacy issues."*

[5] the energy supply issues that were being referred to was the price of electricity in the UK and Western Europe

The example of the US was cited here specifically Rio Tinto, where legislation has forced the company to act. If for example the current exploration efforts in the UK are successful, this potentially provides a commercial incentive for companies to invest in historic mine remediation, as it would act as a testing ground for technological solutions to site remediation where it is a legal requirement for the company to act. At sites where there was no legal requirement for a company to reduce pollution input to within the legal requirements different solutions could be trialled, assessed and experimented with. To identify the most cost-effective approach to take without any fear of failure resulting in punitive measures being taken against the company by an enforcing body. When it came down to collaborative work the "polluter pays principle" was seen as a risk of working with other organisations. The assumption was that:

*"I can tell you sure as eggs is eggs, they will point the finger at industry and say you did it, you've got to remediate, you've got to pay for it…..they go back to the polluter pays mode, which is a lovely phrase, which is everything is industry's fault, but no it isn't, and there is a cost to be paid."*

One of the requirements that the industry representatives thought that any framework would require would be a rigorous and robust measuring regime taking into account the other contributions to metal pollution within a catchment e.g. wetting/drying, flow regimes additional sources, natural variation, to capture what's going on in the system overall. The metal industry consensus is that the

*"EU has a tendency to be very conservative, industry would say over conservative, you might be finding a problem where really it's nowhere bad as it is, or even there is no problem at all."*

This need identified by the metal industry representative, for a framework to bring together:

*"…a number of strands that need weaving together to completely encompass the problem, and therefore to really look at what needs doing."*

The very nature of PES schemes means that there is a requirement for ongoing monitoring and the initial scoping exercise to understand the site would require a detailed understanding of additional inputs to decide whether or not it was a worthwhile approach to tackle a specific mine site. How these aspects of the framework are to be achieved is explained (Section 1.6 and Section 9.5) and where there is scope for improvement and gaps in knowledge in the current monitoring regimes, data and approaches is critically assessed, and potential solutions argued for/proposed. Involvement with other organisations within a catchment with specialised knowledge associated with the area would contribute to an understanding of how river systems function; its inputs and stresses. This information as well as the post installation phase would harvest vast quantities of data which would improve the understanding of the contributions that mine is made to the metal pollution problem in addition to quantifying the impacts that these metals have on the ecosystem (E A, 2014, Large et al., 2007, Brown et al., 2008, Gollan et al., 2012, Bouleau and Pont, 2015). This would also be an iterative process with the data harvested after the technology was installed monitoring how the area changes over time. All of this information could strengthen industry's case that the Environmental Quality Standards (EQS) limits need to be more nuanced so reducing costs to industry by demonstrating that the current emissions of metals allowed into the environment do not take into account the natural variation over different time periods and how this potentially impacts upon the allowable levels of metals entering a system from industry. So understanding how EQS levels relate to the biological profile within a river system (Verdonck et al., 2014, Merrington and Van Sprang, 2014, Bouleau and Pont, 2015).

*"You find that people are talking about no effect concentration or EQS limits which are based upon a cumulative conservatism in generating your EQS standards, you could be saying that there is a problem when there isn't one, and that's correlation of actual biological profiles of your biota in your river system compared with your EQSs, so you think according to your EQS, you should have little fishes dying left, right, and centre and you're not."*

This idea that not everything is industry's fault was highlighted by the industry representative and seen as key to remediating metal pollution within water bodies, that is identifying the other sources of metal inputs within an catchment and recognising that legacy mine site pollution is only one facet of a complex and diverse range of inputs into a system; parameters need to be identified and quantified, the variables accounted for and understood to determine the impacts that in order to determine the input is actually are so that EQS levels are meaningful.

Quantification was something that was mentioned several times in relation to understanding the system in terms of metal inputs and impacts, but also related to being able to quantify the change from any action taken and hence quantification of the benefits and place an economic value on these.

*"If you get the monitoring and statistics right, so that your numbers really mean something that is to actually positively identified cause-and-effect, and therefore can quantify what you're doing, and therefore can put a cost onto it."*

Using quantification and numbers to see what's changing whether or not it is of benefit:

*"…because you don't want to spend money if you're not actually making a difference."*

The other barrier put up by industry towards paying for environmental benefits stated as

*"My personal view is well when you say somebody's got to pay for it, pay for the environmental benefit, that's really nice, but I really don't think you'll find many will take that on board… I think that it is a debate that is absolutely essential to have, but I think that you will find it very difficult, very difficult to pick up a couple of groups and say well you pay for this, because you're getting the benefit from it.... In many ways, everybody benefits from the environment"*

It again came back to an emphasis on putting numbers onto the whole framework in order to convince people to invest in remediation. The industry representative seemed to think that the key is quantification in terms of impacts and economics. Presenting it as a whole;

*"That's why you have to put the bigger picture in and say you what it is going to do, then you come back with what is the real impact.  Putting together technology with the numbers and running costs."*

So although the initial reaction was that industry would not be interested in funding such projects and that

*"…central government funding for doing it..."*

would be an industry preference, there does appear to be valid reasons why industry should be involved in this sort of project and also widely it would be a financial value to them beyond purely the philanthropic and corporate responsibility ethos. The metal industry would be receptive to a robust argument:

> *"As long as you can put something into framework and quantify it, what it's going to cost, skip the emotional Greenpeace, Friends of the Earth stuff, put it into hard chemical engineering, financial terms. It's perfectly valid to do something to pull all the cases together, come down here and say this needs doing. This needs doing. I think you'd find fertile ground. If you do a good enough job, I think you'd find fertile ground and open ears to say, this is what needs doing............. they want to know how much for what gain?"*

### 4.3.3 **Government Agencies**

The interviewees from government agencies were drawn from both the administrative sector with an overview of the relevant areas and also "on the ground" experience; that is individuals who deal with issues, such as monitoring, delivering projects on the ground and contractors in the field and any issues that arise, when trying to deliver the statutory obligations which it has to fulfil.

The current context for the Environment Agency in the UK is that it has to cut 15% of its staff by October 2016, which is as a result of the £21 million cut in its budget between 2013/14 and 2015/16 (HM Treasury, 2010). It is within this context which the interviews were conducted and as such the Environment Agency needs to find innovative new ways to fund the delivery of its statutory requirements. This climate of "austerity" has resulted in a requirement for a strict hierarchy of priorities to be developed in order to meet its statutory obligations as well as fulfil the political pressures that are placed upon it by government ministers.

An interviewee from this sector acknowledged that they are very targets driven and view their own issue as the most important often meaning they are very reluctant to acknowledge or listen to other stakeholders priorities or concerns, especially if they are perceived to conflict with their own targets. This is quite problematic from a balance of power point of view. As this framework requires cooperation between the parties and as such an imbalance in power could potentially prevent the framework from being delivered. The imbalance in power here comes from the fact that the Environment Agency has statutory powers which mean that it can force its own priorities on landowners, for example, to force them to comply with legislation. In the case of abandoned mine site remediation, there is no liability, so this potential problem of power imbalance does not come into play. PES schemes can only be justified when there is a legislative failure which means that alternative motivations need to be employed in order to solve environmental problems highlights the potential for this framework to contribute to the WFD purpose of ensuring that all water bodies meet good ecological and chemical status by 2015 (Vlachopoulou et al., 2014, Bouleau and Pont, 2015, Hüesker and Moss, 2015).

An interviewee explained the way in which the Environment Agency works when assessing whether or not to tackle an environmental problem. This is done on a benefits assessment model in which the decision whether or not to act is based upon a cost-benefit ratio where, if the ratio is between 0.5 and 1.5 or around a particularly contentious issue then further investigation is undertaken following the benefits assessment guidance (Shamier et al., 2014) which is the process developed by the Environment Agency. This process is based upon the national willingness to pay survey, which was conducted in 2007 as well is its updated version from 2013 (Environment Agency, 2013).

*" but basically it's a database or spreadsheet which has been put together with effectively, 1000 people were interviewed a few years ago and were asked how much would you be willing to pay to have a clean environment, a clean water environment and that was a mixture of people from urban areas rural areas and different socio economic classes and that type of thing. And a clean water environment and how that was described was used to try and map those results onto current conditions of waters and how much people would be willing to pay on a per kilometre basis conditions. And this was then divided up into status classes, so poor, moderate, good, high sort of, so what we're doing now is doing is these benefit assessments, where we look at so if you've got 10 km of river in particular management catchment, rather than, as you know there are four and a half thousand water bodies in the country which are divided up into, I think it's hundred or so management catchments, and those numbers, the cost of getting from moderate to good in those catchments per kilometre varies. I don't know how they've done it, but it's a function of the type of the catchment and rural variability in that type of thing. The way that we do cost benefit assessment at the moment is that the willingness to pay survey is supposed to have some element of*

*monentarizing ecosystem services in a very sort of implicit way rather than explicit. And that has been used as a sort of 1st pass, and initial screen,"*

It was highlighted how vital the cost benefit ratio number is as one interviewee explained.

*"But when the accountants actually make a decision as to whether something is of benefit or not the only thing they look at, the only thing that they care about is the number… and if it is above or below the number that they are using as their cut-off. The fact that that number is known to be an underestimate because you haven't properly quantified the total benefit, frankly, is irrelevant."*

In addition to this arbitrary cut-off that has been created, projects are much more likely to have funds released to them if they are in collaboration with other organisations with beneficiaries contributing to the costs.

*"One of the clear priorities that Defra has given us on metal mines is that priority should be given to schemes where somebody else contributes"*

One respondent felt this to be a definite pressure from Defra, although at the moment as there is a funding package until 2015 specifically aimed at meeting WFD targets,

*"we've had a four-year package which is all paid for up front, effectively, so we haven't had to think of other sources, although Defra are trying to pressurise us at the moment to look for match funding amongst beneficiaries, I suppose we do do a bit of screening when we look at these schemes and think who is directly going to benefit"*

When asked specifically about working with private companies. It was acknowledged that

*"…certainly the party line is that we will be completely open to it."*

However, there is a caveat to this position, it was stated that there would need to be no conflict of interest or it seem as if the government was promoting a particular company.

*"As long as there weren't strings attached to it that were going to be difficult for us."*

It was felt that this was a presentational issues and perception issue that could potentially be a problem for the public to accept this method of funding, again coming back to the problems surrounding communication to different groups of stakeholders, which include the general public as taxpayers and voters. Credit was given to the work done by active mining companies which have made these sorts of collaborations and corporate responsibility more acceptable,

*"I think mining companies worldwide, active mines, are changing and have changed. They do a lot of work on paying lots of money to local communities to make the communities better, happier places as an offset for having a mine there and that seems to be a fairly well established thing."*

The Environment Agency has undertaken successful collaborations with other organisations to remediate the pollution from some abandoned metal mines, although not as yet specific PES schemes. An example of a successful collaboration is an agreement with the National Trust in the Lake District which has resulted in an "in-kind" arrangement around access to land (Brassenwaite Restoration Program, 2010, National Trust, 2014). As the landowner the National Trust has specific responsibilities for the scheduled historic monument on the site, its preservation and maintenance. They have accepted the responsibility to take action for a severe pollution problem that has resulted from a collapse and flooding of the lower levels of the mine, resulting in a high level of risk of outbreaks of highly polluted mine water. An interviewee argued that the National Trust made land available for the Environment Agency's work as they recognise the need for it, but

*"they put provision aside for funding that, opening up a lower adit within the mine, so I think they feel that they can't fund our work directly. So the work we're doing, they can help us by making the land available to do the work."*

Another organisation that the interviewee had experience of working with was English Heritage whom it was felt to talk quite a pragmatic attitude as:

*"…they don't have any money to restore any of their sites."*

It was explained how some of the treatment methods, using ponds , for example, use existing tailing dams, which are on site already *"so you end up with a pond which is as it would have looked originally so emphatically not changing the site significantly, so it's a really nice coincidence if we can do it, that means that English Heritage are interested and quite happy with what we're doing and the National Trust are interested in the site because they have an interest in the history of the site any way. So it's worked really nicely."*

When visiting a mine site, a comment was made that English Heritage had required that where work was done it was made obvious that this was a modern intervention. This was around a deteriorating retaining wall, where there had been significant quantities of material released into the river system, which required stabilisation.

*"We are stabilising the wall which contains the tailings and that should benefit us because it will reduce the risk of material getting into the river, but it will benefit English Heritage because it will restore a scheduled monument so again you've got a double benefit."*

This sort of situation, where the direct benefits to them are made explicit, seems to be more about explaining to English Heritage, why they should let work go ahead, rather than them acting as a roadblock to any work taking place. The respondent said that it was important to work early with people who may be impacted by any work taking place.

*"That's fine as long as we can retain what we want out of scheme and then we can build back into any work that we do and take it into consideration. It makes things easier in the long run because all the different groups can get something out of the project."*

This response seemed to hint at problems in the past where impacted parties had objected to work being undertaken to take action on these polluted abandoned mine sites.

When thinking about benefits in terms of ecosystem services and partnership working, an interviewee cited a project currently taking place in the Yorkshire Dales in conjunction with the North Pennines Area of Outstanding Natural Beauty (ANOB) Partnership around peatland restoration (North Pennines Area of Outstanding Natural Beauty Partnership). The respondent linked it to protecting scheduled monuments, reducing pollution, in addition to the ecological benefits of the project.

*"They want to protect their assets effectively, it's in our interest to help them, it makes sense for us to work together on things that may help as to reduce highest peaks of rainfall flood events effectively, which clearly then ties in with all the stuff on peat restoration and peat gripping and all that kind of stuff. And also, it may be that one of the best ways of reducing the diffuse pollution in some of these metal mine impacted rivers would be to do peat grip blocking."*

Thinking about projects at catchment scale, it was acknowledged by the respondent, has been prompted by the WFD. The comment was made

*"I think it has improved us down that path, but the sense I have certainly with the Environment Agency is that we tend to be, we are necessarily focused on particular pressures, so I'm focused on metals, I'm not focused on peat-related things."*

Another interviewee, when directly asked about whether or not they "liked the WFD" said that what it was trying to achieve was good and it was definitely needed, however, seemed quite repetitive and bureaucratic. A legal mandate of article fourteen of the WFD is that the stakeholders should participate in drafting the River Basin Management Plans (RBMP). In an assessment of this process it was found that England and Wales were successful in meeting the requirements for the management plans for each River Basin District (RBD) publishing the plans on time in 2009 and including all the required information (Benson et al., 2014), many participants felt that the whole process was centrally determined by the Environment Agency and was a box ticking exercise rather than a truly inclusive and participatory. This emphasises the point made by the respondent about the Environment Agency being focused on its own agenda, and getting the job done and meeting targets rather than assessing the benefits of doing things differently and working more inclusively will with other stakeholders. When asked about the importance of communication between different stakeholders and explaining different priorities and points of view coherently to try and change this mind-set. The reply was:

*"It's huge, it's huge. We'll get focused on our own little bit and it is something that is difficult to look at wider, and even though obviously we say we will do, everyone just gets head down. Things have been made fairly simple for us, I think that if we're honest about its worth changing what we have traditionally done."*

This is a major problem for a government agency which has to complete a certain task to meet legislative requirements, it becomes about the process itself rather than what it was designed to achieve. This is one of the advantages of the framework being proposed here, using LCA integrated with PES. Stakeholders with a vested interest in achieving a their own goals have to negotiate and cooperate with one another to achieve a balance between the different priorities, giving a purpose give to each of the processes that make up the framework rather than the framework being a "box ticking exercise". The framework is a pathway to achieving improved ecosystem services and each individual stage should foster engagement between the different participants and understanding of how their different priorities interrelate and affect each other, to achieve the negotiated goals of the project. Fulfilling the need as expressed by one interviewee;

*"It's just if the potential benefits of working together could be described better, then it would be a clear reason to work together even if it's just one organisation, let alone different organisations."*

The drive towards a more catchment-based approach could potentially enable government agencies to communicate to potential investors in mine site remediation a tangible and quantifiable benefit to them.  As one interviewee expressed it:

*"…and to me that's the difficult bit of all the cost benefit stuff, costs if you do your sort of standard engineering approach, costs are fairly easy to come up with…., benefits are a difficult thing to confidently quantify, it's a kind of black arts."*

By taking the catchment as a whole, it can be demonstrated that acting in one place can have direct benefit for stakeholders further down the catchment. For example, if the dilution capacity of the river is reduced due to the inputs of metals higher up the catchment, then it would be more cost-effective for a water company to act at the source of the pollution rather than trying to deal with it at their extraction points, additionally

*"…it would be more cost-effective to treat a water companies lower down the catchment or other industrial polluters to actually clean up at the metal mines at the top of the catchment as it would allow them not to do anything at their site because they would have created extra pollution capacity."*

This is a something of direct commercial benefit to companies and search is quite useful to be able to demonstrate.  As has been expressed by a number of interviewees "what is the most cost-effective way of cleaning things up?” Research into this issue has been undertaken by the UK water industry, research group (UKWIR, 2013) and they have found that on a cost per metal removed it is much more cost-effective to deal with low-volume high concentration rather than high-volume, low concentration. It was pointed out that

*“that sort of thinking is certainly been done by the water industry and that is then informing the Environment Agency’s and Defra’s thinking on what makes most sense.”*

This demonstrates a potential receptiveness to doing things differently and this framework does offer a potential way of doing that. However, bringing together a range of different stakeholders who all have different priorities would seem to be problematic because

*“but equally I think it’s also because most of the think that we do know everything, and that our issue is the most important issue and that we know how to do it and listening to other people’s issues and other people’s views on it isn’t always something that you want to spend time doing.”*

This can act as a serious roadblocks to anything actually happening and this attitude was also expressed by interviewees from the from the water industry as previously stated they saw three key problems (see Section 4.3.2);

- Mismatch between skills, knowledge and expertly between the water companies and the partner organisations
- The large burden on time and resources
- Managing expectations of potential partners

All the stakeholders, seeing themselves as the experts will not necessarily therefore be overly receptive to other partners’ views. As such, it is vitally important to identify common areas of interest and direct benefits to all the partners showing how working in new and different ways can have a quantifiable and positive impact on their own activities and priorities. A GA interview did see this framework as a possible solution,

*“I think that you do need a framework, the problem is, you need to make it worth people listening to you. You’ve got to get the window of opportunity to get people’s*

*attention to listen and change how they might be doing things before they start to switch off."*

Although the catchment-based approach has this clear advantage of enabling a linking of different parts of the catchment thinking at this scale was problematic for some potential stakeholders such as the Angling Association.

*"the scale that they were looking at was much, much more localised as in, you know, a few hundred metres the stretch of the river they go to and this stretch of the river they fish in and things like that and that's the focus and that's completely reasonable, then it had to try and bring together the Environment Agency's views which where tens of kilometres scales and marry those up and decide actually what should we go forward with?  It's very difficult."*

This has been found in a number of other research papers that operating at different scales can be problematic for different stakeholders (Artell et al., 2013, Schaafsma et al., 2012, Jorgensen et al., 2013a, Everard et al., 2014, Hoyos et al., 2015, Hüesker and Moss, 2015) and their perception of what is of value, and what they are willing to pay for. This aspect was something that GAs were very conscious of perhaps because of the pressures placed upon them by politicians and the requirement that they walk a tightrope between politicians, acting as an arm of government, their statutory obligations and the public's perceptions of how their taxpayers money is being spent.

*"Metal mines tend to be in beautiful parts of the country, national parks and that kind of thing, clearly people are quite comfortable going to these places and why would you need to pay anything to clean them up?"*

Other stakeholders' attitude towards the Environment Agency was identified as a problem.

*"It's precisely because we prosecute people, which doesn't exactly always give people the best view of you.  So having an independent party to pull people to pull people together, I think that's a being very clearly taken on board… for the current delivery of the Water Framework Directive."*

This has been demonstrated to work in the case of the Environment Agency working with the North Pennines Area of Outstanding Natural Beauty (ANOB) partnership to enable different stakeholders to work together to build trust between them. This is an integral part of the framework being developed, trust and the need for "ethical brokers" is clearly something that the interviewees from GAs identified and the need to build up trust between different stakeholders.

*"I do think at the moment we are on a bit of a roll and things seem to be working quite well and we seem to be being accepted as an organisation in what's going on and trusted."*

So the role of an ethical broker within the framework that is being proposed here, clearly, is an important role beyond purely bringing together different partners with different needs that can also act as a buffer and help foster trust and effective communication between organisations. Also, interviewees from the GA sector identified public awareness and education is vital to inform the public of what the benefits that these schemes could potentially deliver, and how this would benefit them. Public opinion feeds back into government policy, as was seen in the case of the increased public awareness of reducing numbers of honeybees[6] and also the policy of the national forests sell-off, where policy was changed[7],

*"I think that would help us all to decide how much effort we should be putting in and what is the end goal that we are trying to get to."*

The GAs had an awareness of potential conflicts of interest between stakeholders, in particularly where obligations of one piece of legislation clashed with another. For example, in the case of preserving SSSI sites. One example which was cited particularly to do with metal mines, is rare metallophyte communities which have SSSI status (Allen Valleys Landscape Partnership, 2010a), the development of these communities has often resulted from the existence of metal mining in the first place so

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[6] The UK government accepted the EU ban on neonicotinoid, despite disagreeing with the science largely due to public pressure BBC. 2013a. *Government rejects the science behind neonicotinoid ban* [Online]. London: BBC News. Available: http://www.bbc.co.uk/news/science-environment-24024634 [Accessed 10th of September 2013 2013].

[7] UK Government policy changed from selling off national forests to not selling them off due to public pressure in 20120 and2013, BBC, S. A. E. N. 2013b. *"No sell-off" for Public Forests* [Online]. London: BBC News. Available: http://www.bbc.co.uk/news/science-environment-21275432 [Accessed 1 February 2013 2013].

reducing the levels of metal inputs will have a direct impact on the survival of these communities.

*"Downstream of mine site you've got SSSIs, which are protected..., we have to take that into consideration."*

The sorts of conflicts require working with the partnership organisations where again this framework where stakeholders have clearly defined roles could help to manage these problems, bringing in possible solution such as biodiversity offsetting and recreating habitats in different locations.

The key concern of the GAs is

*"for me it's all about how do you quantify or monetise the benefits that you get so you can justify the change or the way to persuade people. And that's, for me, the real difficulty to overcome."*

This echoes the major preoccupation expressed by the industrial sector, particularly the metal industry sector, who also said that it was of vital importance to be able to quantify benefits and give them an economic value with a "real meaning", which can be demonstrated. The ability to quantify the economic and environmental benefits is fundamental to the framework that is being proposed for this research.

The other fundamental sentiment expressed by the interviewees from the GA sector was their desire to improve water quality, and hence the environment and they felt that the framework being proposed could potentially be a tool to enable them to do.

*"I guess what I want to do is help to communicate it better to help to describe why we think it's important, and then how and what the benefits are."*

### 4.3.4 Special Interests, Conservation and Stewardship Organisations (SICSO)

The most diverse group of the stakeholders interviewed was the special interests, conservation and stewardship organisations (SICSO). Five interviews were conducted with members of this sector. Some of those interviewed had experience of working with

PES schemes and developing best practice frameworks and guidelines for PES schemes. This group of stakeholders had no statutory powers, but each had an agenda, in terms of the purpose of their organisation and who or what it represented, be that to anglers, wildlife or maintaining the environment to preserve it in a specific way. The range of focus of this group was also broad, from a specific activity or species to a geographic area and everything contained within it. This group contained stakeholders that could be classified either as "brokers" or service buyers. Although in some cases, where groups were willing to supply volunteers to help deliver a scheme, this line blurs and they could be defined as service providers as well as directly benefiting from the ecosystem service that they were helping to provide.

The interviewees from SICSO sector predominantly had backgrounds in ecology and environmental science though not exclusively so, some coming from the management background, their specific areas of expertise, experience and interest varied greatly. The individual interviewees had a diverse range of knowledge and experience with PES schemes depending upon the purpose of their organisation and their role within that organisation. All of the interviewees from the SICSO sector were familiar with PES schemes, indeed facilitating such schemes and developing best practice guidelines was the primary role of one of the interviewees.

In one case an interviewee had been expected to compile a study assessing the feasibility of using a PES scheme for a specific stretch of a canal, without any previous experience in this area and had found it quite difficult to understand what was actually required:

*"I was new to the whole concept of this so I thought I'd go back and look at some of the studies that had already been completed and I was a bit surprised actually how woolly and kind of vague they really were."*

The interviewee felt that this was because these reports had largely been compiled by consultants

*"so in our experience a consultant came in to do a study about the canal but with very little knowledge about how the canal was managed, so it's up to us to feed them the information and I think that's quite a flawed approach and when the time scales are bad and we were all fairly rushed, consultants tend to fall back onto the areas of knowledge*

*that they already have… They twist the focus to areas that they are very comfortable with which is understandable but the downside is that they possibly miss some of the pure ecological things."*

When asked if they thought the proposed framework would be a good way to circumvent this problem they went on to explain

*"If you had a really good template or framework that's very, very direct that allows people to take the essence of what the larger concept is then you get a better chance of success.... I think the important thing is helping people, who like me, have the whole thing thrust upon them, it's making it understandable in a really direct way so that you can apply it almost instantly."*

This was an area of divergences between the different interviewees, some being actively involved in the development of best practice guide lines for PES schemes being put together by Defra others despite being expected to produce reports and studies on potential PES schemes were totally unaware of the existence of the Defra best practice guidelines (Smith, 2013). This lack of awareness is surprising given the involvement of the organisation with PES schemes it could be due to the individual interviewee being expected to tackle an area that they were unfamiliar. This could be indicative of a lack of understanding within the organisation that there needs to be a level of knowledge and understanding about PES schemes in their own right, alternatively this could result from a weakness in Defra's communications strategy when engaging with organisations who need to be aware of current policy initiatives and the tools that are available to help them implement these initiatives.

The interviewee further went on to explain that it

*"…is quite a hard concept to understand, you get all these terms banded about but actually nobody tells you what they are or what they do or how they relate to something like the canals and rivers."*

At the other end of the scale and interviewee had a fundamental understanding of PES schemes and is actively involved in developing best practice guidelines and implementing PES schemes on the ground. This interviewee had a fundamental understanding of the limitations and advantages of PES schemes explaining that:

*"The key aspects and thing about payments for ecosystem services is how much does somebody want to do something. I always call it "who flinches first" who is affected most?"*

Some of issues and dynamics that this interviewee identified as being important to the way in which PES schemes and needing careful management were if you had more than one potential buyer for the same ecosystem service;

*"it's back to this "who flinches first" so you could get one person saying well I'm going to wait and then they do it and I'm the free rider."*

This highlights the need to identify all potential beneficiaries and getting them to cooperate with one another. As well as cooperation between stakeholders other influences were identified by interviewees as affecting a businesses or organisation's willingness to pay (WTP) for ES (see Figure 4.2).

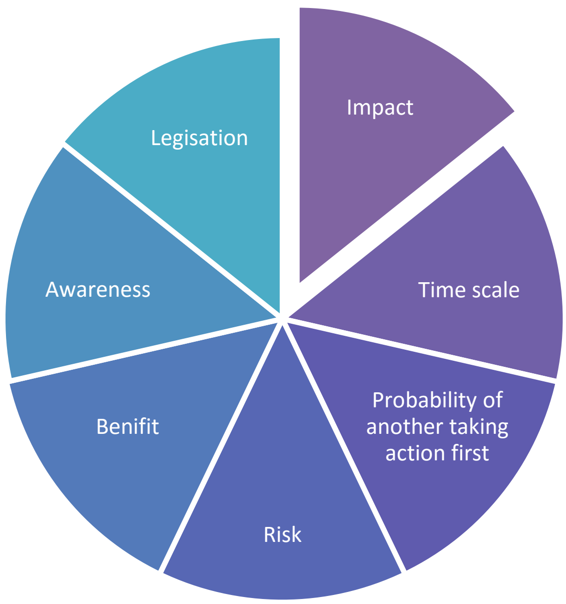


Figure 4.2: Influences identified by interviewees on stakeholders' willingness to pay for ecosystem services

A key aspect bought up by an interviewee, experienced in implementing and delivering PES schemes, was the dynamics between the different stakeholders involved in the process. A concern that was raised up by a number of the interviewees was that of excludability from ecosystem services. The complexity of having bundles of ESs delivered from one management practice or one intervention was seen but as both an asset and a difficulty when explaining to potential ES investors why they should become involved with such schemes, potentially increasing the likelihood of multiple buyers becoming involved.

*"...we picked the story to sell to the individual potential funders"*

These management practices can be difficult to communicate especially in natural systems where uncertainties in the quantification of the benefits to be delivered are inherent.

*"As a scientist, you will be very well aware of the difficulties of communicating the uncertainties of things, you see this in the news every day."*

Another aspect of this non-excludability was that of free riding due to the impossibility of limiting access to ESs to only those who have contributed to delivering the improvement in their functioning.

*"So though me what you need to have is that conversation about who benefits and why they benefit, but most of the interventions that we want to put on the services aren't easily excludable"*

This was seen as a problem by all interviewees when it was raised and is often seen as an issue of "fairness" but also one of commercial importance. Why should one commercial enterprise pay for improvements that could benefit another, essentially subsidising another company? One way to circumvent this was explained by an interviewee with the process of holding reverse auctions highlighting an example where farmers put in for bids for grants to undertake structural improvements and manage their land to enhance ESs which benefit South West water.

*"so we found out how much the farmer would have paid (to improve their farms) compared with what South West Water could have paid (to remove the pollutants) on the dynamic spectrum"*

Both parties here are gaining and they have come to an equitable and commercially justifiable agreement circumventing the "who flinches first mentality".

Another interviewee was also very focused on the problems of exclusion from benefit, and the need for recognition that these things do have an economic value but communicating that effectively is difficult and complex.

*"I suppose people buying the services, whatever they are, would be expected to pay for this something that they are currently getting for free and I think that that is the main problem. I can see a fairly sizeable battle ahead and its political decisions as much as anything else, whether as a society we want to go there or not."*

Getting people to accept that these things actually need paying for was viewed as a big problem. For example the public accepting that they would have to pay 10% or 5% more on their water bill because a water company is investing in a metal remediation scheme and not recognising that this could potentially be better value for money due to a lack of understanding about how ES deliver benefits to the wider environment.

*"Where do you spend your money where don't you spend your money? Because in an ideal world you would probably restore everything to have a completely working ecosystem that part of the working ecosystem is that things collapse other things grow."*

The importance of businesses being made aware of how environmental considerations can have a direct impact upon their productivity was highlighted as a way to interest potential stakeholders in investing in PES schemes. In particular getting businesses to think about what is on their risk registers, which often don't include the way in which breakdown of ESs can affect their bottom line. This conversation becomes easier there events such as the recent storms and flooding in the UK in late 2013 and early 2014 when awareness of the way in which the natural environment can impact upon business operations, be that from direct or indirect impacts, become a reality.

*"…it's only a hop and skip from being administered reactively to people who act proactively, so again it's just having a conversation with them"*

However the interviewee had found that with businesses it tends all to be about

*"…if your business is all about short-term gains then you won't look at any long-term solutions"*

A remedy to this was seen by many interviewees as legislation, both by commercial and non-commercial organisations. This was seen as a way in which to raise awareness and change attitudes towards issues that many businesses and organisations were unaware of being a problem as well is a way to change behaviour.

*"When there are legislative drivers and things that come down that change business mind-set that can have a profound effect. Once you have those sorts of drivers then businesses proactively seek the solutions. When the legislation comes in and that's when they start doing."*

Legislation was also seen as a justification for costs imposed by ways of doing something, for example with water companies the catchment based approach. This was a recurring theme associated with legislation, that it enabled action to be taken so removing the need to explain the more complicated story of the way in which ecosystem services and ecosystem restoration such as the catchment-based approach to managing water to customers. Although in the short term this could potentially enable businesses to act in a more environmentally friendly way there is a danger that the customers and also the businesses do not understand that what they are doing is actually of benefit to them and their profit margins. This is why explanation, communication and understanding about what is actually being achieved in these projects is vital, and ultimately does need to be communicated to avoid the problem of this sort of legislation being seen purely as "red tape".

*"because even if they get their money back through different ways they're having to tell the story and having to do the PR role, that sort of stuff is also an added cost of course"* additionally *"it allows the blame if you like to be transferred to somewhere else and the debate to be resolved somewhere else, it's quite useful to have a scapegoat."*

It came back again to the need to demonstrate how things are of benefit and to be able to quantify those benefits. In a similar vein to the arguments expressed about the need for quantification and real numbers by the industry sector the interviewee expressed it thus;

*"so how'd you talk to business and industry to get people to see that they are part of the natural system and rewarded for good behaviour rather than bad behaviour? Again it comes down to the cold hard numbers, you need to be able to say "it will save you money and we can cost that"- are very specific to them, so by being personal, concise,*

*relevant and costed this gets them to take up our advice so it's all about showing people way is to save money to get people to take the advice cost this and then you can show that would take however long to pay back the money"*

Placing a monetary value on nature is controversial and has been debated within the literature (Jax et al., 2013, Farley, 2012, Robards et al., 2011, Suter and Cormier, 2013) and the media and is often seen as distasteful by the public (Conniff, 2012, Dearden, 2013, Monbiot, 2014). Some interviewees felt that it was possible to place a value upon nature others were more unsure. This perhaps reflects the contentious and moral ambiguity of accepting a monetary value for individual elements of ecosystems. It was also recognised that it would not necessarily be accepted that these things should be protected despite being given an economic value, as is typified by political debates and lobbying by different sectors both for and against green taxes (Environment Audit Committee, 2014). Equally these attitudes and ambivalence towards this part of the process was reflected by interviewees. It was seen as both practically and morally difficult to do, these attitudes were reflected by the interviewees, the first being reflected by;

*"I do think it's important that we try to value things because the default value is zero, the difficulty is just because you value it doesn't mean that someone will protect it"*

The second represented by an outlook that putting an economic value on nature is a fundamental problem for the whole PES approach;

*"I think that the biggest roadblock to me is putting a price on what people are paying for, I think that that's a difficulty and basing it in some form of reality, in all of this stuff were are looking for, in essence, an economic value or an economic cost of doing something which we haven't previously put an economic value on. And I find that still very difficult."*

This divergence in attitudes also reflected the approach taken by different organisations towards acting as "ethical brokers." This difference in approach to stakeholders and investors explaining the reasons for becoming involved in a PES scheme was marked. A pragmatic and economically driven approach was taken by one interviewee;

*"So again it's the difficulty understanding the problem and understanding the solution and knowing who is benefiting who isn't benefited and then if they are benefiting are*

*those benefits something that is tangible to their business because if it isn't then they won't want to invest"*

The alternative way to get stakeholders involved was to appeal to their corporate ethos and promoting projects based upon more nuanced benefits in terms of corporate image and public goodwill;

*"The route that we are taking is more; you are a corporately responsible organisation you have some corporate social responsibility, we can work together to allow you to be able to show more clearly how that corporate responsibility is being delivered on the ground"*

The interviewees had had success with these approaches again demonstrating the need for personal relationships and communications in order to choose the appropriate story to tell the difference stakeholders. Allowing them to understand the benefits in terms that are most relevant for their own organisation and what that organisation wants to achieve, be that an improved public image or an increase in profit. However there was also a fear expressed by these intermediaries that they would be perceived as blaming companies for the pollution and that these organisations would not want to be involved in remediation projects as they would see it as admitting culpability for the problem which would in turn potentially have a negative impact on the way their organisation was viewed by the public.

*"I guess that they would almost be scared that by cleaning up something they will be saying that it is their fault "*

Most interviewees in the SICSO acknowledge that the PES schemes required a three party initiative, with an "ethical broker" as a facilitator between the other two parties. The predominant reasons why an ethical broker is needed are;

- Linking buyers and sellers who are unaware of each other's services and requirements
- Preventing distortions in the market
- Acting as trusted facilitator between parties

The first of these points was expressed through an acknowledgement of the highly specialised way in which organisations have developed. That an expert in one area will not necessarily know or have any interest in another area even if it impacts upon their own. People have a single goal to achieve and they are unaware of, or unwilling to alter behaviour, to achieve this goal while taking into account the wider environment. This was identified as an issue by GA interviewees (see Section 4.3.3).

*"People's jobs are solely around delivering their objectives and it doesn't matter what impact that this has on other people.… So it's really difficult to get people to think of themselves as part of the natural system so you have a situation where people don't want to be seen as part of the system, don't care about being part of the system or even proactively rewarded for not being part of the system."*

So when a PES schemes is first being proposed the ethical brokers are in the position of having the responsibility to seek out potential participants. This can be attributed to a lack of awareness that these sorts of solutions are available and would be of direct benefit to them but also there being little incentive for business to proactively seek these kinds to ES solutions.

*"The onus is very much on us to sell not on them to come to us and that's because the drivers are not in place yet for us to push forward."*

The second of these points is related to the problems and distortions that can occur in a pure market situation. The idea around selling ES and bundles of ES is that services will balance each other out and a system will naturally come to equilibrium, however this requires that every ES has a buyer and that all ESs are equally valued. It is more usual that it is only a single a ES is being bought and sold and trade-off between ES occur (Costanza et al., 1998, De Groot et al., 2012, Hussain and Tschirhart, 2013). Food production and agriculture can be seen as an extreme example of a PES scheme where the predominant service is food production and the other ESs are not as valuable so the natural system is distorted and necessarily so in order for us to produce enough food to feed the population. The different systems of agriculture, the rights and wrongs and the ecological implications of methods of food production have been presented and debated widely elsewhere (Jax et al., 2013, Bacon et al., 2012, Kelemen et al., 2013, Knowler and Bradshaw, 2007). However in the case of metal removal from the water course it is important that the wider environmental implications of water quality are taken into account as is the goal of the WFD (2000/60/EC) (European commission and WISE(water information systems for Europe), 2014(25/03/14 last updated), European

Commission et al., 2010b), which takes a more catchment-based or holistic approach to the River basement management.

*"When you have a full-blown market and you have a seller who can sell and a buyer who can buy they can come together and what will naturally come about is to the best benefit for the seller and the buyer or some dynamic there in and the trouble is the propensity for you to start having bizarre solutions or solutions that are detrimental"*

If these relationships are not carefully managed and negotiated between stakeholders situations could occur with in which the metal is removed from the water course successfully and is bought and sold however the wider impact of that solution is overall environmentally damaging. LCIA can help manage this by determining the most appropriate solution for a specific situation with wider benefits for the system of the whole which would not necessarily be achieved if the whole context and wider impacts of different solutions were not being assessed (European Commission et al., 2010b). It is however necessary for a third party to manage this process in order to ensure that the whole system is taken into account rather than the focus narrowing to a single goal between buyers and sellers to maximise the efficiency of a single dynamic. The dominance of the economic system was something that that many of the interviewees from SICSO struggled with; the way in which a buyer seller dynamic can distort the system, seeing it as their role to try to mitigate this aspect of PES schemes, and were frustrated by the need to put a monetary value on everything.

*"You want to do something good in the world; biodiversity, landscape and those sorts of things, do they have intrinsic value or do they have to be all part of the great big economic world. And in my personal view economy is only one element of what we do"*

The third reason why an ethical broker is required which was identified, that of acting as a trusted facilitator between parties, for two reasons: Firstly that as a negotiator and translation between organisational stakeholders who are directly involved in the decision-making and implementation of a scheme, to negotiate access and use of land etc. Secondly to explain to local communities the implications of having such projects located within their areas, because as one SICSO interviewee stated.

*"these things stand or fall as to whether they are accepted or otherwise by the local community"*

In the case of SICSO with a membership or who rely on charitable donations, explaining why their organisation should participate in such a scheme and how the interests of the organisation will be met by involvement in a specific scheme may be a challenge. SICSO awareness of potential stakeholders organisations and their needs enable links to be made between these different parties. Having access to the trust and knowledge that SICSOs have built up with and about different stakeholders can potentially enable a working relationship to be built more rapidly.

*"We only have a reputation and our persuasiveness, if you like. We are often trusted to facilitate dialogue between companies or communities and regulatory bodies like the Environment Agency and others."*

Thus enabling information to be exchanged between different parties where no previous relationship existed, eventually enabling stakeholders to understand the others' position.

*"So my role there is, I think I save time, but there's always a stage which I need to bow out and consultants and representatives move in."*

Often this is achieved purely by having the knowledge of the actors involved, this sort of information is only built up over time through personal contact. This is why this ethical broker role has such a key part to play in the smooth running of this type of project where individual stakeholders have different priorities and need to negotiate with one another in order to bring about the optimal result for all parties involved rather than a single solution outcome.

*"You can get a very different reaction (from different stakeholders) one is a bit more pragmatic in his approach, and that's just about knowing the person involved and understanding how they operate."*

*"The most critical part is that I feed everything that I get from stakeholders back otherwise I'm a barrier rather than a conduit."*

This role of trusted organisation needs to be protected and can be very quickly destroyed if a particular stakeholder acts in bad faith. This does mean that negotiations between parties need to be carefully managed and any action to be taken agreed upon between all those involved.

*"But if they so wish they could just go ahead without asking, without taking account of others' opinions. And that leaves you in a quandary really because we could spoil our reputation very quickly"*

This facilitator and communication role which the SICSO is also important in explaining to different stakeholders why they should be involved. However this is not always possible, some organisations see their priorities as incompatible with others for example, some metallophyte SSSI sites which depend upon the metals coming down from the rivers, so there is a conflict between two pieces of legislation, the WFD (European Union, 1992)and the Habitats Directive (European Union, 2000).

*"the sites need the metal for their very survival, we haven't really gotten to the stage where we bottomed this out, so it seems to me that there are these two EU Directive, there is Natura 2000 versus WFD."*

In these cases approaches such as offsetting and recreating habitats can be used and put forward by a trusted party to try to navigate through apparently irreconcilable differences. One interviewee thought that it would be helpful if organisations had better communications between different levels about the issues like this.

*"I would like… to feed down to the people on the ground what their policy is on this so that the people on the ground back off a bit and are more helpful and friendly see it as a potential opportunity rather than a threat. That would be very useful."*

In some cases it is SICSOs which are a roadblock, as they have very specific interests and priorities such as the British Lichen Society or the Angling Trust for example and clearly cannot act as a trusted broker due to their narrow focus, giving them less objective. As they are often involved in areas of conservation the special-interest groups often are more aware of the wider environment and the way in which different aspects of it to connect to their own area of interest and see take in more holistic view. An example of which can be seen in the involvement of the RSPB in a variety of conservation schemes (RSPB, 2012) which are aimed at the broader environment rather than just focusing upon birds. They may however be the catalyst for these types of schemes to be undertaken, for example, Angling Passport schemes around the country (Smith, 2013). For this type of organisation communicating with their members and their donors to persuade them that involvement in PES schemes is a legitimate way to spend the organisation's funds is vital as they rely upon these voluntary contributions and need to take their membership with them if they are to retain and increase this source of revenue. These groups often lobby governments to raise the issues that are most important to them hence influencing policy makers. Although they may not always directly contribute monetary, they can contribute in other ways as they often have access to enthusiastic volunteers who are willing to contribute their time to help achieve the organisation stated goal in which they have an interest by dint of being a member of that organisation.

*"We are used to volunteering in doing hands-on work, so we would be interested in looking at that sort of volunteer basis if possible instead of cash. A lot of them are very happy to volunteer and do that sort of work."*

Some of these organisations feel that they already contributing more than their fair share as other sectors are also benefiting, as one interviewee put it:

*"I think that we will be looking around to see what are the sections of the community were paying. We would want other sectors getting the cumulative benefit to take the extra step first really."*

There was a concern expressed by some interviewees whether the average member of their organisation would be aware of the way in which PES schemes would benefit them. It was felt that individual members would be very focused on their own priorities and would be confused by the concept of ecosystem services unless it was explained and demonstrated to them the way that these schemes directly benefit them. Although it was acknowledged that some members would have a greater degree of knowledge and understanding than others.

*"I think that the average member would have difficulty understanding that actual concept, they tend to be more focused on their individual river."*

As a precondition to being involved with the PES scheme it was seen as vital that it could be demonstrated that the schemes would have a direct impact upon, in the case of anglers, their fishing experience. There was less concern about EQS levels, it was more about how these things would directly impact upon the members' interests and then being able to experience this change.

*"It's more about demonstrating what is being done improves fish stocks."*

This illustrates a vital aspect of the more successful PES schemes, that benefits are demonstrated. This is particularly important for special interest organisations who have to sell these schemes to their membership; a membership which may not have access to expert knowledge, or indeed be interested in anything outside their sphere of interest. They need to have the benefits clearly elucidated to them and then once these schemes are in place they need to experience these benefits. In the case of a membership constituency where their organisation is paying directly for a service, that they are receiving the service that they are paying for. This also holds true for communication with local communities in which these schemes may be located. This communication needs to be clear and the benefits understood and seen to be delivered. Also, with other stakeholders and more expert organisations and businesses it needs to be shown that the scheme is delivering otherwise trust can be lost and future investment will be less forthcoming. Additionally if a scheme is not delivering then it is legitimate for stakeholders to withdraw their investment and to cease paying for the ES that they had contracted for.

This aspect of managing and communicating during the operational lifetime of any scheme needs to be managed and SICSO's particularly those that acting as ethical brokers need to ensure that some sort of management plan for this aspect of the scheme is in place as one interviewee said if this is not done correctly it can be a problem for future projects that the SICSO wants to implement and can lose the organisation hard earned trust.

*"That's one of the criticisms that we get as an organisation, then pile of funding into do something,.. to run a project on, saving water voles or bumblebees, we throw people at it we go out there and we communicate and we engage then we disappear.... And we get a lot of criticism for that "*

They considered part of the way in which this can be mitigated it is simply through letting people know what is going on and enabling them to have their concerns heard.

*"I think it was because they had been constantly fed information about it and had this feedback mechanism"*

This process of engagement and feedback is vital between all stakeholders whether they be actively engaged in the project as an investor a service provider or as a member of the wider community or an individual organisational member.  This is a key role for SICSOs either when acting as ethical brokers, where they often are a conduit for information, as one interviewee put it, or special interest group communicating to their own membership clearly and understandably the quantifiable benefits of being involved in a specific PES scheme.

## 4.4 Discussion

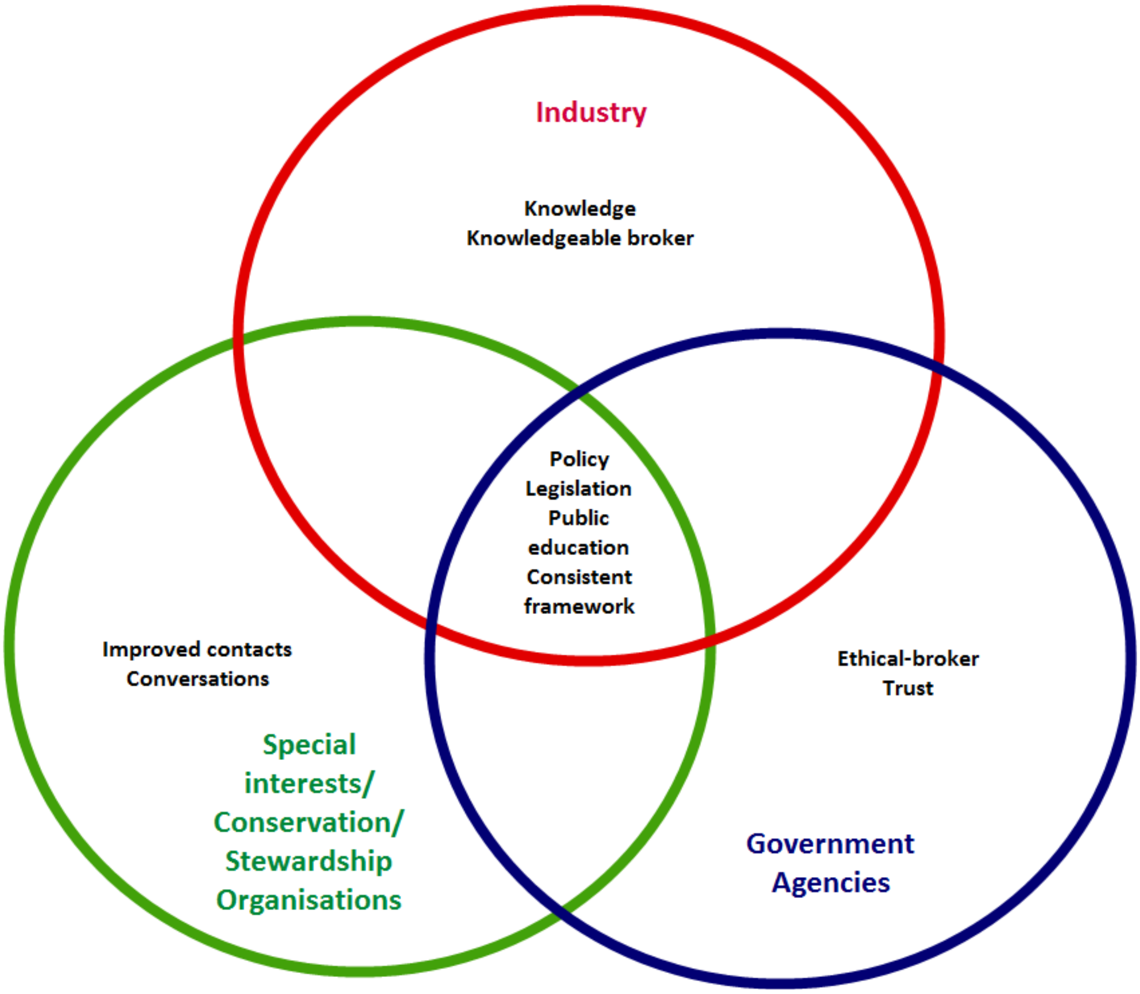


Figure 4.3: Needs identified to drive remediation, areas of agreement between sectors

### 4.4.1 Key Issues Raised

The main areas of importance that were brought out by this series of interviews with different stakeholders from different sectors are summarised below. Not all the interviewees highlighted all of the issues that are listed, there was to a large degree overlap between the different sectors and interviewees (Figure 4.3 and Figure 4.2). Of particular concern was the problem of placing an economic value upon Ecosystem Services and how realistic and acceptable this quantification could be. How to determine the impact of metal pollution, whether or not it was worthwhile to take action, managing the different priorities that stakeholders had and how to negotiate between them. The importance of effective communication and the ability to translate these quantifiable benefits into an understandable form which would be accessible to experts and non-expert stakeholders alike was a key issue. Other areas of importance have been summarised below and in Figure 4.4:

- The need to quantify the level of metal pollution at specific sites, linking this to harm done to specific ESs and quantifying the loss in economic terms.
- The need for legislation in order to force organisations to take action upon the levels of metals in water bodies in order to comply with the WFD
- Communication of why it is important to take action and how the environment as a whole is impacted and an individual organisation specifically.
- Lack of systems thinking; there needs to be a more holistic view of how actions taken impact upon other areas.
- More collaboration between different sectors and within organisations so that better and more innovative solutions to problems can be found. Rather than narrowly focusing upon a single goal.
- Potential disconnect between different stakeholders priorities resulting in an unwillingness to listen to others.
- Concerns around time management issues, building relationships and negotiations between different stakeholders often take too long to the detriment of action being taken.
- The need for a clear process which could be followed in order to determine potential benefits and enable different stakeholders to understand their role in the process.

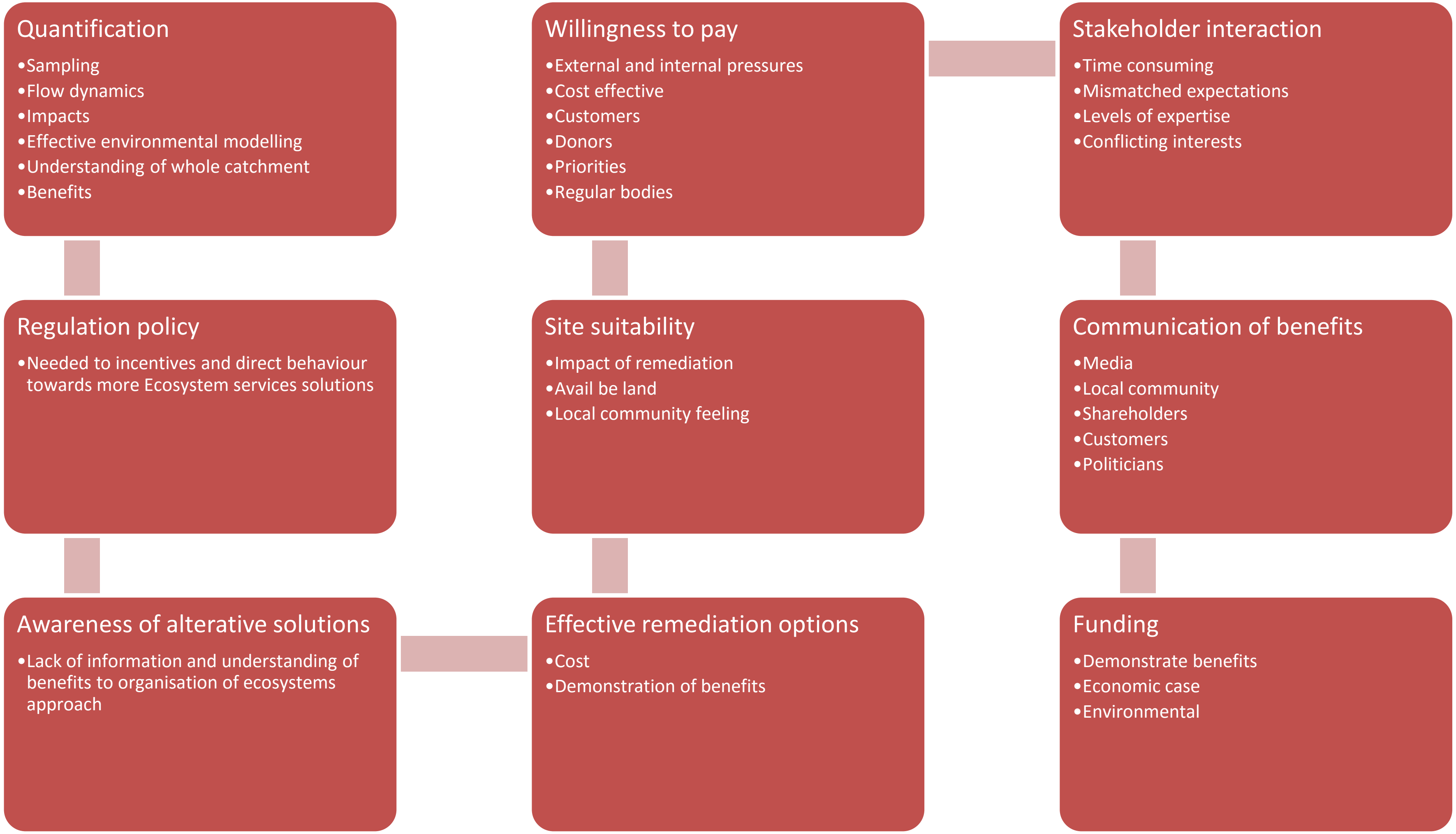


Figure 4.4: Road blocks identified by interviews

### 4.4.2 **What Affects the Different Attitudes and Opinions?**

There was a range of attitudes and opinions expressed by the different interviewees which are largely determined by the sector to which they belong. Different sectors have different priorities and drivers for example the water companies are focused upon cost, having to justify any action taken to their regulatory bodies and to their customers. The way which different sectors operate is reflected in their views of what is needed and what is important. The metal industry sector interviewee was very focused upon the need for quantification and rigour and having "hard facts and economic values" which could be backed up with evidence. The GAs were very target-orientated and about delivering what was required of them in a focused way and possibly not looking beyond single issues. SICSOs were more communication orientated and very aware of the local communities' opinions and priorities. They were concerned with their own reputations and building trust relationships and networks. Organisations with a specific focus prioritise that above other considerations (Figure 4.5).

All the interviewees did recognise that taking a step back from their own priorities and purposes could potentially derive greater benefits, at a lower cost, to their organisation and still meet their own needs. Communicating this to induvial within an organisation and the wider pubic was seen as necessary for this proposed framework (Figure 1.3) to succeed. The approach taken would need to be accepted by the organisation and the public as a justifiable way to meet the organisation's priorities. This requires that the arguments are clearly communicated, robust and based on valid scientific information. The framework will deliver rigours information about the proposed remediation approaches and how these would be expected to perform and the impact they would have. Ensuring that the channels of communication between stakeholders remain open will help communicate the wider benefits of the selected approach. This is a necessary part of making the argument to individuals who are resistant to a holistic approach, so they can understand how this new way of working could be of direct benefit and the organisation or community.

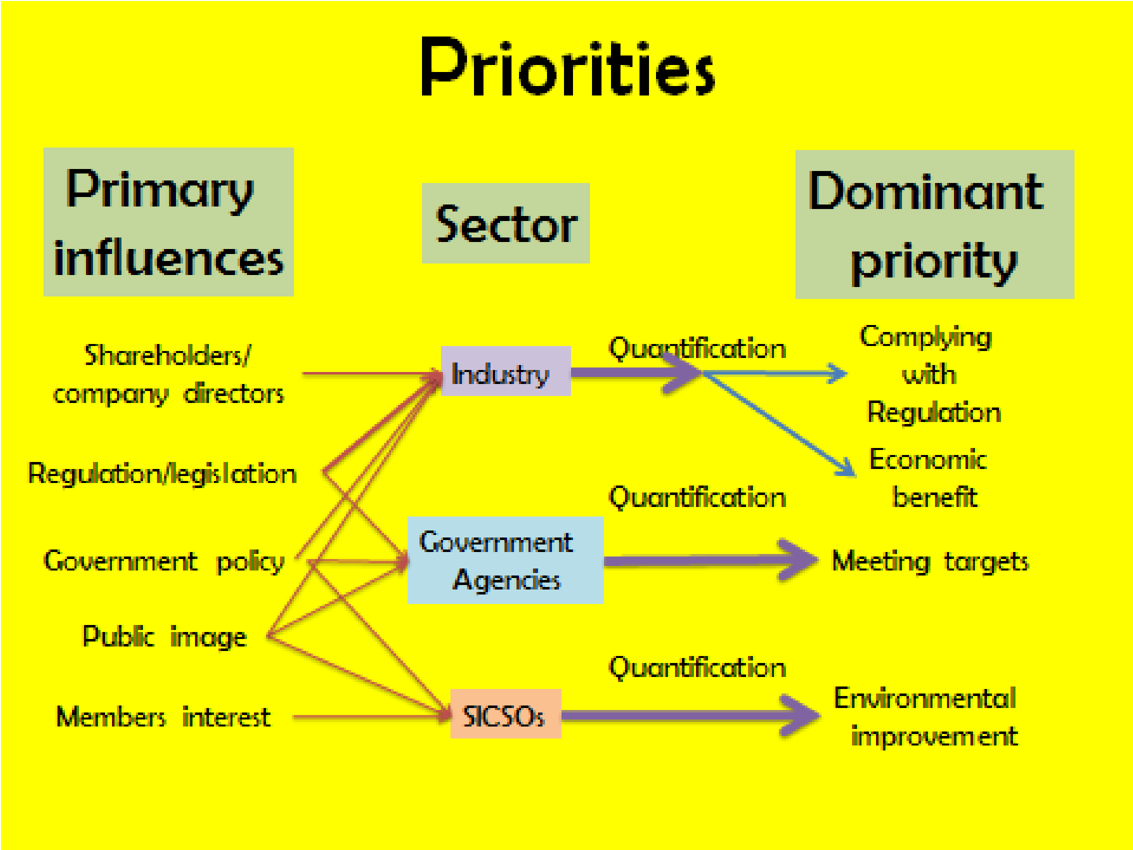


Figure 4.5: Reasons, identified by interviewees, why their organisation would invest in a PES scheme to improve a water body's chemical/ecological status

Research into the ways in which societies, individuals and organisations view Ecosystem Services and how effective they as a method of communicating with different stakeholders is ongoing. A number of studies have found that as a tool Ecosystem Services and its effectiveness as concept is very dependent on the way in which individual actors themselves interact with different environments (Caceres et al., 2015, Kenter et al., 2015, Dutra et al., 2014, Sorice et al., 2014, Fisher and Brown, 2014). Once the concept is accepted and understood it seems to be an effective way to communicate the value of ecosystems and the benefits received from them (Asah et al., 2014). A number of interviewees thought that wider awareness of specific environmental issues linked to specific Ecosystem Services, within the media, is useful to raise awareness and make PES schemes more acceptable to the general public.

## 4.5 Conclusion

When a range of stakeholders, from different sectors with potentially different interests work together it provides a method of ameliorating a market's potential distorting effects. When individual Ecosystem Services are being bought and sold for maximum efficiency in a single area, this can have a negative effect on other ESs. Deliberately targeting stakeholders with a range of requirements from different sectors for different ES has the potential to lead to a more balanced solution to the problem of metal removal. Ensuring that a range of objectives are met as opposed to focusing on a single requirement. A comparative LCSA of different approaches gives an integrated assessment of the options and the expected levels of different benefits and impacts that each option would produce.

Stakeholders whose role would be to act as intermediaries, predominantly from the SICSO sector, though this information would help with balancing different sectors priorities and objectives against one another. It would illustrate how multiple objectives could be met by using a systematic and catchment based solution rather than solving a single problem at a time. By approaching the solution in this way it demonstrates to the different organisations that the whole system needs to be considered to ensure its' continuing ability to deliver ecosystem services, including those that the stakeholders value.

For the framework to work there needs to be an equal distribution of power between the different stakeholders. This will depend on the way in which the PES scheme is administered, as stakeholders discuss selection of remediation technique those that are paying most may try to excerpt an undue influence on the selection of the technique. They may quite reasonably wish to select as it is the most efficient method to achieve their own stated goal. This is where intermediaries, "ethical brokers", need to intervene to ensure that the whole system is included and the full range of the ES taken into account. Achieving a balanced market, especially where economics, society and conflicting interests meet, needs to be explicit and is integral to the framework (Figure 1.3).

Communication of the value of benefits, to stakeholders, was viewed as difficult to achieve. Education was considered an important tool for communication, so that the reasons for taking action to improve ecosystem services could be more widely understood. The purpose of legislation, such as the WFD, needs to be communicated better so that industry and other bodies can justify to themselves, their customers and the public, why there is a need to invest in maintaining ecosystem (Figure 4.6). This would enable a more informed choice be made about how much as a society we are willing to pay for the preservation and improvement of ecosystem services that we rely upon.

*"I think that this would then help us all to decide how much effort we should be putting in what is the end goal that we are trying to get to, this is where we are now, it's polluted and other people go, no, we're not going to get it to a pristine sort of pre-anthropogenic condition, but we want to get to bit better, at a reasonable cost."*

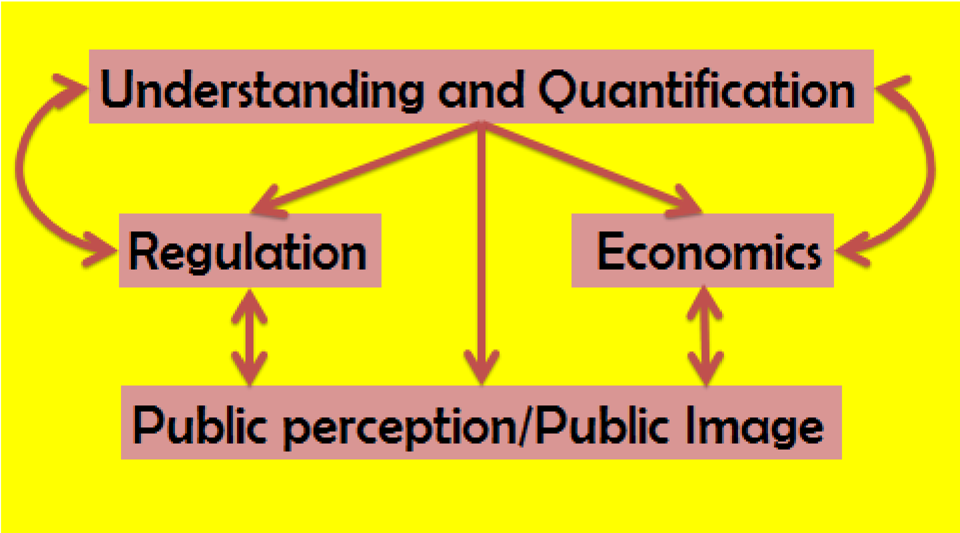


Figure 4.6: Requirements identified to increase the general acceptance of the need for investment in ecosystems to maintain and improve the services they provide

A fundamental requirement that all stakeholders identified was the need to place economic values upon the benefits derived to quantify what was actually be achieved by implementing such a scheme (Figure 4.7). This was viewed as the most difficult aspect of the framework (Figure 1.3) and an area of great uncertainty, controversy and potential disagreement between stakeholders.

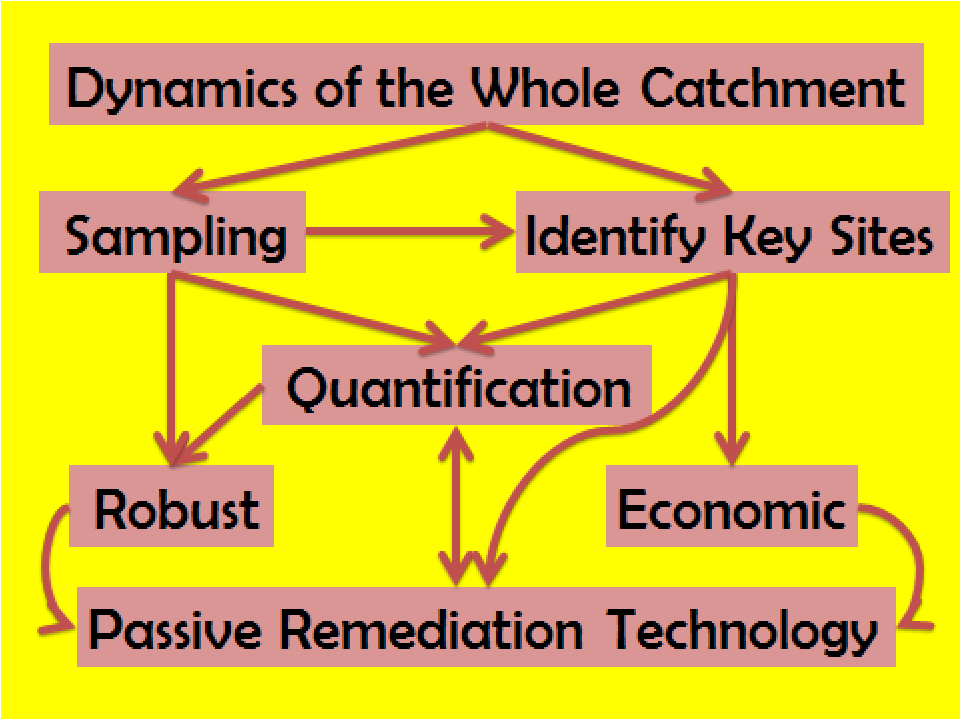


Figure 4.7: The areas which the interviewees identified as needing quantification, the economics, the levels of benefits and the current situation

Consensus for the values arrived at when quantifying impacts both positive and negative is required in order to move forward. This is difficult to achieve, due to the lack of hard data and an universally accepted methodology to place economic value upon ecosystem services' benefits. The moral ambiguity about monetising aspects of the natural environment, as well is the scientific and economic uncertainty around ecosystem services and the benefits derived was something that was mentioned to some extent by every interviewee. In some cases there was a distinct discomfort with the concept of placing an economic value upon nature and the issues associated with valuing future benefits and levels of future payments (Chapter Eight). It was broadly acknowledged that this is the way in which the UK government is currently moving and this is a subtle paradigm shift in the way in which we view nature, this was not a view that was universally welcomed one interviewee summed it up as:

*"it's all about now and never about tomorrow."*

Indeed there was some level of anger and frustration expressed at being forced down this route,

*"...not everything is costable, some things have lots of value that is not necessarily costable."*

Other interviewees openly welcomed PES seeing it as a pragmatic way forward in which placing cold hard facts on the table would enable these projects to be justified and hence move forward. If this framework (Figure 1.3) is to be used all sectors agreed that it had to be a rigorous and transparent process rooted in good science.

# Chapter Five The Hebden Beck Case Study; Baseline Conditions

## 5.1 Introduction

A case study catchment, Hebden Beck in North Yorkshire, has been selected to demonstrate how the proposed framework (Figure 3.1) will be used to solve and fund the remediation of environmental pollution. The purpose of using a case study is to highlight the problems, gaps and weaknesses of the framework which may arise, when being deployed, which may not immediately apparent in the theory of its development. Such issues include what information is most important for the successful use of the framework, data availability, data quality and sources.

The Hebden Beck catchment has been selected as it is typical of many of the water bodies identified as impacted by non-coal mine pollution in recent exercises (Mayes et al., 2009b, Jarvis and Mayes, 2012). It is an upland catchment with circum-neutral pH mine discharges (typical of most sites in the UK: (Jones et al., 2013)), with numerous mine sites located within the catchment boundary. As with many upland mining catchments, it falls within a national park (Yorkshire Dales National Park) and there are various conservation and built environment statutory designations within the area. The Hebden Beck catchment is also one of a number of water bodies affected by non-coal mine pollution within the broader headwaters of the River Wharfe and the wider Ouse and Humber river basins into which it drains. As such, it provides an excellent opportunity to assess remedial options over a number of scales. Hebden Beck has been highlighted as a priority catchment affected by mining pollution in the Humber River Basin Management Plan (Environment Agency, 2009a). River Basin Management planning has resulted from the implementation of the WFD and is a statutory requirement Water Environment (Water Framework Directive) (England and Wales) Regulations 2003 (UK Government, 2003).

This Chapter aims to use modified regulatory guidelines to assess the baseline condition of the Hebden Beck with regard to pollution from abandoned mines. The extent and sources of the polluting discharges will be identified and used as the foundation of an Environmental Assessment (EA) focussing on the key ecosystem services presently impacted by legacy pollution. This is a key element of the framework as it provides the baseline from which the benefits or otherwise of management intervention (e.g. mine site remediation) can be assessed.

Figure 5.1: An example of typical landscape through which Hebden Beck flows.

## 5.2 Methods

The UK government Department for Environment Food and Rural Affairs issued River Basin Management Plan (RBMP) guidance in July 2014 (Defra et al., 2014). It is this guidance that will be broadly followed here to assess the current baseline condition of the Hebden Beck combined with the ecosystem services methodology (Kumar, 2012). Best practice guidelines for Environmental Impact Assessment (EIA) (Morris and Therivel, 2009), will be applied to the EIA of the installation of the proposed remediation options These are the fundamental principles upon which the framework has been developed. In addition to the utilisation of systems thinking as explained in the preceding chapters (Chapter Two, Section 1.5 and Chapter Three).

The boundaries for the area to be assessed within the Environmental Assessment (EA) are more usefully thought about in terms of scope rather than a physical area particularly within the context of the catchment based approach which seeks to encompass the whole catchment area as stated (Chapter Nine). When describing benefits to any stakeholder it is vital to place what is being described within a context that is understandable to them. The local and immediate benefits need to be meaningful and quantified as should be the global impacts. Therefore the scope of the Environmental Assessment should encompass the local site-specific impacts within the global context, seeking to capture the impacts both positive and negative of the current situation. The future scenario should be viewed as part of a global system where impacts will be felt at different geographical scales and over different time periods. The local effects on the impacts relevant to specific interests can be quantified and defined. Figure 5.2 illustrates the range of factors at the Hebden Beck site and how GIS could be used as a tool to assess the relationships between these layers. Creating a visual representation of the physical location of impacts which can be used as an effective way to communicate information to stakeholders.

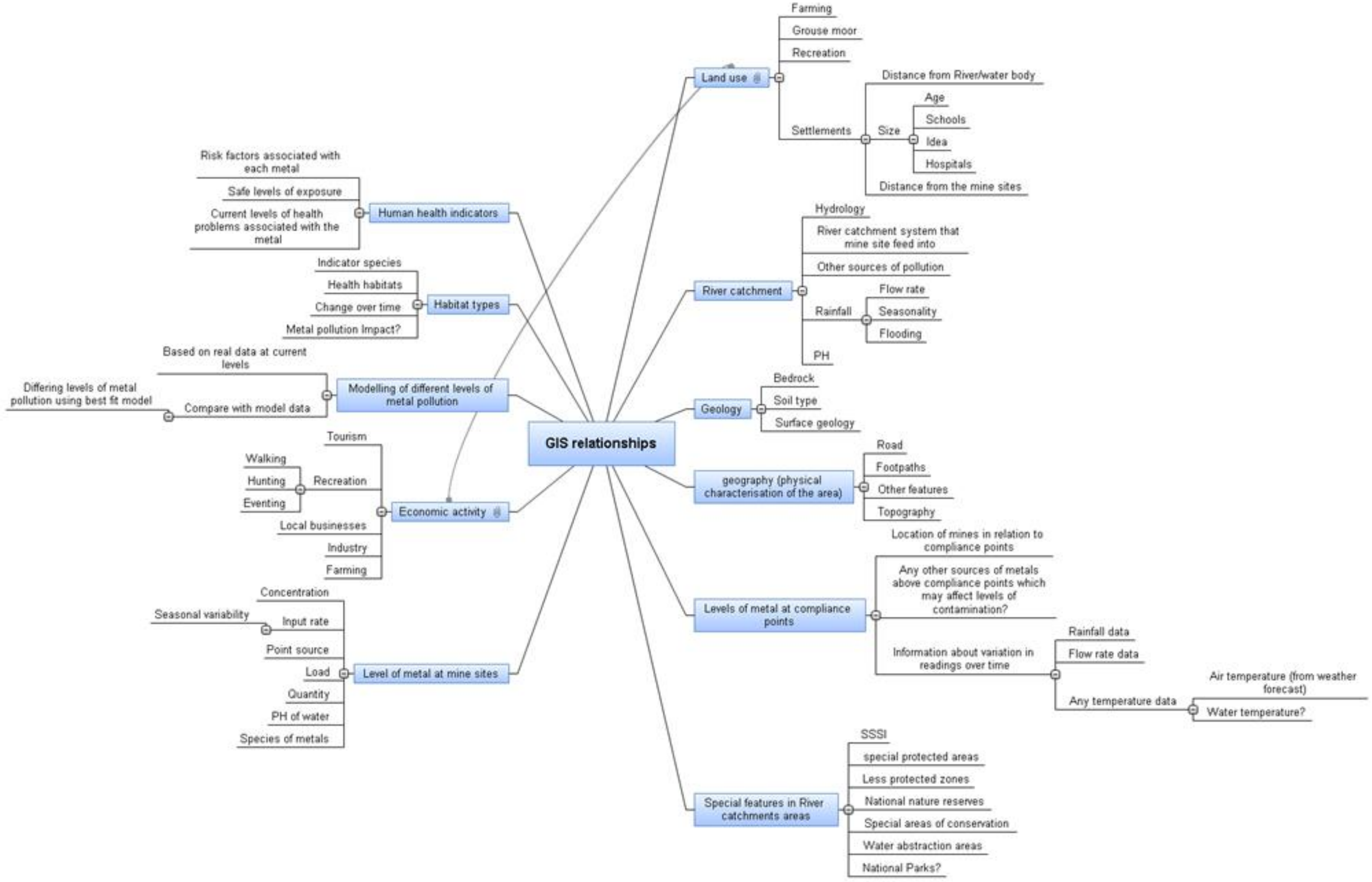


Figure 5.2: Idealised GIS layers for Hebden Beck EIA

### 5.2.1 Site Description

Hebden Beck drains into the Upper Yorkshire Ouse and is located within the Yorkshire Pennine Orefield and is dominated by Carboniferous limestone at its surface which extends to a depth of around 1.5 km. There is significant quantities of mineralisation within the extensive network of faults and the dominant mineral are galena (PbS), sphalerite (ZnS), fluorite ($CaF_2$) and barite ($BaSO_4$). The geology of Hebden Beck is similar to the broader geology of the Grassington area in the Yorkshire Pennine Orefield which has been well described elsewhere (Jones et al., 2013, Black, 1950, Kidd et al., 2006). The history of the Hebden Beck area is that of the Yorkshire Orefield, which has a long legacy of metal mining since pre-Roman times (W.M et al., 2010, Hudson-Edwards et al., 1999, Jones et al., 2013, Macklin et al., 1997). The dominant metal ores which have been extracted are lead predominantly, followed by zinc and copper.

Hebden Beck lies in a shallow river valley (see Figure 5.1 and Figure 5.3) and is surrounded by upland calcareous grassland moving into heathland in higher elevations, as defined by the UK NEA habitat classification. The South Yorkshire Pennine Special Area of Conservation lies 1km to the east of the catchment, while the Black Keld Site of Special Scientific Interest (SSSI) covers the northern quarter of the catchment. The latter is designated on the basis of the limestone geomorphological features apparent in this area (Natural England, 2015). There are spoil heaps on either side of the river from historic mining. These are covered in grass which has stabilised them to some extent (Figure 5.1). These spoil heaps are also a possible enduring source of pollution during periods of high precipitation as the sediment of which these spoil heaps consist can be washed into the beck (Jones et al., 2013). The gauging station towards the south of the catchment also serves as the Water Framework Directive compliance point for this water body. Such compliance points are typically taken as the location by which water body status (with regard Water Framework Directive) is determined.

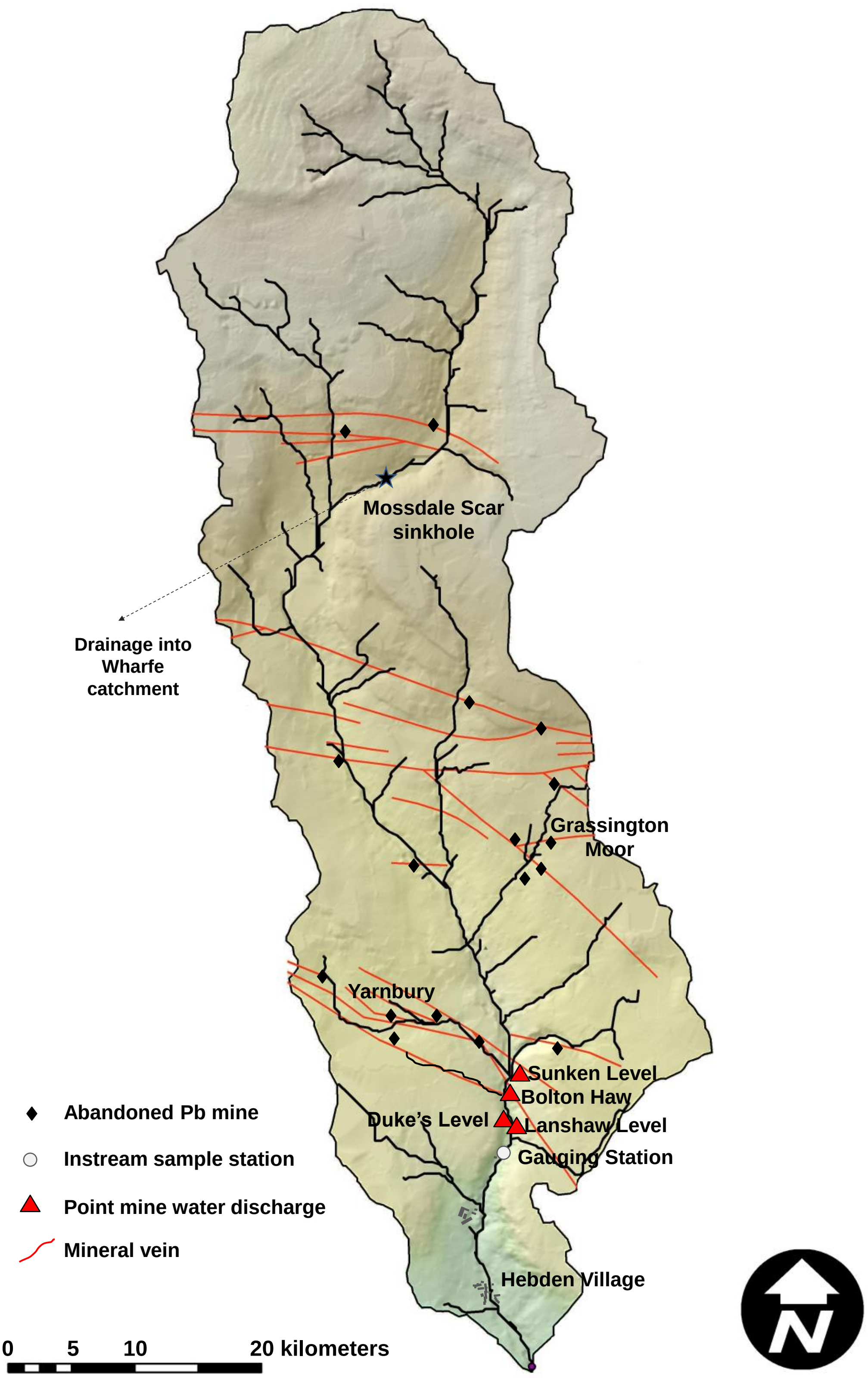


Figure 5.3: Overview of Hebden Beck, mine sites and points of pollution

The mine sites themselves (which includes all building remains and associated waste rock) form part of the Grassington Moor Lead Mines Scheduled Ancient Monument (English Heritage, 2015). There is extensive spoil cover throughout the south of the catchment while there are four main point mine discharges from drainage levels and adits (Figure 5.3). The most significant of these is Duke's Level which is a 5km drainage level driven in the eighteenth century to underdrain Grassington Moor and make deeper Pb veins workable (Jones et al., 2013)

In the immediate vicinity of the point source pollution there is little flat land available which potentially limits the type of remediation technology that can be deployed. This is often the case in these mining areas and has proved to be a particular problem in the Nidd Valley which is located in the North Pennines and was mentioned by an interviewee associated with legacy metal mine pollution in that area as a particular problem (Section 4.4.1).

Grazing pasture for sheep dominates land use around the Hebden Beck and the land is privately owned by eight local farmers. Mining was a particularly significant economic activity for the area during the eighteenth century; the village downstream acted predominantly as a dormitory village for the mining activity and brought prosperity to the local community As the easily accessible ore was mined out the population declined but with the coming of the railway into the Yorkshire Dales which was completed in 1902 the village took advantage of the trend for tourism in the later part of the nineteenth century and developed as a destination for day-trippers. These visitors continued to sustain the village which now has a population of 240. There is a small post office, tea rooms, church, a small primary school located to the south of the catchment. There are a few holiday cottages sustained by the tourist industry, eight working farms, a downstream fish farm and a coach and haulage company which also supplies employment to the local community.

A footpath runs along the length of the Beck and stepping stones cross the water course at various locations on almost immediately adjacent to the source of pollution at Duke's Level. There is a wide network of walking routes that are widely publicised and extensively used by serious walkers and tourists in and around the area. This raises issues in relationship to direct human exposure to the metals pollution and the level of risk to individuals. But it is also means that during any remediation work both during the deployment of any system chosen and also during its lifetime that there will be an impact on visitors perception of the area. During the installation of any system this may have a detrimental impact on the tourist industry as it may restrict access to the area and have a negative impact on any tourists/walkers experience of the area. This may result in negative feeling from local people who may be impacted economically as a result of a short or long term drop in visitor numbers to the area. This sort of situation needs to be managed delicately to prevent any long term impact on visitor numbers and to manage the short-term engineering work to reduce its impact on the local area. Hence prevent this deployment from detracting from any visitors' experience of the area. This is particularly important for the holiday cottages immediately downstream of the point source pollution as vehicle and equipment being transported to the site may "spoil" the tranquillity of the area and hence negatively impact their holiday experience. Any development of work which may have a negative impact upon visitor experience needs to be handled carefully as tourism plays a significant role in the economy of the village which has survived the ending of the mining industry which previously bought economic prosperity to the community. Any short or long-term impacts need to be communicated and explained to the local population and the benefits that would be derived from work taking place to remediate the metal mine pollution. The Yorkshire Dales National Park Authority is the local planning authority for this area and the village is part of the Craven district in North Yorkshire as a result of the 1972 Local Government Act.

There are a number of Sites of Special Scientific Interest (SSSI) which consist of metallophyte communities which could be negatively impacted by the removal of the metal pollution from the Beck as they rely upon it for their very existence. This is something that will have to be negotiated and managed; possibly through biodiversity offsetting or relocating the metallophyte community to a different location within the area that is specifically managed for their continuing existence. This may offer the opportunity for studying these metallophytes about which little is known (Whiting et al., 2004a) ( Section 4.3.4). There are historical sites associated with the mining industry which also need to be taken into consideration as well as a Bronze Age stone circle and remains of a Bronze Age settlement above the village itself. These aspects of the local area need to be considered when determining the level of ecosystem services particularly cultural services which will be impacted by any change in the current situation that will result from remediation work.

Hebden Beck is used by the local farmers as a source of water for their animals, the salmonid community further downstream is also potentially impacted by the level of metals in the water additionally the fish farm is impacted by this point source pollution and there are a number of reservoirs and stream abstractions in the area. This highlights the range of stakeholder interests in this particular case study which is typical of other former mining areas (Mayes et al., 2009b). Figure 5.4 shows the resources in the catchment are assessed to determine the level of impacts upon them. Figure 5.5 illustrates some of the influence on the levels of metal in the catchment.

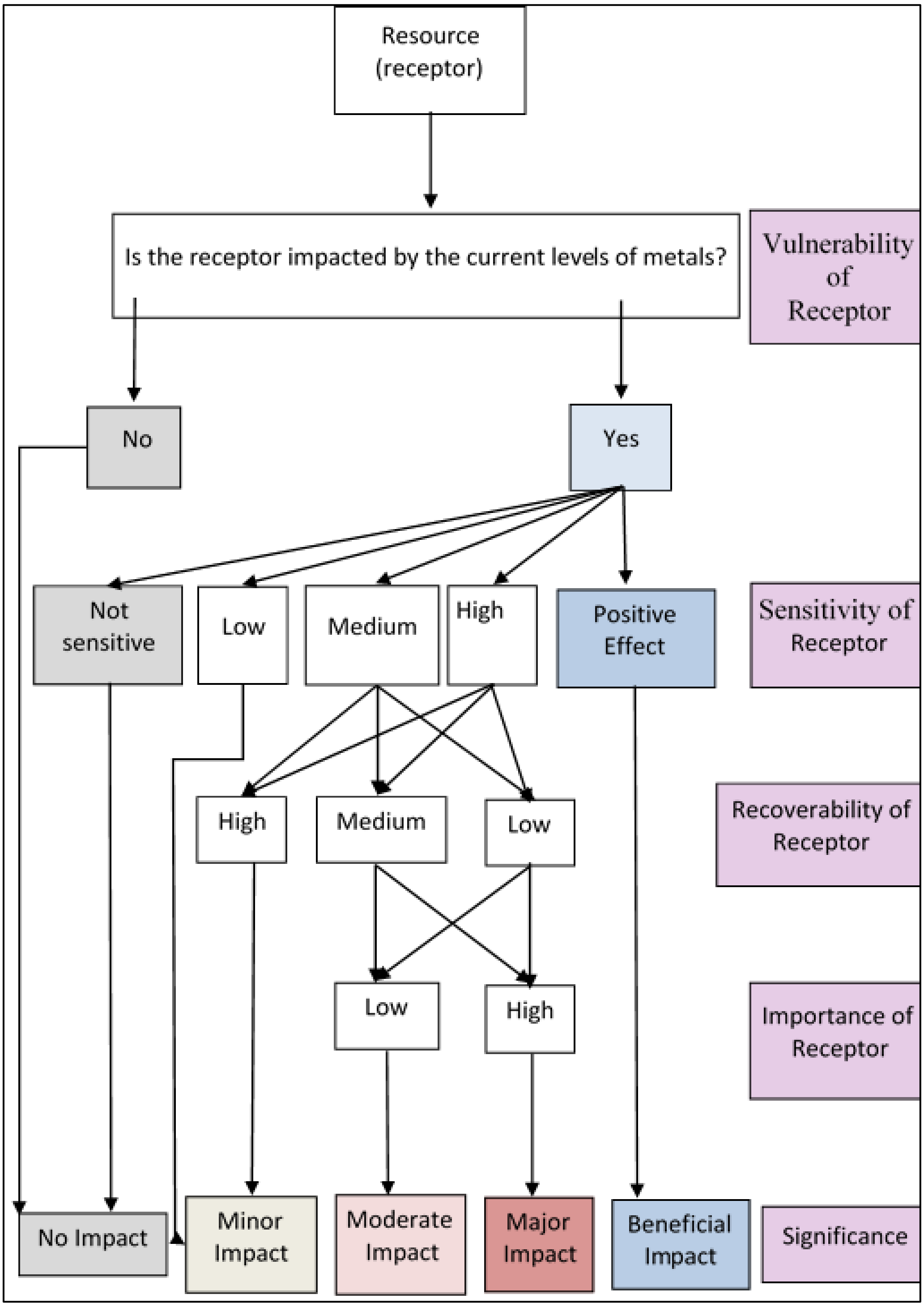


Figure 5.4: Process to assess the impact of metals upon resources in the Humber catctment (Morris and Therivel, 2009)

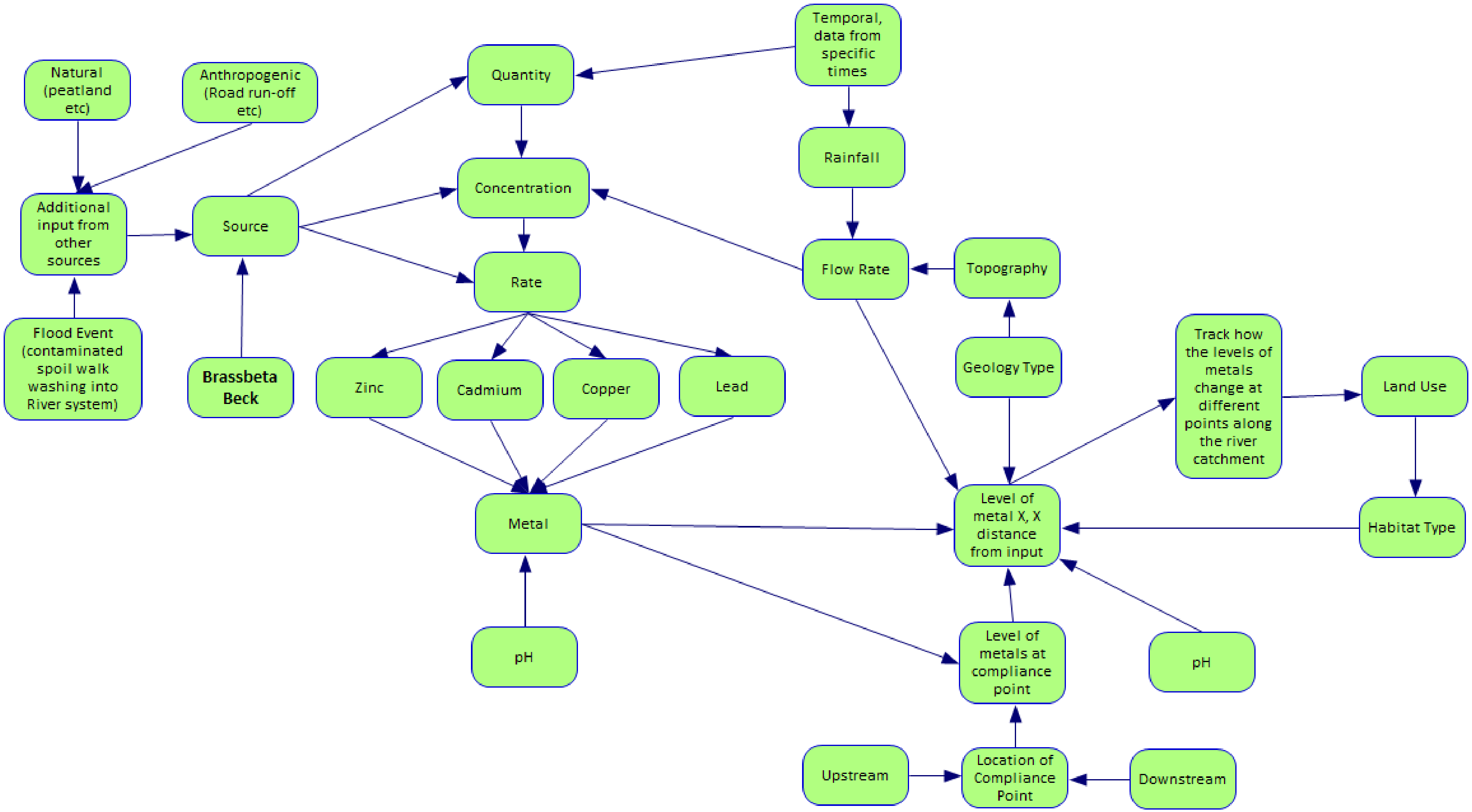


Figure 5.5: Causes of variation in metal levels at different points within the Humber catchment

## 5.3 Establishing the Levels of Current Contamination and the Range of Variation.

To establish the impacts of ongoing metal pollution from the abandoned mine sites in the Hebden Beck a series of exercise were undertaken. These included:

a) Field walkover of the catchment to assess the visual appearance, location of sites of interest and to aid in producing a site conceptual model of key impacts
b) Consultation of a range of hard copy and digital spatial data (Table 5.1) to highlight key receptors
c) Review of water quality and flow data from the system provided by researchers and regulators (Environment Agency) to assess the nature and extent of the impacts on the water environment

Table 5.1: Example of resource available for EIA desk study

| Resource | Value for study | Source |
|---|---|---|
| OS 1:25000 Explorer series maps (Sheet 298) | Reconnaissance assessment – footpaths, roads, rights of way | Digimap |
| Landmark Land Use data (LCM 2008) | Land use assessment within catchment | Digimap |
| List of Scheduled Monuments | Potential impacts and issues | http://data.gov.uk/data/search |
| Geological Data | Assessment of local geology | Digimap |
| SSSI sites | Potential Impact on SSSI | http://data.gov.uk/data/search |
| Extraction site locations | Assessment of current water use | http://data.gov.uk/data/search |
| Hydrological data | Flow conditions assessment effect on any installation | http://data.gov.uk/data/search |
| Land ownership register | Contact information, stakeholder | https://www.gov.uk/get-information-about-property-and-land |
| UK National Ecosystem Assessment | Land classification, habitat types overview of area within UK context, highlights issues | http://uknea.unep-wcmc.org/ |
| EA ambient monitoring data | Assess Environmental Quality Standard compliance | EA personal request (February 2013) |

### 5.3.1 Qualitative Assessment

Typically the categories into which the Environmental Impact Assessment is divided consist of; socio-economic impact, noise, transport, landscape and visual, heritage, air quality and climate, soils geology and geomorphology, water, ecology, coastal ecology and geomorphology (Morris and Therivel, 2009). Within these categories the different components of EIA can be classified into the type of ecosystem services that they affect, when assessing the installation and on-going impacts of the remediation technologies.

The same linking is done for the EA was the base line conditions are being established. This is the purpose of the framework, assessing impacts and benefits in terms of ecosystem services throughout the whole process enabling direct assessment to be made between impacts and benefits throughout the whole process this has been explained in more detail in Chapter Three, Chapter Six and Chapter Eight. Referring to ecosystem services and classifying and quantifying impacts in these terms allows a more coherent and consistent assessment of a whole process to be established. This enables a more systematic approach to be implemented including the different aspects of the WFD, taking on the ethos of a more catchment-based approach and establishing remediation projects as part of the whole river system. This method of working has been advocated by a number of different authors (Apitz, 2013, Balmford et al., 2011, Cimon-Morin et al., 2014, Dick et al., 2014, Häyhä and Franzese, 2014, von Stackelberg, 2013, Everard, 2012, Everard and McInnes, 2013). These impacts, once characterised can then be assessed in terms of economic costs, an example this process is outlined in Figure 5.6.

### 5.3.2 **Water Environmental Impacts**

Within much of the literature on abandoned mine impacts on the environment, the most reliable quantitative evidence comes from monitoring of impacts of mines on the water environment (Younger et al., 2002, Jarvis and Mayes, 2012). As such, these impacts are interrogated in detail here. The approach most widely adopted by the Environment Agency currently to assess impacts of mine pollution at a catchment scale concerns a load-referenced approach to source apportionment (Mayes et al., 2009b, Jarvis and Mayes, 2012). This uses both chemical and hydrological data to assess what proportion of the metal flux arises from each monitored point (drainage level) and diffuse (spoil heap) source. This is the approach adopted here to highlighting where remedial efforts could be targeted. Flow rate is of particular importance as it impacts upon the concentration of the metals within the system but may also cause polluted sediment to enter the system increasing the absolute metal load. Increased precipitation increases the overall energy of the system which will increase the re-mobilise sediment (spiralling) within the system again increasing the overall levels of metals within the system and transporting it further down the catchment (Macklin et al., 1997, Macklin et al., 2006). Increased precipitation levels may lead to metal release from natural sources such as peat lands and also increase metal contamination from road run-off which is a significant source of metal contaminants (Neher et al., 2013b), though likely to be of peripheral importance in Hebden Beck given its rural nature. The pH of the water also influences the bioavailability of the different metals and the efficiency of the remediation technology deployed as well as being a significant environmental factor influencing the functioning of ecosystems in its own right. Therefore seasonality due to variation in unexpected precipitation needs to be taken into consideration when assessing the predicted reduction in the metal pollution as a result of deploying a remediation technology to address a specific point source.

By assessing impacts at a catchment scale, these data can then be scaled up to consider the relative metal fluxes at the river basin (i.e. multiple water bodies) scale to determine whether or not removing this particular source of metals will result in improved ecosystem functioning and hence improve delivery of ecosystem services. It may be the case that during the base flow the removal of this source is significant however during more extreme precipitation events and increased rates of flow there may be additional sources of metal pollution which are not addressed.

Establishing the baseline situation on local, regional, national and global scale both positive and negative is necessary to determine the current level of harm from the pollution entering the catchment. This will ascertain if it is worthwhile to deploy a specific remediation technology to this specific abandoned mine site. That is if the current levels of harm would be reduced to a predetermined level, in this case it is the requirements of the WFD for water bodies to meet good chemical and ecological status (European Union, 2000). The frame work seeks to include, the impacts of remediation, the benefits of remediation and the wider environment benefits and harms at multiple geographic and temporal scales. There is extensive debate around the value of ecosystem restoration (Holl and Aide, 2011), how to evaluate whether to take action and what level of restoration to ecosystem is desirable (Abson et al., 2014, Davidson, 2013, Jax et al., 2013). This debate is active both in the academic literature and the more mainstream media (Monbiot, 2014) and is complex and fraught with political, ideological and philosophical considerations. The purpose of this framework is to establish whether or not a specific remediation technology will have a positive overall impact upon the environment and its ability to deliver ecosystem services. Taking into account the need to fund this therefore its economic viability as well as its environmental and social impacts need to be quantified. The current situation's impact needs to be established using rigorous and robust scientific methodology and environmental assessment and its value to the wider economy within the context of ecosystem services (Section 2.5) as previously outlined. Assuming that it has been accepted the harm done to the environment does have an economic cost it is necessary to establish how these costs manifest themselves with in a specific context.

In addition to assessing the sources of pollution, a fundamental component of the framework is to assess the specific impacts of these metal inputs. These impacts upon ecosystem services needs to be quantified, following long establish and accepted methods of environmental assessment (Morris and Therivel, 2009) a process such as that outlined in, Figure 5.4 is followed. It is impossible to do this for every single aspect of the site being assessed it would be to complex and time-consuming. Though it is important to capture as much of the impacts as possible, dividing the impacts into different classifications, within those selecting those of most significant to a specific case study.

### 5.3.3 **Identifying Regulating, Provisioning, Supporting and Cultural Ecosystem Services Impacted by Metal Pollution from Hebden Beck.**

The recognition that restoration of rivers at network scale has the potential to deliver multiple ecosystem services has been acknowledged by a number of authors (Ausseil et al., Gilvear et al., 2013, Cook and Spray, 2012). As part of the assessment as well as taking into account spatial distribution from the local to the global scale it is also necessary to consider the time over which these benefits accrue. Ecosystems sometimes restore themselves given enough time, and therefore it is not all ways necessary to actively restore damaged environments (Holl and Aide, 2011). Alternatively, as with the development of metallophyte communities, ecosystems adapt to conditions which may previously have been thought to be detrimental and deliver different ecosystem services from those before they were impacted by changing conditions. It is important to bear this in mind and consider that restoration does not mean travelling back in time to some point before anthropogenic influences. A balance is needed between delivering individual ecosystem services locally and the whole system, at multiple geographic and temporal scales. This will include negotiation and compromise between different ecosystem services and different aspects of those services. The link between ecology, the state of the environment and its resilience and ability to deliver ecosystems services has been made specifically in a the UK National Ecosystem Assessment (NEA) (UK National Ecosystems Assessment, 2011, UK National Ecosystem Assessment et al., 2014) and the interrelated nature of these different environments. These environments are directly impacted by water quality and as such river restoration and the removal of contaminant such as heavy metals need to be considered when assessing how to go about improving ecosystem resilience. Figure 5.6 show the how chronic exposure to pollution can give rise to an economic cost.

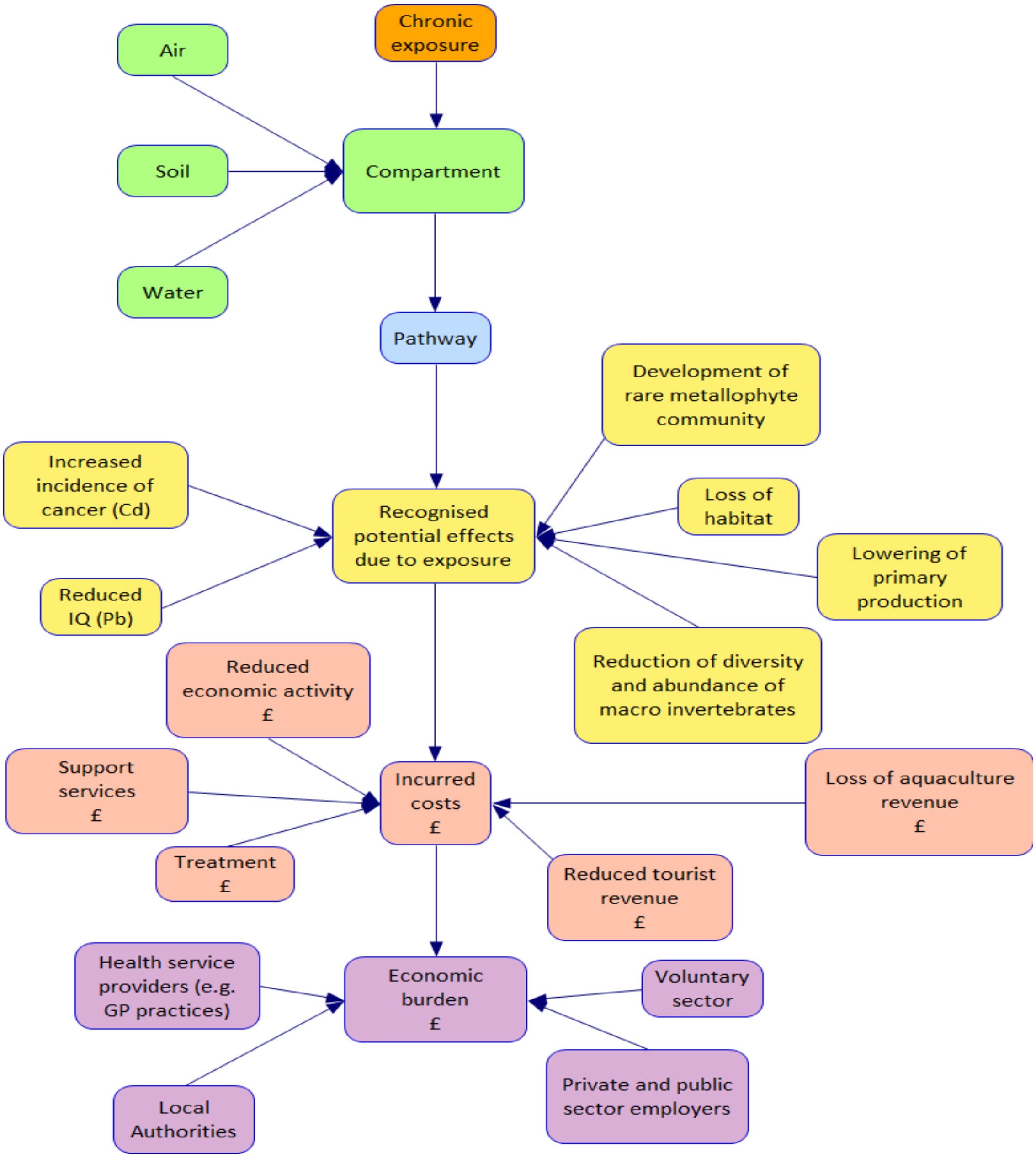


Figure 5.6: Examples of process to assess the economic costs of impact of metal pollution, authors own

Establishing the specific costs of these impacts and the burden that it places on the local community, the national government and ultimately the global economy is open to a wide degree of interpretation (Figure 5.6). Determining these costs is vital in order to justify undertaking a remediation project at a specific location. Defining these costs for the case of Hebden Beck was done using the methodologies established using the TEEB framework and methodologies within the literature (Chapter Eight). These individual impacts can be then further broken down and analysed in order to determine individual costs. This process can be highly complex and it may be difficult to capture all of the different components' economic value and arrive at an accurate figure. This complexity is illustrated by Figure 5.7 which illustrates some of the associated costs that may result from cadmium exposure. It may not be necessary to quantify all of these costs, as they may not be significant. This diagram does illustrate the difficulties about the judgements that need to be made in order to truly represent the economic burden that environmental pollution places on society as a whole both locally, nationally and globally.

Not all impacts from metal pollution are wholly negative, some SSSI sites result directly from metal pollution and these sites may contribute to the economy of the area and the ecological richness of the Hebden Beck area. Scientific study of these naturally occurring metallophyte communities can contribute to understanding natural metal removal mechanisms. These plant could be relocated to other contaminated sites to ensure their survival (habitat-off-setting) and also be used to as a form of natural remediation process (Whiting et al., 2004a, Lucassen et al., 2009, 2010) on post-industrial brown field sites. The ecology of these endangered sites has an intrinsic value and their continued existence is important to a diverse ecology. Organisations and societies[8] exist in order to ensure lichens and metallophytes continue to thrive. The requirement of these threatened habitats and needs to be considered when investigating the overall impacts of any remediation taking place for the removal of metals (2012, Bizoux et al., 2011, Lucassen et al., 2009).

[8] The British Lichen Society (http://www.britishlichensociety.org.uk/)

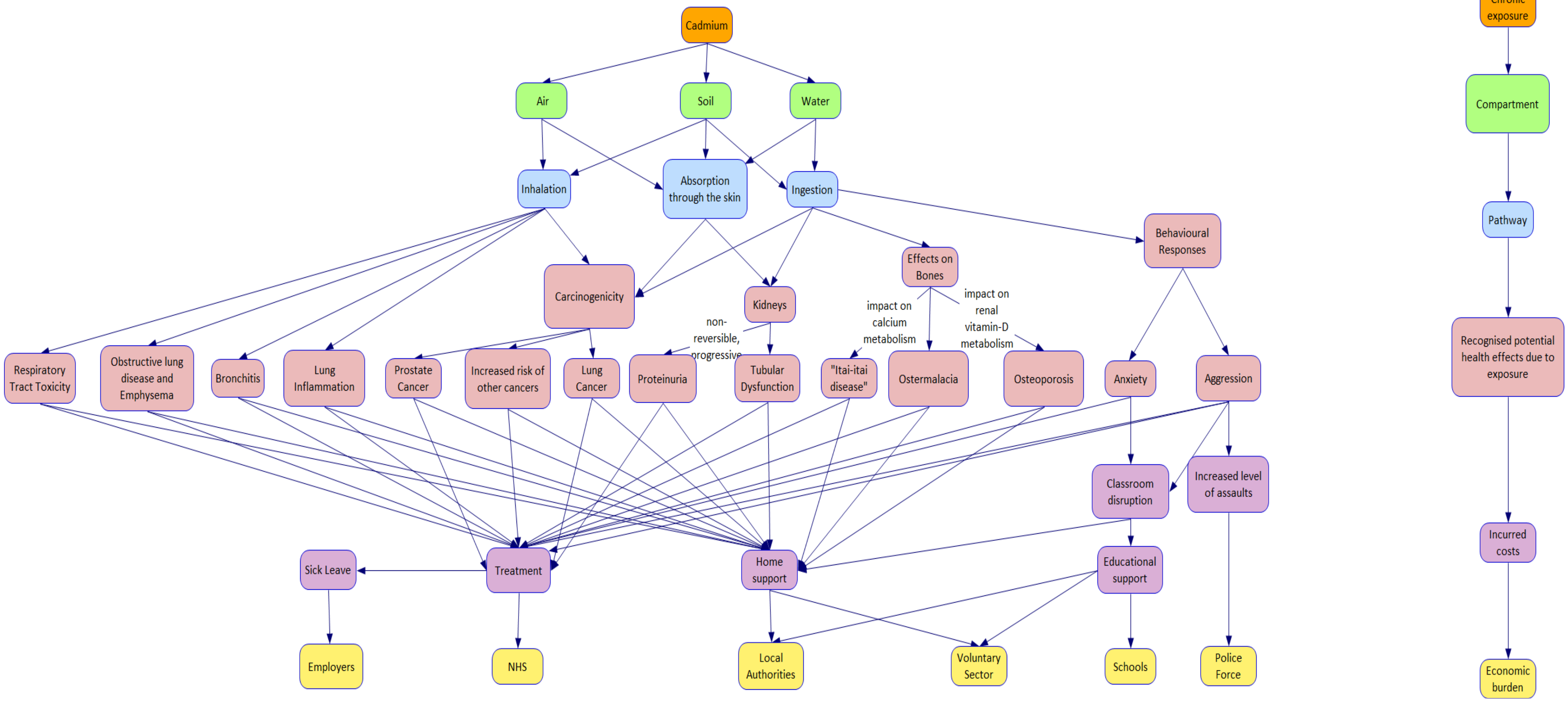


Figure 5.7: Examples of some of the impacts, and the economic costs which result, associated with cadmium exposure in the UK, authors own.

The most significant metal, by quantity, is zinc which has impacts upon the ecology and is a significant problem for the ability of the UK to meet WFD targets (Mayes et al., 2009b). Lead, copper and cadmium have implications for human health as well the local and regional ecology placing burdens upon the NHS how extensive these burdens are again is difficult to quantify. These metals at these levels (see Table 5.2, Table 5.3 and Table 5.5) have implications for the resilience of the ecosystems in Hebden Beck. This affects the appearance of the area and hence the cultural services which are of importance to the area due to its reliance upon tourism. All the Environmental Assessment categories and ecosystem services are interrelated, as with any system one part of it will always affect another (Hartmut, 2007, Meadows, 2009).

Figure 5.8 illustrates the basic situation at Hebden Beck which would also apply for other metal mine-impacted water bodies. The absorption is the point at which a remediation would take effect, but as can be seen from the diagram other natural processes also impact the rate of metal pollution. This is more clearly illustrated in Figure 5.5. LCIA of the remediation technology is taken into account when assessing the overall effectiveness of the environmental impact of the absorption at different scales. It is the primary or local impacts which are sought to be reduced with any remediation (Lemming et al., 2012), by using LCIA methodology it is the secondary impacts of these remediation techniques which are being quantified. In the baseline assessment the primary impacts are assessed.

For Hebden Beck the scope of the Environmental Assessment will seek to capture the dominant effects of the metal pollution and interpret them in terms of ecosystem services affected. This means that it will not capture all the impacts as this will be overcomplicated as previously argued, but will seek to determine the most significant impacts for the local community and the potential stakeholders in order to maximise the potential for a PES scheme to be adopted. This approach has been adopted based upon the stakeholder interviews preference for ease of communication of results both to experts and non-expert. The preference for a single number answer or a range of key indicators of relevance to the stakeholder/stakeholders was expressed in the interviews Chapter Four) been found by other researchers in this area (Bockstael and McConnell, 2006, Doherty et al., 2014, Drake et al., 2013, Howley, 2011, Shoyama et al., 2013, Syme and Nancarrow, 2013, Hime et al., 2009).

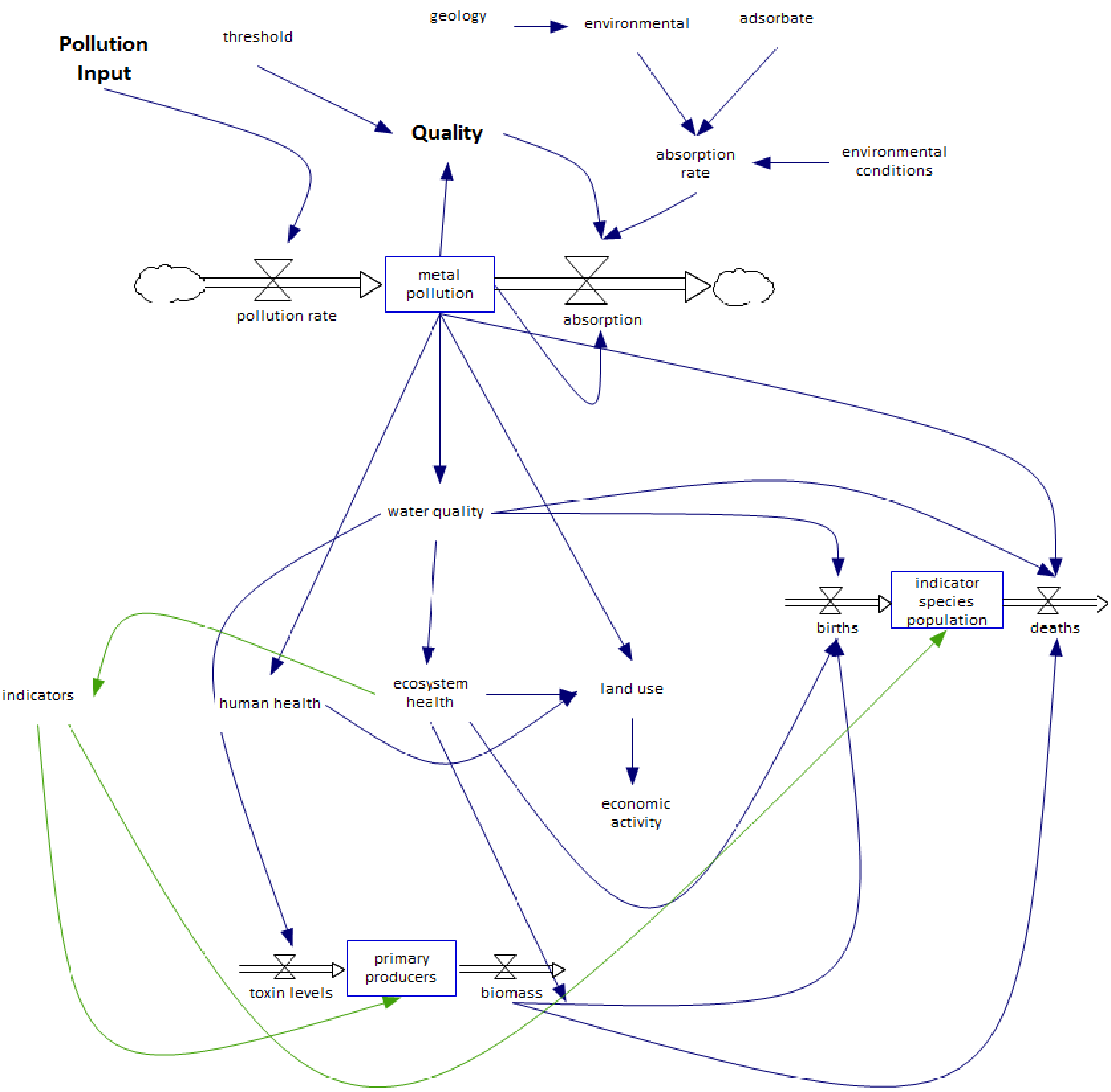


Figure 5.8: Simplifying simulation diagram for the impact point source of pollution at Hebden Beck (absorption refers to the rate of removal of metals by the selected remediation technology)

For the results to be meaningful this methodology needs to be rigorous to determine whether or not remediation will improve the overall environmental resilience of the system. The purpose is to demonstrate the balance of benefits different remediation options, or none, if there is an adverse impact due to point source of pollution. If a positive balance of benefits can be achieved and whether an overall improvement to the resilience of ecosystems and the services they provide (local, national, global) will be the result (Bateman et al., 2011a, Evans et al., 2013, Hanson and Stark, 2011).

The ongoing impacts of no action being taken to reduce the current level of metal pollution are illustrated by Figure 5.8 which shows the influence that point source pollution has on the ecosystem. It is equally applicable both before and after action being taken to remediate the point source of pollution.

Meeting the requirements of the WFD areas assessed, by reducing the levels of metals in order to achieve good environmental and chemical status, will automatically benefit other areas. There are implications associated purely with the WFD requirements which are the statutory obligations and the associated sanctions that can be imposed for not complying with the directive.

- Local human health
- Agriculture productivity
- Ecological impact (ability of the area to support wildlife)
- SSSI and Habitat Restoration Assessment (HRA)
- Fishing (fish farming and levels of *salmonids* within the catchment)
- Tourism (heritage sites)

Some of these areas overlap, for example enhanced numbers of wildlife may increase numbers of visitors (Table 5.7 and Table 5.6). This provides the potential for the bundling of services to be sold to stakeholders and also the possibility of selling single ecosystem services to multiple buyers (Everard and McInnes, 2013). This was also suggested as an option by some interviewees (Section 4.3.4) as a possible option in PES schemes. This was seen as an obstacle in terms of the *"who flinches first"* principle.

These six areas listed above that have been chosen as representative of the most significant costs and impacts to the local area and the wider UK policy context. They have been selected as easily understood and meaningful to potential stakeholders. The fundamental controller of the six impacts is water quality which is directly affected by the mine pollution issue being addressed by the remediation.

## 5.4 Results and Discussion

### 5.4.1 Establishing the Levels of Current Contamination and the Range of Variation.

The impact of the metal contamination being contributed to the Humber catchment from Hebden Beck is noticeable throughout the catchment (Macklin et al., 1997, Cave et al., 2005, Environment Agency and Defra, 2009, Environment Agency, 2014a). Sediment-related metal contamination in the wider Ouse basin has been widely linked with historic mining activity (Macklin et al., 1997), while current water quality assessments show significant impacts. Figure 5.9 shows the status of river systems in the upper Wharfe catchment with regard to none-coal mine pollution (Jarvis and Mayes, 2012). Hebden Beck is highlighted as *Impacted* which is based on demonstrable instream pollution being related to known polluting mine discharges within the same water body (Jarvis and Mayes, 2012). Hebden Beck consistently fails water quality standards for zinc, cadmium and lead (Table 5.3; Environment Agency, 2015) and these instream failures propagate at least 30km downstream of the Hebden Beck catchment itself, hence the *Impacted* status of the upper Wharfe with regard mine pollution (Figure 5.10). Personal communications with the Environment Agency suggest that Hebden Beck is likely to be the source of these downstream failures also.

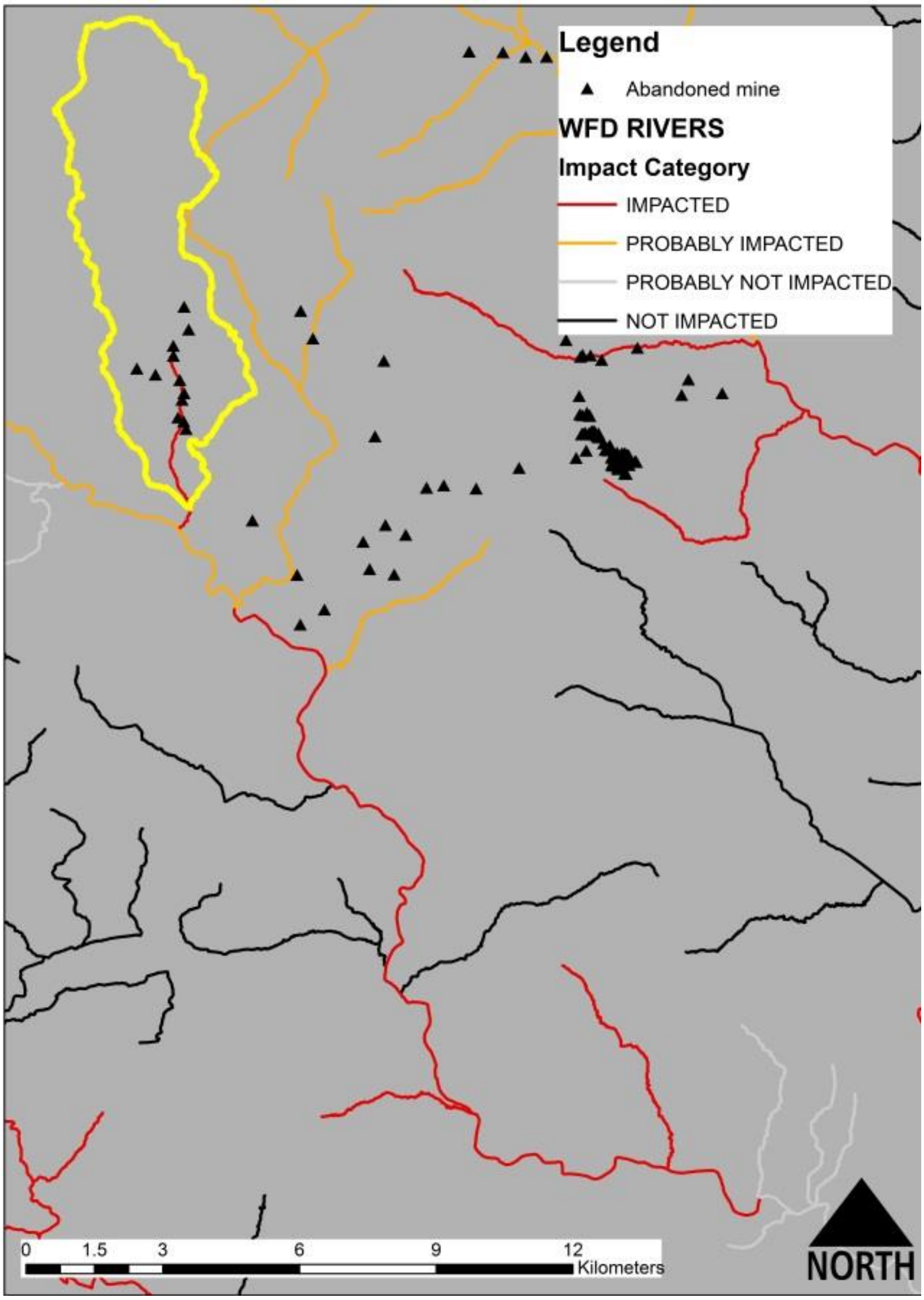


Figure 5.9: Rivers in the Upper Wharfe colour coded based on impacts from non-coal mine pollution (based on Jarvis and Mayes, 2012). Hebden Beck catchment outline shown in yellow.

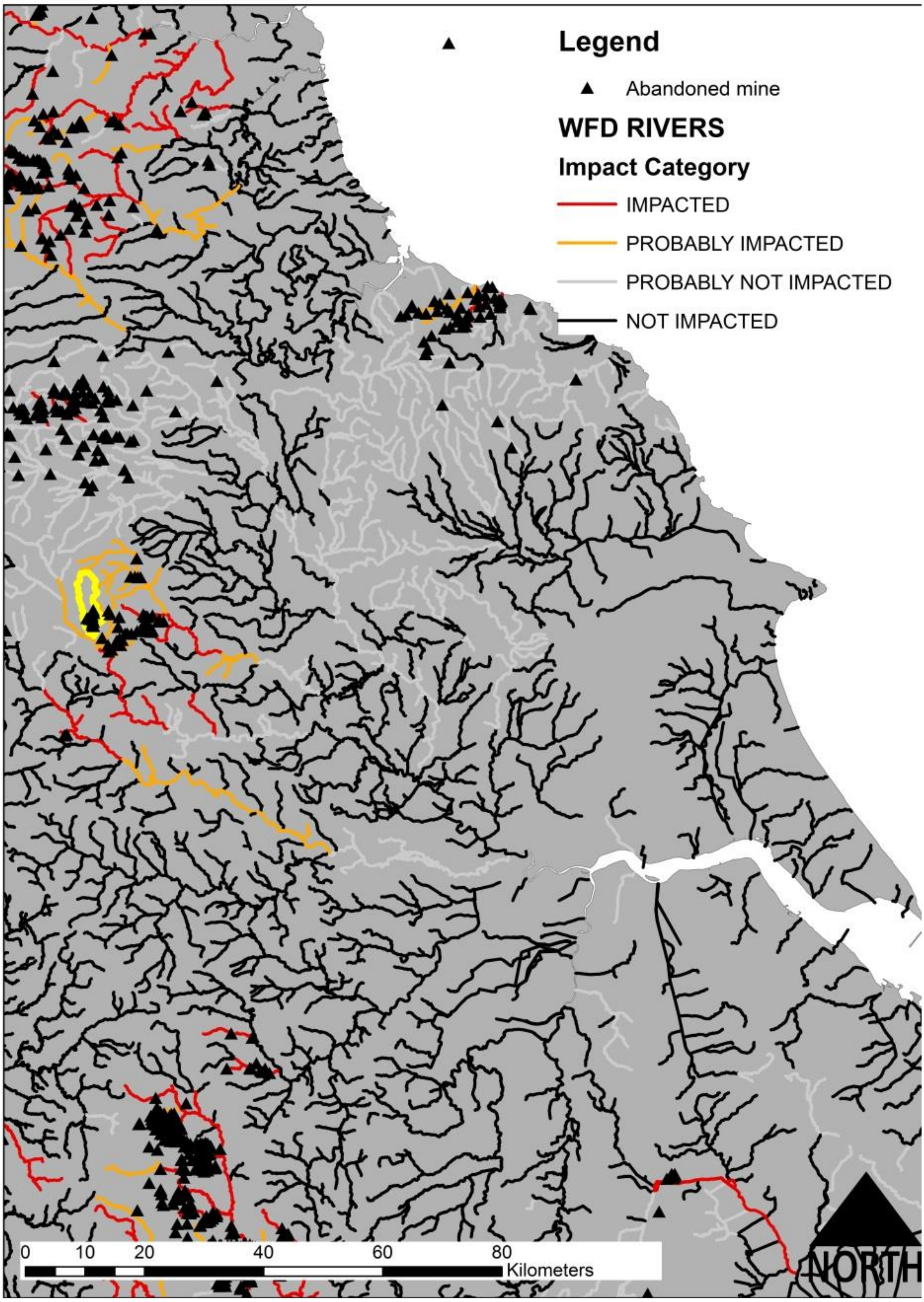


Figure 5.10: The broader context of non-coal mine pollution in the Humber basin (after Jarvis and Mayes, 2012). Note the *Impacted* and *Probably Impacted* catchments around Hebden Beck (in yellow outline) in the upper Wharfe and Nidd, alongside those in the Aire (to the south) and upper Swale (to the north of Hebden).

A conceptual model for the key pollutant sources in Hebden Beck is presented in Figure 5.11. This shows four key adit discharges (point discharges) and areas of spoil along the main branch of the channel, in Yarnbury in the east of the catchment and on Grassington Moor to the north and west of the catchment.

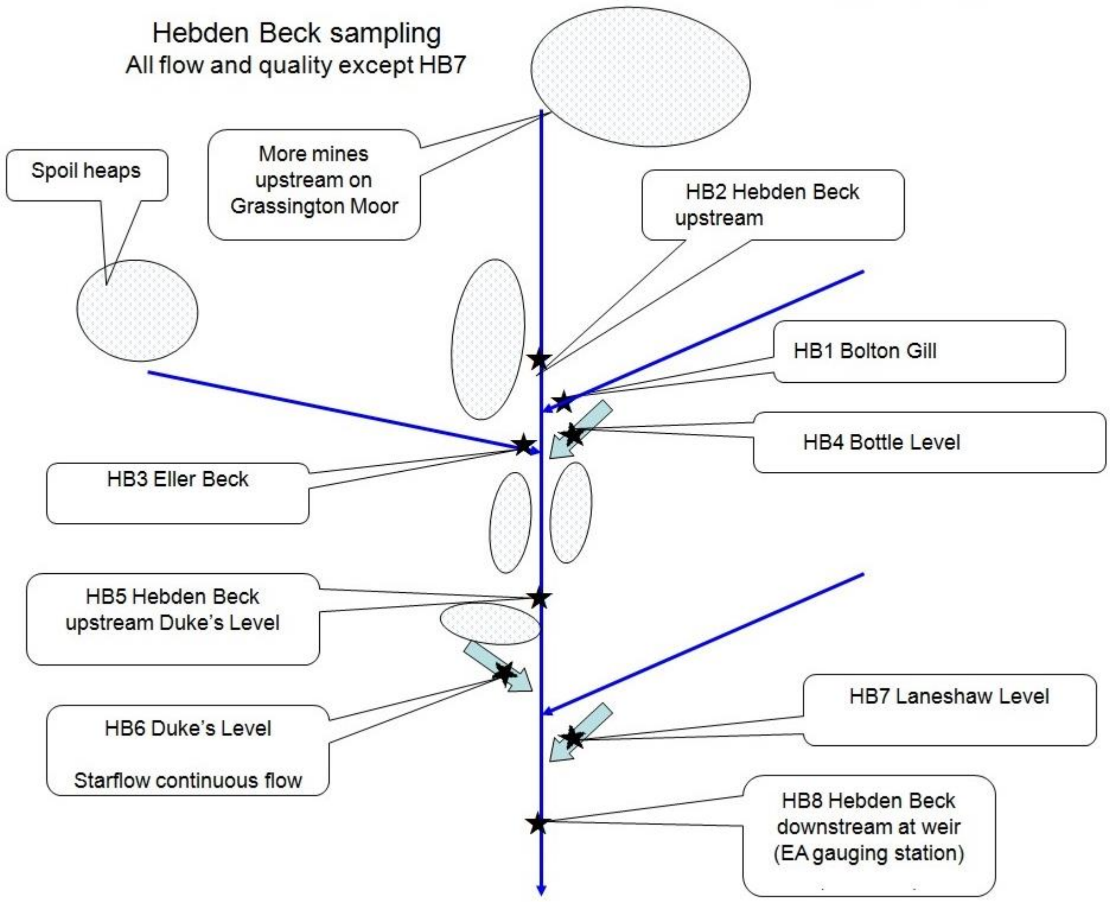


Figure 5.11: Conceptual model of key contaminant inputs into Hebden Beck based on walkover survey and desk-based review.

Table 5.3 show the variation in levels of zinc (Zn) between August 2011 and October 2012 (data supplied by the Environment Agency) at the Hebden Beck gauging station. The levels of metals entering the catchment varies between sites (Appendix Five), fluctuations in concentrations of metals is controlled by local conditions at each site (Figure 5.5) and changes in precipitation levels. The hydrology, is strongly affected by these temporal variations in rainfall and individual catchments characteristics and conditions (Byrne et al., 2012). When the highest concentrations of pollution occur is important for individual species, within the catchment. Individuals are more sensitive to pollution at different phases of their life cycle(Gozzard et al., 2011, Manneh et al., 2012).

Table 5.2: Data showing how much the instream concentrations of relevant metals exceed prescribed quality standards through the Hebden Beck catchment based on average seasonal Environment Agency data.

| Site Ref | Location | Pb EQS Exceeded | Zn EQS Exceeded | Cd EQS Exceeded |
|---|---|---|---|---|
| Upstream | Entering study area | 14x | 46x | 20x |
| Gauging station | Leaving study area | 5x | 5x | 18x |
| Hebden Village | Further downstream | 2x | 4x | 14x |

Table 5.3: Hebden Beck zinc levels; based on data collected by the Environment Agency from the gauging station sample station in Hebden Beck

| 2011/12 Month | Flow l/sec | Temperature (°C) | pH | Total Zn µg/l | Filtered Zn µg/l |
|---|---|---|---|---|---|
| August | 20.55 | 19.03 | 7.72 | 393 | 340 |
| September | 8.50 | 13.64 | 7.81 | 413 | 385 |
| October | 13.44 | 8.59 | 7.95 | 444 | 424 |
| November | 11.73 | 7.14 | 7.1 | 450 | 432 |
| January | 88.77 | 3.28 | 6.6 | 424 | 421 |
| February | 116.04 | 3 | 6.83 | 392 | 340 |
| March | 167.40 | 3.95 | 6.16 | 358 | 353 |
| April | 9.62 | 7.74 | 7.64 | 453 | 410 |
| May | 113.86 | 6.21 | 6.65 | 389 | 369 |
| June | 19.70 | 9.83 | 7.98 | 362 | 359 |
| July | 32.75 | 12.65 | 7.51 | 358 | 352 |
| August | 8.29 | 16.15 | 8.17 | 432 | 420 |
| September | 20.55 | 13.1 | 7.56 | 394 | 373 |
| October | 32.00 | 9.56 | 6.15 | 511 | 490 |

Hebden Beck water quality is adversely affected by the current levels of zinc, cadmium, lead and copper being discharged into it, all four of these metals pose significant risks to freshwater organisms in the UK. (Donnachie et al., 2014). The Donnachie et. al. (2014) study ranked chemicals using three different methodologies (Table 5.4) which classify the metals according to risk to the ecological environment. According to this study both copper and zinc pose a significant risk to UK freshwater ecosystems and the risk posed by cadmium and lead is also significant (Table 5.4). In the Hebden Beck case, all of these elements are significantly elevated above EQS (Table 5.2) according to Environment Agency primary monitoring data.

Table 5.4: Risk rankings of metals to UK river ecosystems using 3 different methodologies, from supplementary information (Donnachie et al., 2014)

Decreasing Concern

| Risk Ranking | | | | | |
|---|---|---|---|---|---|
| Median Ranking | | 5%ile Ranking | | BCF Ranking | |
| Chemical | Risk Ratio | Chemical | Risk Ratio | Chemical | BCF Ratio |
| Copper | 0.0940 | Aluminium | 1.895 | Mercury | 6000 |
| Aluminium | 0.0913 | Copper | 1.059 | Zinc | 3957 |
| Zinc | 0.0290 | Nickel | 0.505 | Triclosan | 3116 |
| Triclosan | 0.0043 | Zinc | 0.332 | Copper | 1514 |
| Nickel | 0.0039 | Iron | 0.180 | Silver | 1233 |
| Iron | 0.0034 | Triclosan | 0.083 | Cadmium | 1116 |
| Manganese | 0.0021 | Cadmium | 0.060 | Lindane | 450 |
| Lead | 0.0010 | Lindane | 0.057 | Lead | 376.5 |
| Arsenic | 0.0005 | Lead | 0.043 | Aluminium | 215 |
| Cadmium | 0.0004 | Chromium | 0.035 | Nickel | 100 |
| Lindane | 0.0003 | Manganese | 0.022 | Iron | 50 |
| Chromium | 0.0002 | Mercury | 0.007 | Manganese | 17.8 |
| Silver | 0.0001 | Arsenic | 0.007 | Arsenic | 4 |
| Mercury | 0.0001 | Silver | 0.002 | Chromium | 2 |

It has been reported that a level of 2.5 µg/l of copper can reduce algal productivity by 57 to 81% (Leland and Carter, 1985), this was the lowest level at which Cu was found to have a harmful effect on freshwater organisms this is indicative of the risk that copper poses to ecosystem service resilience. *Oncorhynchus mykiss* (Rainbow trout) were found to be sensitive to 2.8 µg/l of copper (Hansen et al., 2002b, Hansen et al., 2002a) and to levels as low of 20 and 2809 µg/l of zinc (Mebane et al., 2012) found evidence that their level of survival was reduced at these low concentrations. A primary producer *Lemna gibba* (duckweed) was found to be impacted by 10 µg/l of zinc (Okamura et al., 2012). At these levels of sensitivity, it is reasonable to expect that Hebden Beck is experiencing reduced levels of productivity resulting from the levels of zinc and copper that are being released into it from the abandoned site. This will impact upon the area's ability to deliver specific ecosystem services, thus having a potential economic impact on the area.

The Environmental Quality Standards (EQS) that apply to the Hebden Beck (Table 5.2) are those produced by EC compliance with the WFD for lead, zinc, copper and cadmium (European Commission et al., 2008, European Commission and WISE, 2014, European Union, 2000). The impacts that levels of different contaminants have, specifically metals, is subject to ongoing research (Chon et al., 2010, Crommentuijn et al., 2000, Hoppe et al., 2015, Merrington and Van Sprang, 2014). The establishment of robust standards which can be applied across Europe is an area of active research (Iwasaki and Ormerod, 2012, De Schamphelaere et al., 2014, Merrington and Van Sprang, 2014, Reyjol et al., 2014). These standards are developed to understand the potential risk that these chemicals pose and are used to produce the European Union technical guidance documents. These are developed using current knowledge on quantitative risk assessment and are produced within the Framework of Council Regulation 793//93/EEC on existing chemicals. These standards are produced within a political context and so may be influenced by considerations other than pure science, special interest groups with vested interests contribute to these documents.

Given the changes in contaminant input, it is therefore vital to understand the flux in the levels of metals and the causes and interactions of this flux through improved environmental models which are being developed (Balistrieri et al., 2012, Farley et al., 2014b, Tipping and Lofts, 2014). To determine the significance of the point sources in Hebden Beck and whether or not it is a worthwhile proposition to remediate them, the Environment Agency loadings (i.e. flow multiplied by concentration) data need to be considered (Table 5.5).

Loading data shows that the key inputs of metals into Hebden Beck under base-flow are from Duke's Level and to a lesser extent from Bottle Level further upstream. If the percentage of the flux measured at the gauging station is compared with what is discharged from the various sources, it is clear that Duke's Level is a significant contributor to the instream water quality failures (Table 5.5). The sum of all the point discharges exceeds that of the gauging station suggesting some Zn attenuation from the water column, for example being absorbed by benthic biofilms (Jones et al., 2013). However, it is clear that Duke's Level, as a major underdrain of numerous mines accounts for the majority of the Zn in the system.  Similar patterns are apparent for both Pb and Cd (Environment Agency, 2015). This is a useful exercise in identifying the key contributors to instream water quality failure, and helps in targeting where remedial efforts would be best directed.

Table 5.5: Zn Levels in Hebden Beck, brake down at individual gauging stations

| Site | Base-flow Zn flux (kg/day) | % |
|---|---|---|
| Gauging station | 2.24 | 100% |
| Duke's Level | 1.98 | 89% |
| Bottle Level | 0.28 | 13% |
| Bolton Gill Level | 0.14 | 7% |
| Laneshaw Level | 0.017 | 1% |

### 5.4.2 **Mapping Impacts onto Ecosystem Services**

Following the process illustrated in Figure 5.4 and using the diagram Figure 5.5, the influence that the current metal concentrations are having on the Hebden Beck area and the areas of greatest impact can be determined; thus translated into ecosystem services and the potential for improving ecosystem resilience established. Table 5.6 illustrates the categories of relevance for the baseline study and how they map onto the ecosystem services categories.

Table 5.6: Simplistic assessment of areas affected by point source metal pollution entering Hebden Beck.

| EA Area of Impact | Ecosystem Service Category Affected | Impacted by current level of point source pollution from Hebden Beck |
|---|---|---|
| Economic | Provisioning, Regulating, Supporting, Cultural | Yes |
| Social | Cultural, Provisioning, Regulating, Supporting | Yes |
| Soils, geology and geomorphology | Provisioning, Regulating, Supporting | Yes |
| Water | Provisioning, Regulating, Supporting, Cultural | Yes |
| Landscape and visual | Provisioning, Regulating, Supporting, Cultural | No |
| Heritage | Cultural | No (potential to develop this) |
| Ecology | Provisioning, Regulating, Supporting, Cultural | Yes |
| Coastal ecology and geomorphology | Provisioning, Regulating, Supporting, Cultural | Yes |

Of specific concern to the area are;

- Fish stocks, particularly in relation to the local fish farming industry and the potential for improvement in production
- Primary production within the water course, maintaining and enhancing higher-level wildlife, enhancing areas visual appearance, attracting visitors

- Maintaining metallophyte communities, SSSI sites of particularly interest for research and also attracting visitors
- Impacts on non-metal tolerant taxa
- Human health implications
- Impact on farming livestock
- Appearance of adit,  unattractive off-putting to visitors
- Water extraction (by farmers and water companies)
- Impact downstream when deposited material is re-suspended during high-energy storm events

The final point, re-suspension of sediment is important as existing already deposited metals will gradually become overlaid by non-contaminated materials so having a “capping” effect on already contaminated sediment making it less available during high-energy periods. When sediment is re-suspended it becomes available within the water column and can be taken further down the catchment to contaminate downstream areas, potentially reaching the ocean (Miller, 1997, Macklin et al., 2006, Nordstrom, 2011).

These 8 key concerns also apply to the other metals being released by the historic Hebden Beck mine site point source pollution, copper, cadmium, and lead (Appendix Two and Appendix Three). How they map to ecosystem services and hence how they can potentially be monetised and sold to stakeholders, forms part of the initial environmental assessment and is an initial phase of the framework of process being proposed.

Table 5.7 shows the analysis of the areas of concern and which ecosystem service classification they relate to. Appendix Three shows individual impacts of Zn, Pb and Cu, these were compiled based on available literature and knowledge of the Hebden Beck site and are the authors own opinion. The assessment in Table 5.7 combines information from the literature and the author’s knowledge of the Hebden Beck site. This process is fundamental to the framework (Figure 1.3) as it is one element upon which decisions are about whether it is justifiable to take action to remediate an abandoned metal mine site.

Table 5.7: Ecosystem Serveries Impacted

| **Area of Concern** | **Summary of impacts and expected outcomes** | **Ecosystem service category** | | | |
|---|---|---|---|---|---|
| | | **Provisioning** | **Regulating** | **Supporting** | **Cultural** |
| Fish farming | Annual turnover of salmon farming in an area should increase as productivity increases. Costs should decrease as there will be less requirement to filter the water as frequently for the metals which have been removed upstream.<br>Free range and wild fish stocks (salmon and trout) should also experience improved health and thus improve productivity downstream which will also will have a positive impact on economic activity | Yes<br>Food. | Farmed fish are isolated and are not integrated into natural ecosystem as opposed to fish stocks within the river catchment. There is the potential for fish to escape which can impact on the natural system, the extent of this impact depends upon the quantity and frequency of fish escapes. Effluent from farms has a negative impact on regulating and supporting services. | | Yes, impact on visual appearance River system |

| | | | | | |
|---|---|---|---|---|---|
| Primary production | See Appendix Three for individual metal toxicity tables. Quantity and health of primary production is impacted by the presence of these metals, this is fundamental for the entire ecosystem structure and its resilience having a cascading effect throughout the food web (Armitage et al., 2007). Plants within the water course which are intolerant to current levels of metals may simply displace those species which have developed a tolerance, so it is possible that the overall level of primary production may not increase. The quality of primary production may improve as those plants which can tolerate metals become healthier and less metal tolerant plants displace metallophyte species. Overall it is expected that primary production and the overall resilience and health of the ecosystem freshwater ecosystem will be improved. It is important to bear in mind that, as these are historic sites the presence of an adaptive population which has developed over time needs to be taken into consideration (Batty et al., 2010). | Yes<br>Wild food | Yes<br>Water quality<br>Air quality<br>Climate regulation | Yes<br>Photosynthesis<br>Nutrient cycling<br>Maintenance of biodiversity | Has a high impact on the appearance of the area and clarity of water etc. |

| | | | | | |
|---|---|---|---|---|---|
| Metallophyte communities | Size and distribution of metallophyte SSSI, metallophyte and heavy metal vegetation is coded as calaminarian grassland which is protected under the EU's Habitats Directive and is a diminishing resource in the UK (Jefferson et al., 2011) and as such is protected. A number of metallophyte communities are present downstream of Hebden Beck within the upper Wharfe (Allen valleys landscape partnership, 2010b) that could potentially be impacted by reduced metal loads under remedial scenarios. Possible scope for biodiversity offsetting due to the negative impact that the removal of metal from the water may be possible (e.g. use spent media from treatment systems for calaminarian grassland development). In addition to the metallophyte lichens are also present which have developed as a result of historic land use and metal. These lichens are of particular interest and there are societies which exist specifically to study and protect them[9]. These groups have a vested interest and need to be participants in the ecosystem services stakeholder process of this framework. | No | Yes, removes metal from water and soil<br>Water quality<br>Air quality<br>Soil quality<br>Climate regulation | Yes primary production<br>Photosynthesis<br>Nutrient cycling<br>Maintenance of biodiversity | Yes research and of interest |

[9] The British Lichen http://www.thebls.org.uk/about-lichens/what-is-a-lichen

| | | | | | |
|---|---|---|---|---|---|
| Human health | Health complaints directly attributable to exposure. Evidence for the impact of lead on IQ, increased cancer and noncancer effects resulting from exposure to cadmium, zinc and copper (Appendix Three) chronic exposure. Very difficult to verify linkages/impacts in this setting. These impacts are likely to be minimal due to disruption of pathway and ingestion of water will only occur once it has been treated or rarely if from a direct source of extraction. | No | Yes, impact and change landscape | Yes management of landscape | Yes |
| Impact on sheep | Exposure to metals via the water pathway is being assessed here; the impact of grazing on mine waste contaminated land and ingestion of metalliferrous plants has been assessed elsewhere (Chenery et al., 2012, Smith et al., 2009, Thornton, 2002). It is assumed that the contaminated soil and their flora will not be altered significantly. It is difficult to assess what proportion of livestock's intake results from drinking directly from Hebden Beck hence the nutritional status may not be altered significantly by the remediation intervention. | Yes<br>Food<br>Wool | Yes<br>Soil formation<br>Seed dispersal | Yes<br>Protects sheep gene pool | Yes<br>Maintain farming culture |
| Visual of adit appearance | The appearance of the adit will change as a result of the remediation technology installed. Part of the installation process will be to recreate a "historic" appearance. Information boards about the remediation project and the history of the area in terms of the metal mining will also be included in the project. This will create an added point of interest on walks around the area. | No | No | No | Yes<br>Tourism<br>Visual Appearance |

| | | | | | |
|---|---|---|---|---|---|
| Water extraction | Any water extracted from Hebden Beck for human consumption or use for agricultural purposes will have less metal content and thus require less treatment in order to meet human consumption standards and also be of higher quality if untreated and used directly on the land or for animal consumption, removing any associated problems which may previously have resulted from this direct exposure pathway. | Yes possibly depending on use<br>Water availability | Yes possibly depending on use | Yes possibly depending on use | No |
| Downstream impact | Removal of the source of contamination upstream it will result in a reduced metal contamination further downstream. As sediment within the whole catchment system settles and is increasingly uncontaminated it will create a cap of uncontaminated of material which eventually will seal in the contaminated sediment, if the area is not dredged. | Yes<br>Wild food | Yes<br>Water regulation<br>Sediment quality | Yes<br>Maintenance of Biodiversity | Yes<br>Research area |

As can be seen from Table 5.7 and the Appendix Three, the area is being significantly affected by the metal mine pollution. This impacts the quality and quantity of the ecosystem services in the area. Not all of these effects are readily quantifiable numerically or economically however they are of value to stakeholders who form an integral part of the framework enabling it to move forward. It is the impacts on the water environment that are best quantified currently and therefore arguments for remediation (and ES improvements) should be built around this data.

### 5.4.3 **Environmental Impact Assessment of Installation of Remediation; Short-Term Impacts**

Undertaking an EIA of the different remediation technology options under consideration, assess potential impacts of remediation at a site related to construction works and any resultant improvements from treating the discharges. This is a particularly important exercise in being able to alert stakeholders of any short term disturbance/impacts that may arise ahead of management interventions.

The impacts on the local area while the installation of the remediation technology is taking place will be limited to the duration of the engineering work. These impacts have briefly been discussed earlier in this chapter, and are predominantly social and economic and should cease once the work has been completed. To prevent any long-term consequences from these effects it is important to manage them carefully and maintain good communication local communities and other stakeholders who are directly impacted by the work as it takes place. This was highlighted by interviewees who had experience of implementing engineering type projects in order to ensure that the projects ran smoothly or even in some cases went ahead at all (Section 4.3.4). By maintaining a good information flow between interested parties particularly those related to the tourist industry to retain the areas reputation and prevent an economic impact persisting into the future (Figure 5.12).

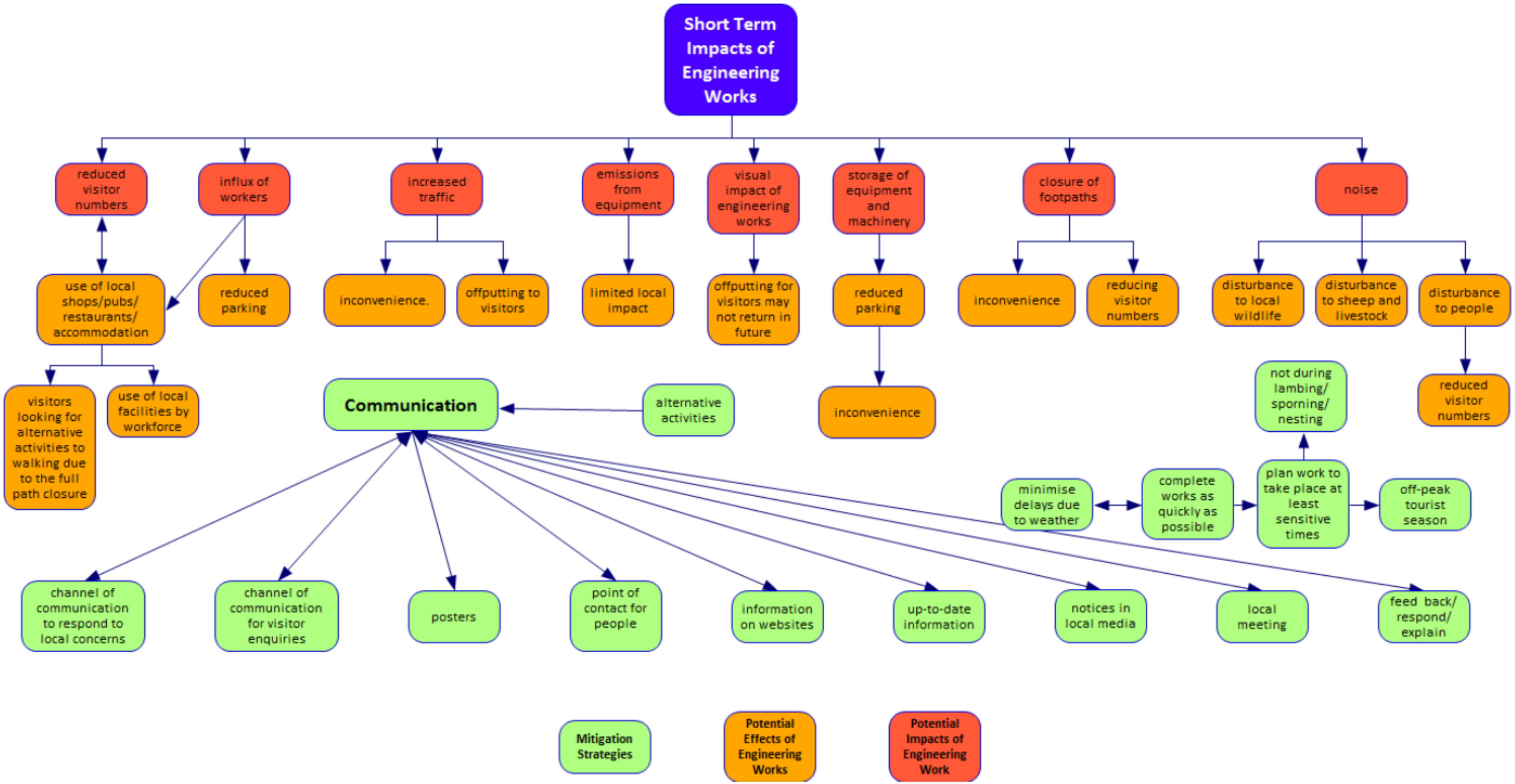


Figure 5.12: Short term impacts of engineering work with mitigation strategies

### 5.4.4 **The Long-Term Impacts of Remediation; Environmental Impact Assessment**

Figure 5.13 illustrates key areas of improvements that Hebden to the Beck community should directly experience resulting from the remediation at the contaminated site. Long-term impacts resulting from the installation of an appropriate remediation technology should be to address all those issues identified in Table 5.7 (Appendix Three). Evidence has been found for positive downstream impacts over larger temporal and spatial scales for a mine impacted river beyond the immediate area which had been remediated in Montana USA (Hornberger et al., 2009).

The need for protection of the calaminarian (metal-rich) grasslands has also to be considered and suitable environmental offsetting or relocation of the affected areas worked out. One potential solution could be to create an area through which the metal loaded water passes before treatment creating suitable habitat for these plant species. This would have the added benefit of removing a proportion of the metals before treatment (Wang et al., 2014, 2012, Lucassen et al., 2009). The need to preserve these metallophyte communities is of value in different ways to the environment to society and also to the economic. If the fate of these areas which are impacted by the proposed remediation of Hebden Beck is not negotiated sensitively and effectively it could result in the whole project is being blocked. Managing stakeholders concerns and using effective communication is vital aspect of this framework as previously stated. However the value and importance of these metalliferous communities is also part of the framework and the possibility that they are seen as of greater importance and value and the potential benefits derived from remediating a specific site should never be excluded. It is important to include this aspect of the effects as integral to this framework is the attempt to balance various impacts within the whole system, geographically, environmentally at different timescales and attempt to weigh them against one another to understand how to improve the current situation so that the result is of benefit overall by not excluding the consequences of any aspect of the remediation (as far as practically possible) positive or negative.

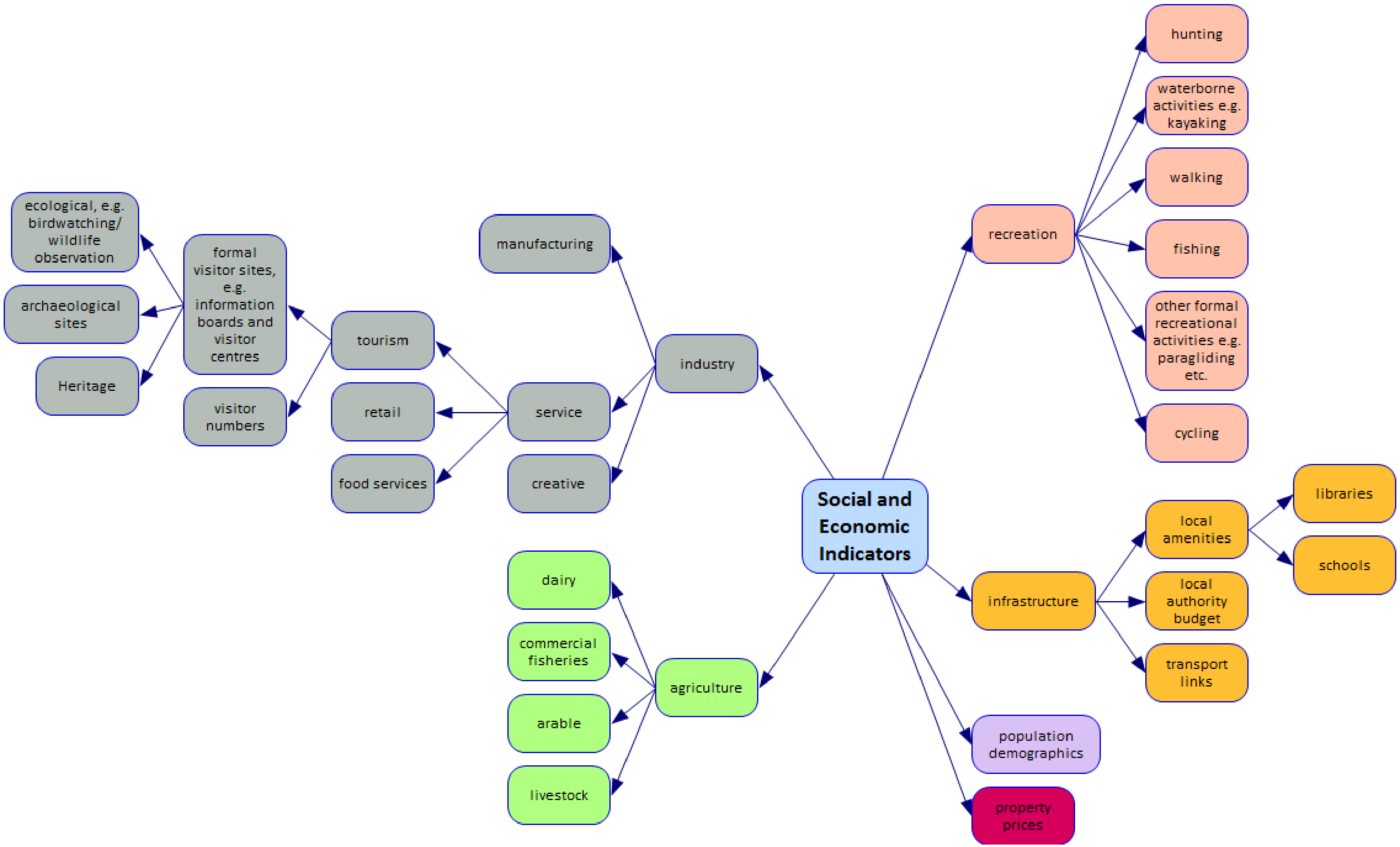


Figure 5.13; Social and economic indicators for impacts of remediation at Hebden Beck

Integral to the PES process is monitoring to ensure compliance, and this is also a long-term impacts of the remediation the need for maintenance and data collection. So ensuring that the economic burden of the scheme is met and can continue to be met into the future has to be included in the overall calculations. This continuing monitoring has the potential to increase understanding and knowledge of ecosystem functioning and improvement and improve the models for the LCSA (life cycle sustainability assessment) going forward into the future as well the potential improvements to ecological models. This positive feedback cycle which results from continuing monitoring is an aspect of this framework which offsets the economic burden that maintenance and monitoring of any remediation scheme will inevitably place upon it. In addition to this other indicators such as those outlined Figure 5.13 can be assessed, which will contribute to SLCA (Social LCA) models and selection of appropriate impact categories. This framework is a particularly useful as an approach as it establishes the baseline from which these indicators can be measured and appropriate categories are selected for future assessment of areas which have been impacted by anthropogenic activity and whether it is of overall benefit to use resources to restore them.

For Hebden Beck the remediation work as part of the negotiation with various stakeholders will be set up in such a way as to generate a point of interest. For example, information boards could be installed in the immediate vicinity the work in such a way as to be sympathetic to the history of the area. This will directly contribute to the cultural ecosystem services of the area; it may not be directly economically quantifiable as with the improvement to the supporting and regulating ecosystem services. However these directly contribute to the resilience and quality of the overall system and improve the quantifiable ecosystem services ability to deliver.

Establishing this principle that it is a systematic improvement which can be seen at different geographical scales, and over different timescales and that it is not only be the immediate effect or the local improvement that is being considered. This equally goes for the impact of the production, installation, operation and decommissioning of the remediation approach taken and why LCIA is so fundamental part of this framework.

The decommissioning phase of the remediation approach will potentially have similar impacts to the short-term effects of installation if it is decided to remove the remediation equipment from the site however in this case Hebden Beck it is envisaged that the remediation approach taken will be long term and that beyond replacing the reactive media there will be no further significant engineering works. Typical timescales for such maintenance are usually of the order of every 10-15 years (Younger et al., 2002).

## 5.5 Conclusions

Locally the metal mining pollution is having a tangible impact on local ecosystem services, including provisioning services such as fish stocks, as well is impacting on the overall resilience and functioning of the ecosystem.  The metals are contributing overall ecological and environmental status of the catchment not achieving good, or better, status (Zhao and Marriott, 2013, Environment Agency, 2014e, Environment Agency, 2014d, Hughes and Quinn, 2014, Macklin et al., 1997, Cave et al., 2005, Environment Agency, 2009b, Environment Agency, 2014a).  By assessing patterns in loading data, it is clear that key contaminant sources can be identified in the Hebden Beck system.

When establishing a baseline, it is important to determine the boundaries of the assessment. By the very nature of the ecosystem services approach there are no boundaries and it seeks to capture the impacts of environmental damage globally. The percentage of total contribution to metals entering the oceans from a particular point source is difficult to calculate. Geomorphology processes and chemical, physical and environmental interactions affect the levels of metal that ultimately enter the oceans (Figure 5.2 and Figure 5.5) Modelling metals progress along a river catchment is fraught with uncertainties (Miller, 1997, Macklin et al., 2006, Nordstrom, 2011). It is necessary to be pragmatic when seeking to capture the impacts and the economic costs of these impacts. An exhaustive study would place an excessive financial burden on the project and costs need to be taken into account at all stages of the project. It also needs to be borne in mind that the results of the EA need to be meaningful and easily understood by potential stakeholders in the PES aspect of the framework. Table 5.7 show illustrates one approach of presenting this information. It concentrates on the most significant impacts that will be tackled by the removal of the metal at a local level where the stakeholders will be most engaged. Other benefits which occur at different temporal and geographic scales should not be ignored and this process should capture and communicate additional benefits for the downstream system which may be of more interest to stakeholders engaged with a more catchment-based ethos.

For some stakeholders, such as commercial companies, investment in such project has an additional benefit of meeting corporate social responsibilities and improving their public image (Chapter Four).

There will be short-term negative impacts of installing the remediation options selected that these will quickly resolve once engineering work has finished the ongoing benefits derived from the remediation options locally will overall be of benefit compared to the current impacts resulting from the metal pollution.  Therefore based on the Environmental Assessment of the local area and the potential downstream benefits overall taking action to prevent the metals entering Hebden Beck at this point source of metal pollution would be of overall benefit to the local community and the wider river basin catchments.

# Chapter Six Methodology and Case study; Remediation System Scenarios

## 6.1 Introduction

A range of treatment systems have been tested globally for metal removal from mine discharges (Jarvis et al., 2014a). These generally fall under the categories of:

A) *Active treatment:* which are conventional chemical engineering approaches typically demanding a constant input of reagents (e.g. lime) and energy (in mixers and clarifiers) (Younger et al., 2002). Such systems have typically been used for high flow, high metal concentration discharges such as Wheal Jane in Cornwall.

B) *Passive treatment:* is where natural energy gradients such as gravity, biological metabolism and photosynthesis are used and treatment systems require routine albeit infrequent maintenance (Younger et al., 2002). Much research effort has gone into such systems given they are generally characterised by far lower operating expenditure than active systems and therefore are potentially more suitable for deployment at remote, abandoned mine sites (Mayes et al., 2009b).

This chapter highlights the different remedial systems being modelled for the Hebden Beck case study. An active lime-dosing system based on the Wheal Jane system in Cornwall is described alongside a passive hydrous ferrous oxide (HFO) system, which is a hybrid of different experimental systems using recycled waste media (in this case from coal mine treatment) as a sorbent for Zn, Cd and Pb (Mayes et al., 2009c, Macías et al., 2012, Macias et al., 2012b, Macias et al., 2012a), with settlement ponds and a wetland. A third scenario is also considered which is a semi-passive bioreactor based on a system recently piloted at Force Crag Lead mine in Cumbria (Jarvis et al., 2014a). This system uses bacterially-mediated sulphate reduction to remove dissolved metals (e.g. Zn, Cd and Pb) as insoluble sulphide minerals. The system requires some ongoing dosing of organic media as the carbon source for these reactions, hence it is considered semi-passive (Jarvis et al., 2014b).

The goal of the LCIA of remediation options is to determine the impact that the production, deployment, use, and decommissioning of these systems has on the wider environment. The output of the LCIA can be used to determine the impacts that each system has upon ecosystem services in order to provide a consistent and cohesive framework when balancing the life cycle of the different remediation options against the potential for risk reduction and improvement in ecosystem services for each of the systems considered (European Commission et al., 2010b).

The LCA will also provide an overall impact score for each remediation option, acting as the benchmark which, simplistically, the benefits derived need to be greater than in order to justify the remediation of the specific sites or site being considered. The risks which result from the site at current levels of contamination also need to be considered in the overall benefit balance and this reduction in risk brought into any judgement about appropriate remediation options for specific sites. These alternatives will be balanced against the risks associated with the current baseline situation at the specific sites being evaluated.

### 6.1.1 System Boundaries and General Assumptions

Detailed assumptions are made about the specific sites; the remediation methods being evaluated and the impact that these interventions will potentially have (Chapter Seven Chapter Eight). The model will be limited by the specificity of the location and remediation technology and the assumptions required in order to tailor the research to the specific remediation techniques and specific location. The LCIA aspect for each of the remediation techniques chosen will be able to be applied to different sites. This will determine whether or not the minimum benchmark, for levels of metal removal, can be met. This will resolve whether or not the benefits derived for ecosystem services are positive or negative for a specific site.

Any assumptions made will be made explicit and based upon current best practice and as outlined in the International Reference Life Cycle Data System (ILCD) Handbook (European Commission et al., 2010a) and the International Standards Organisation (ISO) regulations. Use will be made of current literature and best practice to justify and explain the assumptions and the reason for their inclusion.

The functional unit to which all the scenarios have been normalised to for comparison is **2 kg of zinc treated over a 24-hour period**. The justification for this is twofold: the first being that the maximum level of zinc found at the Hebden Beck site was recorded at a flow of 24 L/second at a metal concentration of 0.959 mg/L (Chapter Five), resulting in a load of approximately 1.98 kg of zinc over a 24-hour period. Thus any system would need to be able to deal with this quantity of zinc and consequent increase in the metals being discharged.

The second justification being that zinc will act as a proxy for the removal of the other metals of concern namely cadmium, copper and lead. Zinc removal is considered indicative of the removal of the other metals given it is more geochemically mobile than the other metals (Langmuir, 1996). This approach was taken by the Environment Agency in their 2014 report investigating compost bioreactor systems (Jarvis et al., 2014a). Most mine water treatment systems typically target a removal efficiency of 90% (i.e. 90% of influent metals are held in the system; Jarvis et al., 2014) and this target is also adopted here. System sizing calculations are based on removal of 90% of 2 kg Zn/ day.

The operational lifespan of the systems being modelled is assumed to be a ten-year period, this lifespan has been selected as a reasonable time period over which the PES system could be operated for being reviewed a contract time period any longer than this would be unrealistic for potential investors (Younger and Henderson, 2014). At this point it is envisaged that renegotiation and a review of the scheme would take place. Therefore complete decommissioning of the systems would not be expected, as in reality all the systems being modelled have a longer life cycle than this and would not require replacement after a 10 year period. There is a significant environmental burden associated with the disposal of the systems/reactive media deployed, which is often overlooked (Mayes et al., 2009b).

### 6.1.2 Scope

The scope of the LCA aspect of this research will encompass the foreground systems (Figure 6.1) of the production, deployment and use of each of the different remediation technologies and background systems incorporated in the energy requirements over their life-cycle. Decommissioning is not included in this assessment of the ten year life-cycle that is being assessed. It is envisioned that the two systems will either continue in use into the future will be left in situ and used to create an environment suitable for rare metal tolerant flora. This will potentially recreate any habitat loss resulting from the remediation scheme in perpetuity. The system boundaries and scope of the LCIA section of this research is as outlined below in Figure 6.1. The production and energy requirements for the manufacture of the individual components of each of the systems will be included in the scope of the LCIA. Equipment and vehicles production, needed for transportation and deployment of the different technologies, will not be included in the LCIA, their energy requirements will be. Therefore the inflow of the LCIA study will be considered to be raw materials and energy used in fabrication of materials and construction and the outflow the emissions to the different compartments (air, water, soil and sediment).

More detail diagrams of the LCIA for each of the remediation options being considered are in the case studies section (Sections, 6.1.2, 6.3, 6.4, 7.3,7.4 and 7.5)

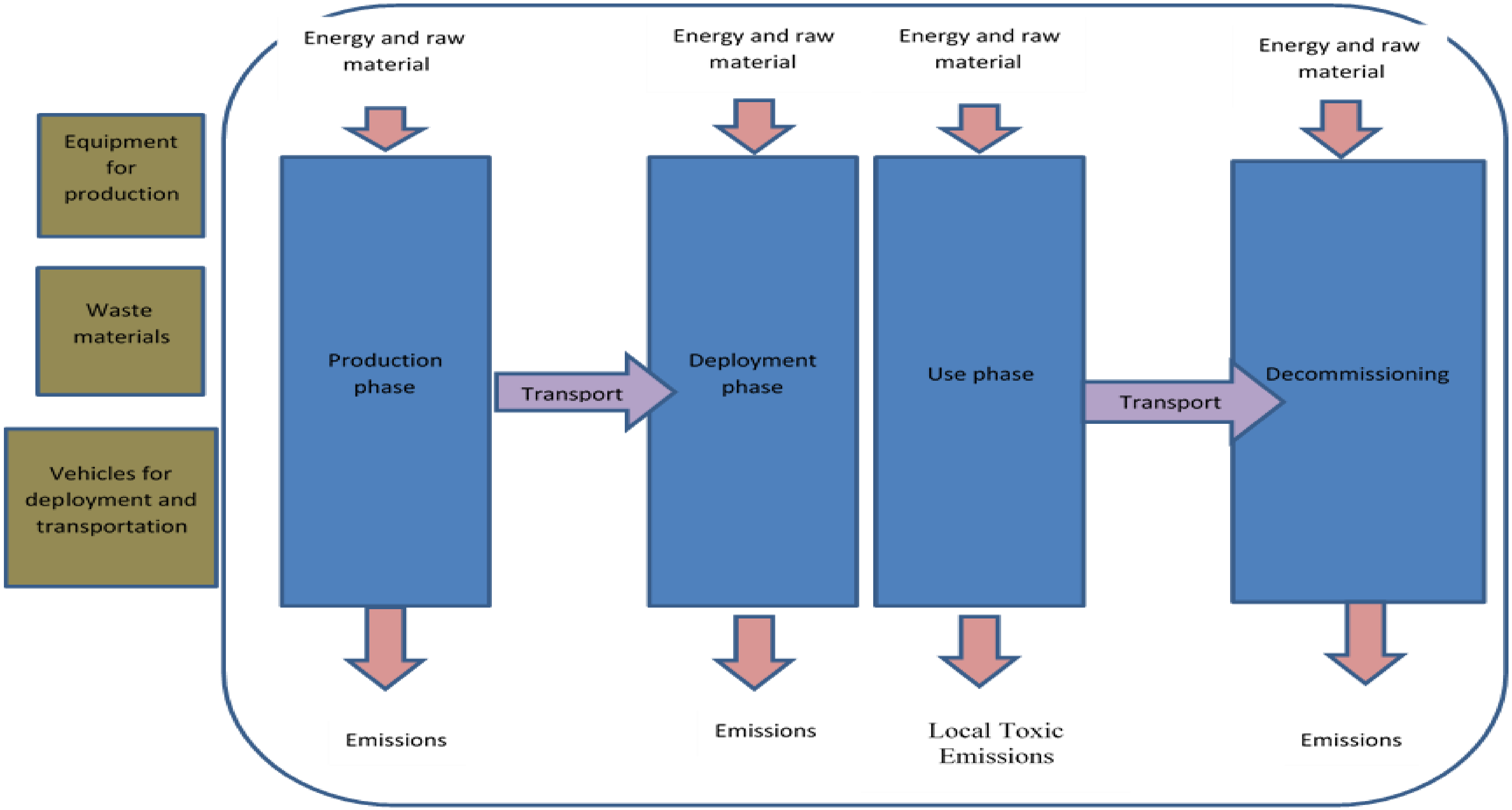


Figure 6.1: System boundary under consideration

### 6.1.3 **Inventory Data**

The inventory analysis phase of the LCIA requires that environmental information be collected about remediation options being considered.  These data relate specifically to each option and the specific site where it is proposed to be installed. The component parts of each option can be seen (Table 6.1, Table 6.4, Table 6.5 and Appendix Four). The sources and costs of these different parts have been taken, where available, from manufacturers (Appendix Four). For the process emissions and energy mixes the European Platform on Life Cycle Assessment (EPLCA, 2010) has been used. The European commission has created a resource directory[10], which contains The European Reference Life Cycle Database (ELCD) used in conjunction with the OpenLCA[11] software selected for use in the Hebden Beck case study (Section 6.1.4 and Chapter Seven). Many databases are provided by a range of institutions and organisations, academic and commercial as well as those provided by the European Commission. For example, the Ecoinvent database version 2 (Frischknecht et al., 2007) which provides information and data on the background processes such as electricity generation. The ELCD has been selected as the data is vetted, by them before inclusion and the sources of information from which it has been compiled are transparent and trustworthy additionally it is free to use which is also a consideration (European Commission et al., 2011). The LCA resource directory aims to create a collaborative and rigorous tool to improve life cycle thinking practices where the most recent information and data can be added by contributors and it is vetted, by the EPLCA, with the goal of promoting robust life cycle thinking practices (Sanfelix et al., 2013).

Sources of data (Appendix Four) used also include direct information provided by manufacturers of the materials needed, generic sources, and the academic literature. Wherever possible, process-specific data are utilised for each of the remediation options, data are selected based upon accuracy, trustworthy in and transparency in order to reduce as far as possible levels of uncertainty.

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[10] http://lct.jrc.ec.europa.eu

[11] http://lct.jrc.ec.europa.eu

The quantities of materials required in order to fulfil the decontamination requirements of each site can be obtained through direct site assessment. Flow rates and metal concentration data are typically used to scale and design a full-scale system. Published metal removal rates (Mayes et al., 2009c, Younger et al., 2005, Jarvis et al., 2014a, Macias et al., 2012b) for different systems were used in this case to determine the required size of systems for Hebden Beck. Such practice is typical in mine site remedial planning (Younger et al., 2002).

### 6.1.4 **Software Selection**

The software produced by openLCA is used in conjunction with the Integrated Life Assessment (ILCA) impact model, which incorporate CF factors from Usetox (Goedkoop et al., 2009, Hauschild et al., 2013) as the most suitable approach to assess the Hebden Beck case study. The selection of the openLCA software was largely pragmatic, based upon its open access availability and its comparability with SimaPro (Ciroth et al., 2014) software which is commercially available and has been widely applied (Hengen et al., 2014). USetox is another widely used model embedded within openLCA, which is commonly used for LCIA studies and takes into account, geographical considerations for freshwater metal ecotoxicity and human health ; (Henderson et al., 2011, Hauschild et al., 2013, Dong et al., 2014, Diamond et al., 2010, Gandhi et al., 2010, Gandhi et al., 2011, Gandhi, 2012) . The impacts being quantified by the LCIA will depend upon;

- Quantity of the metal being released into the environment
- Metal characteristics (which metal, toxicity)
- Rate of release into the environment
- The physical and chemical characteristics of the area
- Pathway to the receptor

The normalisation and weighting of the LCIA impact categories can be done with reference to the conversion into ecosystem services, based upon stakeholder input and relevant impacts and benefits which will then be interpreted in terms of their economic value. The normalisation of impact categories is so that all the impacts relate to the functional unit, in this case to remove 2kg of zinc a day. That means all quantiles are normalised to what is required to achieve this (Bauman and Tillman, 2009). Weighting is how much each impact category is deemed to matter and can be subjective depending upon concerns of stakeholder or based on geography, impacts that occur further away may have less weigh. The harm that each impact has is based upon robust information so a more harmful impact could have a greater weight. Converting impacts to ES can combine a weighting process with stakeholders' values and potential harm. It should be made explicit when weighting has been done and why (Cortés-Borda et al., 2013, Johnsen and Løkke, 2013, Ahlroth, 2014). There is the option to include weighting in OpenLCA but is not being applied in this case study as it can have a distorting effect on the results (Bauman and Tillman, 2009). Applying no weighting is also weighting but by no doing so an addition layer of judgements has been removed and so the result are more transparent It is easier to add weighing in retrospect than remove those that are potentially distorting.

### 6.1.5 **Interpretation**

The interpretation of the impact category results obtained from the modelling of the production, deployment and use of the different remediation methods being assessed will be related to ecosystem services, the impact within the river catchment system and the wider global context. This interpretation will be specifically aimed at enabling an assessment to be made between the potential for a PES scheme to be implemented at the local level and the wider impact on the global environment. Determining the overall benefit of remediating a site compared with the impacts associated with doing so. Ultimately, the economic case (Chapter Eight) for implementing a PES scheme and whether or not what it is viable will also be based upon these results.

The uncertainties inherent within the LCA process which come from data collection, modelling methodology and choices associated with boundaries allocation and time horizons will be included and discussed within the interpretation of the results (Section 7.13). This will enable a more nuanced approach to be taken in terms of how these results are represented and incorporated into a PES framework.

When interpreting the results, it is important to communicate them in a comprehensible way to the range of stakeholders. It is important that their priorities are included in the interpretation, for example how the results relate to their specific goals and reasons for being involved in remediation of a specific site.

The monetary aspect of the LCIA and the fundamental role that it plays in the framework, balancing as it does the costs against the benefits, needs to be rigorous and transparent in order for stakeholders to trust the results. It is also this monetisation that will determine the overall balance of whether it is cost-effective to move forward with the remediation technology.

## 6.2 Passive Multistep Remediation System.

The system being assessed using LCIA methodology to demonstrate the efficacy of the framework proposed in this research is based upon the multistep alkali passive treatment system developed in Spain at the Monty Romero abandoned mine complex (Caraballo et al., 2011, Macias et al., 2012b, Macias et al., 2012a, Caraballo et al., 2009). This disbursed alkali substrate (DAS) plus natural Fe-oxidizing lagoon (NFOL) was deployed and the pilot study demonstrated successful treatment of acid mine drainage (AMD) containing an average of 390 mg/L of zinc, 10 mg/L of copper, 140 μ g/L of lead and traces of cadmium to below the recommended limits for drinking water (Caraballo et al., 2011, Macias et al., 2012b). The NFOL + DAS system was attributed with being capable of achieving complete metal removal for the highly metal polluted AMD being treated at the Monty Romano abandoned mine complex with an approximate 3.4 years lifespan before zinc breakthrough occurred, at a flow rate of 0.5 L/minute (Caraballo et al., 2011, Macias et al., 2012b). A key aspect of this system is MgO (caustic magnesia) powder is a waste material available locally to the Monty Romero study site, it is proposed that this reactive material will be replaced with hydrous ferric oxide (HFO) pellets, a waste material widely available in the UK and with promising sorption properties. The decision to use HFO pellets rather than MgO is justified based upon two primary considerations; firstly that HFO has been widely found to be effective at metal removal in lab scale studies and is a promising material for treatment of zinc-contaminated waters (Aryal et al., 2011, Streat et al., 2008, Mayes et al., 2009c, Mohammed et al., 2012), secondly that HFO is a waste stream resulting from coal mine water treatment in the UK and throughout Europe with large quantities of this material being widely and freely available (Mayes et al., 2009c). The effectiveness of the HFO has been shown to be equivalent to the MgO based upon the absorption studies available for HFO pellets and the results from a study conducted by (Mayes et al., 2009c) using HFO pellets for the removal of zinc from circum-neutral mine waters.

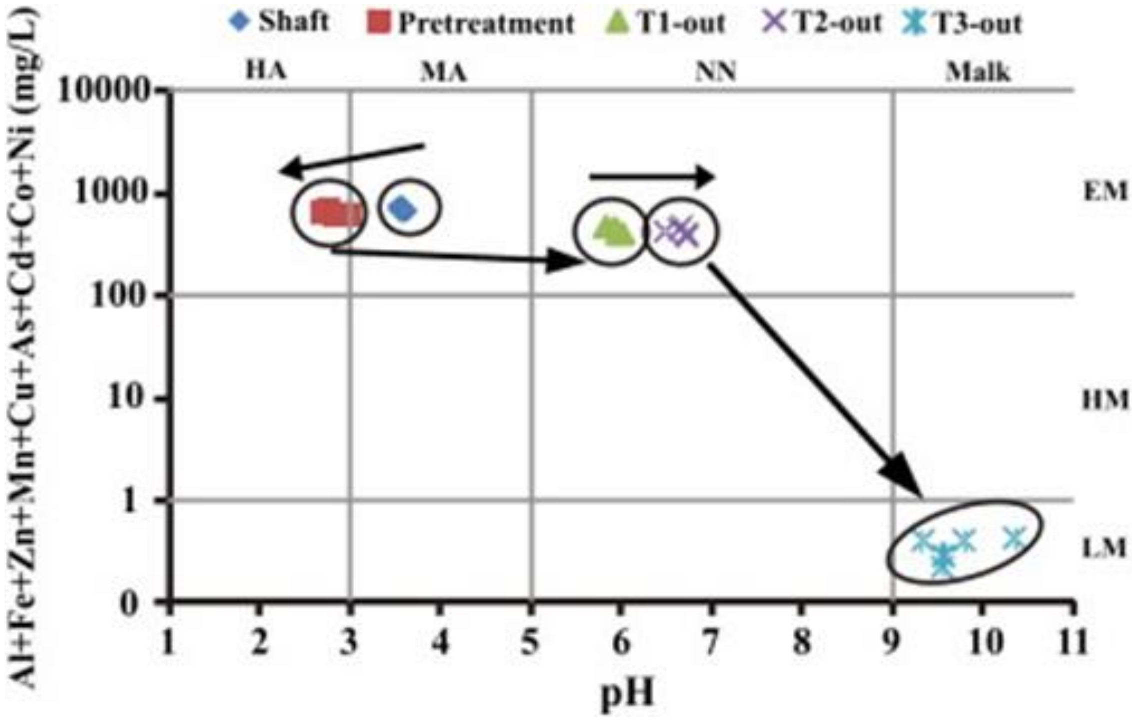


Figure 6.2:Modified Ficklin diagram for the different steps in the NFOL+DAS treatment. HA: high acidity, MA: moderate acidity, NN: near neutral, Malk: moderate alkalinity, EM extreme metallic, HN: high metallic, LC: low metallic T1: tank 1, T2: tank 2, T3: tank 3

Based upon the findings of the treatment system proposed by (Macias et al., 2012b) it is proposed that a passive system based upon the DAS system and HFO pellets will be modelled. This is justified based upon Figure 6.2 which shows circum-neutral pH waters (Figure 6.3), such as those at Hebden are adequately treated in this manner.

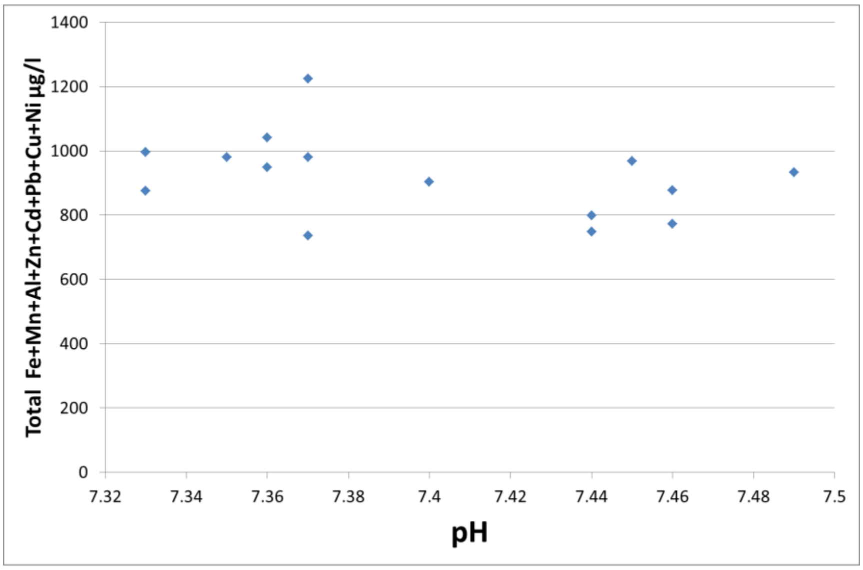


Figure 6.3: Data obtained over a 12 month sampling period at Hebden Beck (from Environment Agency) showing relatively constant total metal concentration under the range of pH measured

The system that will be modelled and the individual components are outlined in Table 6.1, while an idealised system configuration is given in Figure 6.4.

Table 6.1: Detailed description of treatment constituent parts, based upon (Macias et al., 2012b, Mayes et al., 2009).

| Name | Constituent part | Reactive material |
|---|---|---|
| T1 | 3 $m^3$ Cylindrical fibreglass tank (3000 litres) | 20% (v/v) High purity limestone sand (normal grain size 3 to-6 mm) 80% (v/v) wood shavings |
| T2 | 3 $m^3$ Cylindrical fibreglass tank (3000 litres) | 20% (v/v) High purity limestone sand (normal grain size 3 to-6 mm) 80% (v/v) wood shavings |
| T3 | 0.168 $m^3$ rectangular fibreglass tank (168 L) (basal area 0.35 $m^2$) | 180 kilograms HFO pellets (75% HFO 25% Portland cement (v/v)) |
| D1-2 | 6 m $^3$ decanting ponds, dug into the ground and isolated with UV proof plastic | |

Table 6.2: Hydro chemical composition of the mine water in and out (all values in milligrams per litre) based upon results from (Mayes et al., 2009d)

| | Values into treatment tank | | | Values out of the treatment tank | | |
|---|---|---|---|---|---|---|
| | Mean | Standard deviation | Max | Mean | Standard deviation | Max |
| pH | 7.8 | 0.5 | 8.5 | 8.7 | 1.1 | 11.9 |
| Temperature | 7.3 | 3.2 | 12.6 | 6.1 | 2.4 | 9.4 |
| Metals | | | | | | |
| Al | <0.05 | | 0.3 | 0.056 | 0.037 | 0.1 |
| As | <0.01 | | | <0.01 | | |
| Cd | <0.01 | | <0.01 | <0.01 | | <0.01 |
| Cr | <0.01 | | <0.01 | <0.01 | | <0.01 |
| Fe | <0.1 | | 0.5 | 0.13 | 0.12 | 0.35 |
| Mn | <0.05 | | 0.1 | 0.05 | 0.02 | 0.07 |
| Ni | <0.01 | | <0.01 | <0.01 | | <0.01 |
| Pb | <0.05 | | <0.05 | <0.05 | | <0.05 |
| Si | 2.9 | 1.1 | 4.8 | 1.7 | 1.6 | 3.9 |
| Zn | 1.5 | 0.5 | 2.2 | 0.9 | 0.3 | 1.5 |

Maintenance intervals for the passive system of 5 years is applied as per Macias et al. (2012b) given this is when reactive media would be spent at the 2kg Zn / day functional unit (Mayes et al., 2009d).

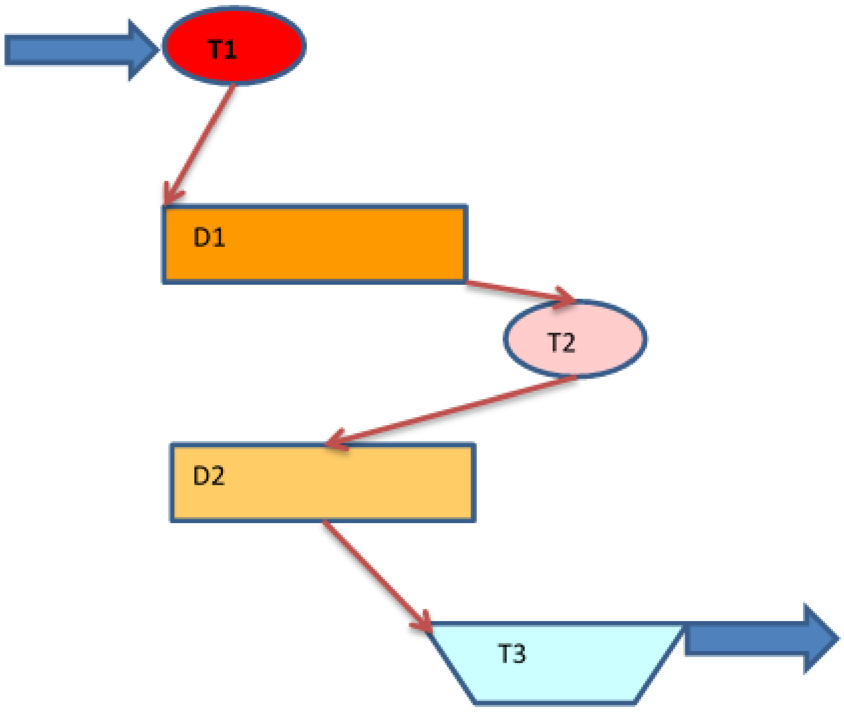


Figure 6.4: Passive HFO, based on DAS passive treatments system based upon (Macias et al., 2012b) T1: 3 $m^3$ Cylindrical fibreglass tank (3000 litres), T2: 3 $m^3$ Cylindrical fibreglass tank (3000 litres), T3: 0.168 $m^3$ rectangular fibreglass tank (168 L) (basal area 0.35 $m^2$), D1-2: 6 $m^3$ decanting ponds, dug into the ground and isolated with UV proof plastic

## 6.3 Active Lime Dosing Treatment System

The parameters for active lime dosing treatment system that is to be used in this case study based upon the active water treatment plant design deployed for the remediation of the abandoned Wheal Jane tin mine in south-west Cornwall (CL: AIRE, March 2004, Coulton et al., 2003).

Table 6.3 shows that the discharge quality at the most important site for treatment in Hebden Beck (Duke's Level) is far less contaminated than the water successfully treated by the active lime dosage treatment plant at the Wheal Jane abandoned tin mine. Based upon these parameters it is reasonable to assume that the same system would successfully achieve the requirement of the functional unit of removal of 90% the lead, cadmium, zinc and copper at the proposed case study site. The system configuration is therefore based on the Wheal Jane system with amendment to dosing rates based on the lower metal loading (Table 6.4)

Table 6.3: Average metal loads at Dukes level and Wheal Jane active treatment plant (before treatment)

| Source of metal contaminant | pH | Average Fe (mg/l) | Average AL (mg/l) | Average Zn (mg/l) | Average Cd (mg/l) | Average Pb (mg/l) | Average Cu (mg/l) | Average Ni (mg/l) |
|---|---|---|---|---|---|---|---|---|
| Hebden Beck (data supplied by environment agency) | 7.39 | 0.074 | 0.078 | 0.702 | 0.005 | 0.052 | 0.003 | 0.002 |
| Wheal Jane (untreated Colton et al., 2003, CL: RAIRE, 2004)) | 3.9 | 150 | 50 | 2.5 | 0.12 | 0.15 | 0.5 | 0.55 |

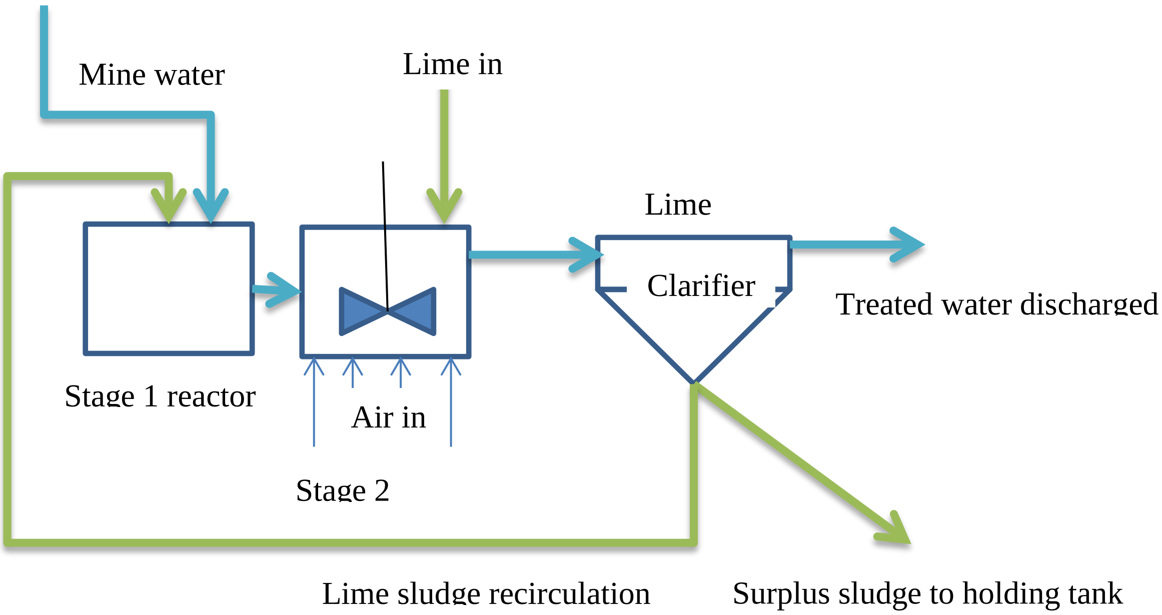


Figure 6.5: Process streams schematic arrangement adapted from (Coulton et al., 2003)

Table 6.4 show and Figure 6.5 the constituent parts of the system based upon those used in Cornwall at the Wheal Jane abandoned mine site. As illustrated in Figure 6.1, the system boundaries also include transportation of each of these elements to the proposed remediation site suitable forms of transportation of these components and distances are included in the LCA for all of the remediation options being considered.

Table 6.4: Constituent parts of active lime dosing system based upon Wheal Jane design (Coulton et al., 2003)

| Name | Constituent part | Reactive material |
|---|---|---|
| Stage one reactor | 10 m² depth 5.5 m concrete tank<br>4kW mixes (x 2)<br>150 mm plastic piping | Recycled lime sludge |
| Stage II reactor | 10 m squares depth 5.5 m concrete tank<br>75 kW mixer motor bottom mounted vertical blade turbine<br>150 mm plastic piping | Lime (flocculant dose rate 0.064 mg/L adjusted based upon (Coulton et al., 2003)) |
| Air blower | 30 kW and 25 kW | |
| Clarifier | 150 mm underflow pipe<br>4 kW pump<br>1.5 kW pump<br>1.1 kW motor<br>150 mm plastic piping<br>Materials for tank | |

| | | |
|---|---|---|
| Sludge surplus tank | 368 m³ concrete tank | Potential for metallophyte community offsetting on surplus sludge. Development of evaluation potential of metallophyte effectiveness for metal decontamination |

## 6.4 Semi-Passive Bioreactors

The final treatment scenario being modelled at Hebden Beck is that of a semi-passive bioreactor system developed at Newcastle University and currently being deployed at Force Crag (Cumbria) in partnership with the Environment Agency, Defra, and the National Trust (National Trust 2014). Similar systems have also been piloted at other mine sites internationally (Christian et al., 2010, Gibert et al., 2008). It has been found is that at field-scale the bioreactors are less efficient than at lab scale, which may be due to the fluctuation inflow rate and vagaries of performance under ambient environmental conditions (Christian et al., 2010). This would suggest that controlling the flow through the use of a pumping system and flow regulator would be a useful way to ensure that the operational efficiency of the semi-passive bioreactors.

The scale of the project being deployed at Force Crag is significantly larger than would be practical at the site such as Hebden Bridge, where the available land is limited. Some of the work done on upscaling the proposed system (Gandy and Jarvis, 2012, Mayes et al., 2011a, Song et al., 2012) suggests that appropriate downscaling could be achieved based upon the lower loading rate of Duke's Level in Hebden Beck. The appropriate sizing for such a system can be obtained using the system worked out by Sapsford and Williams (2009). Selection of an appropriate compost to be used within the semi-passive bioreactors needs to be based upon its ability to fulfil the need of metal removal at the levels at the specific site (Table 6.3) and being appropriate for use within the bioreactors. The minimum requirement is usually that the material meets the British Standards Institution (BSI PES 100) criteria, which sets thresholds on metal and pathogen concentrations. Additionally, the compost needs to be easily available and transportable to the site and affordable. Furthermore, if the compost was a waste product (i.e. it did not have a current end use consuming the volumes produced) additional benefits could be yielded by reducing production burden. Such aspects are readily accounted for in LCA and have shown to be of importance by other workers assessing the life cycle of mine remediation systems (e.g. (Hengen et al., 2014)).

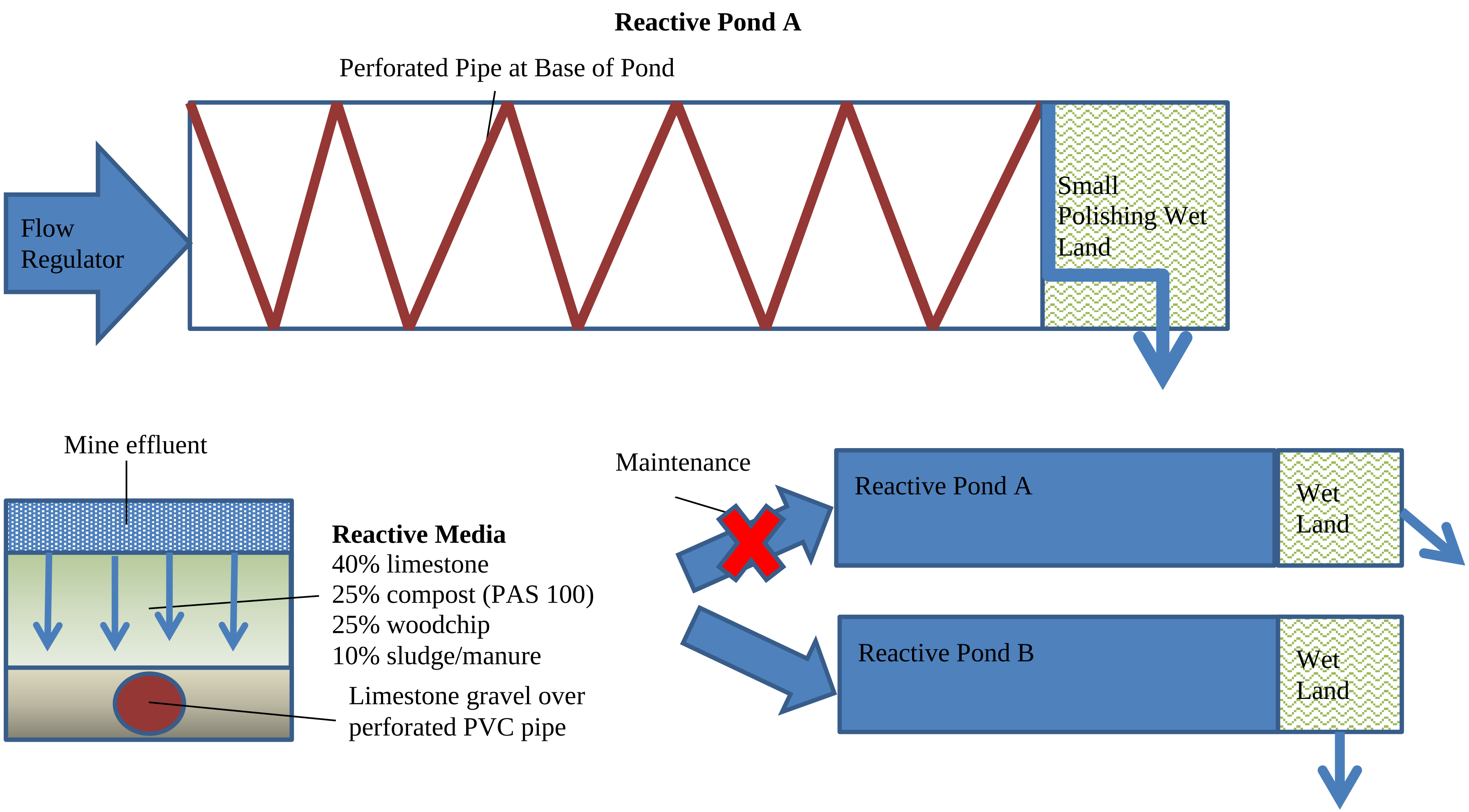


Figure 6.6: Semi-passive Bioreactor

The configuration of the semi-passive bioreactors for the case study based upon the Hebden Beck site is shown Figure 6.6 and the individual components of the system are shown in Table 6.5.

Table 6.5: Constituent parts of semi-passive bioreactor

| Name | Constituent part | Reactive material |
|---|---|---|
| Channel | Plastic pipe to direct mine water to the pump and flow regulator (dimensions as appropriate) | |
| Flow regulator | Pressure Controlled U-shaped flow regulator | |
| Reactive tank A | Excavation of pond to a depth of 1.5 m, length 13 m, width 4.5 m lined with UV proof plastic (need to work out specific dimensions required based upon (Sapsford and Williams, 2009) | Compost 25% (v/v)<br>activated sludge/manure 10%<br>wood chips/straw 25% (v/v) lime pebbles (5 to 8 cm diameter) 40%<br>Limestone gravel at base (<20mm diameter, 0.5m depth) |
| Perforated PVC plastic pipe | Pipe 625m approx. | |
| Reactive tank B | Excavation of pond to a depth of 1.5 m, length 13 m, width 4.5 m lined with UV proof plastic | Compost 25% (v/v)<br>activated sludge/manure 10%<br>wood chips/straw 25% (v/v) lime pebbles (5 to 8 cm diameter) 40%<br>Limestone gravel at base (<20mm diameter, 0.5m depth) |
| Polishing wetlands | Appropriate reeds and plants | |

## 6.5 Available Sources of Reactive Media

A suitable source of limestone for all of the systems is the lime which is produced as a by-product of the sugar beet industry this is called chitosan (CH). This lime is currently sold to farmers to use on the land by British Sugar this source is readily available within the UK and more sustainable than using virgin mined lime. A study found that CH is particularly efficient at removing metal mixtures (which included Cu, Cd, Zn and Pb) (Shaheen et al., 2013) and there is a suitable source of for use within these proposed systems. Using waste materials for the reactive media where possible, for example HFO and CH (commercially known as LimeX) means that the zero burden assumption[12] can be applied when conducting the LCIA. This significantly reduces the environmental impact of the options being considered (Guinee et al., 2011, Ekvall et al., 2007).

[12] use of a waste material does not have any production or use impacts as this material would "exist" whether or not it was used in this system and thus does not have any additional impact as there are accounted for in other systems which generated the waste

Once the HFO, and CH have been spent, they are metal enriched and so will be classified as hazardous waste. If the approach of using this material to recreate an area for metal tolerant flora is not chosen then disposal of the material at the end of the remediation options' operation will be necessary. There is the opportunity of removing the metals from the spent material, which would have addition environmental and economic benefits (Chapter Eight). This option is not being examined here therefore the spent material would need to be sent to a managed landfill site which is suitable for the disposal and handling of this type of hazardous material. The gate fees and haulage cost for disposal of hazardous material are included in Appendix Four. These additional impacts should be born in mind when considering what approach to take, but are not within the boundaries of this study.

## 6.6 **Summary**

All of the three options laid out here could potentially be used to remediate the levels of metals currently being discharged from the Hebden Beck site ( Sections 6.2, 6.3 and 6.4), as they have all been trialled successfully at more polluting sites (in terms of total metal loads). The HFO passive system has only been trialled at pilot scale (in the UK and Spain) so there is arguable greater uncertainty about full-scale performance for this system than the active or semi-passive options. The design is as outlined above have been configured to be able to manage 2 kg of zinc every twenty-four hours. The inventories of system requirements give a useful indication of the raw materials required and the scale of the systems (Appendix Four). System size is usually a key remediation issue in upland systems such as Hebden Beck, where flat land area is often at a premium. The HFO passive reactor is the smallest of the three systems based on design requirements. Chapter Seven presents the full LCA of these different configurations for the case study catchment.

# Chapter Seven Practical Application of LCA to Hebden Beck Remediation Scenarios

## 7.1 Introduction

Life Cycle Analysis (LCA) is often used to assess the environmental impact of a product or process from its “cradle” to its “grave” or production including the extraction of raw resources to its disposal. Depending upon where the boundaries of the system being drawn, the inclusion or exclusion of certain processes that go to make up the whole system can be included or excluded from the assessment. The boundaries of the three systems being assessed are detailed in Sections 7.3 and 0. Results of LCAs are described quantitatively and comprise of relevant impact categories (See Section 3.3.2).

This chapter provides a comparative analysis of LCA applied to three different approaches for treating mine waters (active, semi-passive, passive) in the case study catchment of Hebden Beck, North Yorkshire detailed in Chapter 6. The three remedial scenarios are compared against an assessment of the current *status quo* in Hebden Beck: that of a costed (Chapter Eight) and environmental assessment (Chapter Six) of the impacts of current metal release from the abandoned mine sites to the water environment.

In addition to providing an assessment of the relative costs of different management approaches to a typical mine water treatment scenario in the UK, this chapter provides the example framework of how LCA can be used in assessing the full costs of treatment systems as part of the remedial planning decision making process at abandoned mine sites. This costing is crucial for linking with the potential economic benefits of remediation (Chapter Eight) when considering PES.

## 7.2 Methodology

Background to the methodology has previously been discussed in Chapter Four and Sections, 6.1.1 - 6.1.5. In this section of the research a basic LCA of each of the remediation options has been conducted using OpenLCA software and the recommended Life Cycle Data System (ILCD) methodology, which has been developed by the European Joint Research Council (European Commission et al., 2010a, European Commission et al., 2011, Hauschild et al., 2013, Owsianiak et al., 2014). To determine the most appropriate characterisation modelling, a number of different methodologies were assessed and compared (Hauschild et al., 2013, Owsianiak et al., 2014). This assessed the best methodologies modelling to the midpoint and end point impact categories based upon six categories; 1) completeness of scope; 2) environmental relevance; 3) scientific robustness and certainty; 4) documentation, transparency and reproducibility; 5) applicability; and 6) stakeholder acceptance. Based upon this ranking alongside its inclusion of characterisation factors for the relevant metals (Pizzol et al., 2011b) the ILCD methodology which uses USEtox was deemed the most appropriate method. This method was selected as the database which was used to assess the different options is the European reference Life Cycle Database (ELCD) version 3.1 which is compatible with this methodology, is freely available and the data is verified by the European Platform for Life Cycle Analysis research council (EPLCA and JRC, 2014)

Each system has been normalised for the removal of the levels of zinc at Hebden Beck. System size has been determined based on published removal rates of zinc (as the chief contaminant of concern at most metal mine sites (Mayes et al., 2009b, Jarvis and Mayes, 2012, Mayes et al., 2013)) and scaled to a level where a set quantity of zinc is removed. This would equate to a point where negative ecological impacts would no longer be anticipated instream (Chapter Six). As previously stated, for a full and comprehensive application of the framework these avoided impacts would also need to be assessed. This could be readily incorporated during site remedial planning works using ecological modelling software, such as SAGIS and AQUAFLORA (Kim et al., 2014, Jiang et al., 2012, West Country Rivers Trust, 2013, Comber et al., 2013, Feio et al., 2012, Tipping and Lofts, 2014) to determine the benefits derived and incorporated into the overall assessment.

System lifetime has been set at 10 years, which is a typical management timeframe at legacy mine water sites (e.g. Jarvis and Mayes 2012). It is important to remember that the impacts from the semi-passive bioreactors system and the passive HFO system are loaded towards the manufacturing and installation/deployment phases given the minimal operational requirements of such systems compared to an active system. Although some of the impact categories effects such as climate change have long-term implications, these contributions all happen in a single time periods and are not distributed over the life time of its operation. As such; these broad differences between the active system and the more passive approaches in terms of distribution of impacts should be borne in mind.

For the assessment of baseline conditions in the system, data on metal flux (Jones et al., 2013) and ambient Environment Agency monitoring data are used to assess the impacts of metal release to surface waters in Hebden Beck.

## 7.3 Passive HFO System

The passive hydrous ferric oxide (HFO) system has been assessed using the data in the appendix (Appendix Four, Appendix Five and Appendix Six) and the information as previously stated in Section 6.1.2.

The zero burden assumption[13] has been made for different components of the HFO passive system. Where this has been applied, it has been assumed that the environmental impacts will be from the transportation of these elements to the Hebden Beck site or wherever the technologies to be deployed. This assumption has been applied to the HFO, wood shavings and also the limestone sand which has been replaced with LimeX[14] and is represented in Figure 7.1 by the boxes calcium carbonate and chitosan, but no environmental impacts has been attributed to them other than the transportation to the site.

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[13] this assumes that these materials would be produced and available whether or not they were used in the system as described here therefore there environmental impacts of production are not included.

[14] LimeX is a by-product of sugar beet processing and is commercially available, from a subsidiary of British Sugar, it is essentially a commercial form of chitten.

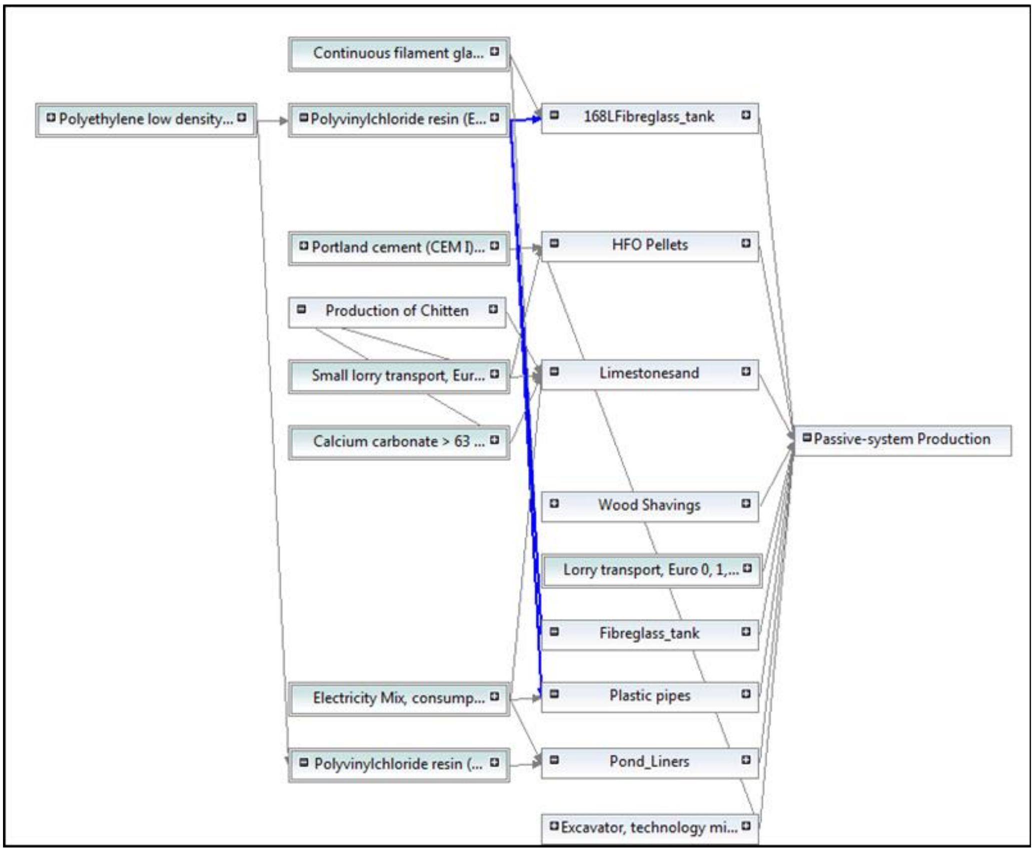


Figure 7.1: The passive HFO system as modelled in OpenLCA

The reed beds (for residual metal removal) which are also part of the system do not appear in Figure 1.7, although their transportation from where they have been sourced has, as can be seen in the Appendix Four, and is included in the transportation box. All the different materials transportation burdens are included in this box on the model, this is because it has been assumed that the same type of heavy goods vehicles (a 7.5 tonne vehicle: information about which was available in the ELCD (3.1) database) are used to transport all the different components of the system. To assess the impacts the total kg*km for the whole system was modelled using the information in Appendix Four and Appendix Five. For example the total mass and distance of all components were summed together, and included in this single parameter within the OpenLCA software.

The excavation and installation of the system has been included in the box excavation technology using a 500 kW hydraulic excavator to move 38,000 kg of soil. The other components of the system, the fibreglass tanks, pond liners, plastic pipes and fittings were modelled based upon the environmental burdens of these materials and the additional electricity required to make them, and were calculated using information available about manufacturing processes for these components (Appendix Four). The electricity mix that was selected from the database was the GB electricity mix 2013 as this was the most recent and relevant available in ELCD (3.1).

## 7.4 Semi-Passive Bioreactors

The functional unit for the semi—passive bioreactor is also 2 kg of zinc removed over a twenty-four hour period. The semi-passive bioreactor has been assessed using the data in the appendix and the configuration previously detailed in 6.4 and 6.5.

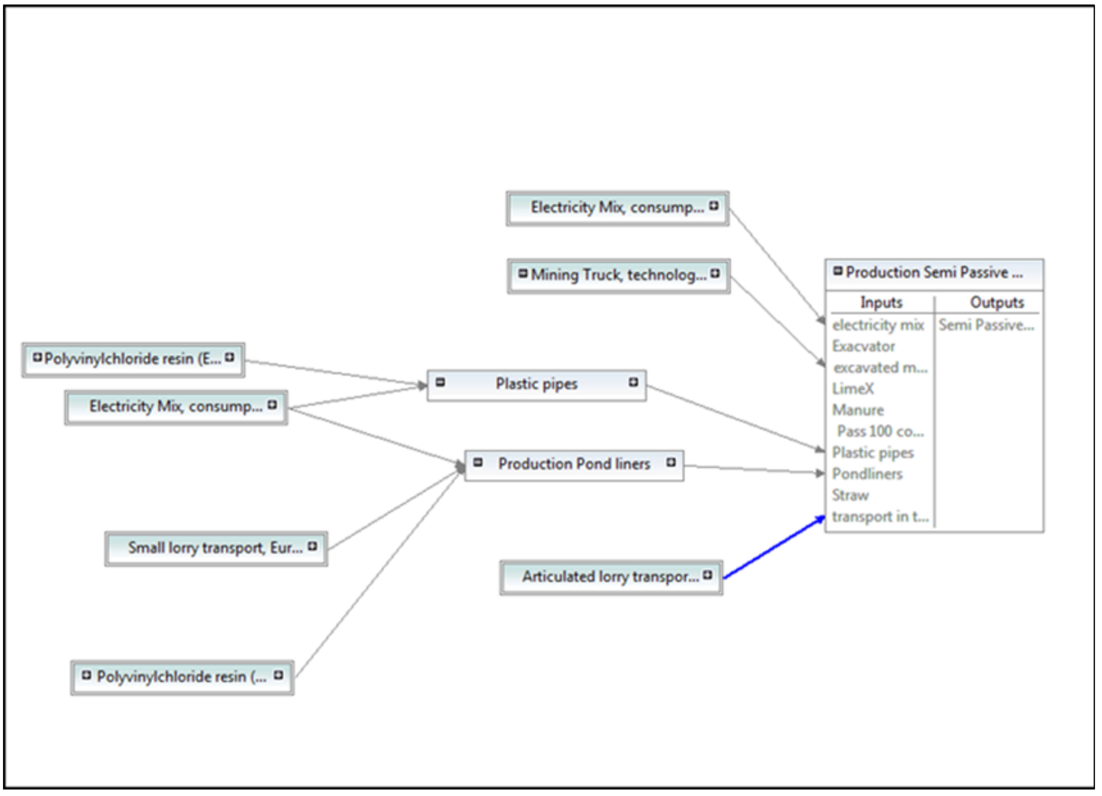


Figure 7.2: Semi passive bioreactor flows modelled in OpenLCA

Figure 7.2 illustrates the way in which the model is built in OpenLCA, and shows the individual elements. The excavated material is limestone which is used for the ultra-fine limestone (UFL) or limestone gravel and has an additional energy requirement which is included in the model.

The amount of energy required to convert the excavated material limestone into either UFL or limestone gravel was assumed to be approximately the same based upon information from literature sources (Lindqvist, 2008, Norgate and Haque, 2013). These studies provide data for quantifying the energy costs (and emissions) of comminution of raw materials which are widely used in LCA and geoengineering applications.

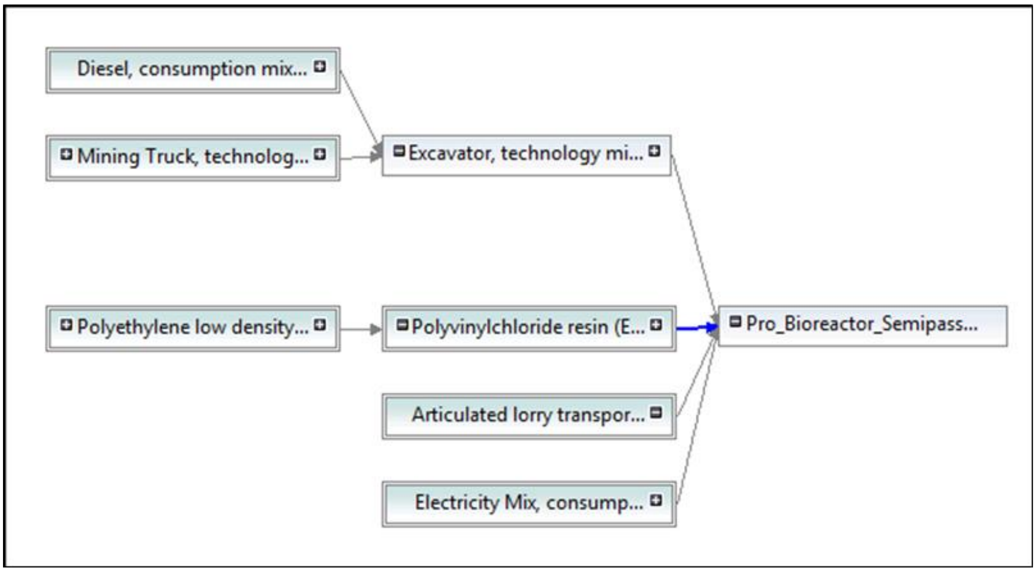


Figure 7.3: Semi-Passive Bioreactor, elements being included in the OpenLCA model

However for the OpenLCA to work the individual components such as electricity and transport need to be brought together into individual flows as can be seen from Figure 7.3. This helps reduce the likelihood of double counting, where a single input is counted twice. The different quantities, for example distance and mass for each of the elements are controlled within the parameters of the software and can be altered as required.

The zero burden assumption for some components of the Semi-Passive Bioreactor was applied to the compost, manure, straw, polishing reed beds and limestone sand, which was assumed to be replaced with LimeX. As per the HFO passive system, the transportation of these materials was modelled but not any aspect of their production. The other parts such as the plastic piping the pond liners and the limestone gravel were included such as the electricity required to produce them which was calculated. The energy burden associated with these materials can however be significant, for example it requires 319 MJ of energy to produce 1 m of plastic pipe[15].

## 7.5 Active Lime Dosing

The active lime dosing system represents the most established of the treatment options considered, but is a system that relies on continuous energy input and regular replenishment of active reagents. The system considered here has been configured to cope with the functional unit and was detailed in Section 6.3.

[15]PVC http://www.dpiplastics.co.za/Green_Facts/

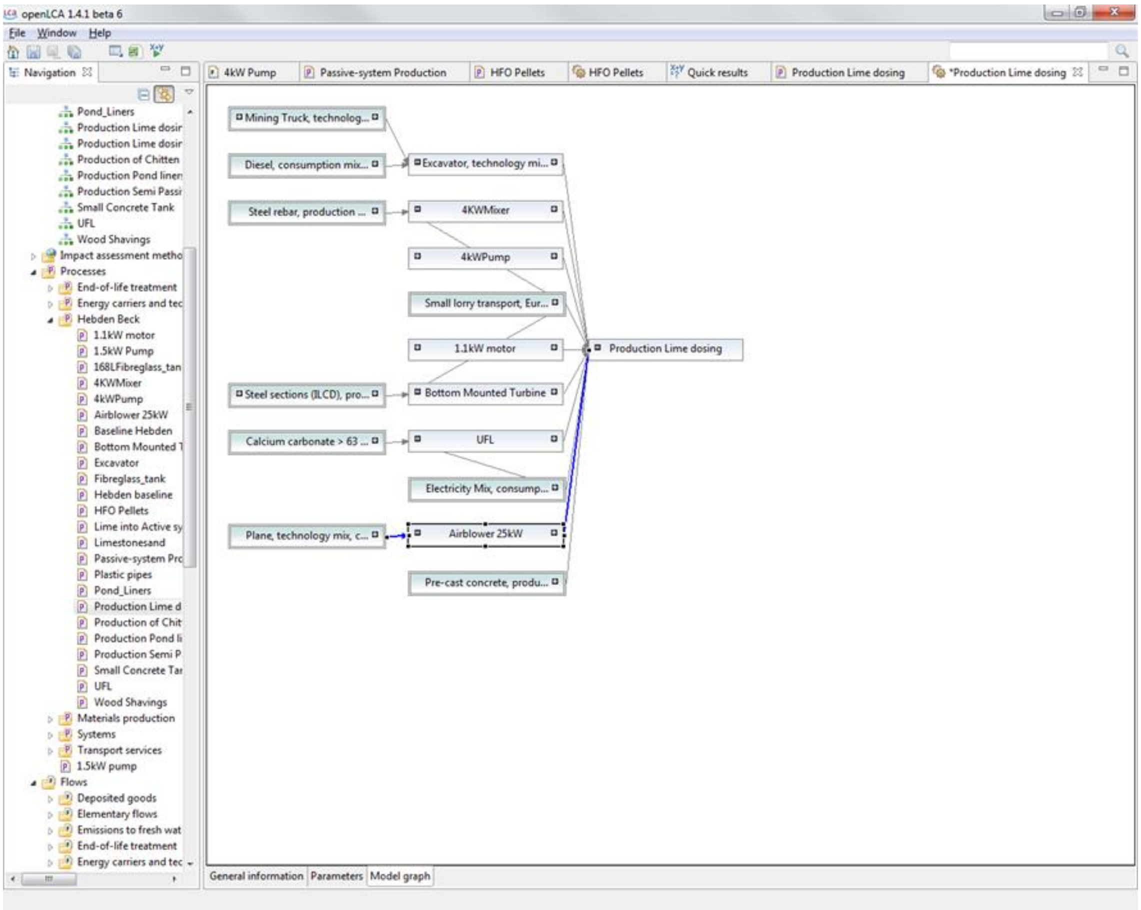


Figure 7.4: Screenshot of OpenLCA for the active lime dosing system

The active lime dosing system (Figure 7.4) is much more complicated with many different individual components. Not all of these constituent parts had available data in the ELCD (3.1), however information about the system and component availability was collected as can be seen in Appendix Four. No element of this system has the zero burden assumption associated with it.

To illustrate the environmental impact of this system key individual elements have been modelled but the system as a whole has not, given the complexity. It has been included in this project to illustrate the magnitude of the environmental burden that this approach represents. Equally, by illustrating the environmental burdens of UFL production and the quantities which would be required to treat these levels of contamination it places these smaller scale passive options into context. An additional justification for only modelling one aspect of the affected system is that many best practice guidelines where once enough information has been gathered to either justify an approach taken or discounted entirely the process stops at that point as no further information is required to make a decision. As is seen in Section 7.7, this shows that an individual element of the lime dosing system has a greater burden on its own than the whole of the semi-passive bioreactor or the passive HFO system. Therefore the modelling does not need to be taken further to the purpose of this case study to illustrate this framework (see results section 7.7)

The additional inputs of the electricity requirements for the active system based upon the needs of the motors and the pumps has also been quantified using the OpenLCA software and the same electricity mix from the ELCD (3.1) database. This illustrates the relative importance of this input compared to the UFL.

## 7.6 **The Current Baseline: Ongoing Release of Metals from Abandoned Mine Sites to the Water Environment**

This scenario assumes continued *status quo* and therefore continued discharge of metals from abandoned mines into the Hebden Beck catchment. It is informative to cost the environmental impacts of such releases relative to management intervention scenarios. The impact category of toxicity has been calculated for metals entering fresh water from point discharges in the catchment. Metal release to freshwater is the most certain impact category as the metals directly enter the water environment. This is a midpoint category (See also 3.3.2), which illustrates the impacts to the physical environment. The endpoint categories are more concerned with the societal impacts resulting from these environmental impacts and have a higher degree of certainty than endpoint categories (Hauschild et al., 2013). Fresh water eco-toxicity impact is fundamental in decision making for operational management at abandoned mine sites (Mayes et al., 2009). Other impacts such as those on human health are far less certain as the exposure pathway and the number of people exposed is difficult to determine in this case. Due to the more qualitative assessment done in Chapter Five for the purposes of this case study, only the eco-toxicity has been determined here. The impacts can be considered an underestimate of the total overall impact burden associated with metalliferous discharges from abandoned mines. Furthermore, given only point discharges are considered (e.g. from mine drainage levels and adits) it can be seen as an underestimate of the total metal flux associates with mine sources given the considerable potential diffuse sources in the catchment (e.g. exposed spoil heaps (Jones et al., 2013)).

The fluxes (i.e. concentration multiplied by flow) of metals being released into Hebden Beck were obtained from data collected by the Environment Agency during catchment investigations of metal mine impacts and Jones et al, (2013) (Appendix Five). The eco-toxicity impact of Cd , Cu , Pb and Zn have been calculated in comparative toxic units (CTU) also known as comparative toxic potential is (CTP) the unit of which is (PAF.day.m $^3$/kg), where PAF is the potentially affected fraction. As previously explained in the Chapter 3 (Section 3.3.1) this value is multiplied by the quantity in kg of the material in this case metal, released into the environment in the specific compartment, in this case freshwater (Dong et al., 2014, Pizzol et al., 2011a).

$$\boldsymbol{CTP = FF.BF.EF} \qquad \textbf{Equation 2}$$

CTP are determined from fate factors (FF in days) bioavailable fraction (BF) and effect factor (EF)

CTP for fourteen metals have been developed for generic freshwater specifically for the use in LCAs where typically sites specific information is not taken into account when calculating these impacts (Dong et al., 2014). Different water archetypes across Europe were assessed and an EU weighted CTP for six metals including Cd, Cu, Pb and Zn were derived using equation 2.

$$\boldsymbol{CTP_{Wt} = \sum_{i=1}^{n} CTP_i \, . \, EF_i} \qquad \textbf{Equation 3}$$

Whereas CTP $_i$ is the metal in water archetypes i, Wt is the weighting factor of the water archetypes i and n is the number of water archetypes. EF is the effect factor. It was found that these values were a good proxy for generic site CTP for Europe and also other continents (Dong et al., 2014). These values have been used for emissions from Hebden Beck, a single value has been used for each metal but it should be borne in mind that the levels of metal released are dependent on a flow rate, are weather dependent and hence variable. As well has the uncertainty associated with generic CTP values identified by (Dong et al., 2014), this means that there is a high degree of uncertainty associated with the eco-toxicity impact from metal released into the river basement catchment from these abandoned mine sites.

Monte Carlo analysis and other statistical analyses (Groen et al., 2014, Niero et al., 2014) can be applied to obtain a range of results based upon available data on the variation in metals release over a number of years, depending upon the datasets available (European Commission and JRC, 2013, EPLCA and JRC, 2014, Leung et al., 2015, European Commission et al., 2011, Guo and Murphy, 2012, Sanfelix et al., 2013). This highlights another advantage of the framework being proposed here, (using an environmental assessment, an EIA for a specific site for the proposed remediation technology as well is an LCIA) a more thorough understanding of the impacts of the metals will be achieved. Additionally due to the monitoring required for the PES to determine compliance, the data collected will contribute to improving the accuracy of CTP being used in models and improve the accuracy of existing models, such as WHAM 7.0 and other others (Farley et al., 2014b, Tipping and Lofts, 2014).

Other abandoned metal mines within the local catchment, where data on the levels of Zn released have also had their CTP is calculated Appendix Five), based upon the assumption that removal of Zn is a good proxy for removal of the other metals present (Jarvis et al., 2014a, Jarvis et al., 2014b).

## 7.7 Results

## 7.8 International-Reference Life Cycle Data-System (ILCD): Midpoint Results

The midpoint results represent the emissions and changes to the physical environment and the impacts upon it, Section 3.3.2) as previously discussed. Table 7.1 shows the ILCD midpoint results obtained using OpenLCA. For the active lime dosing system impacts have been modelled for not the whole system but for the key additional lifetime inputs; the amount of ultrafine limestone that is required for one year of operation elements and the energy requirements to run the pumps and motors. This conclusively illustrates the greater environmental burden this sort of active system places upon the environment. The single element of UFL having a significantly higher impact in the majority of relevant midpoint categories selected compared to the entire passive HFO and semi-passive bioreactor systems which include all the elements shown Appendix Four and Sections 7.4, 7.5 and 7.3.

Four ILCD midpoint metrics have been selected to look at in more detail, these have been selected as providing a good cross-section of types of impact that are of particular concern and of relevance to the WFD and the U.K.'s $CO_2$ emissions targets. They also contribute significantly to the endpoint categories which are reflection of the impacts on society;

- Climate change in kg $CO_2$ equivalent (kg $CO_2$ eq),
- Human health both carcinogenic and non-carcinogenic Comparative Toxic Unit for human (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme) (Rosenbaum et al., 2011, Rosenbaum et al., 2008)
- Fresh water eco-toxicity Comparative Toxic Unit ecosystems (CTUe) is an estimate of the potentially affected fraction of species (PAF) integrated over time and volume, per unit mass of a chemical emitted (Henderson et al., 2011, Rosenbaum et al., 2008, Rosenbaum et al., 2011).
- Respiratory/particulate matter is expressed in kg of particulate matter equivalent (kg PM2.5 eq.). The 2.5 it refers to the particle size and in this case is less than 2.5 microns in diameter and is implicated as a chief cause for many acute respiratory problems for animals and humans[16]

[16] http://www.epa.gov/pm/basic.html

Table 7.1: Selected ILCD midpoint results, normalised to the functional unit of 2 kg of zinc removed over twenty-four hours.

| **LCIA category** | **Normalised Semi passive Bioreactor** | **Normalised Passive HFO** | **Normalised UFL** | **Normalised Electricity17 requirements Active system** | **Unit** |
|---|---|---|---|---|---|
| Climate change | 7.76E+01 | 4.59E+00 | 1.00E+04 | 5.40E+02 | kg$CO_2$eq |
| Freshwater Ecotoxicity | 3.62E+00 | 3.61E-01 | 7.53E+02 | 1.55E+01 | CTUe |
| Human toxicity Carcinogenic | 2.1E-05 | 3.78E-06 | 3.2E-06 | 1.65E-07 | CTUh |
| Human toxicity non-carcinogenic | 1.1E-06 | 1.76E-07 | 2.05E-04 | 8.93E-06 | CTUh |
| Particulate matter /Respiratory inorganics | 2.13E-02 | 1.62E-03 | 1.95E+00 | 1.98E-01 | kgPM2.5 eq. |

[17] Electricity required to run the pumps, blowers and mixers on site for the active system (Figure 6.5)

Table 7.2: LCIA midpoint results

| **LCIA category** | **Bioreactor** | **HFO** | **UFL** | **Electricity requirements Active system 1yr** | **Unit** |
|---|---|---|---|---|---|
| Acidification | 1.82E+03 | 1.10E+02 | 1.78E+04 | 1.36E+03 | Mole H+ eq. |
| Climate change | 2.83E+05 | 1.68E+04 | 3.66E+06 | 1.97E+05 | kg CO2 eq. |
| Freshwater ecotoxicity | 1.32E+04 | 1.32E+03 | 2.75E+05 | 5.64E+03 | CTUe |
| Freshwater eutrophication | 6.36E-01 | 7.68E-03 | 6.90E+00 | 2.67E-02 | kg P eq. |
| Human toxicity - carcinogens | 7.54E-02 | 1.38E-02 | 1.20E-03 | 6.04E-05 | CTUh |
| Human toxicity - non-carcinogens | 4.11E-03 | 6.41E-04 | 7.47E-02 | 3.26E-03 | CTUh |
| Ionizing radiation - ecosystems | 1.37E-01 | 5.01E-02 | 8.77E+02 | 3.72E-01 | CTUe |
| Ionizing radiation - human health | 1.39E+04 | 2.39E+03 | 6.59E+05 | 3.76E+04 | kg U235 eq. |
| Marine eutrophication | 6.41E+02 | 1.35E+01 | 7.10E+03 | 1.55E+02 | kg N eq. |
| Ozone depletion | 1.15E-02 | 1.96E-03 | 1.28E-01 | 3.11E-02 | kg CFC-11 eq. |
| Particulate matter/Respiratory inorganics | 7.79E+01 | 5.90E+00 | 7.12E+02 | 7.24E+01 | kg PM2.5 eq. |
| Photochemical ozone formation | 1.81E+03 | 4.40E+01 | 2.08E+04 | 4.79E+02 | kg C2H4 eq. |
| Resource depletion - mineral, fossils and renewables | 2.86E-01 | 4.36E-02 | 7.38E-01 | 4.11E-01 | kg Sb eq. |
| Terrestrial eutrophication | 7.05E+03 | 1.52E+02 | 7.80E+04 | 1.69E+03 | Mole N eq. |

### 7.8.1 **Human Health**

One impact metric in which the greatest impact is not from the UFL is in human health and carcinogens, the greatest impacts here is for the semi-passive bioreactor, see Figure 7.5.

The semi-passive bioreactor has a far greater impact for human toxicology than any of the other options, as total impact of 0.075 CTUh. The second greatest impact is from the passive HFO system which is also significantly greater than the contributions from the UFL. The reason for this is because the greatest human carcinogenic contribution comes from the plastic components within each of the systems, e.g. tanks and pond liners. This human health implication would not be the case for the active line dosing system as its constituent parts consist of concrete tanks and metal components, such as the pumps and mixes, Figure 7.4. If other aspects of the hard infrastructure were to involve plastic then this would apply to the active system but it has been assumed that, as at Wheal Jane, concrete has been used for the holding tanks. The impact of the electricity requirements relative to the UFL for the active system is not significant. These requirements have a greater impact than those of the passive HFO system but less than the overall impacts of the semi-passive bioreactor.

The pond liners, which are made of heavy duty PVC, component of the semi-passive bioreactor system contributed the most to this midpoint category. In addition to this (Appendix Six) this system comprises of the most plastic elements in the lengths of piping required as well is the pond liners. The HFO system also has some plastic components but these are not as significant and it uses fibreglass tanks rather than plastic tanks.

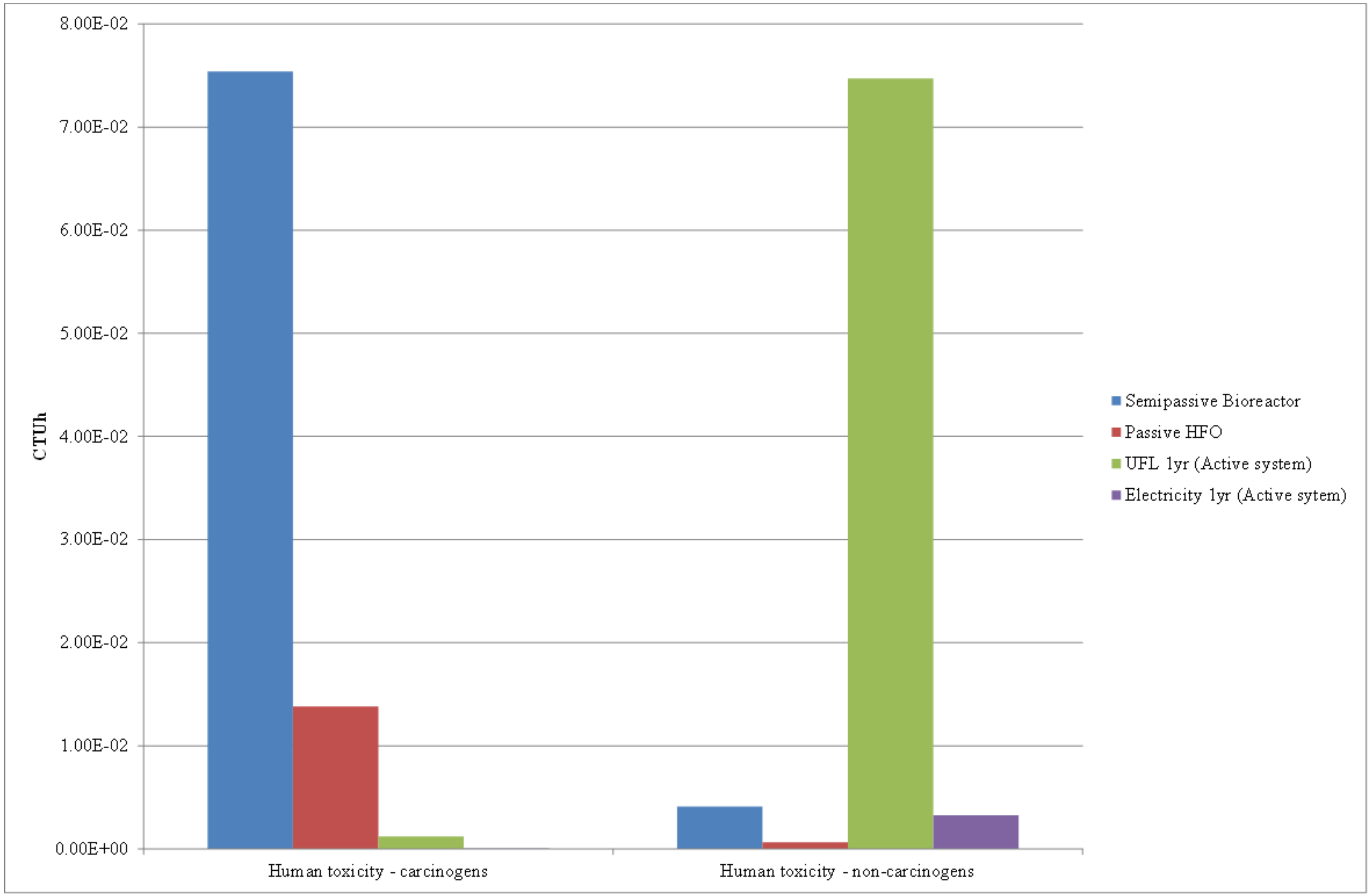


Figure 7.5: ILCD, midpoint results, human toxicity

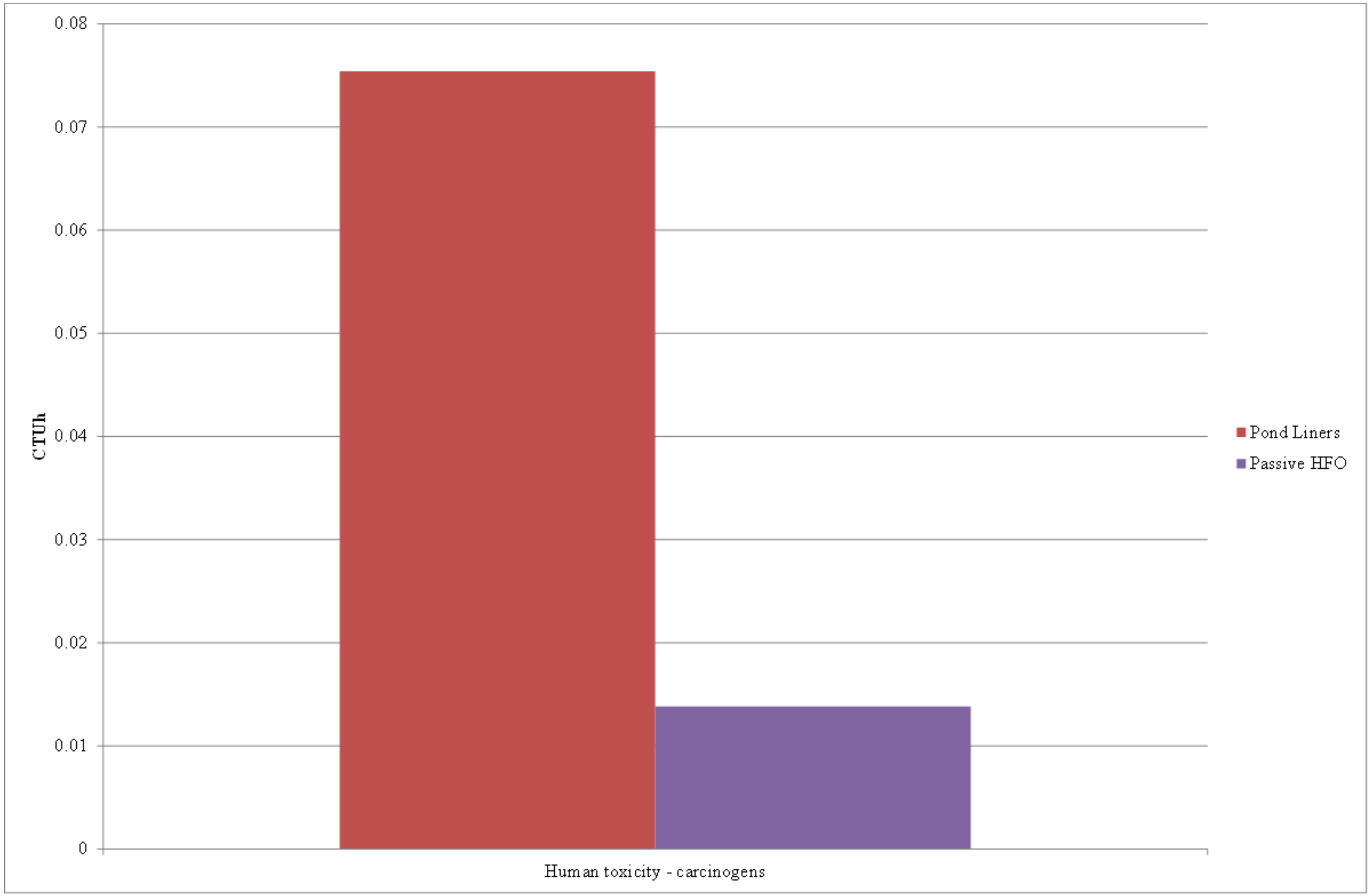


Figure 7.6: ILCD midpoint results plastic components (semi-passive bioreactor & passive HFO), carcinogens

The reason for the use of a high density PVC for the pond liners is due to the effluent which they contain with high levels of metals which could leak into groundwater (Section 6.4). Some other material could conceivably be used with a lower environmental impact such as lining the ponds with clay. This would need to have the same degree of certainty that it could contain the polluted liquid within it and meet the necessarily strict standards to which the PVC pond liners adhere.

### 7.8.2 **Climate Change**

The climate change impact is associated with the gases discharged to the atmosphere, such as nitrous oxide and methane as well as carbon dioxide, are all converted into kg of $CO^2$ equivalent as recommended by the Intergovernmental Panel on Climate Change (IPCC). The bioreactor its emissions for the whole of its ten-year operation are 283403 $kgCO^2e$, for the passive HFO system, 16751 $kgCO^2e$ over its entire ten-year life cycle and for the ultrafine limestone 3656700 kg $CO^2e$ for a single year, see Table 7.2. In addition to this is the impact from the electricity requirements which is, 197000$kgCO^2$ e for a single year[18]; this figure however is dependent upon the source of the electricity. Were it to be generated from renewable this impact would be significantly lower, if the source of electricity were from coal fire power stations, which are still in operation in the UK, it would be much greater. This highlights the need to include in uncertainty into LCA studies. For this illustrative purposes electricity has been included, but this aspect of the LCA would not be done for the framework as this option would be completely disregarded.

These are striking differences, the majority of which can be accounted for in the contributions made by the mining and processing for both the UFL and the limestone gravel which is used in the semi-passive bioreactor. The energy required for the individual components and the transportation of these elements to the site also contribute to the greenhouse gas emissions. The HFO system uses waste materials and the zero burden assumption has been applied to both the HFO and the LimeX this dramatically reduces its environmental impacts. The contributions made by the Portland cement (another highly burdensome process in terms of $CO_2$ emissions) which is used in the production of the HFO pellets, but is such a small quantity that it does not make a

[18] based upon the GB electricity mix twenty thirteen obtained from the ELCA 3.1 database

significant contribution to the overall emissions from this system. Most of the emissions-related impacts for this system are related to transportation and the energy needed for production of the PVC components of the system.

The semi-passive bioreactor uses mined material in the form of the limestone gravel component which increases the greenhouse gas contribution of this system relative to the HFO system. By substituting the other limestone element, which in the Force Crag System (National Trust, 2014, Jarvis et al., 2014b) uses limestone sand, with LimeX this significantly reduces the potential impact from this system to climate change. This highlights the benefit of using waste materials wherever possible in these sorts of systems as it significantly reduces their environmental impacts and costs (Warrender et al., 2011).

### 7.8.3 **Particulate Matter/Respiratory Inorganics**

Particulate matter and respiratory inorganics are particles found in the air, these particles are created during crushing and grinding processes which is a particular problem for the manufacture of both the UFL and the limestone gravel used in the semi-passive bioreactor. Due to the quantities involved as can be seen from Figure 7.7, again the UFL has by far the largest impact. This continues over the entire operational lifetime. Unlike the impact from the semi-passive bioreactor, as previously noted this impact would be much greater were the LimeX component be replaced with limestone sand, where this impact would be a one-time issue.

These particles cause problems for human health and can cause tissue damage in the respiratory organs of animals and humans, having a carcinogenic effect (US-EPA, 2003). These particles (PM 2.5) have a diameter of less than 2.5 micro metres which is responsible for pollution haze.

In this category as can be seen in Figure 7.7, the passive HFO system by far outperforms the other two options despite the use of a waste material in the semi-passive bioreactor. Therefore this would seem to be the most appropriate choice based on a single metric.

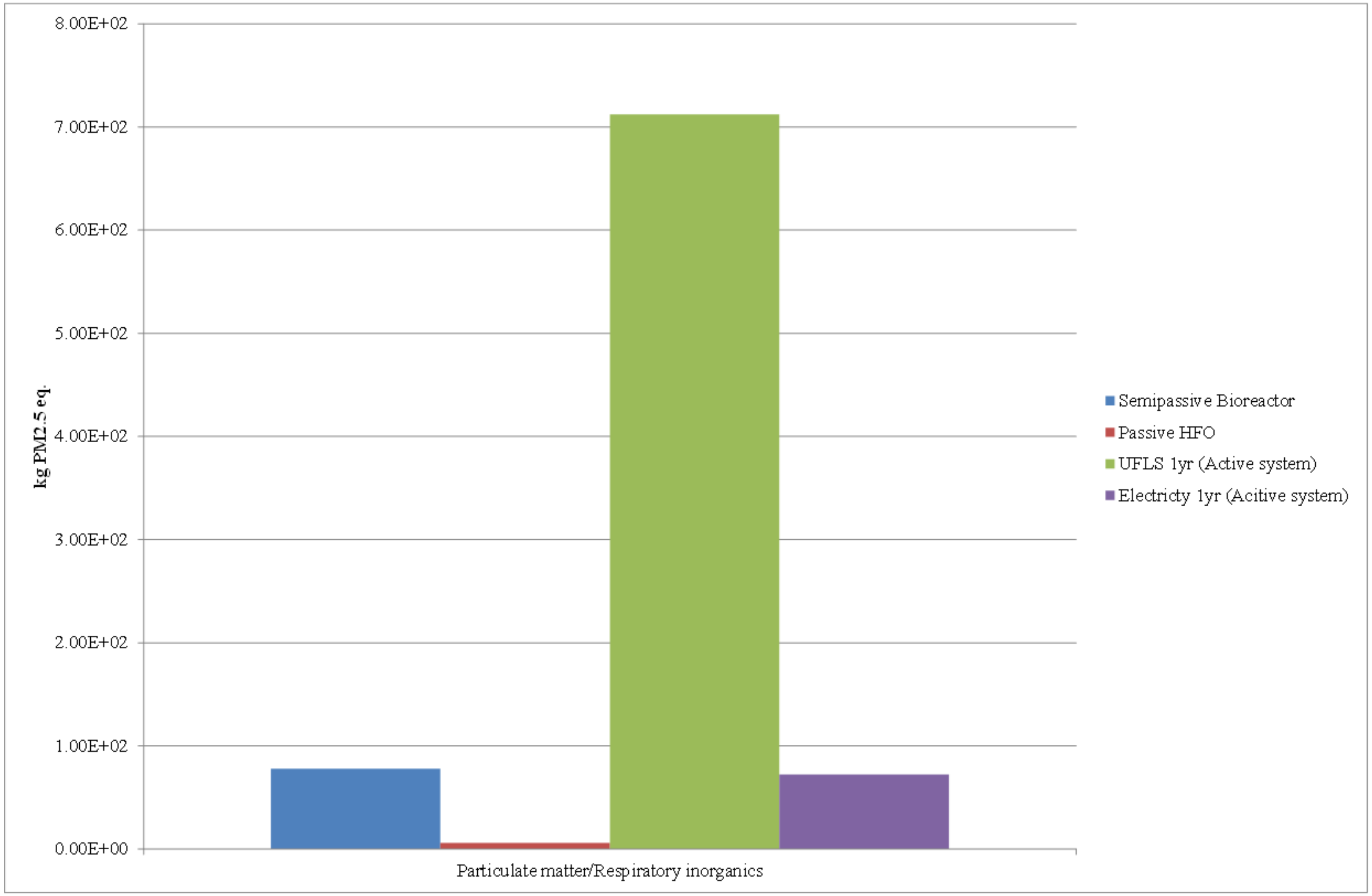


Figure 7.7: ILCD Midpoint results, particulate matter/respiratory inorganics

### 7.8.4 Freshwater Ecotoxicity

This category is of particular relevance to the remediation as it relates directly to the primary goal of metal removal from the river basement catchment. It is principally this impact which is being sought to be mitigated through remediation. This presents the opportunity to assess the impact of the status quo (i.e. no treatment) against remedial scenarios. Therefore it is vital that the overall impact from the remediation of the site does not outweigh the potential benefits derived. This category expresses how toxic the freshwater environment is to the ecological components within it because of the metal entering the system. Those elements within it which are sensitive to the metals which in this cases is Zn, as having been identified as the metal of most concern and being used as a proxy for the other metals (Jarvis et al., 2014a).

As can be seen from Figure 7.7 and Figure 7.9, the impacts from the semi-passive bioreactor and the passive HFO system are minimal over their whole lifetime. These impacts are limited to the production and installation phase and once the systems are in place there are no additional impacts, with the exception of the possibility of replacing the HFO at the five-year point but these impacts are negligible. The active, lime dosing conversely has a much greater impact actually in terms of the ongoing requirements for the UFL (Figure 7.8 and Figure 7.9). The impact of one year appears to be significant, certainly it is much greater than the other options whose impact is negligible. Table 7.1, illustrates how when the impacts are normalised to the functional unit the impact is much reduced. It is still significant but when compared with the eco-toxicity impacts which are currently occurring due to the emissions from Hebden Beck, even with their large degree of uncertainty on this single indicator this approach could be justified (Table 7.1).

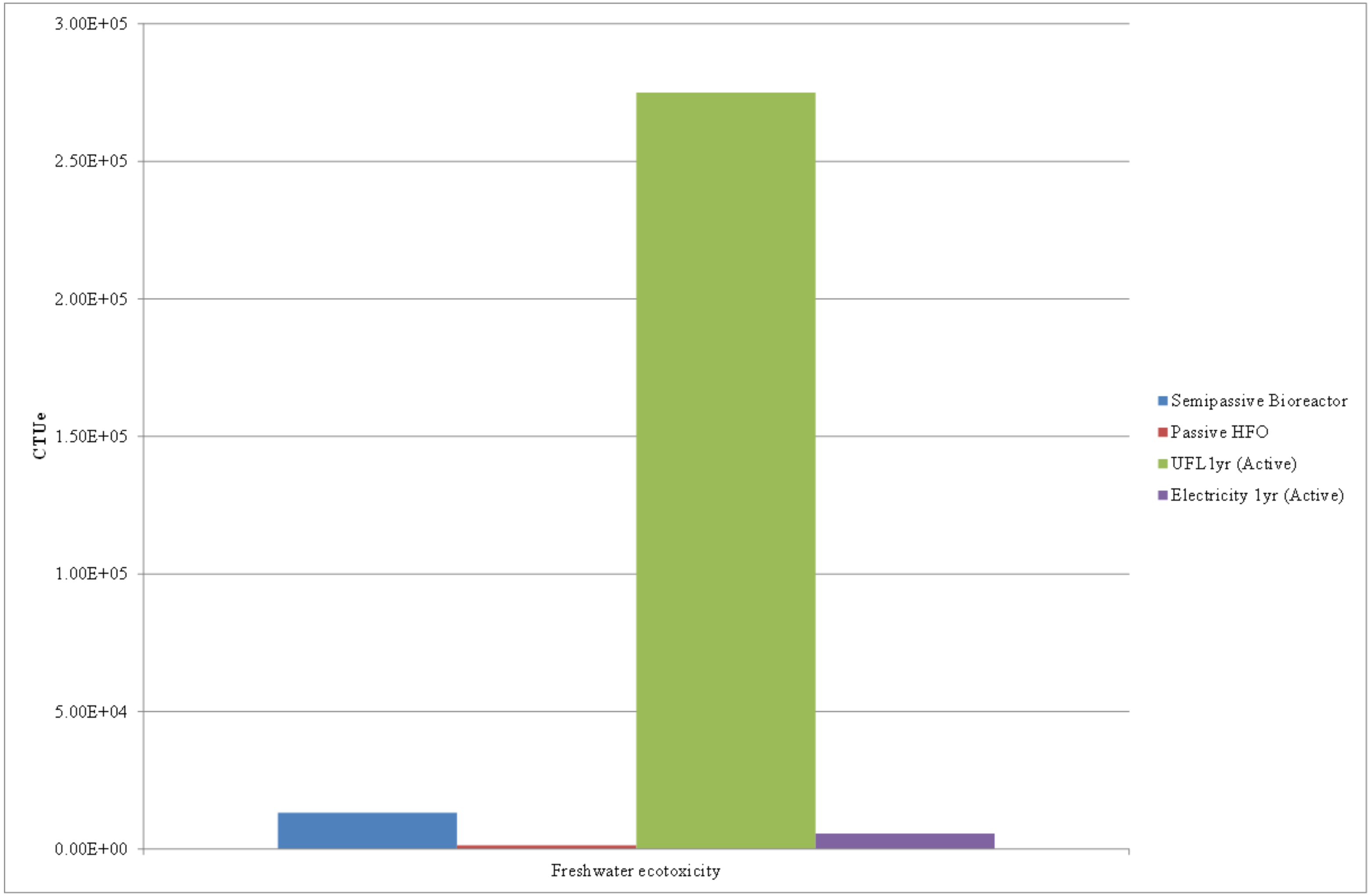


Figure 7.8: ILCD, Midpoint results, freshwater ecotoxicity

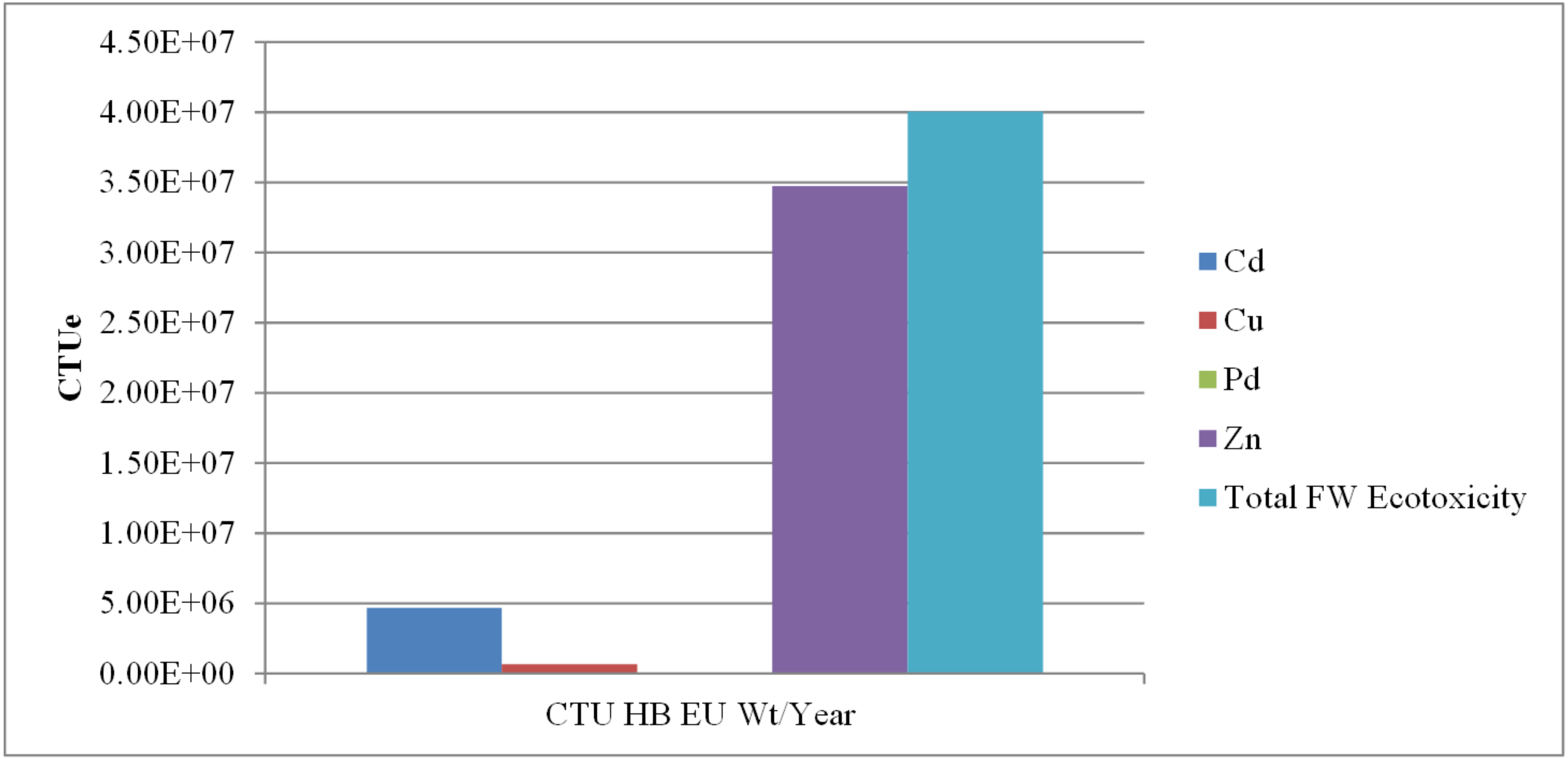


Figure 7.9: Fresh water Ecotoxicity from metals released into Hebden Beck from abandoned mine site EU emission weighted CTP from (Dong et al., 2014) over one year

Table 7.3: Ecotoxicity results Hebden Beck site

| Hebden Beck | kg a day (Hebden) | CTU EU Wt/day | CTU EU Wt/Year |
|---|---|---|---|
| Cd | 8.00E-03 | 1.28E+04 | 4.67E+06 |
| Cu | 2.40E-03 | 1.80E+03 | 6.57E+05 |
| Pb | 3.51E-02 | 1.05E+01 | 3.84E+03 |
| Zn | 1.16E+00 | 9.51E+04 | 3.47E+07 |

On this metric alone if the predicted results (Figure 7.10 and Table 7.3) are achieved and these systems are effective it would appear that either the semi-passive bioreactor or the passive HFO system would make a significant environmental improvement as with the lime dosing. As only the UFLS requirements have been modelled this is not necessarily a fair comparison although the other aspects would only add to this system's contribution it eco-toxicity.

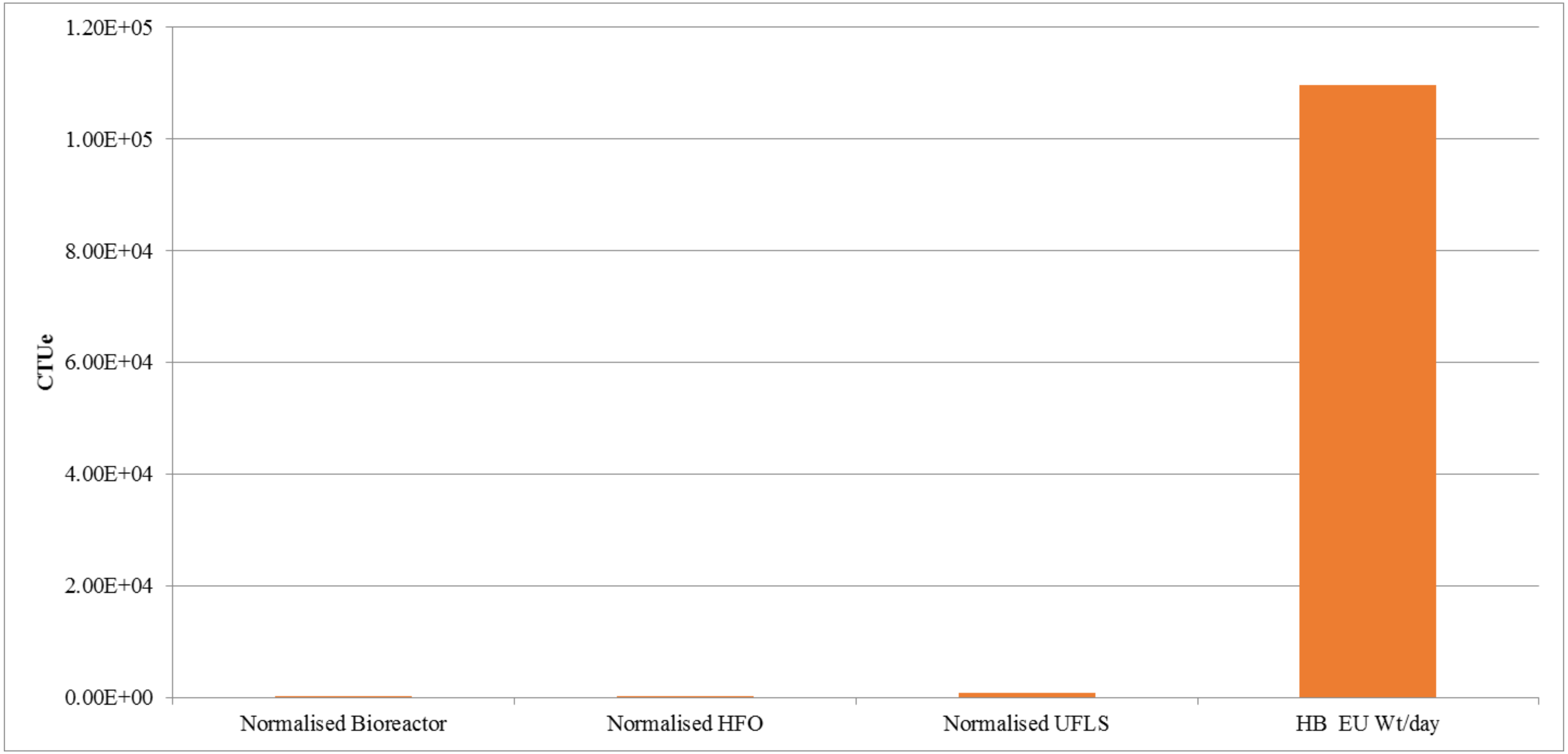


Figure 7.10: Fresh water ecotoxicity impacts a day for the production of the Passive HFO system, the Semi passive bioreactor and UFLS requirements (active lime dosing) compared to the combined ecotoxicity impacts of Cd, Cu, Pb and Zn currently being released into Hebden Beck

## 7.9 International-Reference Life Cycle Data-System (ILCD): Endpoint Results

The endpoint results are primarily concerned with translating impacts into social consequences, these sorts of metrics are often more easily understood by the general public as they are less obscure than the midpoint categories, even if they do tend to be more uncertain (Dong and Ng, 2014, Hengen et al., 2014, Hauschild et al., 2013). The tables below (Table 7.4 and Table 7.5) show the normalised and non-normalised impact for all three systems. The results for the electricity usage for the active lime dosing system have been included in the tables but due to the large degree of uncertainty associated with the impacts of electricity usage dependent on its mix of suppliers, it has not being assessed in the endpoint categories. Relative to the UFL used in the active system energy requirement impacts are not as significant as the UFL usage.

The three categories focused on here are the damage to human health which is expressed in the number of life years lost per hundred thousand people over their whole life cycle of the process and includes all aspects of human health (Table 7.4 and Table 7.5). The second is the damage to ecosystems which is characterised by the predicted loss of species as a result of the activities undertaken (production and use of the remediation options) and again assesses impacts on different ecosystems (e.g. freshwater, terrestrial habitat etc.). The final category that assessed is the financial quantification of the loss of materials/minerals on non-renewable resources and is quantified in US dollars. Like the other metrics being assessed this is of some of the total resources lost and is used as a comparative unit.  As such, it is not necessarily meaningful in actual resource prices today (Chapter Eight) given inter-annual volatility of global commodities.

Table 7.4: ILCD Endpoint results, total impact

| **Impact Category** | **Semi passive Bioreactor** | **Passive HFO system** | **UFL 1yr Active Lime dosing** | **Electricity Requirements 1yr Active Lime dosing** | **Reference Units** |
|---|---|---|---|---|---|
| Ecosystems - Acidification | 8.04E-06 | 4.89E-07 | 2.49E-05 | 6.03E-06 | PNOF |
| Ecosystems - Climate change | 2.25E-03 | 1.33E-04 | 1.43E-02 | 1.56E-03 | PDF |
| Ecosystems - Eutrophication freshwater | 2.79E-08 | 3.37E-10 | 4.41E-08 | 1.17E-09 | PDF |
| Ecosystems – total | 2.26E-03 | 1.34E-04 | 1.43E-02 | 1.57E-03 | species*year |
| Human health - total | 1.42E+00 | 1.95E-01 | 3.05E+00 | 4.16E-01 | DALY |
| Human health - Climate change | 3.97E-01 | 2.35E-02 | 2.52E+00 | 2.76E-01 | DALY |
| Human health - Human toxicity, carcinogenic | 8.67E-01 | 1.59E-01 | 2.66E-03 | 6.94E-04 | DALY |
| Human health - Human toxicity, non-carcinogenic | 1.11E-02 | 1.73E-03 | 1.86E-01 | 8.80E-03 | DALY |
| Human health - Ionizing radiation | 2.28E-04 | 3.92E-05 | 1.07E-02 | 6.17E-04 | DALY |
| Human health - Ozone depletion | 2.03E-05 | 3.47E-06 | 3.27E-04 | 5.50E-05 | DALY |
| Human health - Particulate matter/Respiratory inorganics | 1.40E-01 | 1.06E-02 | 3.34E-01 | 1.30E-01 | DALY |
| Human health - Photochemical ozone formation | 7.06E-05 | 1.72E-06 | 1.85E-04 | 1.87E-05 | DALY |
| Resource depletion - Mineral, fossils and renewables | 1.42E+06 | 7.53E+04 | 1.14E+07 | 7.70E+05 | $ |
| Resource depletion - total | 1.42E+06 | 7.53E+04 | 1.14E+07 | 7.70E+05 | $ |

Table 7.5: ILCD Endpoint results normalised to the functional unit 2 kg zinc removed per day

| ILCD 2011, Endpoint Impact category | Normalised Semi passive bioreactor | Normalised Passive HFO | Normalised UFL (Active) | Normalised Electricity Requirements (Active) | Reference unit |
|---|---|---|---|---|---|
| Ecosystems - Acidification | 2.20E-09 | 1.34E-10 | 6.81E-08 | 1.65E-08 | PNOF |
| Ecosystems - Climate change | 6.16E-07 | 3.65E-08 | 3.91E-05 | 4.28E-06 | PDF |
| Ecosystems - Eutrophication freshwater | 7.66E-12 | 9.24E-14 | 1.21E-10 | 3.22E-12 | PDF |
| Ecosystems – total | 6.18E-07 | 3.66E-08 | 3.92E-05 | 4.30E-06 | species*year |
| Human health - total | 3.88E-04 | 5.33E-05 | 8.37E-03 | 1.14E-03 | DALY |
| Human health - Climate change | 1.09E-04 | 6.44E-06 | 6.91E-03 | 7.56E-04 | DALY |
| Human health - Human toxicity, carcinogenics | 2.38E-04 | 4.35E-05 | 7.29E-06 | 1.90E-06 | DALY |
| Human health - Human toxicity, non-carcinogenics | 3.04E-06 | 4.74E-07 | 5.09E-04 | 2.41E-05 | DALY |
| Human health - Ionizing radiation | 6.23E-08 | 1.07E-08 | 2.94E-05 | 1.69E-06 | DALY |
| Human health - Ozone depletion | 5.55E-09 | 9.52E-10 | 8.97E-07 | 1.51E-07 | DALY |
| Human health - Particulate matter/Respiratory inorganics | 3.84E-05 | 2.91E-06 | 9.14E-04 | 3.57E-04 | DALY |
| Human health - Photochemical ozone formation | 1.94E-08 | 4.72E-10 | 5.06E-07 | 5.12E-08 | DALY |
| Resource depletion - Mineral, fossils and renewables | 3.90E+02 | 2.06E+01 | 3.13E+04 | 2.11E+03 | $ |
| Resource depletion - total | 3.90E+02 | 2.06E+01 | 3.13E+04 | 2.11E+03 | $ |

## 7.9.1 **Human Health**

This category for the production and deployment of the three systems is probably the one that would capture the attention of the general public (Figure 7.11). As was mentioned in the stakeholder interviews (Chapter Three) they try not to mention the impacts on human health as people tend to focus upon it. As can be seen the impact of the systems even the UFL, which has the greatest impact, is very minimal, expressed in DALYs, being just 8.3 7E -03 a year.

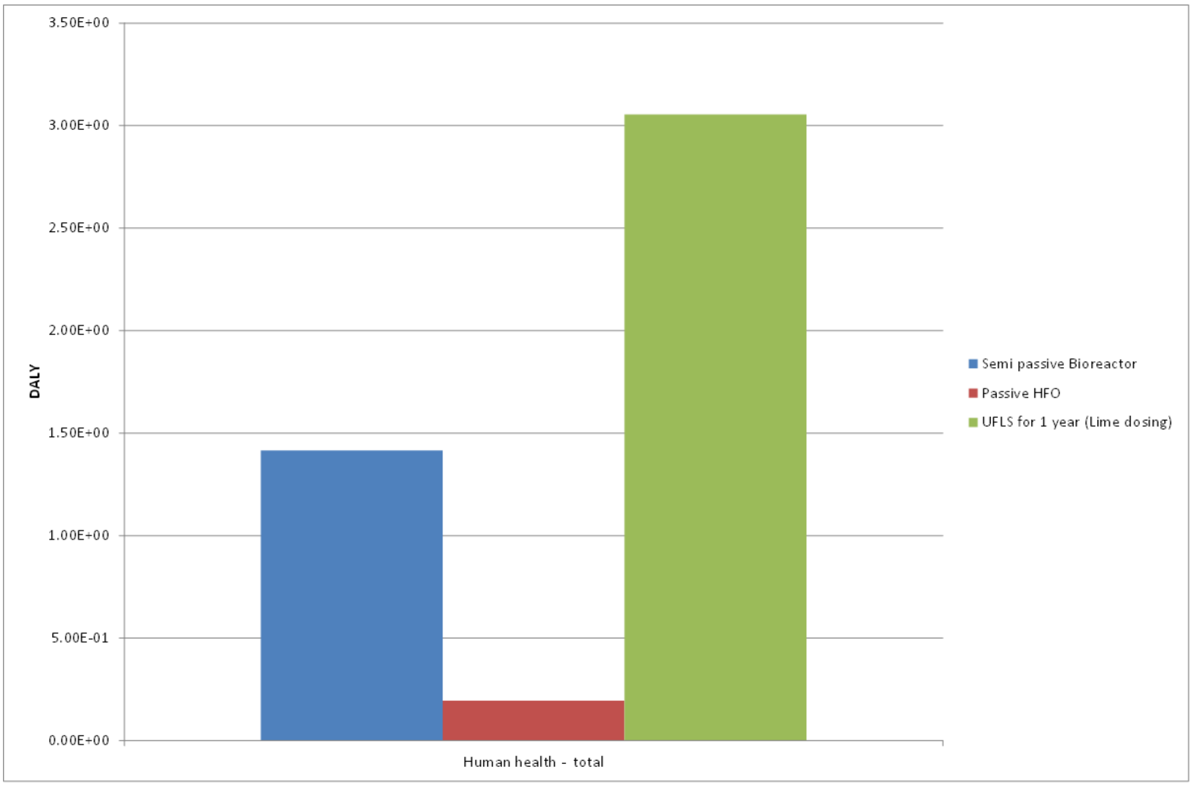


Figure 7.11: Total damage to human health (DALYs)

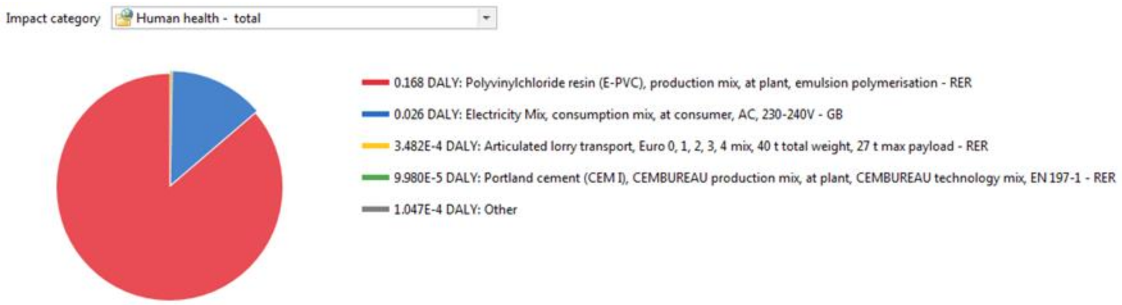


Figure 7.12: Passive HFO system, production and use, process contributions to total damage of human health

The passive HFO system total human health damage is 1.9 5E -01. These impacts all happen during the installation and production process and this is perhaps a fairer comparison to the impact of the USF. On this basis the semi-passive bioreactors at 1.42 DALYs can said to be have the greatest impact on human health. Even so it is minimal (Figure 7.12 and Figure 7.13), the majority of these impacts results from the production of the PVC components of the system.

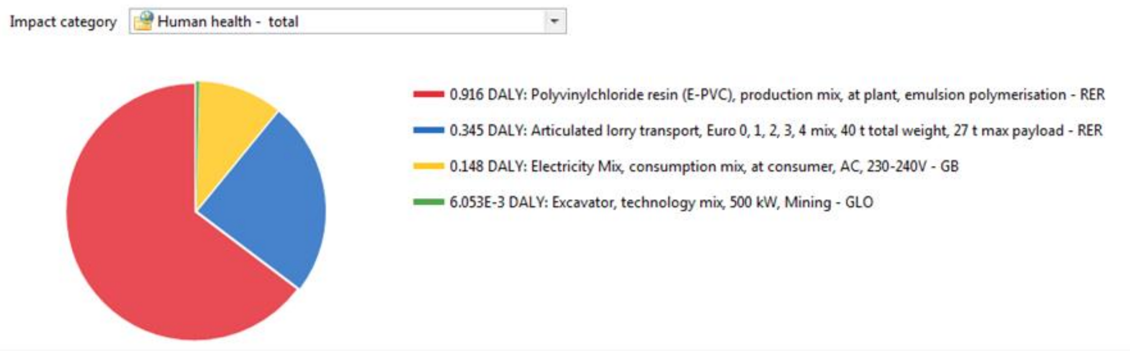


Figure 7.13: Semi-passive bioreactor, production and use, process contributions, to total damage to human health

Extrapolating the impacts of transport from the semi-passive bioreactor to the lime dosing system which would require multiple deliveries a week (Appendix Four) this would significantly increase the human health implications of the system and again the human health category when compared to the other two options rules out the active lime dosing system.

### 7.9.2 **Ecosystems**

The total damage to ecosystems for the UFLS is 3.92E-05 (species.year) for a single year (Figure 7.14), compared to the impact of 2.26E-03 for the semi-passive bioreactor over the whole ten-year period and the passive HFO system of 1.34E-04, also over the whole ten year time scale, is significant. This further emphasises the difference in impacts of adopting a large-scale active system with continuous inputs compared to the alternative approach of using smaller more targeted systems.

The very small impact of the passive HFO system (Figure 7.14) is primarily due to the application of the zero burden assumptions, that is that the majority of the materials are said to have no environmental burden as whether or not they were used for this purpose they would exist. Consequently the process contributions of the HFO system are primarily from the electricity which results from the production of the plastic component, the Portland cement binder and the transport.

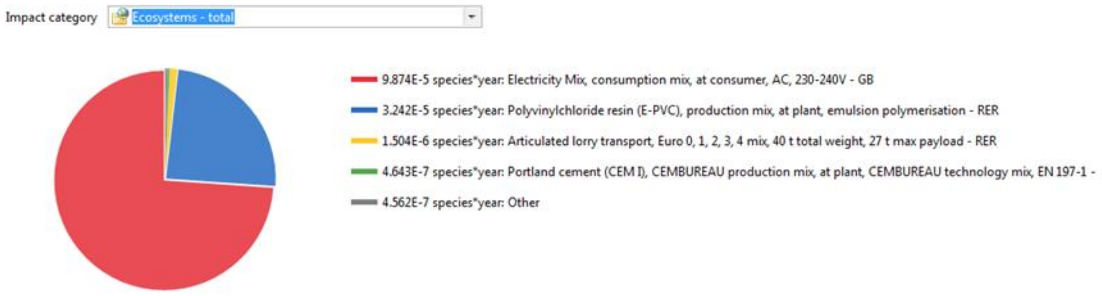


Figure 7.14: Passive HFO, process contributions to total damage to ecosystem

The majority of the impact for the semi-passive bioreactor (Figure 7.16) to ecosystems comes from the transportation of the materials. This is because such large quantities of LimeX and limestone gravel are required, thus increasing the proportion of the impact that this process has. The electricity and the production of the PVC components also have significant impact but again due to the large quantity of excavation required to install the remediation ponds and is also contributes to the impact on the damage to the ecosystems.

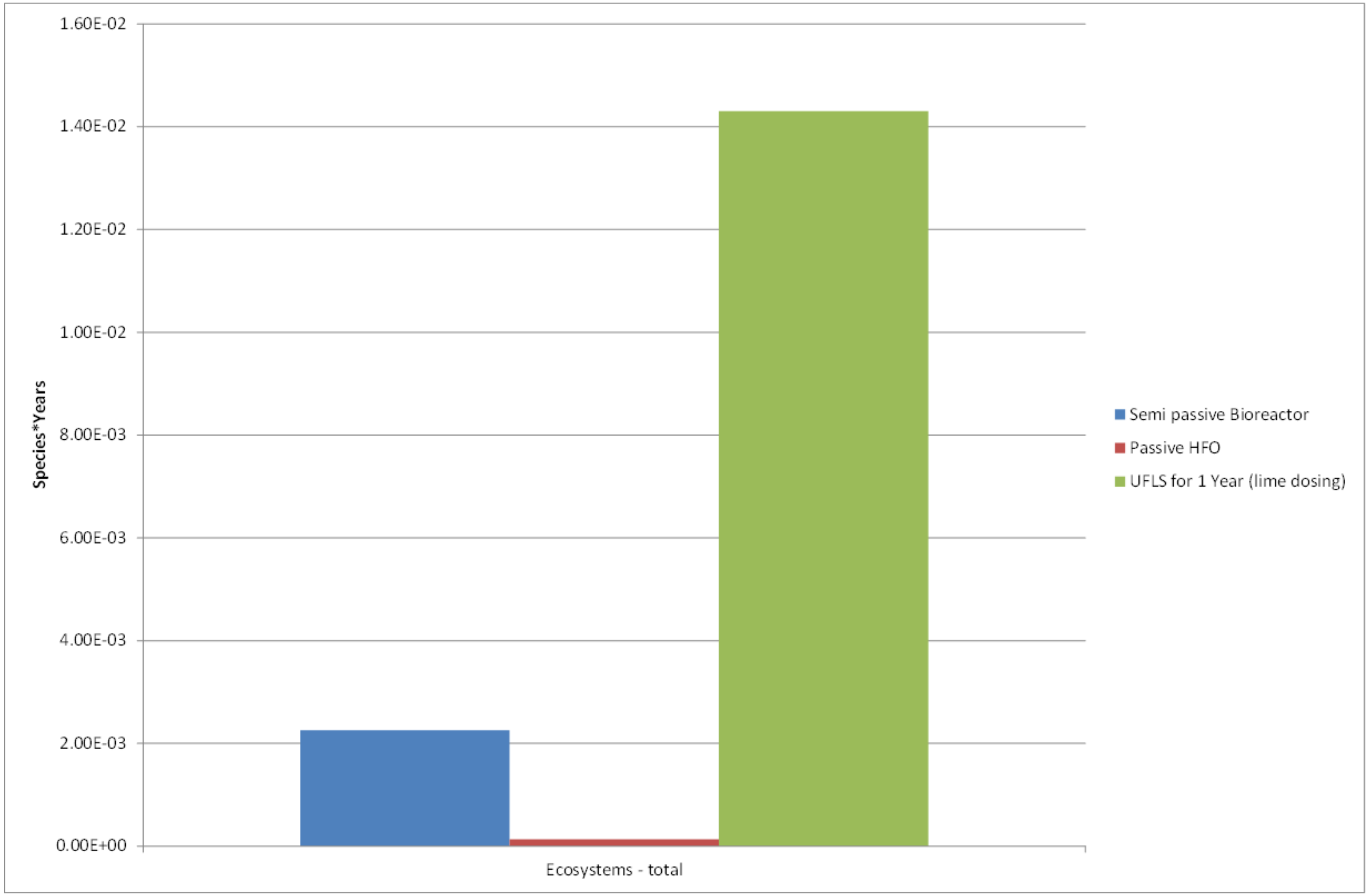


Figure 7.15: Total damage to ecosystems (species. year)

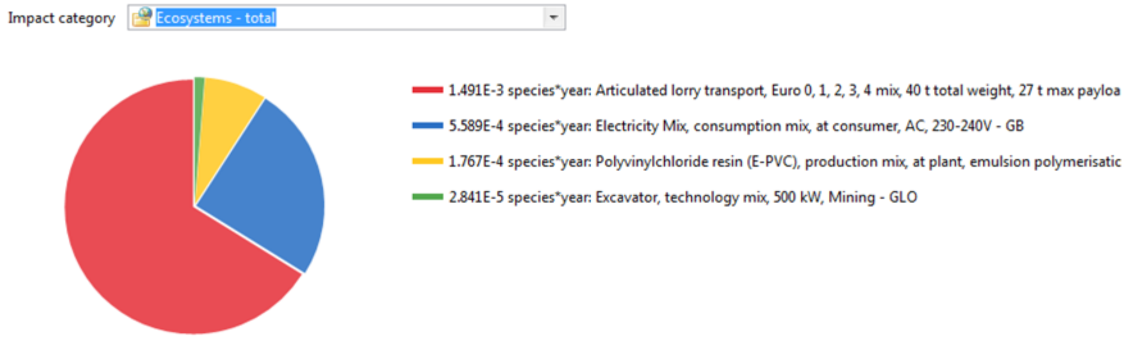


Figure 7.16: Semi-passive bioreactor, process contributions to total damage to ecosystems

Based on this single endpoint (Figure 7.15) metric the best option still comes out as the passive HFO system as its impact and the damage it does to ecosystems is minimal.

### 7.9.3 **Resource Depletion**

A similar pattern to that followed by all the other impact categories again is repeated in the total resource depletion (Figure 7.17). The passive HFO system does not have any significant impact due to the use of waste materials as reactive media. The semi-passive bioreactor has a larger impact mainly due to the use of limestone gravel, and its heavy reliance on plastic components. It would have a greater impact were the LimeX to be replaced with limestone sand as previously mentioned, but environmentally due to the existence of a suitable medium, in the form of LimeX, this is not necessary and so cuts down on its overall impacts. The primary resource depletion is from lime dosing and the element, modelled here is UFL, which is a heavy environmental resource depletion. It removes both the resource of limestone and is energy intensive in its removal, and processing. However as can be seen in Table 7.6, Chapter Eight and Appendix Four, its greatest burden economically is the cost of disposing of the UFL to landfill once it has been spent, not the cost of the limestone itself. Such costs could potentially be minimised where metals are recovered from reactive media (Mohan and Chander, 2006).

Table 7.6: Costs of spent UFLS disposal to landfill based upon Wrap gate fees report 2013

| Hazardous waste material disposal fee to land fill | UFL a year to be disposed of, assumed 5% kept for Habitat offsetting | Total cost excluding transportation (Approx.) |
|---|---|---|
| £65 per tonne19 | 2300866 | £150000000 |

The justification for the choice of using the passive HFO system is particularly strong in this category as compared to the other options as it has by far the lowest impact, Figure 7.17.

[19] http://www.wrap.org.uk/sites/files/wrap/Gate_Fees_Report_2013_h%20(2).pdf

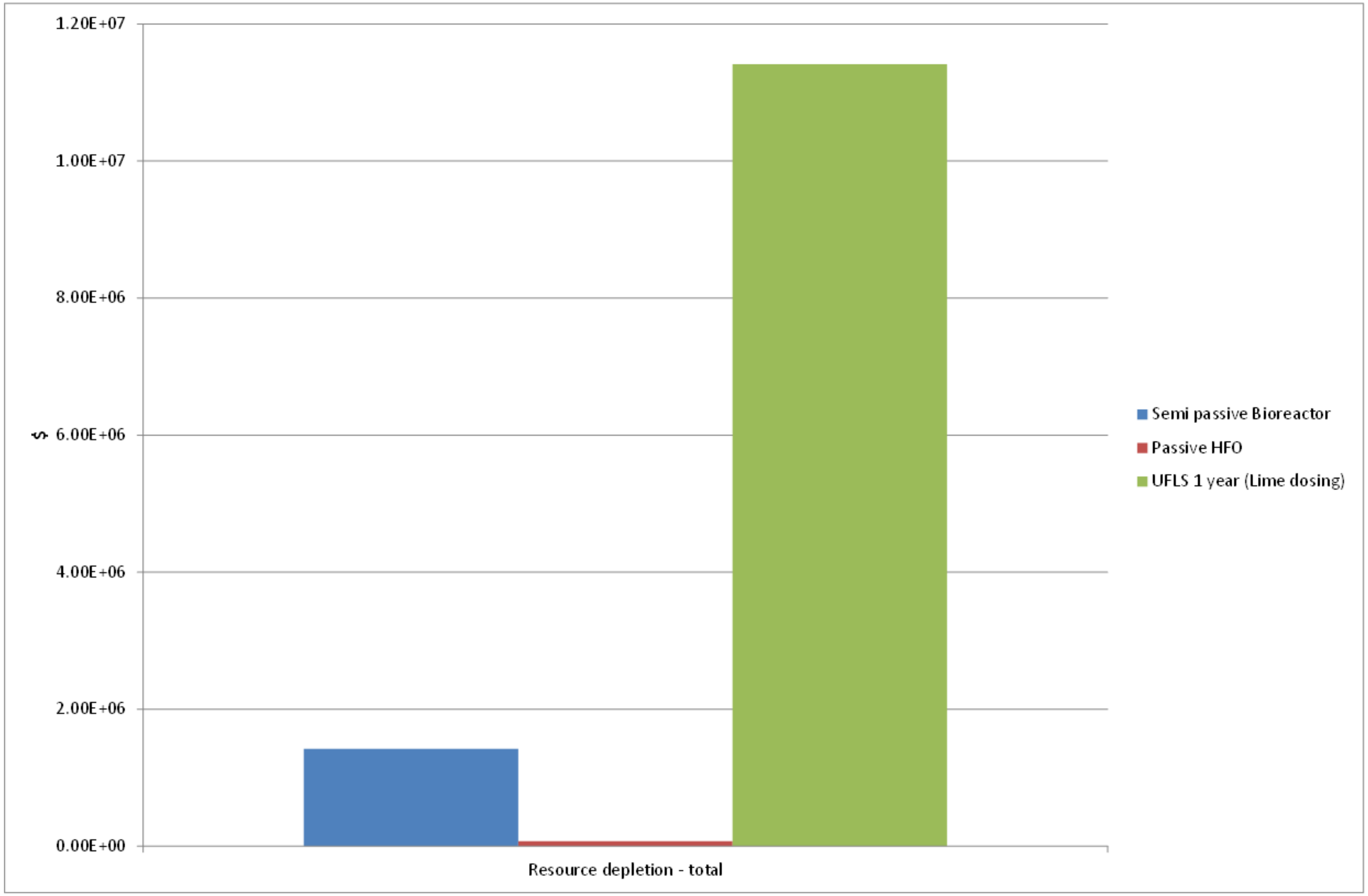


Figure 7.17: Damage to resources quantified in US dollars

## 7.10 **Conclusions from Midpoint and Endpoint Remediation Option Comparisons**

In all the impact categories, both endpoint and midpoint the passive HFO system comes out ahead of all the others, with the exception of the human toxicology carcinogenic impacts which it comes second to the UFLS. Were the whole active lime dosing system to be modelled, it is probable that this impact would be greater. This is due to the impacts from transporting the UFL to the site and the carcinogenic impacts associated with vehicle emissions. Therefore, on this basis it would be recommended that this system (passive HFO) be the choice for remediation of the Hebden Beck mine site when all aspects of its life cycle are considered. Although the time aspect has not been explicitly modelled here, the point at which the impacts occur is vital to take account of when assessing different systems. Comparing systems and when their impacts occur can give a fuller picture of the options and impacts when weighed against one another. Additionally, elements such as metals cause ecological impacts at different points in time (Lebailly et al., 2014). There is a need for dynamic LCA modelling and integrating this with ecological modelling, looking at the recovery times of ecosystems (and issues such as acclimation (Leorri et al., 2008, Moore and Langner, 2012)), using software such as WHAM (Farley et al., 2014b, Tipping and Lofts, 2014)). This has a vital contribution to make to our understanding of the interactions between technological solutions to environmental problems longer term.

The relative impacts of the infrastructure required for an active lime dosing system (compared to the lifetime input over a ten-year period for the functional unit being assessed here (removal of 2 kg of zinc over a 24-hour period)) are significantly lower than the impacts of the ongoing inputs required to run the system Figure 7.18. Due to the other considerations (7.5 and Chapter Eight), the scale of this option and the requirements of additional infrastructure even were a more environmentally sound option than UFL to be used it would still not be suitable for the purpose of remediating multiple small scale site such as that found that Hebden Beck.

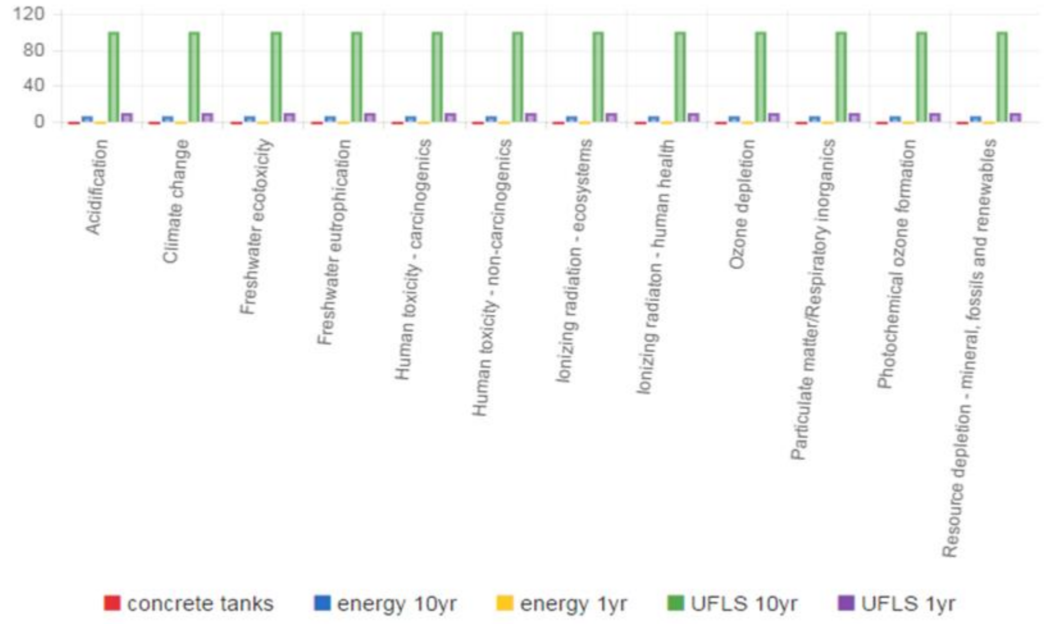


Figure 7.18: Relative ILCD midpoint impacts for the active lime dosing system comparison between impacts of the concrete tanks, energy usage and ultrafine limestone

## 7.11 **Multiple Site Remediation**

As previously explained in Chapter Five there are multiple sites within the catchment which are contributing to the metal pollution within the broader river basin in which Hebden Beck is located (Figure 5.9). Thus multiple remedial interventions are likely to be needed to improve the status of the various water bodies failing WFD requirements in the Humber due to metal mine discharges. It is therefore informative to model the potential deployment of multiple passive HFO systems and consider options for doing this. One such comparative scenario is the deployment of multiple small scale systems, versus a larger system (semi-passive or active) treating the water at a downstream location where a single effort could readily remove all metals from a single stream. Multiple systems means that the impacts will also multiply. Using OpenLCA the implications of this scenario has been modelled the results of which are shown below (Figure 7.19).

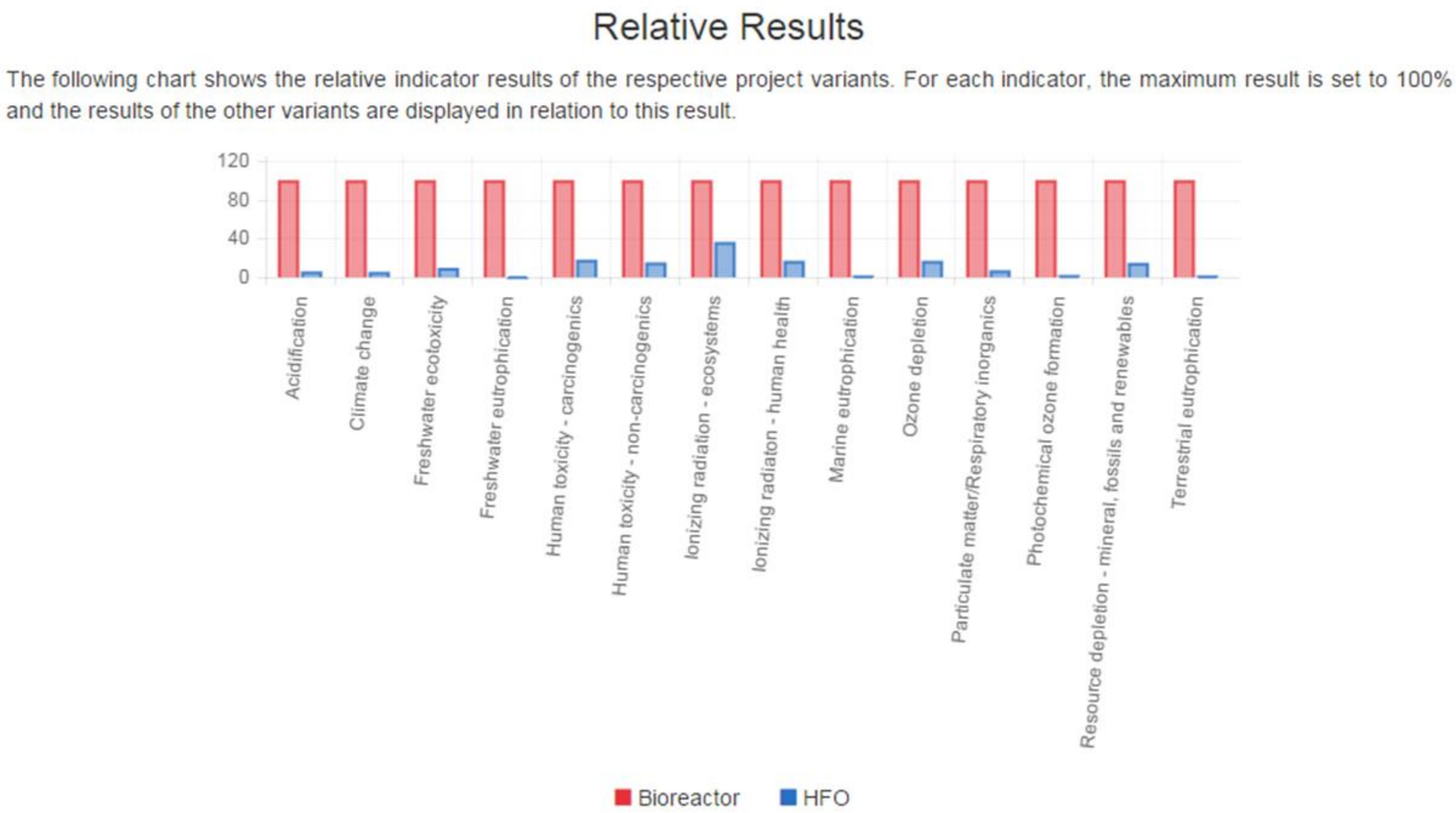


Figure 7.19: Direct comparison between the ILCD midpoint results for the passive HFO option (HFO) and the semi-passive bioreactor (Bioreactor)

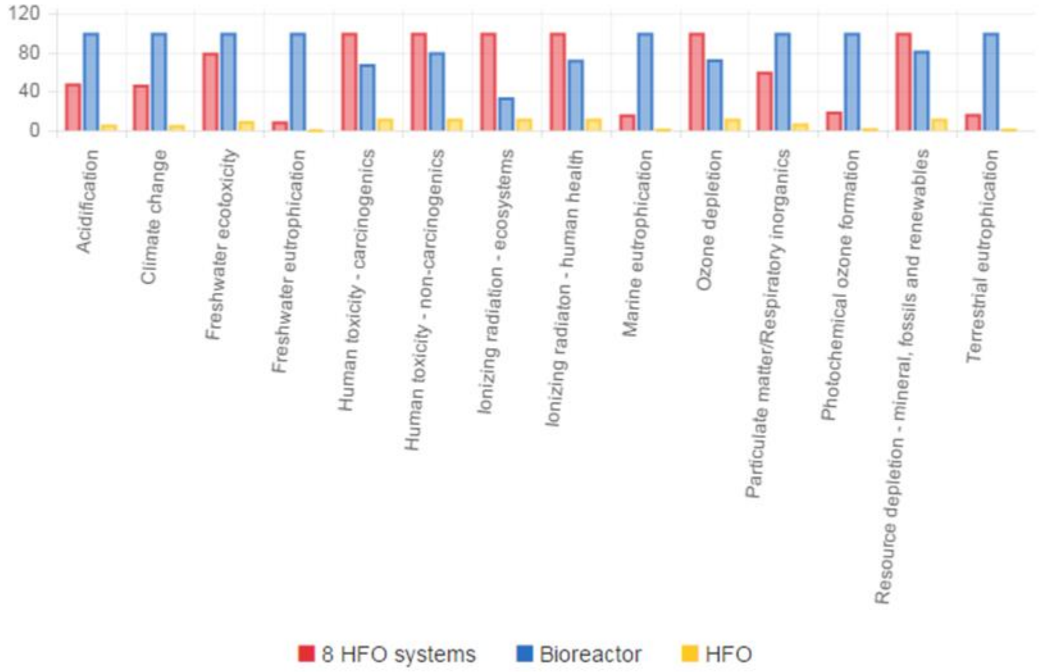


Figure 7.20: ILCD Midpoint relative results (max impact 100%), comparing impacts of multiple site remediation with single site remediation, for 8 &1 passive HFO systems (8 HFO systems, HFO) and a single semi-passive bioreactor (Bioreactor)

Figure 7.20 shows the impacts of deploying eight HFO systems around the local catchment to remediate the most polluting mine discharges at source. The relative comparison of the deployment of a single semi-passive bioreactor the impacts of deploying eight HFO systems are greater only in six of the fourteen midpoint ILCD categories modelled (Figure 7.21). The levels of these contributions overall are not overly significant when compared to the impact of an activity such as concrete production for example (Habert et al., 2011).

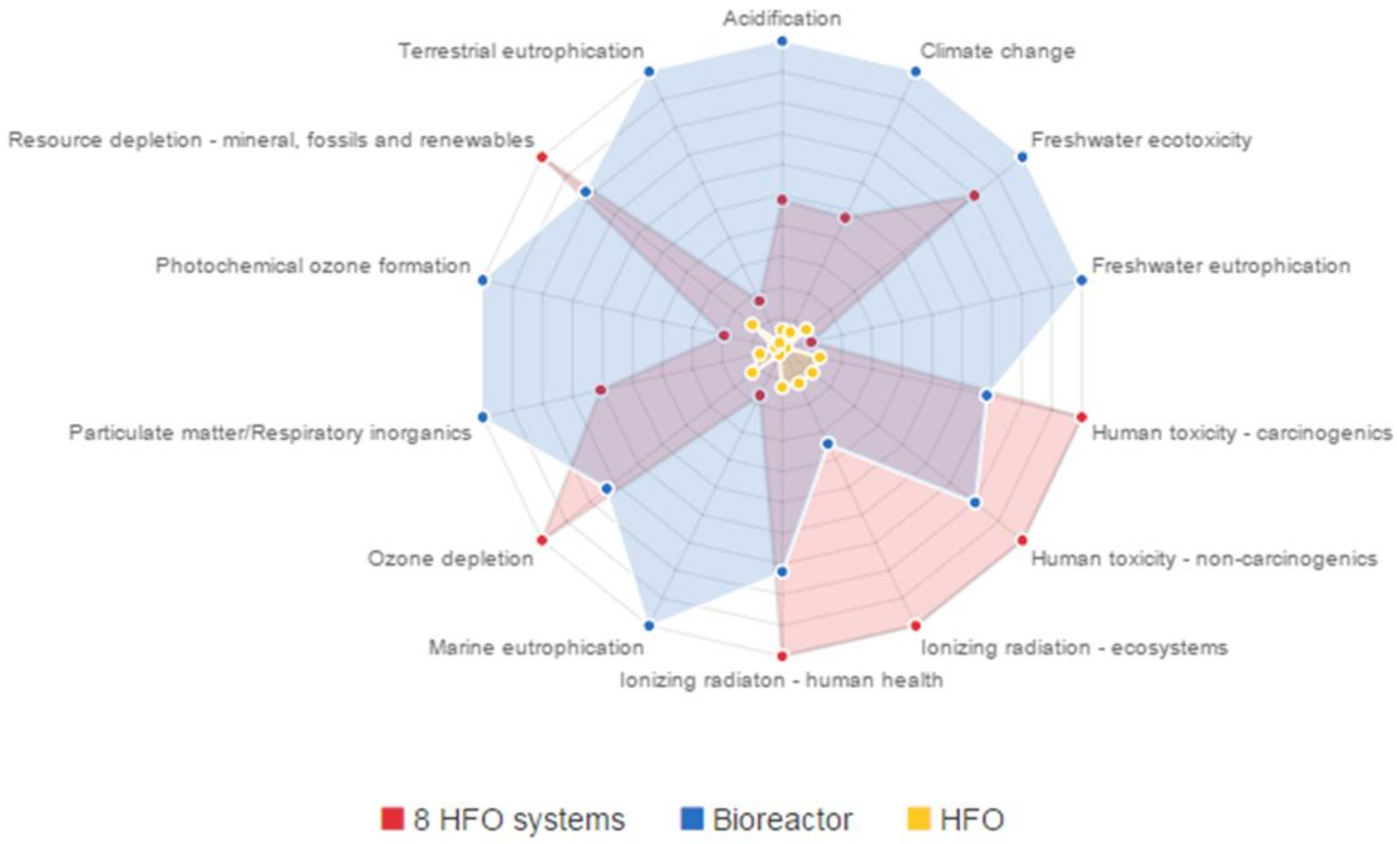


Figure 7.21: Single indicator ILCD midpoint results comparing impacts of multiple site remediation with single site remediation, for 8 &1 passive HFO systems (8 HFO systems, HFO) and a single semi-passive bioreactor (Bioreactor)

When the freshwater eco-toxicity of the metals entering at Hebden Beck is compared to the eco-toxicity impacts of eight passive HFO systems, clearly the balance of benefits is on the side of the single HFO systems (Figure 7.22). Not all the sites within the catchment are as polluting as the most polluting site, (Appendix Five), nor are the levels of metals entering the catchment from these point source pollution constant (e.g. Mayes et al., 2010). One way to take account of this would be to use statistical analyses such as the Bayesian or Monte Carlo analysis (Carmona et al., 2013, Clavreul et al., Guo and Murphy, 2012, Clavreul et al., 2013, Groen et al., 2014, Jung et al., 2014, Niero et al., 2014). Instead the eight least polluting sites from the area have been taken and their eco-toxicity calculated for their Zn which can be used as a proxy for the removal of metals from these sites (Jarvis et al., 2014a). Figure 7.22 and Figure 7.23 shows the eco-toxicity of the Zn from these eight sites, per year and per day. Comparing the total impact a single passive HFO system has on the freshwater eco-toxicity and eight passive HFO systems have on the eco-toxicity over the ten years that they would be in operation (Figure 7.23). These results conclusively show that the benefit derived from removal even at these low polluting sites in terms of eco-toxicity would far outweigh any impacts of deploying eight of these systems. The magnitude of this difference is such that even if there is a level of uncertainty, the life cycle impacts of remediation would have to be 75% greater to outweigh the impacts freshwater eco-toxicity from current discharges.

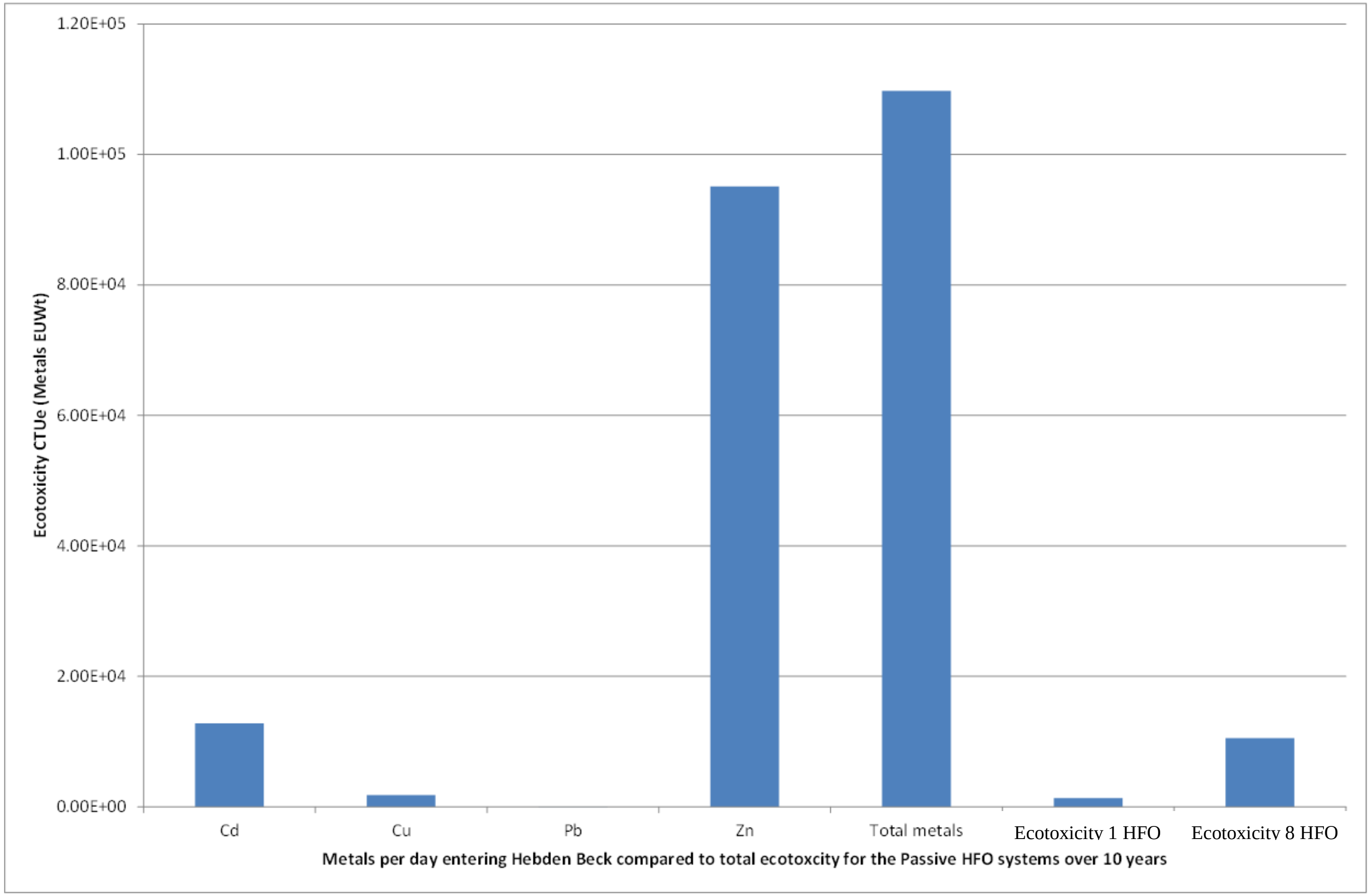


Figure 7.22: Metals entering Hebden Beck each day and total freshwater ecotoxicity (metal) from a single passive HFO system and eight passive HFO systems

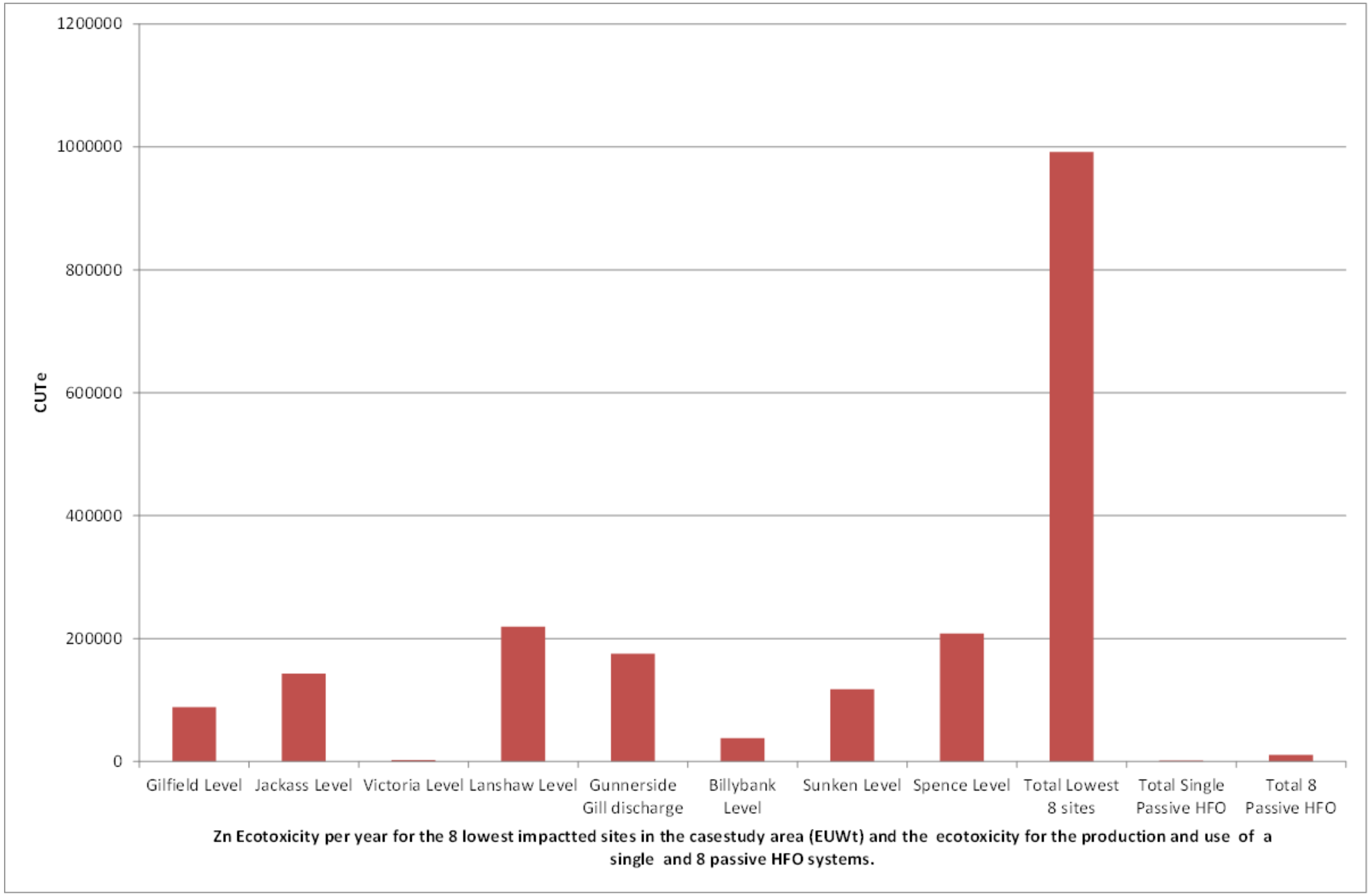


Figure 7.23: Zn entering catchment system per year for the eight least polluting sites in the catchment and the total freshwater ecotoxicity from metals for a single passive HFO system and eight passive HFO systems

## 7.12 **Uncertainty**

There are elements of uncertainty associated with the results shown that are inherent in any LCA exercise. These can be summarised into two key areas: (1) the uncertainty associated with the modelling methodology (see section 7.2) and quantification of the impacts being modelled, and (2) the uncertainty associated with the data being used, e.g. the quality of databases and their accuracy. No matter how good the modelling techniques are, if the data being used in those models is of poor quality or inaccurate then the results will be meaningless.

The data being used here was obtained from a trusted source (EA ambient monitoring and published reports) as previously outlined in section 7.2. All of the information used in this research comes from quality assessed and vetted sources, including; academic literature, published UK government reports, and the European reference Life Cycle Database (ELCD) version 3. The quality of the data used in this research is as high as could be reasonably obtained.

The assessment of the quantities of material required for each of the systems was based upon reasonable assumptions (Section 7.2). The degree of the uncertainty associated with the requirements of each system varies as stated in Chapter Six. The quantities of material requirements were calculated using methodologies from academic literature and information published reports. This contributes to minimising uncertainties in the results. In an actual project the quantities would be known so eliminating this uncertainly.

There are also uncertainties relating to system performance. Little full-scale trial data exists for the HFO and semi-passive options, so the performance assumptions were based on published pilot data.  However, based on these accounts and the site-specific information about water quality and metal loading, the assumptions made here that they will be effective at removing 2 kg of zinc per twenty-four hours is reasonable until improved data becomes available (Mayes et al., 2009c, Jarvis et al., 2014b, Lindsay et al., 2011, Macías et al., 2012, Macias et al., 2012b, Macias et al., 2012a, Hengen et al., 2014).

## 7.13 **Conclusions**

Based upon the assessment of the remediation options undertaking here using OpenLCA software and the quantification of the eco-toxicity impacts of the metals entering the catchment from the assessed sites, the most environmentally beneficial option with the lowest additional impacts is the passive HFO option. The benefits to the catchment of a whole would be enhanced by multiple deployment of this option at all of the identifiable polluting sites. Its small size relative to the semi-passive bioreactor makes it more easily deployable and hence more practical. The accrued benefits of multiple deployments of this system to the freshwater environment and the goals of the WFD of water bodies meeting good ecological and chemical status would be potentially achieved by this proposed multiple deployment.

## 7.14 **Summary**

The greatest environmental impacts of the remediation systems occur during the production phase. When the impacts and benefits occur should be considered in order to gain a fuller picture of the benefits and impacts of remediation. Small-scale passive systems deployed at multiple sites is more effective than a single large scale remediation system. To maximise the benefits received multiple deployment is more effective than fewer larger scale systems. Use of waste materials where appropriate significantly reduces the environmental impacts of remediation. The framework will reduce uncertainties associated with assessing the impacts and benefits of future projects in two ways: 1) Using specific information for material and resource requirements for the remediation approaches to be compared. 2) Contributing data from ongoing monitoring of the remediated site or sites to LCA data bases and to comparison to existing ecological models.

# Chapter Eight    Environmental Economic Assessment of Remediation

## 8.1 Introduction

Placing an economic value on ecosystem services is a contentious issue; as is how to do arrive at a realistic value. There are moral arguments associated with this process which contribute to the difficulties of quantifying the economic value of these services (Costanza et al., 1998, Boyd and Banzhaf, 2007, Zhang et al., 2010, Sagoff, 2011, Farley, 2012, Baveye et al., 2013, Davidson, 2013, Bateman et al., 2014, Cordier et al., 2014, Costanza et al., 2014, Farley et al., 2014a, Hou et al., 2014, Klain et al., 2014, Latacz-Lohmann and Schilizzi, 2014, Plumecocq, 2014, Van der Ploeg and de Groot, 2010). There debate about these issues within the academic literature as well as the wider media as previously discussed (Chapter Two). One of the key findings of stakeholder discussions (Chapter Four) was that there is a reasonable amount of momentum and goodwill for remediation of legacy mine sites to take place across a range of sectors. One key constraint, particularly for backing of industry (e.g. utility companies, metal processors) was the lack of a clear means to demonstrate the economic arguments for and against remediation. This chapter aims to integrate a suite of different methods to provide such an economic framework for comparing the full system (i.e. economic, environmental, social) cost of the current baseline situation in mine-impacted catchments, with a full life cycle costing for different management interventions. Fundamental to the whole approach is combining site-specific and local consequences of mine pollution and applying the benefits of the intervention to a range of geographic and temporal timescales.

## 8.2 Methods, Approach and Justification

The basic approach taken for the economic aspect of the Hebden Beck case study is of a input-output cost benefit approach as outlined by the TEEB organisation ((TEEB), 2012)). The key benefit of this approach is that it is straightforward, transparent and easily understandable. Integrating this methodology into LCSA is a useful form of assessing sustainability (Hoogmartens et al., 2014) for decision-making in both commercial and political spheres. In this chapter, the costs of the individual remediation options have been quantified as well as the monetary value of the benefits derived from remediation, where possible. This has been done using data from a wide range of sources, including the Environment Agency, TEEB, commercial companies, and the wider literature (Appendix Four). The individual remediation options costs have been quantified using information from suppliers of the individual components that compose the individual elements of each system. The costs for the scoping of the site, project management, costs for workers and monitoring of the site into the future have been based upon information supplied from personal communications (Dr Hugh Potter, Environment Agency National Senior Advisor for Abandoned Mines), derived from the costs of the Force Crag remediation (National Trust, 2014) project in the Lake District.

Costing of scoping studies, construction and maintenance of treatment facilities draw upon those elements costed in LCA alongside published examples from elsewhere. An additional semi-qualitative assessment of suitability of treatment options for a given location is provided using site-specific criteria (e.g. available land area, remoteness, aesthetics of the treatment system) can be included. This illustrates some of the key decisions that are common in remedial planning at abandoned mine sites (Clark et al., 2012, Environment Agency, 2012b, Environment Agency, 2012a, Jarvis and Mayes, 2012).

The costs of acquiring the land for the site have not been included as it is assumed that the landowner would allow use of the land as part of the in-kind stakeholder investment, as is the case of the land donated by the National Trust for the Force Crag Remediation Project (National Trust, 2014). Conversations with suppliers of materials and equipment many companies, revealed that many were willing to give a discount on materials or supply time and resources for free when the purpose of the project was explained to them[20]. This was mentioned by some of the interviewees, a willingness to supply resources and time when not willing to make a monetary commitment (Chapter Four). Justifying the assumption that were such a project to go ahead the landowner would be an active stakeholder with the potential for the land to be an in-kind investment.

To fund the remediation of abandoned mine sites and demonstrate to potential stakeholders that it is a worthwhile investment. It is necessary to quantify the benefits derived from preventing metals entering the catchment system from the abandoned

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[20] during the process of obtaining quotes for materials and equipment several companies expressed a willingness to be involved in such a project and were interested in the whole framework, some companies asked for more information and as a result gave reduced rates on costs of materials.

metal mine site at Hebden Beck, which is the most contentious aspect of the whole approach. This side of the cost benefit analysis has been done using the harms and benefits identified in the previous chapter (Chapter Six) as well as information from the River Basin Catchment (RBC) plans, EA reports, the TEEB database (Van der Ploeg and de Groot, 2010) as well is a variety of other sources, Table 8.1 and also in Appendix Five and Appendix Seven.

Table 8.1: Summary of approaches to assess key areas of economic impacts resulting from metal contamination

| Cost of Baseline Impacts | Assessment Approach | Resource/ information sources |
|---|---|---|
| **Local** | EIA/LCIA/WTP | TEEB database, Environmental models (Usetox CFs), Economic assessment, ONS statistics, Site-specific information, GIS |
| **River Basin Catchment** | LCIA/WTP | NWEB Environmental/hydrographic models (Usetox CFs) ONS statistics TEEB database, ELCA database, GIS, Academic literature. |
| **Remediation Options** | Cost estimates/LCIA | Suppliers, Pilot studies, Existing data on existing remediated sites Academic literature |

Not all benefits have been quantified, the dominant ones have, using information that was available and verifiable. In this respect, the quantification of benefits is likely to be an underestimate of the total potential benefits that may accrue. It is important to communicate to stakeholders that there are additional benefits. This is a “bonus” selling point and may be of interested as an added incentive either to become actively involved in a PES scheme and invest, or help to overcome minor objections that they may have to the scheme being enacted. Health effects are difficult to quantify (Taylor et al., 2010, van der Voet et al., 2011, Alves et al., 2014) in many environmental exposure situations. Even for metals which are relatively well-studied as environmental pollutants, there remain difficulties in linking exposure directly with health effects given the vagaries of exposure pathways, transient populations and numerous confounding factors that can affect dose-response relationships. Reducing any potential public health effects is an important economic contribution (Pizzol et al., 2010, Pizzol et al., 2013) that could potentially be made from reducing the levels of metals entering river catchments (Figure 5.6 and Figure 5.7).

## 8.3 Quantifying Non-Use Benefits

One approach taken by the EA to quantify the benefits derived from remediation of RBC relies strongly upon the willingness to pay (WTP) principle. This approach where the value of an asset is derived from interviews and surveys has been widely used to quantify the value of non-market services (Bateman et al., 2011a, López-Mosquera and Sánchez, 2012, Cameron and DeShazo, 2013, Neher et al., 2013a, Solino et al., 2013, Doherty et al., 2014, Breffle et al., 2015). There are difficulties with willingness to pay as people by their very nature are inconsistent and the use of the value placed upon landscape and environmental non-use values are very different things in theory and practice (Doherty et al., 2014). The value that people place upon the natural environment can be derived from the expected improvement in house prices (Clark et al., 2012, Environment Agency, 2013, Hejnowicz et al., 2014, Banos-González et al., Soliva and Hunziker, 2009, Bateman et al., 2011b, Gomez-Baggethun and Ruiz-Perez, 2011). Visitor numbers to areas which are "beautiful" indicate the value of these landscapes from how far visitors are willing to travel and hence invest in transport costs for these experiences (Iniesta-Arandia et al., 2014, Benson et al., 2013, Neher et al., 2013a, How, 2013, Scarborough Tourism Economic Activity Monitor (STEAM), 2013). It was found that those who used the recreational ecosystem services (cultural) had a greater understanding of how they directly benefited from maintaining the natural environment and placed a higher value upon these services (D'Antonio et al., 2012, Kil et al., 2014). These individuals had already invested time and money in order to enjoy or undertake an activity within such an environment so have demonstrated a WTP. The WTP values that have been used in this evaluation are those obtained by the Environment Agency (National Water Environment Benefit Values (NWEBV)) from a national survey using the updated values (Environment Agency, 2013), this survey was also mentioned by one of the interviewees (Chapter Four) as a key advance in how environmental management decisions are beginning to be justified at a ministerial level.

A case study undertaken for Defra using willingness to pay values also incorporated the distance decay aspect of ES values, applied to rivers. Distance decay is the further away a household is from an environmental amenity (river or lake) the less value it is to that household (Schaafsma et al., 2012, Jorgensen et al., 2013b, EFTEC, 2010). The EFTEC (2010) case study found when applying a value per household per year including accounting for spatial factors that there was a large discrepancy between this value and a value for the same area taking no account of spatial factors. It was concluded that although this discrepancy is significant the assumptions made and the requirements of applying this methodology would be difficult to justify (EFTEC, 2010).This was because other factors also influence the value, such as tourism, recreational users, population density, ecological status and other ecosystem service improvements. The type of landscape through which any river passes varies along its course and the value placed upon it within different landscapes will vary. Taking an average value for distance decay over a whole catchment rather than a specific area, incorporating the other variations in value along the course of a catchment is a pragmatic solution to a complex valuation and is the approach taken here. There is the additional complication that individuals value things differently. Taking an average value from a national survey is a justifiable way to determine a population's WTP for improvements given the heterogeneous nature of any population, this is only one single aspect of the total economic value (TEV) and should never be used singularly without reference to other indicators (Ring et al., 2010). The Environment Agency (2013) WTP values are national averages taking into account, distance decay and other factors discussed above.

The population within the local impacted catchments has been calculated using stream length and catchment area taken from Environment Agency stream network data; urban cover from the Flood Estimation Handbook (CEH and Centre for Ecology and Hydrology, 1999); population density taken from ONS Regional Statistics (ONS, 2015); household data assume 2.3 people per household as per the national average in the 2011 Census (Office for National Statistics, 2015).

Therefore the improvement and the monetary value calculated by this national survey (Environment Agency, 2013) will be used for this economic assessment. Additionally, an increase in visitors numbers will also be included which will be assumed to result from the creation of the remediation site itself becoming a draw as has been documented elsewhere (National Trust, 2014). These aspects are included in the values applied to this case study which have been derived by other bodies (Environment Agency, 2014b, Environment Agency, 2014c) following UK government guidelines on the appropriate methodologies (Shamier et al., 2014). GIS software can enable different values to be given to different areas depending upon a set range of criteria which may include (Figure 5.2); distance from the river, type of use (e.g. housing, industrial, agricultural aquaculture recreational), population density etc. Using GIS and values to individual areas would give a more nuanced and potentially more accurate value for the whole catchment and people's willingness to pay for such an amenity (Swetnam et al., 2011, Jackson et al., 2013, Villamagna et al., 2014). As data becomes available about these aspects of national geography a more detailed picture of the impacts and WTP for ecosystem services can be drawn using GIS software. As concluded in the EFTEC (2010) case study and also acknowledged in the Environment Agency guidelines (Shamier et al., 2014) modelling and quantification of the economic benefits need only be taken as far as necessary to demonstrate that the balance of benefits is positive, if this is indeed the case.

## 8.4 Locating and Quantifying the Direct Costs and Benefits

Figure 8.1 illustrates the direct quantifiable costs of remediation for an individual remediation technology and the external non direct costs. Ideally the specific components for each phase of the life cycle should be quantified (Appendix Three). The external harm to the environment should be included and is captured in the LCIA impact categories. Translating theses impact into economic values determined by the LCIA is a useful way to include this aspect into the overall economic evaluation (Pizzol et al., 2014).The traditional approach has been to exclude these costs from standard business models (TRUCOST Plc, 2013) it is arguable that if the economic benefits included are non-direct then the costs these external costs should also be taken account of.

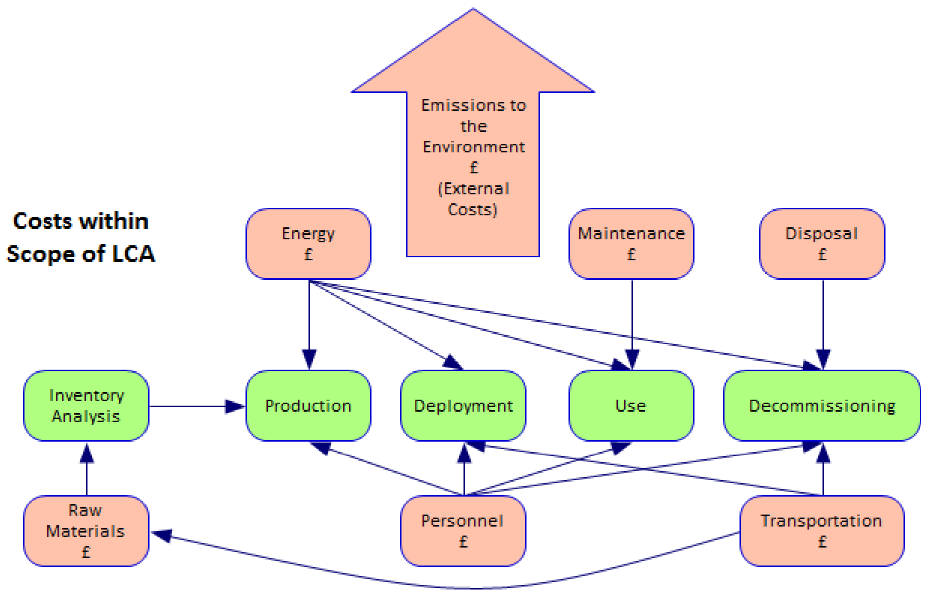


Figure 8.1: Direct quantifiable upfront costs of remediation option being assessed

Figure 8.2, shows benefits of monitoring remediated sites to extract economic value and to ensure compliance with the PES contract. These data will contribute to science and research, linking changes caused by the remediation to benefits, improving models and contributing to databases. There is an economic cost of a monitoring regime which is ongoing and can be significant (Sommerville et al., 2011, Gollan et al., 2012, Faber et al., 2013, Morandi et al., 2014). This should be include in any economic valuation of a remediation project to ensure that monitoring does take place so that data can be collected and used.

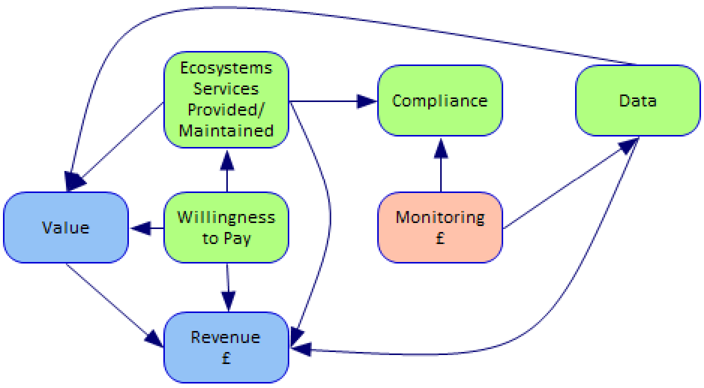


Figure 8.2: Generic ongoing economic costs and benefits of monitoring a remediated site

Figure 8.3 illustrates the extent to which the benefits will be felt at different geographical scales. Thus illustrating the problem particularly with PES schemes of locating stakeholders and whether or not they wish to engage in such a scheme when the benefits arguably are not felt directly by them. This raises the concept of excludability, that you cannot exclude anyone from receiving the benefits of some ecosystem services. Moral arguments and ideas of social responsibility can be put forward as to why these schemes are of value in themselves. When creating a market a system where benefits are received by those who do not contribute, this can create a situation where the argument of no one pays or everyone pays becomes a stumbling block to any action being taken. This was recognised by a number of interviewees, (Chapter Four) in the “who flinches first” principle.

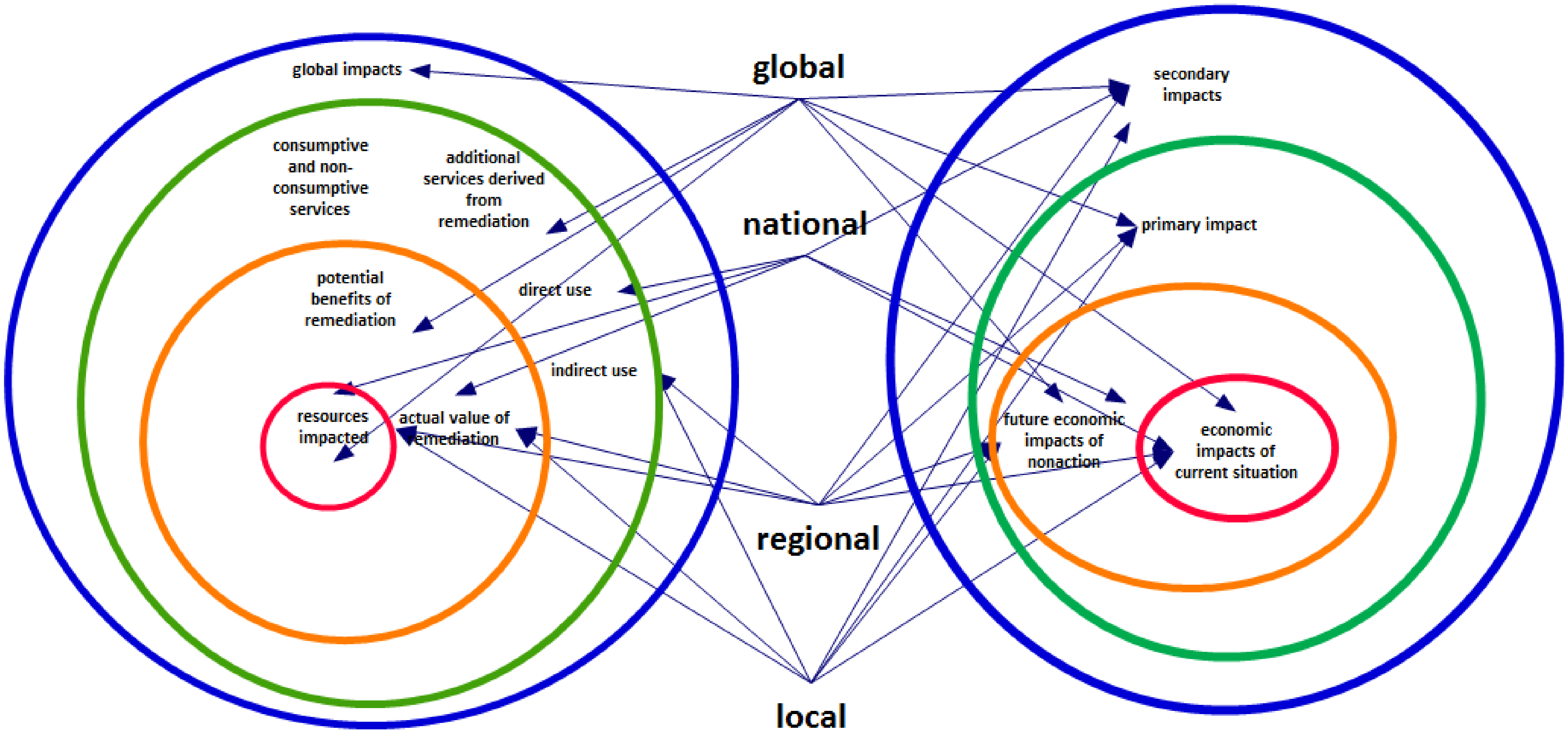


Figure 8.3: Geographic location and type of economic impacts based upon (Shamier et al., 2014)

It is these three situations that are being balanced against one another and quantified economically in order to determine the overall likelihood that this framework can determine and facilitate the remediation of abandoned non-coal mine sites and similar sources of pollution.

Quantifying not only the geographic location of these benefits and where they have the greatest impact but also the temporal variation, when these benefits occur and of what value they are, is a fundamental consideration when quantifying the benefits and impacts (Andersson et al., 2014, Owens et al., 1999, Hornberger et al., 2009, Pinsonnault et al., 2014). As Pinsonnault et al. (2014) demonstrate, the point at which impacts of metals fall vary temporally. The work of Owens et al. (1999) on historic metal pollution also illustrates the importance of temporal variation on impacts of metals. In economic terms, this future benefit and when it occurs is important for quantifying the value of benefits and the value of the investment and return. This is often sought to be captured by discounting the value of money to obtain the present value of the benefits derived. Predicting the present value of benefits in the future is inexact as it is based upon the assumed rate of inflation over a period of time, and that the impact will have diminished economically (Field and Field, 2013). The selection of the discount rate is also difficult and economists and policies makers agreed that this value should be of the order of 1 to 2% (Field and Field, 2013). Some environmentalists fear that discounting can reduce the value of future environmental damages (Jones-Walters and Mulder, 2009, Ring et al., 2010, Balmford et al., 2011, Bateman et al., 2011b, Field and Field, 2013, Jax et al., 2013, Farley et al., 2014a, Latacz-Lohmann and Schilizzi, 2014, Ritchie and Dowlatabadi, 2014). A policy document produced by the Environment Agency suggests a discount rate of 3.5 % taken from the “Green Book” (Shamier et al., 2014). When applied to benefits derived additionally Shamier et al.(2014) claim that the National Water Environment Benefit (NWEBV) significantly undervalued the non-use values that they seek to capture and that a valuation of the other assets not included in NWEBV assessment would increase this value (Figure 8.4).

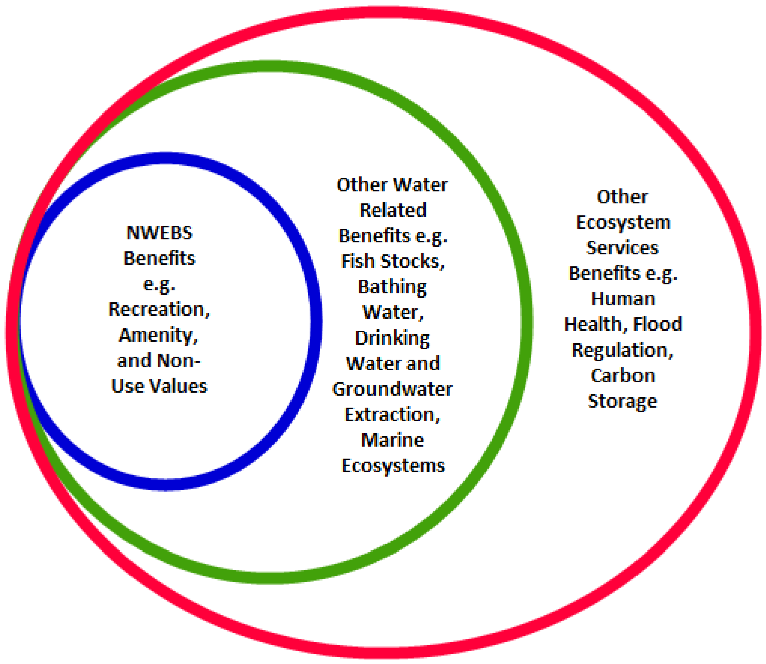


Figure 8.4: Benefits economically quantified by methodology proposed. Does not capture benefits in the red circle, does quantity those in the blue circle (Shamier et al., 2014)

The economic valuation for the River basement catchment plan for the Humber catchment (Environment Agency, 2014c) and the benefits derived for improvements based on five different scenarios undertaken here seeks to capture the elements which are not included in the NWEB assessment (see green circle in Figure 8.4). This has been the basis for the estimate of the overall benefits derived for each improvement measure which raises the status of the water body to good or better in WFD terms.

## 8.5 Discount Rate

In these case studies, a simplistic discounting approach has been taken, and the benefits and costs will be calculated to present value (PV) of the costs and benefits for 2014. This is when the estimates of the costs of the different components of each system were collected. Selection of the discount rate is difficult but because this project has only been assessed over a short time period, ten years which is the length of time over which the initial PES is to run, it is less problematic. It needs to be acknowledged that this discounting will have significant influence over predictions of costs and benefits derived, depending upon at what point over the lifetime of the remediation they occur (Field and Field, 2013). When applying forward and backward discounting to determine PV of costs or benefits the longer the time horizon the larger the impact of the discounting, and hence potentially the less accurate the prediction.

In the UK the rate of inflation that the Bank of England monetary committee is tasked with maintaining is 2%[21], since the 2008 financial crash this rate has not been consistently achieved (Monetary Policy Committee (MPC), 2014). It is this 2% rate which will be applied here when not otherwise stated, assuming it to be normative. IN a situation where the Bank of England MPC say inflation will "temporarily dip below zero in first half of 2015"[22] and the current base rate of inflation is being held at 0.5% by the MPC it is used with a with a degree of caution. There is a fundamental problem with applying an economic value to resources as can be seen from current volatility of commodities markets[23]. The erratic fluctuation of the price of oil and other raw materials illustrates how predicting the value of future impacts and costs based on inflation and commodity prices is not possible to any real degree of accuracy. Equally as these fluctuations directly influence rates of inflation and GDP allocating an economic value to future impacts and using this as a weighting mechanism is perhaps not a suitable way to illustrate what the impacts of future environmental harm will be. Predicting the costs of future imports such as energy[24] and raw materials in order to maintain a remediation option such as the active lime dosing system being considered here becomes extremely difficult with any degree of accuracy. Commodity and energy prices are influence by many factors including, climate policy and the geopolitical situation. This was a point drawn out by many of the interviewees (Chapter Four).

Other ways to express value which capture the importance of maintaining ecosystem services are being sort, including concepts of levels social justice and ecosystem integrity (Chaudhary et al., 2015, Hall, 2015, Kolinjivadi et al., 2015, Matulis, 2014). How to express these concepts in a meaningful and acceptable way is difficult and unfortunately economic value is still the most direct and accepted way to communicate value (Field and Field, 2013). This is why discounting will be used here to predict the future costs of energy inputs and materials for maintenance of the system. Until a consensus is reached on alterative concepts of value and how to quantify them discounting is a pragmatic way to undertake an economic assessment. The justification for the selection of a 2% discount rate is that it lays between the current rate of inflation and the 3.5% recommended by the Green Book (Shamier et al., 2014). Over a longer time period the fluctuations in inflation tend to smooth out and a 2% rate is a close to a

[21] http://www.bankofengland.co.uk/monetarypolicy/Pages/default.aspx
[22] normansmith@BBCNormanS 10:25 AM - 21 Jan 2015
[23] http://www.indexmundi.com/commodities/
[24] https://www.gov.uk/search?q=energy+prices

normative inflation rate over longer time frames, typically one hundred years (Field and Field, 2013).

## 8.6 Excluded Option (Active Lime Dosing System)

The active lime dosing system would consist of a single large-scale installation located at the convergence of maximum pollution input from abandoned mine sites. This option of using a single site to tackle the maximum levels of pollution would require the optimal location to be identified in order to have the greatest impact on the levels of metal entering the catchment. The positive aspects of taking this approach are that the site could be potentially located in an area already industrialised with good access to infrastructure. Arguments for potential metal recovery favour such approaches given the centralised position by which metal resources can be processed into the supply chains (Mohan and Chander, 2006). This option may be more attractive as it is a proven technology which as some interviewees mentioned may be more attractive to water company investors due to its increased level of certainty (Chapter Four).

Table 8.2 and

| **Project Management and scoping costs and monitoring** | |
|---|---|
| Scoping and feasibility | £101,000 |
| Outline design/planning<br>• Outline design/planning<br>• Permits, consents and land costs<br>• Project management. /Technical input<br>• Detailed design | <br>£54,000<br>£25,000<br>£117,000<br>£54,000 |
| Ground investigation | £59,000 |
| Project Management and construction phase | £485000 |
| Ongoing monitoring costs<br>£12,000 per annum (assumed annual increase of 2%) | £131396.652 |
| Total | £1,026,397 |

shows the initial costs for this option which are substantially more than the other options being considered (Table 8.4 and Table 8.6). This option would be the least feasible financially. It requires the largest area of land which is limited and depending upon the site identified it is likely to raise the largest number of planning objections from stakeholders (section 4.3.3 and section 4.3.4). Any effects upstream of this facility would still suffer from the impacts of the pollution and as such these benefits both economic and environmental would be lost. This scenario has been discounted as unfeasible due to the difficulty in finding a location with available infrastructure and where the maximum environmental benefits would accrue. Another fundamental problem with the active lime dosing system or the location of the single large-scale treatment plan is that the benefits accrued from metal removal need to happen at the local scale in the small rivers and streams where the discharges occur. This option requires the maximum inputs and hence generating the maximum environmental harm for the minimum benefit derived (7.5). For these reasons this option has not been considered here. For completeness and so that the economic costs of the other two options can be put into context, the traditional approach of large-scale remediation, the costs for this option have been included. A further argument against this scenario is the location of these sites in National Parks and AONBs where planning restrictions apply.

## 8.7 Results and Discussion

The economics costs of remediation for the Hebden Beck case study have been investigated and assessed for the three selected options previously outlined in Chapter Six. The focus of this assessment has been based upon information obtained from various sources including the Environment Agency and cost estimates for constituent parts have been obtained directly from suppliers (Appendix Four, Appendix Five and Appendix Seven).

### 8.7.1 Quantification of Costs Associated with Individual Options

For this case study it will be assumed that the individual scheme at Hebden Beck will result in an economic improvement of £10,000,000 pounds (PV) over the ten year timeframe being used for this case study.

This value has been derived from the Humber RDBC (Environment Agency, 2014c) and the extended economic analysis undertaken by the EA and seeks to capture the direct economic benefits to ecosystem services, for example improved provisioning services increasing aquaculture revenue, and income from angling (rod licences). The exact breakdown of how these benefits would be split among the local stakeholders has not been undertaken. For example particular end-users such as two fish farms downstream of Hebden Beck may be expected to benefit more than others as they may see a direct economic value due to the decreasing levels of metals in the watercourse, resulting from reduced treatment costs and potential increase in production and health of fish stocks.

Table 8.2, Table 8.3, Table 8.4, Table 8.5, Table 8.6 and Table 8.7 provide an overview of the monetary costs associated with construction and maintenance of the various remedial options considered in Chapter Six.

Table 8.2: Costs of constituent parts and energy requirements for the active lime dosing system

| **Component Part Lime Dosing** | **Material** | **Cost £ (Excluding VAT)** | **Delivery Cost £** |
|---|---|---|---|
| 25 kW air blower | Cast Iron | 12375 | Delivery Free |
| 1.1 kW motor | Aluminium | 90 | Delivery Free |
| 1.5 kW pump | Cast Iron | 571 | Delivery Free |
| 4 kW pump | Cast Iron | 900 | Delivery Free |
| 4 kW mixers | Steel | 4140 | 50 |
| Bottom mounted vertical blade turbine | Stainless steel | 450 | 75 |
| 55 m³ concrete reactor tank | Concrete 75mm thick, 3.13cu.m weight 2403kg/cu.m | 7613 | 950 |
| 360 m³ sludge surplus tank | Concrete | 45675 | 2700 |
| Total Cost PV excluding VAT no installation or energy costs no UFL | | 71813 | 3775 |
| Total Cost Component Parts excluding VAT Including Delivery Costs Approximately PV (2014) No UFL | | £715588 | |
| **Ongoing material and energy costs estimate cost £ over ten years** | | | |
| UFL | UFL | £600,000 | Free delivery |
| Approximate electricity usage based on continuous operation for active lime dosing. Price estimation[25] | Electricity 320616 kilowatt-hours (kWh) per year based on continuous operation. Fixed tariff over 10 years | £37,000,000 | High degree of uncertainty |
| Disposal of UFL based on gate fees for hazardous waste disposal (Appendix Four) | UFL | £15,000,000 | High degree of uncertainty |
| Total on going costs over ten year operation | | £58,000,000 | |
| Total ongoing costs per year | | £58,00,000 | |
| Potential value of metal recovery at current prices over ten years this would incur additional costs not factored in here and is a very uncertain quantification | Metals recovered from spent UFL | £10,000000 | |

[25] http://www.businesselectricityprices.org.uk/cost-per-kwh/#my-rates

Table 8.3: Initial and continuing administrative expenses, active lime dosing system

| **Project Management and scoping costs and monitoring**[26] | |
|---|---|
| Scoping and feasibility | £101,000 |
| Outline design/planning<br>• Outline design/planning<br>• Permits, consents and land costs<br>• Project management. /Technical input<br>• Detailed design | <br>£54,000<br>£25,000<br>£117,000<br>£54,000 |
| Ground investigation | £59,000 |
| Project Management and construction phase | £485000 |
| Ongoing monitoring costs<br>£12,000 per annum (assumed annual increase of 2%) | £131396.652 |
| Total | £1,026,397 |

Table 8.4: Basic upfront costs of component parts for passive HFO system

| **Component Part HFO Hybrid System** | **Material** | **Cost £ (Excluding VAT)** | **Delivery Cost £** |
|---|---|---|---|
| **3000 L fibreglass tank** | Glass fibres and Resin | 310 | 78 |
| **Pond liner 6 m³ pond** | Heavy Duty PVC, additional energy to produce 56MJ/Kg included in the LCA | 1100 | 9 |
| **Wood shavings** | Wood shavings saw dust waste material | 768 | 0 |
| **Limestone sand** | In LCA Estimates about energy consumption for crushed have been made. | 45 | 0 |
| **Alterative LimeX** | LimeX | 21 | 0 |
| **168 L fibreglass tank** | Glass fibres and Resin | 188 | 78 |
| **PVC half pipe piping** | PVC | 28 | 9 |
| **HFO pellets (25% Portland cement 75% HFO)** | Cost for Portland Cement only | 13 | 0 |
| **Plants for Wetland** | 4 Reed Trays | 2000 | 50 |
| **Earth excavation hydraulic excavator (for wetland installation)** | Used over a week to excavate approximately 20m$^2$ | 645 | 0 |
| **No Input Energy Required during operation Total costs** | | 5120 | 224 |
| **Total Cost Component Parts excluding VAT Including Delivery Costs Approximately PV (2014)** | | £5425 | |

[26] information based upon Force crag remediation project, supplied by a personal communication with EA,

Table 8.5: Approximations for administration and ongoing costs, passive HFO system

| **Project Management and scoping costs and monitoring**27 | |
|---|---|
| Scoping and feasibility | £101,000 |
| Outline design/planning<br>• Outline design/planning<br>• Permits, consents and land costs<br>• Project management / Technical input<br>• Detailed design | <br>£54,000<br>£25,000<br>£117,000<br>£54,000 |
| Ground investigation | £59,000 |
| Project Management and construction phase | £485000 |
| Predicted costs of replacing reactive media once during the ten-year life time (it is assumed that this material will be used to enhance the area of biodiversity offsetting previously created for the metallophyte community therefore no disposal costs have been factored into this calculation)<br>Earth excavation hydraulic excavator | £150<br><br><br><br>£700 |
| Ongoing monitoring costs<br>£12,000 per annum (assumed annual increase of 2%) | £131400 |
| Total | £1027247 |

Table 8.6: Basic upfront costs of component parts for semi passive bioreactor

| **Component Part**<br>**Semi Passive Bio reactor Based on Force Crag Design** | **Material** | **Cost £ (Excluding VAT)** | **Delivery Cost £** |
|---|---|---|---|
| PVC plastic tubing pressure control flow regulator | PVC | 28 | 0 |
| Pond liners high-density polyurethane | Plastic | 44000 | 9 |
| Manure | Manure | 23914 | 0 |
| Pass 100 compost | Compost | 22084 | 0 |
| Limestone and sand LimeX | LimeX | 13992 | 0 |
| Straw | Straw | 9815 | 0 |
| Limestone gravel | Lime stone | 3700 | 0 |
| Perforated PVC plastic piping | PVC | 5916 | 0 |
| PVC plastic piping | PVC | 28 | 0 |
| Plants for wetland | 4 Reed trays | 2000 | 50 |
| Earth excavation using 500 kW hydraulic excavator (for wetland installation) | Used over a week to excavate approximately 20m$^2$ | 645 | |
| No Input Energy Required during operation Total costs | | 126123 | 59 |
| Total Cost Component Parts excluding VAT Including Delivery Costs Approximately PV (2014) | | £126185 | |

[27] information based upon Force crag remediation project, supplied by a personal communication with EA,

| Project Management and scoping costs and monitoring[28] | |
|---|---|
| Scoping and feasibility | £101,000 |
| Outline design/planning<br>• Outline design/planning<br>• Permits, consents and land costs<br>• Project management / Technical input<br>• Detailed design | <br>£54,000<br>£25,000<br>£117,000<br>£54,000 |
| Ground investigation | £59,000 |
| Project Management and construction phase | £485000 |
| Ongoing monitoring costs<br>£12,000 per annum (assumed annual increase of 2%) | £131397 |
| Total | £1026397 |

Table 8.7: Approximations of administration and ongoing costs, semi-passive bioreactor

It is assumed that there will be no disposal costs associated with this semi-passive bio reactor. When it is decommissioned it is predicted that the contaminated material which will have been stabilised within the ponds will be converted into a metallophyte habitat which will naturally remediate the contaminated substrates (Lottermoser et al., 2011, Harding and Whitton, 1978, Gavrilescu, 2004, González and González-Chávez, 2006, Szarek-Lukaszewska, 2009, Ashraf et al., 2011, Marchand et al., 2011, Rascio and Navari-Izzo, 2011, Abreu et al., 2012, Chenery et al., 2012, Erskine et al., 2012, Wójcik et al., 2014, British Lichen Society, 2014, Baker et al., 2010, Whiting et al., 2004a, Purvis, 2010) and act as an area of preservation for calcareous grasslands and rare lichen. An alternative scenario is that the contaminated material will be “mined” for their metal content and thus be a source of revenue. This process will inevitably have a higher environmental burden in terms of the recovery process and the technology, predicting how this will be done it is too uncertain based on current knowledge so will not be undertaken here. Applying LCSA methodology to this aspect of the project would be fairly straightforward and supply additional information for selecting the appropriate action to be taken at the time of decommissioning. As this case study is being modelled for a ten year period the decommissioning phase is not included.

The additional costs associated with remediation include the initial scoping phase as well is the installation and manpower required in order to take such a project forward (Table 8.6 and Table 8.7). The costs of this initial phase of planning and commissioning

[28] information based upon Force crag remediation project, supplied by a personal communication with EA,

a plan based upon those for the Force Crag remediation site[29]. This project is significantly larger in scale than those envisaged for Hebden Beck thus it has been assumed that these costs will be lower but not significantly so as the same process still has to be undertaken despite the scale of the proposed remediation being smaller. These costs (Table 8.5) are therefore likely to represent an overestimate of those for the Hebden Beck case study.

The ongoing running costs associated with the passive systems are those related to monitoring (Section 8.5, Section 8.4 and Table 8.5). It is important to include the costs of monitoring and ensure that this aspect of the remediation is locked into the system as it is fundamental to the conditionality required for any true PES scheme. Another key element of this cost is the benefits derived directly from it in the form of research revenue and information which contribute to the knowledge economy and cultural ecosystem services. This specific benefit is assumed to be included in the overall assessment of benefits derived. The figures published by the ONS (Office for National Statistics, 2015) show that the contribution that research (universities and private research organisation) and the knowledge economy makes to UK GDP is significant, this information as a source of revenue is a fundamental part of the framework. Additionally this garnered information will contribute to improving future modelling and accuracy in assessing the predicted benefits and impacts of implementing remediation at mine affected sites in the future. This aspect is the iterative element of the framework is a necessary part of the remediation in order to derive the maximum benefit in terms of the cultural ecosystem services harvested from any remediation scheme. It is recognised that there is a probability that this would be an "easy" cost to drop; it must be made clear that this cost is necessary and as fundamental as the physical remediation in order to derive the maximum economic benefits from this system.

The costs associated with the material inputs are similar to those for other schemes (CL: AIRE, March 2004, Jarvis et al., 2014a) such as those at the Wheal Jane site in Cornwall and Force Crag in Cumbria (Appendix Four, Table 8.2, Table 8.4 and Table 8.6). Based upon the quantities of the different materials and energy requirements for an individual site and dependent upon the market at the time of purchase.

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[29] information supplied by a personal communication with the EA.

### 8.7.2 **Additional Criteria**

There are six factors that affect the choice of remediation system these are;

- The degree of certainty of the option to deliver metal removal from site
- The size of remediation option (is there enough suitable land to install the remediation scheme?)
- The ease of installation, is the infrastructure in place to facilitate the installation and running of the option (how accessible is the site?)
- Upfront costs of the scheme
- Ongoing costs and maintenance
- Appearance of the scheme (does it fulfil the criteria of fitting in with the industrial heritage of the area and thus creating a point of interest?)

These additional criteria are summarized in Table 8.8 and would be included in any assessment of the viability of a proposed remediation scheme. The practicalities associated with installing any one of these three systems need to be taken into consideration as well is the funding costs and their likely effectiveness. There are a wide range of different costs associated with each of the three systems as well is initially it appears that the first system, the passive HFO system with the lowest upfront costs and no ongoing requirements beyond a replacement of the reactive component at the five-year point and would be the first choice. This is a relatively untried system and there are uncertainties surrounding its effectiveness (Mayes et al., 2009c, Macías et al., 2012, Macias et al., 2012b). Additional considerations for ease system compared with the other two systems being assessed are summarised in Table 8.8. On the economic and also practical grounds of available land and infrastructure required option three, lime dosing has been excluded as a plausible solution to the small-scale remediation required at a site such as Hebden Beck

Table 8.8: Summary of additional factors to be considered for each remediation option

| **Remediation option being considered**<br>Factor affecting choice of remediation system | **Passive HFO** | **Semi-Passive Bio Reactor** | **Active Lime Dosing System** |
|---|---|---|---|
| Certainty of options effectiveness Rank (1-3) 1 being the most certain 3 being the least certain. | **3** Fairly certain will be effective, least certain of three options available, should deliver remediation but the system as configured here has yet to be tested | **2** Currently being tested at force crag extensive research into the effectiveness highly likely it will deliver. Low risk of failure | **1** Effective, already widely used |
| Footprint of option being considered | Yes land is available at most sites | Yes and is available for most sites | Too large to install at proposed sites |
| Ease of installation | Fairly simple to install little excavation needed equipment all small-scale fairly easy to get to sites with tracks and footpaths small quantities of material | More difficult due to levels of materials required to be delivered larger footprint and more excavation works still possible to install in more remote sites as evidenced by force crag but larger levels of disruption and temporary infrastructure requirements | Very difficult to install but not impossible similar considerations to those of The Semi-Passive Bio Reactor |
| Infrastructure requirements | None -beyond initial installation requirements | None -beyond initial installation requirements | Access to source of power for pumps either via generator (hydropower or wind turbine possibilities) connection to existing grid presents additional difficulties. Road infrastructure for ongoing deliveries of line need access to site for large vehicles |
| Ongoing costs | Monitoring costs and replacement of active media after five years | Monitoring costs | Monitoring costs<br>Energy requirements and lime |
| Appearance | Does not fit in with the traditional appearance of historic mine sites however due to let relatively small size and the addition of wetland can be made a point of interest with information board so does not present a big visual intrusion also may become a point of interest. | Can be made to appear as the mines themselves once did with settling ponds etc. historic point of interest fits into the historic industrial past of landscape overall not too intrusive can become a point of interest with information board | Visually intrusive does not fit in with historic industrial appearance of site large footprint nor current agricultural setting, may be point of interest they due to active nature of system may be prohibitive for public access |
| **Conclusions** | **Viable Medium risk Highly feasible** | **Viable Low risk Feasible** | **Unviable Low risk Unfeasible** |

## 8.8 **Benefits Derived**

The expected benefits to be derived from the installation of the remediation system can be seen in Table 8.10 and also Chapter Five. The purpose of this section is to illustrate the benefits that can potentially be "sold" to stakeholders, therefore this will not be a comprehensive economic valuation of all the benefits that will be derived from remediation of the abandoned mine sites. Double counting which must be avoided in LCSA (ISO, 2006a) as it can distort the results significantly is not necessarily such a problem in PES schemes as the goal is to achieve maximum investment for the remediation options in order to the best affordable solution. It has been argued that double counting and selling of single benefits to multiple stakeholders and the bundling of ecosystem services is in fact desirable (Robert and Stenger, 2013, Turner et al., 2014, Bateman et al., 2014, Costanza et al., 2014), where double counting occurs this will be indicated. Transparency is key to the whole issue of trust relationships in PES, it must be made explicit where an ecosystem service or services are being sold to multiple byers. This does not necessarily mean that stakeholders will know the position of other stakeholders or what they are investing in, particularly where there are issues arising to do with sensitive business information or blind auctions for example. Individual stakeholders should know what is expected of them, what they are investing in and their role within the overall scheme this aspect is the reasonability of the "ethical brokers". This refers back to what an individual stakeholder requires from the scheme. This is particularly salient for water companies who have legal requirements and statutory obligations imposed upon them by government and enforced by regulators, such as Ofwat and the Environment Agency, beyond providing safe and clean drinking water and treating waste water and sewerage (OFWAT, 2014b, Yorkshirewater Services Ltd, 2014, Yorkshirewater, 2014). Thirty-six percent of the average Yorkshire Water customer bill pays for meeting the requirements of the six categories for "enhancing and improving the water environment" which has been predicted to come to a total expenditure between 2015 to 2020 of approximately £137,000,000 (Yorkshirewater, 2014).

Table 8.9: Water Company Requirements Fulfilled Through Engagement with Hebden Beck PES Scheme

| Commitment | Relevant aspect of PES scheme |
|---|---|
| Length of river improved (against WFD component measure) | Overall improvement of water quality due to the reduction in levels of Lent metals entering the River catchment |
| Solutions delivered by working with others | Negotiation with other stakeholders and active involvement with local community to deliver viable PES scheme |
| Amount of land conserved and enhanced (total cumulative area) | Enhancement of local area resulting from reduced levels of metal entering the system |
| Recreational visitors satisfaction | Enhanced area of interest at the specific site |
| Long-term stability and reliability factor: waste water quality | Overall enhancement of ecosystem resilience and improvement in overall water quality |

As illustrated by Table 8.9 these commitments provide a strong incentive for water companies to actively seek out PES schemes as a cost-effective and viable option for their environmental improvement obligations.

Table 8.10: Additional benefits derived from metal removal from river basin catchments

| **Benefit**<br>**Ecosystem Service** | **Stakeholder/**<br>**Sector** | **Economic Valuation/Captured by/Methodology** | **Source of Investment** | **Geographical location** | **Timeframe** | **Conflict?** |
|---|---|---|---|---|---|---|
| Metal removal WFD<br>Improved ecosystem functioning and resilience | GA (local and national)<br>SICSO<br>Water Companies | Avoided finds from EU non-use value improved ecosystem resilience water environment benefits (value to individual households) | GA<br>Local Authorities<br>Water Companies<br>SICSO | Local, effects dominate, immediate improvement in EQS values locally Catchment Scale, reduction of overall metals entering the system dependent upon percentage contribution of site being remediated Global reduction in overall metals entering a system | Immediate to long-term. Immediate reduction in levels of metal in the water at the local level, long-term effect of capping as long contaminated sediment deposits and overlays contaminated sediment reducing storm event releases.<br>Gradual improvement in ecosystem resilience and improvements to individual species as they recover. | Metal dependent species may decline (protected species of special interest particularly metallophyte and likens) change in characteristics of the local ecosystem of protected species |
| Tourism | Yorkshire Dales National Park<br>Local Businesses (service sector)<br>Local Authority | Increase in tourist revenue (based on predictions from STEAM surveys and methodologies) | Individual Local Businesses<br>Yorkshire Dales National Park | Increase in visitor numbers and revenue to local businesses, increase in stress on local Infrastructure (increase number of cars need for additional parking interest increase number of passengers on transportation)<br>increase in traffic on local businesses<br>very localised impact) | Time lag as improvements become known to general public and potential visitors, word-of-mouth about interest of area, initial interest at opening of information board etc. dependent on publicity.<br>Long-term increase in visitor numbers as site becomes areas of interest | Potential conflicts from competition for car parking in local area increase traffic usage (minimal damage to roads)<br>additional public transport usage (minimal) save the |
| Environmental off setting metalliferous community | SICSO<br>GA | Avoided EU fines (minimal economic) potential for negative | Lichen Society government biodiversity offsetting fund | Immediate local impact to metallophyte ecosystems and | Long-term requirement for establishment of metallophyte Habitat and | Conflicts arising about adequacy of establishment and |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | publicity and ill will negative impact on area increased visitor numbers as awareness of SSSI and relocated habitat | EU biodiversity fund/grant | individual species | area, time lag as community establishes itself long-term requirement of maintenance of community habitat | relocation of SSSI sites environmental offsetting in perpetuity (difficulties arising in recreating habitat) |
| Groundwater | Water industry, local landowners, aquaculture (local fish farms) | Improvement to EQS levels improved levels of productivity reduction in treatment costs | Fish farms impacted by the pollution water companies | Immediate local downstream impacts catchment scale | Long-term an immediate pass levels of metals are reduced and maintained | |
| Industry and Other Uses (including Abstraction) | Water companies EA Aquaculture Farmers and Local Landowners | Reduces treatment requires improved water quality, difficult to quantify economically | Water companies EA local industrial users (Fish farms) | Immediate local water quality improvement and record down catchment scale | As above | |
| Biodiversity and non-use | Improved overall ecosystem resilience and health | Captured by water improvement benefit values | SICSO | Local to catchment scale more noticeable at the local level | Long-term as ecosystem changes and adapts to new levels of metals | Issues surrounding metallophyte community as previously stated |
| Heritage, landscape and archaeology Visual appearance of Adit | SICSO Yorkshire Dales National Park Local community | STEAM potential increase in tourist numbers previously captured | English heritage Yorkshire Dales national Park Government Economic Development Funds Etc. | Local impact | Immediate impact as soon as the work is finished permanent change as long as remediation continues | Objections due to changing characteristics of potential archaeological heritage negotiation with interested parties |
| Angling | Angling Association EA | Potential increase in recreational fishing licenses purchased | Angling Association EA | Local downstream improvement | Time delay is fish stocks improves long-term improvement | |
| Property prices | Local community local council/authority | Property prices index, difficult to quantify prove causation especially in the current economic climate | Not applicable | Immediate local area | Fluctuation due to different causes also improvement in water quality will not have a negative impact | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Human health<br>Zinc<br>Copper<br>Lead<br>Cadmium | Local health authority<br>GP practices<br>local council | Difficult to quantify though proven links between levels of chronic and acute metal exposure to both social and health effects | N/A | Immediate local effects | Temple time delay due to previous exposure and reduction in health and social effects are seen | Difficult to account for correlation and causation and correct for other environmental and social factors |
| Downstream Impacts<br>Sediment capping<br>hydrological transport<br>WHAM modelling<br>Less dredging etc.. | EA<br>Downstream<br>Aquaculture | Difficult to quantify potential for reduction in dredging and improvement to fish stocks | EA<br>Port authorities responsible for dredging in estuaries (contaminated sediment removal) | Catchment scale | Delays as contaminated sediment is transported down the catchment and a suitable air of "clean" sediment is deposited and built up a protective layer. | Difficult to quantify also has implications for management practices and requirements for dredging which may be needed to keep shipping channels clear. |

### 8.8.1 Quantification

#### 8.8.1.1 National Water Environment Benefit Values

The National Water Environment Benefit Values (NWEBV) is used by the Environment Agency (Environment Agency, 2013) seek to capture the benefits derived economically for improvements in water quality for non-market benefits, resulting from improvement rivers status in accordance with the WFD objectives. This methodology will be applied to the case study is to quantify the overall economic value of the remediation of the Hebden Beck site. The levels of the NWEBV are dependent upon the catchment characteristics in terms of the population and the number of households within the catchment area being assessed as well the length of water body being assessed. For households to benefit from improved ecosystem services in terms of non-use values households need to be within the catchment in order to receive this benefit. The levels of benefits shown in Table 8.11 are dependent upon the factors shown in Table 8.12. These factors explain the wide variation in NWEBV, which are calculated per km per household.

Table 8.11: Values derived from updated NWEBS for remediation of individual water body listed (Environment Agency, 2013) (Appendix Seven).

| Catchment name | Impact category (based on current WFD status with regard mining pollution: Jarvis and Mayes, 2012) | PV total over 10 year operation expected NUV benefits £s | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| Gunnerside Gill (Swale) | Impacted | 68865 | 83987 | 99290 |
| Barney Beck / Hard Level Gill (Swale) | Impacted | 169935 | 207249 | 245012 |
| Nidd (source to Howstean Beck) | Probably Impacted | 2561637 | 3125579 | 3689521 |
| Nidd (Howstean to Ashfold Side) | Probably Impacted | 3109532 | 3794094 | 4478655 |
| Ashfold Side Beck (Nidd) | Impacted | 597865 | 729142 | 862001 |
| Nidd (Ashfold to Birstwith) | Impacted | 3372092 | 4112524 | 4861878 |
| Nidd (Birstwith to Oak Beck) | Probably Impacted | 1660368 | 2025897 | 2391426 |
| Wharfe (Park Gill to Barben) | Probably Impacted | 1703670 | 2078732 | 2453794 |
| Barben Beck / River Dibb | Probably Impacted | 104993 | 128107 | 151222 |
| Hebden Beck (Wharfe) | Impacted | 25079 | 30585 | 36158 |
| Fir Beck / Blands Beck (Wharfe) | Probably Impacted | 189353 | 231039 | 272725 |
| Wharfe (Barben to Hundwith) | Impacted | 10297651 | 12558775 | 14847142 |
| Washburn Beck (Wharfe) | Impacted | 1049448 | 1279883 | 1513093 |
| Aire (Eshton to Worth) | Impacted | 46987496 | 57304856 | 67746522 |
| Aire (Worth to Gill Beck) | Probably Impacted | 23421538 | 28577772 | 33734007 |
| Aire (Gill Beck to Calder) | Probably Impacted | 63260017 | 77186662 | 91113308 |

Table 8.12: Stream length and population characteristics for mine-affected rivers in the Yorkshire Ouse catchment

| Catchment name | Stream length (km) | Catchment area (km2) | Urban extent (% cover) | Population density (people/km2) | Households | Low value improvement per km per household | Central value per km per household | High value per km per household |
|---|---|---|---|---|---|---|---|---|
| Gunnerside Gill (Swale) | 7.9 | 39.9 | 0.03 | 40 | 20.8 | 37.8 | 46.1 | 54.5 |
| Barney Beck / Hard Level Gill (Swale) | 12.4 | 62.6 | 0.03 | 40 | 32.7 | 37.8 | 46.1 | 54.5 |
| Nidd (source to Howstean Beck) | 23.6 | 119.2 | 0.15 | 47 | 365.3 | 26.8 | 32.7 | 38.6 |
| Nidd (Howstean to Ashfold Side) | 26 | 131.3 | 0.15 | 47 | 402.5 | 26.8 | 32.7 | 38.6 |
| Ashfold Side Beck (Nidd) | 9.6 | 48.5 | 0.15 | 47 | 148.6 | 37.8 | 46.1 | 54.5 |
| Nidd (Ashfold to Birstwith) | 22.8 | 115.1 | 0.15 | 47 | 352.9 | 37.8 | 46.1 | 54.5 |
| Nidd (Birstwith to Oak Beck) | 19 | 96 | 0.15 | 47 | 294.1 | 26.8 | 32.7 | 38.6 |
| Wharfe (Park Gill to Barben) | 17.1 | 86.4 | 0.19 | 47 | 335.3 | 26.8 | 32.7 | 38.6 |
| Barben Beck / River Dibb | 18.5 | 93.4 | 0.01 | 47 | 19.1 | 26.8 | 32.7 | 38.6 |
| Hebden Beck (Wharfe) | 4.4 | 22.2 | 0.03 | 47 | 13.6 | 37.8 | 46.1 | 54.5 |
| Fir Beck / Blands Beck (Wharfe) | 5.7 | 28.8 | 0.19 | 47 | 111.8 | 26.8 | 32.7 | 38.6 |
| Wharfe (Barben to Hundwith) | 35.4 | 178.8 | 0.19 | 47 | 694.1 | 37.8 | 46.1 | 54.5 |
| Washburn Beck (Wharfe) | 11.3 | 57.1 | 0.19 | 47 | 221.6 | 37.8 | 46.1 | 54.5 |
| Aire (Eshton to Worth) | 29.1 | 147 | 0.9 | 67 | 3852.8 | 37.8 | 46.1 | 54.5 |
| Aire (Worth to Gill Beck) | 24.4 | 123.2 | 0.9 | 67 | 3230.5 | 26.8 | 32.7 | 38.6 |
| Aire (Gill Beck to Calder) | 40.1 | 202.5 | 0.9 | 67 | 5309.2 | 26.8 | 32.7 | 38.6 |

Additional benefits derived have been quantified using data from the Humber river basin catchment plan (Environment Agency, 2014e, Environment Agency, 2014c) to try to capture the level of expected additional revenue that would be generated from the range of benefits described in Table 8.10. These benefits, incorporate none use values (NUV), cultural services and impacts on property prices as well as water extraction, are difficult to capture but nevertheless do have an economic value which needs to be included in the assessment (Shamier et al., 2014). This value is likely to be an underestimate which is difficult to capture but vital to be included. Additional benefits from provisioning ecosystem services such as increase in fish stocks and improved health of livestock are also assumed to be contained within this figure. In a real-world situation when stakeholders have been identified and approached their specific interests would be directly addressed using the best available methodology, for example how reduction in levels of metals would be expected to impact upon a fish farm located downstream of the source of pollution. This would give a much more detailed analysis of the expected benefits to individual stakeholders and would be a worthwhile exercise once specific stakeholders were being approached. In the initial scoping exercise this level of detail is not necessary, a more general idea of levels revenue is a more practical approach to take.

#### 8.8.1.2 **Expected Increase in Revenue due to Benefits Accrued from Water Body Raised to Good Ecological Status or Better**

Additional values (see section 8.3) of the quantifiable benefits has been arrived at using figures from the Humber river basin management plan (Environment Agency, 2014c), per improvement, have been calculated to be approximately £1000,000 (PV). Using the same set of figures a value of approximately £10 million over the ten-year period (PV) per water body improved to good ecological status or better has been calculated. It is the figure for the multiple water body improvement scenarios rather than per improvement that is being used here, as it is unclear whether the improvements are classified in the document as a single intervention or as a collection of installations for an improvement (Environment Agency, 2014a, Environment Agency, 2014c). This figure will be used as the revenue derived from ecosystem services per water body improved. This figure of ten million pounds (PV) plus the non-use values (NUV) derived from the NWEBS which have been taken here to prove the principle that the benefits both direct and indirect will have a tangible economic effect resulting from remediation, see Appendix

Seven. Additional economic benefits are expected however, if an initial general economic assessment demonstrates adequate remuneration a further more detailed assessment is not necessary (Shamier et al., 2014). A more detailed assessment may be something that is demanded by individual stakeholders before committing resources to a scheme, relating to their particular area of interest. A specific assessment can be undertaken per stakeholder as required. As proof of principle and an initial starting point this assessment is deemed adequate for this case study and proves the principle that it is possible to remediate a site and derive greater monetary benefits than the initial outlay.

A calculation to estimate the benefits derived due to water body improvement was done using information from the Wharfe and Lower Ouse catchment management report (Environment Agency, 2014e) which estimates that the benefits derived from improving the four water bodies to good ecological status over the long term (up to 2027). A twelve year timeframe will result in benefits of the value of £17.5 million (PV) which is approximately £360000 per water body per annum. These figures relate specifically to the Upper Wharfe catchment in which Hebden Beck is situated and are very localised thus excluding some of the downstream benefits which are captured in the value derived when assessing the whole Humber river basin catchment and go some way to explaining the disparity between this figure and the £1000,000 per annum obtained from the whole Humber river basin catchment. A break-down of these figures can be seen in Appendix Seven.

This value of benefits derived per water body of between the range of approximately £360,000 and £1000,000 per annum for water bodies improved to good ecological status is broad but can be explained. The larger figure is derived from the benefits over the whole catchment which include a wide range of ecosystem services and their benefits derived. The local estimate captures a much smaller number of services associated specifically with that area and does not include aspects such as extraction by water companies which contributes significantly to the overall economic value of improvement.

Priorities of potential stakeholders such as fish farmers downstream of the intervention should be targeted with the specificities of the benefits to them; for example the expected increase in revenue resulting from reduction in instream pollution. This will increase the likelihood of them investing in such a scheme making the benefits real and quantifiable to a potential investor (see Chapter Four). A specific benefit to water companies is a reduction in treatment costs of approximately£ 0.42 $m^{-3}$ of water treated per year (Clark et al., 2012) from decreased levels of metals entering the treatment system. This benefit impacts at the regional scale and so not included in the local assessment but is included in the catchment scale assessment and could be sold to all water company as the benefits of reducing metals entering the catchment are felt downstream.

These figures suggest that an annual economic benefit spread over the different stakeholders who benefit will be somewhere between £360,000 pounds and £1million (PV) per annum in addition to the NWEBS of £3000 pounds annually which is widely acknowledged to be an underestimate of these benefits derived (Shamier et al., 2014). It is realistic, particularly in the light of the importance of small gravel bed streams to the health of wild salmon fish stocks (Whelan, 2014) which contribute significantly to the UK economy both in terms of commercial and recreational fishing (Cefas, 2013). It has been estimated that if a thousand more days were spent by anglers fishing in the Yorkshire and Humber region this would generate an additional £30,000 a year for the regional economy (Mawle and Peirson, 2009). The economic impact of a day visitor to the Yorkshire Dales national Park in 2013 was £104,200,000 divided over 308 3000 visitor days making the value to the local economy of one visitor day being worth approximately £34 pounds to the economy (STEAM, 2013). If the remediation also results in the creation of a visitor attraction (for example see the *This Exploited Land* Heritage Lottery Bid in North Yorkshire[30] as an example of tourist interest in industrial archaeology) which increases numbers to the local area this also contributes to the economic viability of a remediation schemes, these benefits all contribute to the total economic argument for remediating the water bodies. An additional consideration is that of avoided fines imposed by statutory bodies are when water bodies fail to meet required ecological and chemical status are significant for example the fine imposed on Ireland for not meeting WFD standards was €4 million (O'Sullivan, 2012). These considerations are of relevance to organisations such as the Environment Agency and the water companies who are subject to fines from statutory bodies.

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[30]http://www.northyorkmoors.org.uk/looking-after/our-projects/this-exploited-land

## 8.9 Scenarios

Two scenarios have been considered here based upon the findings of Chapter Six which illustrate how the costs of a single and a multiple site remediation scheme compare with one another. These examples use cost benefit comparisons and all the information is available in the literature or shown in Appendix Four, the evaluation is repeatable using the same, information or the same process can be used assess different scenarios.

The more sites that are remediated within a single catchment the more the benefits are felt. The quality of the ecosystem services delivered are improved at multiple geographic and temporal scale. This relates back to the importance of considering how individual schemes impact upon the whole river basin catchment at multiple scales, linking schemes together to maximise the resilience and functioning of ecosystems which.

To assess the relative economic benefits, two scenarios have been modelled to quantify how the costs of implementing multiple remediation options compare with a single scheme. This assessment also illustrates the potential for a single pilot scheme to be undertaken to prove the concept and be economically viable, before a larger investment in multiple site remediation takes place.

### 8.9.1 Scenario One

This scenario is at Hebden Beck where a single remediation option will be selected from two options, passive HFO and semi-passive bioreactor (sections 6.26.4 and 6.6). The two options will be evaluated economically using simplistic cost benefit comparisons. Either the passive HFO system or the semi-passive bioreactor would be feasible (section 0 and 7.7). The option with the smallest environmental impacts shown in the LCIA results is the passive HFO system (section 7.13), it is relatively untested and as such stakeholders may have a preference for a more proven technologies such as the semi-passive bioreactor.

The single installation at the Hebden Beck site of the passive HFO system could be used as pilot scheme for a multiple site solution such as that proposed in scenario two. This would test both the effectiveness of the system for metal removal and reinforce the principle of PES schemes within the wider framework of this research, for historic metal mine site remediation.

It has been assumed here that the economic value derived from the NWEBV and the Humber River Basin Catchment Plan’s assessment of the economic benefits, resulting from water quality improvement, will be fully realised (Environment Agency, 2014a, Environment Agency, 2014c, Environment Agency, 2013). A range of values within these two components have been included in the evaluation to show the uncertainly in benefits accruing from the assumed improvement in ecosystem service delivery which are difficult to accurately quantify (European Union, 2008, Jones-Walters and Mulder, 2009, De Groot et al., 2012). As the values used here have been derived from reports published by the UK Environment Agency using recommended methodologies it is assumed that this is a fair assessment of the range of economic value of the improvement to this water body to a good ecological status as demanded by the WFD. The costs for the two options selected for this scenario are shown in Table **8.13** it is these values which have been used though out this chapter (Appendix Four and Appendix Seven)

Table 8.13: Scenario one; overview of costs and benefits derived from the two options being considered (passive HFO and semi-passive bioreactors)

| Hebden site only | Passive HFO | | | Semi-Passive Bioreactor | | |
|---|---|---|---|---|---|---|
| Initial upfront costs of materials and installation | £5425 | | | £126185 | | |
| Scoping, feasibility, project management | £895000 | | | £895000 | | |
| Total initial outlay | £900,425 | | | £1,021,185 | | |
| Ongoing costs of monitoring (PV) per annum | £12,000 | | | £12,000 | | |
| Reactive media replacement after 5 years | £850 | | | N/A | | |
| Benefits derived NUV (PV) per annum from NWEBV | Low | Medium | High | Low | Medium | High |
| | £2508 | £3059 | £3616 | £2508 | £3059 | £3615.839 |
| Benefits derived economic value (PV) per annum approximate | £360,000 (Low) | £680,000 (Medium[31]) | £1,000,000 (High) | £360,000 (Low) | £680,000 (Medium) | £1,000,000 (High) |
| Revenue after one year if all costs are covered in the first year | -£550,767 | -£230,216 | £90,341 | -£670,677 | -£350,126 | -£29,569 |
| Year 2 Net Benefit | £357,518 | £684,480 | £1,011,448 | £357,518 | £684,480 | £1,011,448 |
| Total Net Benefit after 10 years of operation (PV) at 2% inflation | £2,936,688 | £6,446,629 | £9,956,641 | £2,816,778 | £6,326,719 | £9,836,731 |

[31] this value is the average value of the high and low values derived by the two Humber RBP reports EA reports and is called the medium for convenience

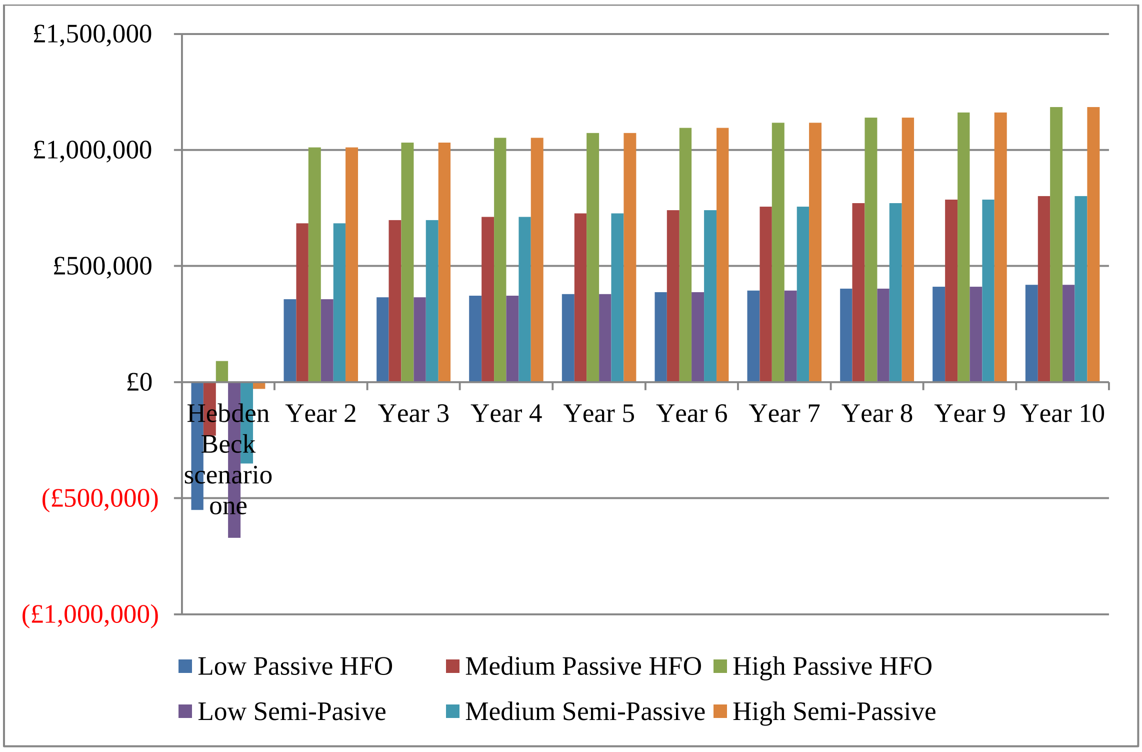


Figure 8.5: Scenario one; total benefits expected each year (use and non-use value)

As can be seen from Figure 8.5 and Table 8.13 the first year of operation for both options run at a loss; this is because it has been assumed that all the costs of installation scoping etc. will be taken from the first year's revenue leaving the project in overall deficit in the first year. The one exception is the high return scenario for the passive HFO system where a slight profit of £90,000 pounds is shown. All the subsequent years, for which costs, other than those for ongoing monitoring, are not subtracted from the estimated revenue show that a significant profit accrues, Figure 8.5. The total revenue over the ten-year operation proposed for the PES aspect of the framework is positive for all the scenarios modelled. Based upon these figures it would be economically viable to move forward with either of the proposed remediation options at this single site. It should be borne in mind that remediating a single stretch of river and the impact that it will have downstream if other sources of pollution are left untreated would significantly deplete the impacts expected from this remediation beyond the immediate downstream geographic area. If there were significant sources of pollution further upstream in the catchment (e.g. diffuse pollution inputs) the effects of this remediation would be significantly reduced environmentally. Hence the expected improvement in the functioning and resilience of the ecosystem services, the benefits derived from them would be lessened and their economic value, would decrease. Such issues are usually considered during scoping and feasibility phases of mine site remediation through catchment scale studies (Gozzard et al., 2011) to ensure the benefits of point mine water treatment are not undermined by other pollutant sources. Taking this into account it is probable that the Hebden Beck site, would see significant improvements to ecosystem services given the predominance of point discharges under base-flow conditions (Jones et al., 2013 Chapter Five). This is why the framework proposed is necessary, as the best modelling techniques can be used in order to assess how effective the expected environmental benefits would be however based on these pre-existing economic analyses, this simplistic analysis of remediating the single site at Hebden Beck would be an economically viable proposition.

A more detailed economic analysis of individual impacts for specific stakeholders is desirable and would be expected for an actual scheme to be put in in this location. This initial outline does suggest that it is highly probable that this would be a successful proposition economically and should be considered. Of the two options, the semi-passive bioreactor or the passive HFO system both seemed to deliver economically, the HFO system being preferable due to its lower costs and also its lower environmental footprint (Chapter Six and Chapter Seven).

### 8.9.2 **Scenario Two**

This scenario consists of multiple remediation of all known point mine discharges using the passive HFO system detailed in Chapter Six and Chapter Seven. This system is chosen based on documented performance in metal (notably Zn and Cd) removal (section 6.1.2) and in the favourable performance in the LCA assessments relative to other options. Eight of these systems would be installed at the key sites identified, initially only those sites which are definitely impacted. The same assumptions about economic value of ecosystem services as those used for scenario one have been used. Multiple installations in the same project may result in the scoping feasibility costs being slightly less and material costs being reduced. These costs have been kept the same for each site and at the same level as those for scenario one. The ongoing monitoring costs may remain the same as sites could be simultaneously monitored as part of the same scheme, here this assumption has not been made in order to cover additional unforeseen expenses that may arise. Therefore, it is assumed that the material and installation costs would be the factors multiplied up by the number of sites here. This option may be feasible provided that stakeholders and local community planning have no objections. This scenario presents an attractive way to increase the impact of remediation by tackling a number of problems sites simultaneously, thus multiplying the benefits. Due to the increased number of installations this scenario would be potentially more difficult to negotiate, as it may involve multiple landowners and as such may prolong the negotiation phase of the project and hence increase costs. In addition to this the multiple site approach would increase the risk that the scheme would not move forward due to the increased likelihood of objections from interested parties. This aspect of the proposal would again come back to stakeholder engagement and careful communication, management and education and would provide a key role for the "ethical broker" and trusted stakeholders such as North Pennines ANOB or the RSPB, assuming that they were in favour of a multisite approach.

Conversely multiple sites would result in a higher probability of the ecosystem services delivering the expected benefits at a broader catchment scale and hence the accrued benefits would be greater than the individual sites benefits both temporally and geographically (Gandhi et al., 2011, Howe et al., 2014, Everard, 2013, Hughes and Quinn, 2014)

Figure 8.6 (Appendix Seven for a more detailed breakdown of the figures) illustrates how when multiple sites are remediated within the same scheme then the benefits accrued can be offset against one another as the total benefits after one year with multiple sites is overall positive for the medium and high values. The low value does show a loss after one year (Figure 8.7) that this is quickly recouped as it was seen with scenario one. This multiple site approach although harder to implement does deliver higher environmental and economic benefits.

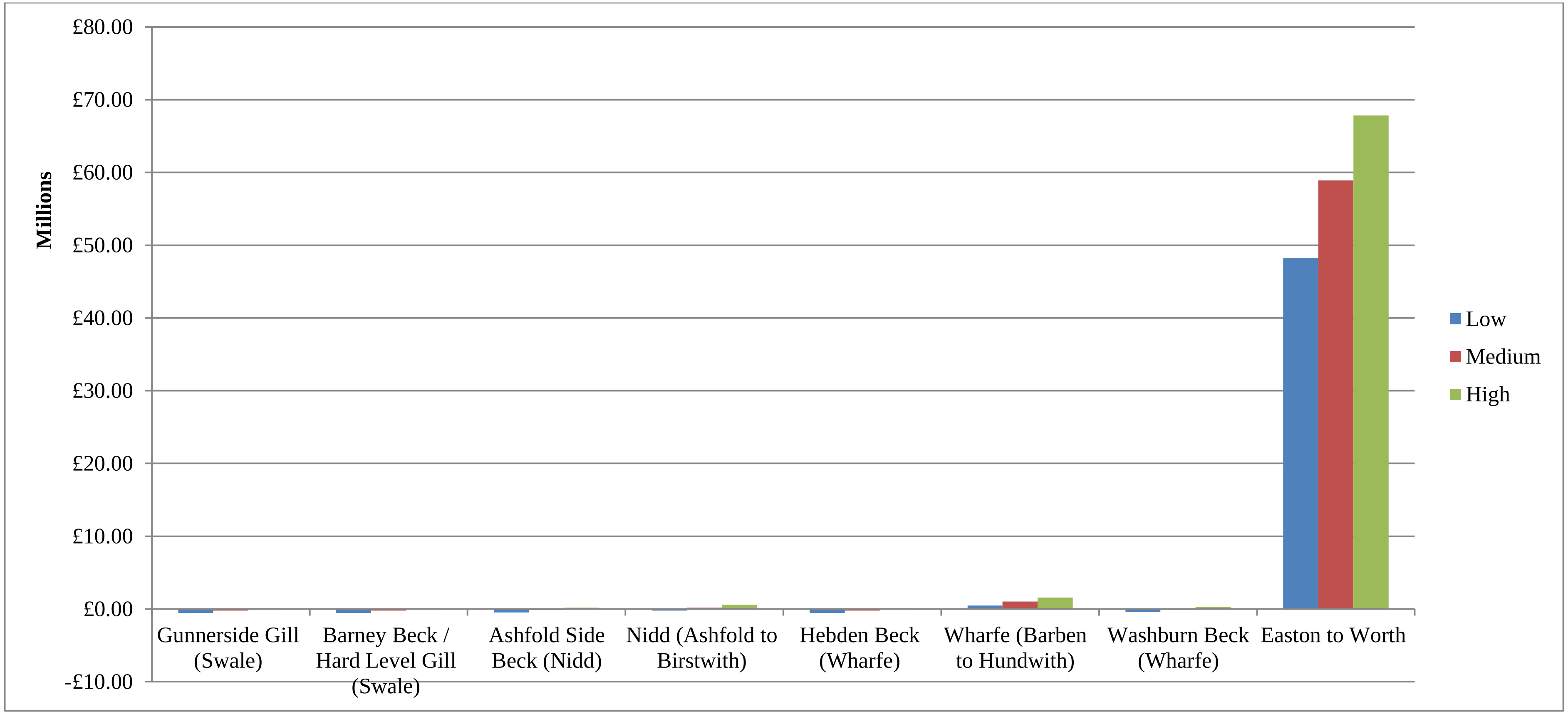


Figure 8.6: Net revenue generated (£) from remediation of impacted sites only, after one year (NWEBV and HRBCP economic valuation inclusive)

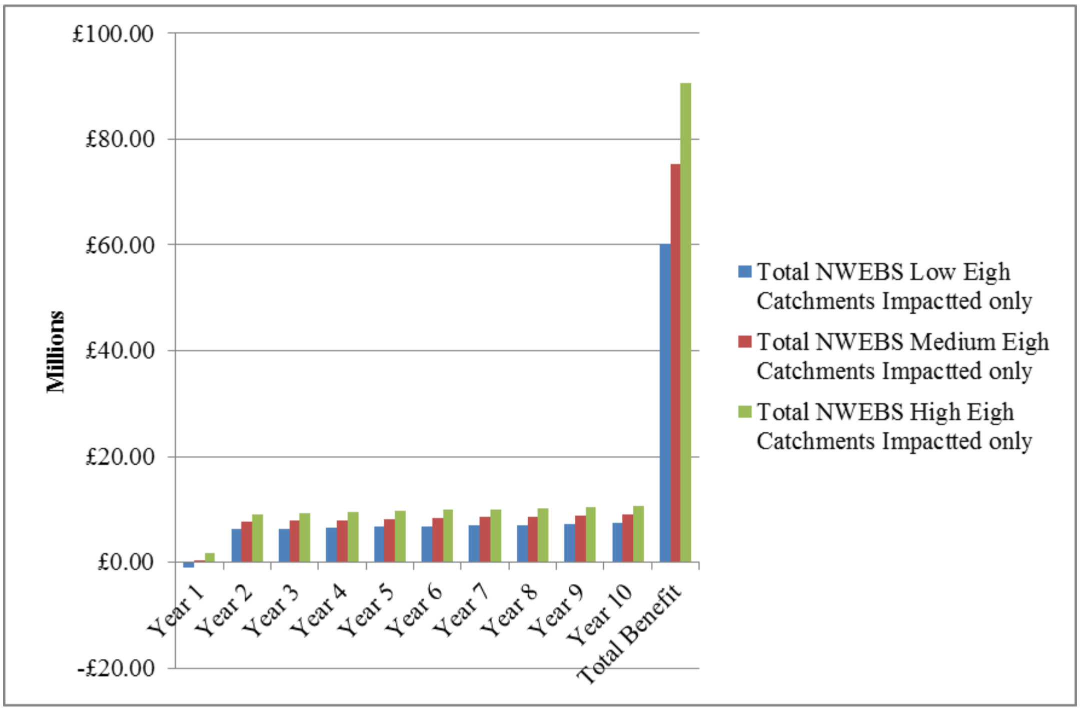


Figure 8.7: Impacted sites, NWEBS only

The Eshton to Worth catchment clearly outperforms any of the other impacted sites in terms of revenue generated this as can be seen from Figure 8.6 and Figure 8.8 also Table 8.11. This because this stretch of the catchment has the largest number of households and is also one of the longer stretches to be remediated therefore multiplying the number of households who receive benefits derived and hence the multiple increase in benefits received. This illustrates the point that the more households in an area to receive the benefits derived the greater the benefit. So assessing the benefits purely in these terms is highly dependent upon the population characteristics of the local area. This is an important factor to highlight given many of the former metal mining regions are in upland and /or remote settings. As such, upscaling analyses of both impact and potential opportunities of remediation to a catchment or basin scale is essential. This however brings its own uncertainty given it becomes more difficult to apportion the cause of ecological and chemical failure in water body status with increasing scale (Mayes et al., 2013).

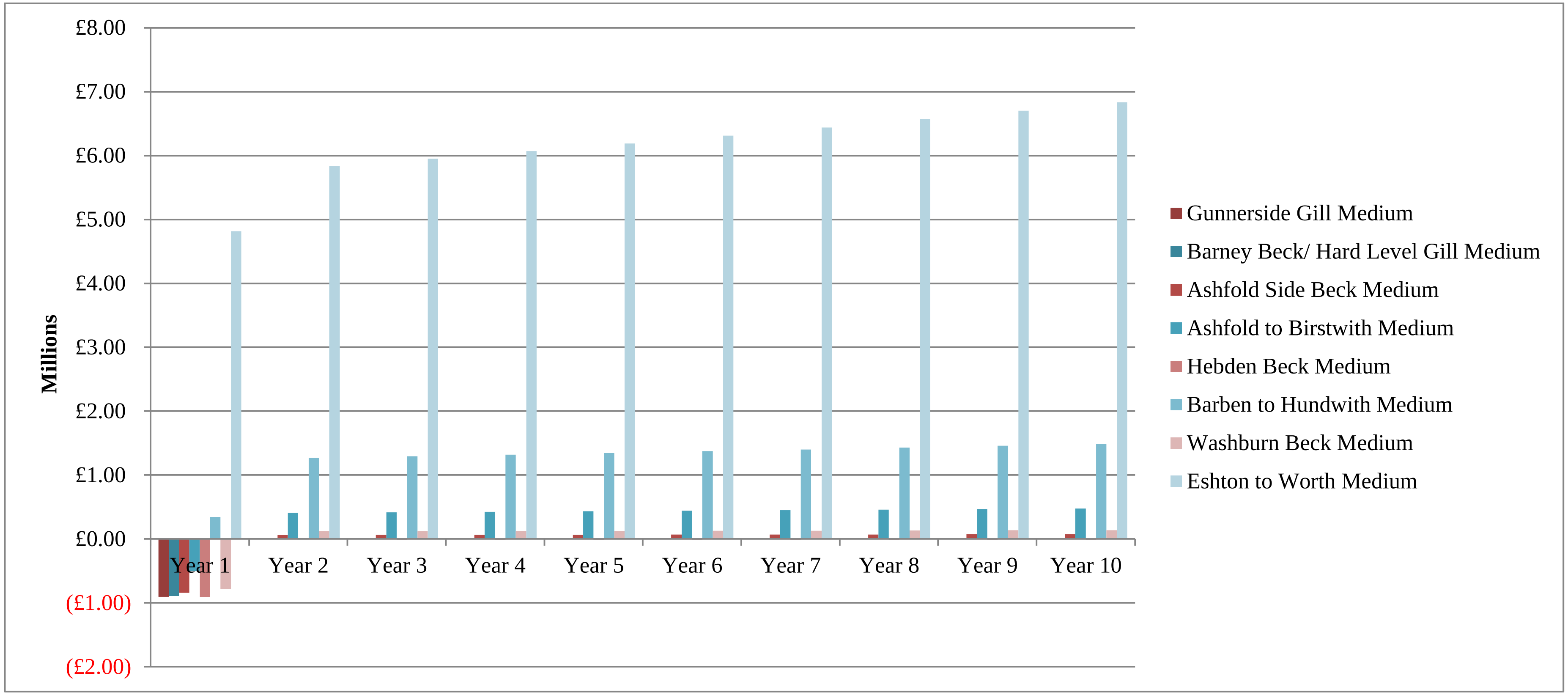


Figure 8.8: Impacted Sites, NWEBV medium values only

When this method of assessment, using the NWEBV only is applied to all the sites which are both *Impacted* and *Probably Impacted* by mine pollution under current EA categorisation, it can be seen that the sites with the greatest number of households in their immediate vicinity benefits most from remediation (Figure 8.9). As was previously recognised in the (EFTEC, 2010) case study, and in other studies looking at distance decay (Schaafsma et al., 2012, Jorgensen et al., 2013b) and value derived from ecosystem services, multiplying by number of households in an area needs to be applied with caution. For this case study where the immediate local area is being assessed applying a distance decay is not deemed necessary where it would be useful for larger geographic areas. This is because for such a localised area the difference in values where distance decay is applied and not applied would be minimal and is within the range values for benefits derived. For a larger geographic area, the difference in values from applying and not applying distance decay would be more likely affect the outcome of the economic evaluation (EFTEC, 2010).

This approach could be said to distort the assessment of which sites are most economically viable to remediate, suggesting that it is only worthwhile in areas of high numbers of households where there is a population able to receive the benefits. This is further illustrated by Figure 8.9 which shows the total benefit for the low values of NWEBV when all the sites are mediated including those only probably impacted. This makes it very clear that when the number of households increases and are able to feel the benefits from remediation the economic benefits increase. Therefore it is highly important to take into consideration the type of economic valuation being considered and who actually receives this benefit. This is very important when communicating with different groups of stakeholders. For example this case that individual households benefit equally from the remediation of the scheme will be of importance to local communities. That the benefits are not divided among households but remained the constant in terms of NUVs. This will be of interest to other stakeholders, such as water companies, with an interest in these wider benefits beyond tangible economic benefits to themselves. Conversely, the benefits that are of interest to other stakeholders are not necessarily captured by these NWEB and so an alternative evaluation of direct ecosystem services delivered to them would be of more significance and relevance to this group of stakeholders this point was emphasised by an interviewee with experience of implementing PES schemes (Section 4.3.4).

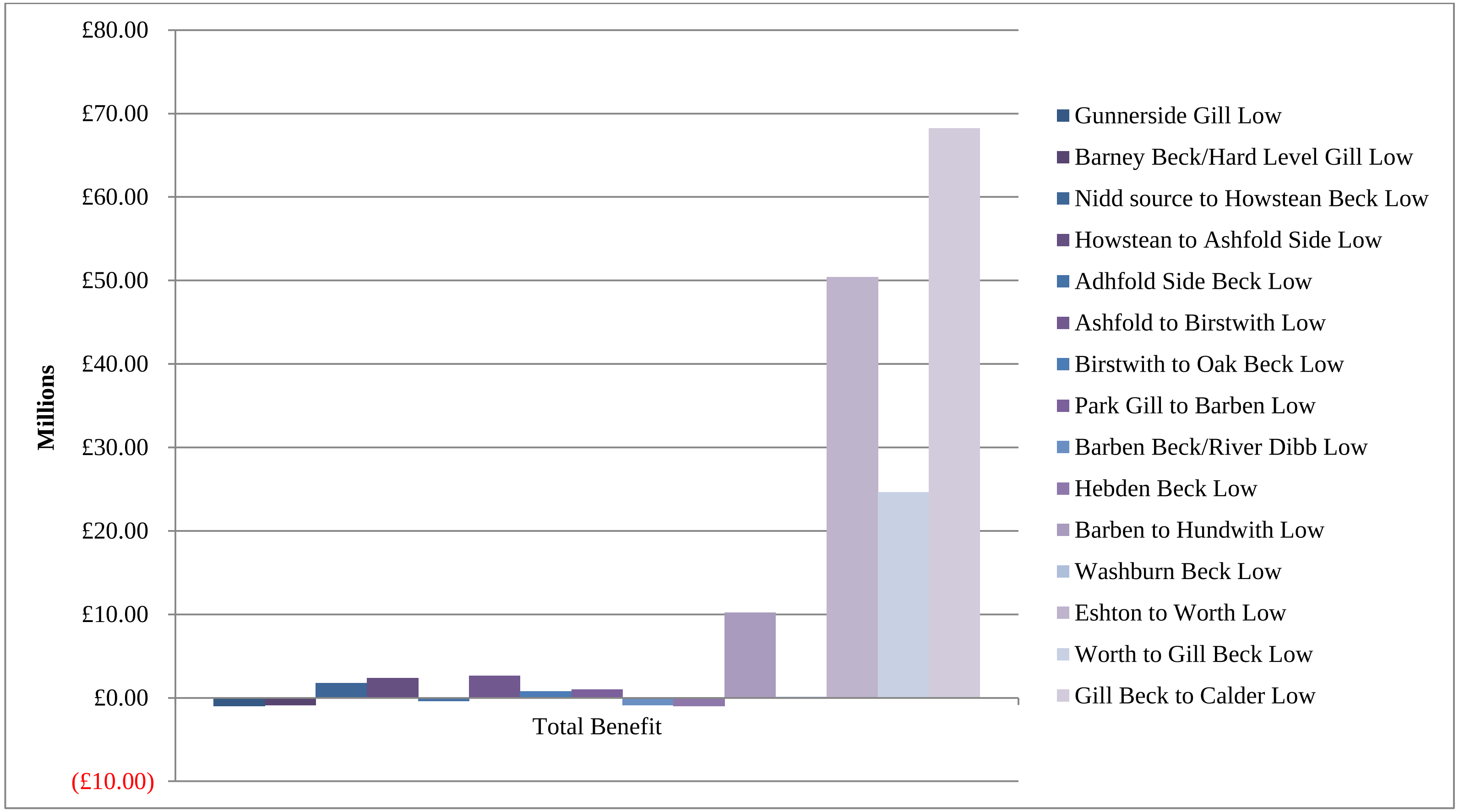


Figure 8.9: Total benefit for impacted and probably impacted sites over ten years; for low NWEBV only

Figure 8.10 (Appendix Seven) illustrates the economic values derived from the local Humber individual reports (Environment Agency, 2014a, Environment Agency, 2014c, Environment Agency, 2014d, Environment Agency, 2014e).These seek to capture tangible increases in revenue resulting from improved ecosystem services; the assumptions inherent is that for each water body improve the same economic value is derived. This would not be true as different sites may deliver different levels and types of ecosystem services depending upon the area. As a general guide to the levels of economic value that are delivered from the resulting improvement in ecosystem services, this is a fair reflection of the dividend derived from site remediation of these eight sites. These benefits will be received at multiple geographical and temporal scales. The issues associated with non-excludable benefits and who should ultimately invest in remediation schemes as previously discussed (Chapter Two and Chapter Four) is again raised here as these benefits would not only be delivered to investors in the PES scheme, but all those downstream of the intervention to a greater or lesser extent. However it is hoped that the benefit derived both economically and in terms of goodwill would be a good enough incentive for stakeholders to invest.

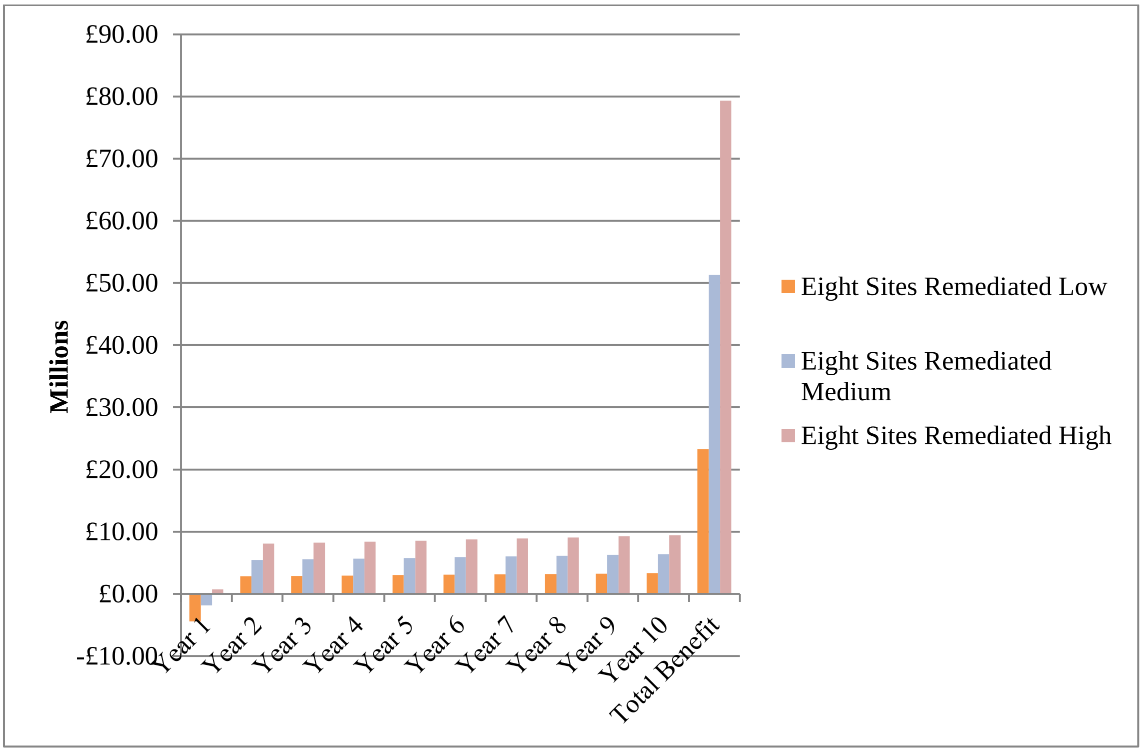


Figure 8.10: Total annual revenue from impacted sites, Humber river basin catchment management plan assessment values only

When all the eight impacted sites are remediated together there is an economic benefit both in terms of the figures derived from the NWEBV and the use values derived from the Humber basin catchment plan. The value multiplies by the number of sites and it is probable that this is an underestimate of the value resulting as the benefits derived from ecosystem services will cascade down the catchment as a whole and hence be of greater value, delivering services at multiple geographic scales (Everard, 2012). This could be particularly the case with metal removal at source as this would have a secondary impact on sediment quality in the basin, which can provide a longer term transient source of water pollution (Environment Agency, 2006). This is why it is so important to identify the key sites for the sources of pollution entering a catchment and deal with these in order to maximise the benefits derived from remediation (Mayes et al., 2008, Mayes et al., 2009b, Mayes et al., 2010, Jarvis and Mayes, 2012, Jones et al., 2013, Mayes et al., 2013).

## 8.10 Conclusions

Based upon the scenarios assessed economically both scenario one (Hebden Beck) and scenario two (multiple sites within Humber basin) would be feasible. For scenario one either of the lower cost remediation options would be viable economically, however due to the smaller size and ease of installation of the passive HFO system this option would be more practical. Due to its relatively untried nature there, is a greater risk that it would not be able to handle the level of metals entering the catchment at this source. As a pilot scheme for the passive HFO system this would be a suitable starting point for implementing scenario two at multiple sites initially the eight impacted sites and ultimately the eight probably impacted sites in order to maximise the environmental benefits resulting.

An economic case can be made for remediating an individual site provided that the level of metals that it releases into the catchment system are significant enough for their removal to make a difference. The level of metal removal used here is well within documented passive treatment system performance so confidence is high that such an approach would be effective. Furthermore, remediating multiple significant sites is economically viable specifically with these small scale relatively inexpensive passive systems.

The best option would be multiple site remediation using the passive HFO options, scenario two (Section 8.9.2). This would deliver maximum environmental and economic benefits and the costs would be fully met potentially in the first year of operation. The LCIA7.11) results also supports this conclusion

Monetisation of ecosystem services is contentious and not all economic benefits can be captured and quantified. Using a simplistic input output approach to it can still be shown that it is economically viable to remediate significant individual polluting sites. In-kind goods and services have the potential to reduce the input costs of remediation projects. Transparent and understandable quantification of costs and benefits is necessary. Quantification and accounting for costs and benefits needs to be consistent and traceable Prediction of future economic costs and benefits is uncertain due to external market behaviour and world events which impact upon inflation and commodities prices The actions taken need to be appropriate and effective to the specific situation in order to maximise the benefits derived and ensure that the costs of action do not exceed the value of taking action to the stakeholders. In-direct benefits are of greater value to stakeholders than not taking action. The total value of NUV benefits received is dependent upon the number of households within a catchment. Multiple site remediation delivers greater economic benefit than single site remediation and economic benefit will be received by all users of ecosystem services within the catchment whether or not they have invested in the PES scheme.

# Chapter Nine Taking the Framework Forward: Conclusions and Research Needs

## 9.1 Introduction

Throughout the previous chapters the structure of the framework has been detailed along with a case study of its application to a historic abandoned mine site pollution at Hebden Beck and in the surrounding Humber River Basin District. The potential value and acceptability of this approach has been investigated through a series of interviews with a range of experts with experience in the areas that are encompassed by the framework. The areas that it integrates are; managing metal pollution, PES, WFD, environmental protection, special interests, dealing with local communities and balancing the interests of industry and government agencies (Figure 9.1). This chapter discusses ways in which the adoption and application of the framework can be taken forward and put into practice and reviews the key findings of the thesis.

The interviews with experts identified key facets that are necessary for the successful implementation of this framework, Figure 9.1. The generic process developed over the course of this research, illustrated in Figure 9.4, possesses the elements which are necessary to resolve an environmental problem such as abandoned metal mines.

The characteristics of the environmental problem presented by abandoned metal mine sites are that; there is no identifiable party who is liable for the costs of the remediation of the site, there are potential solutions for the problem, benefits can be quantified and predicted and there are identifiable stakeholders who would directly benefit from remediation. The findings from the interviews and the case study suggest that for action to be taken on an environmental problem which possess characteristics similar to those of abandoned metal mines certain criteria have to be met (Figure 9.2): The potential benefits need to be quantified, the available options have to be demonstrated to work to the satisfaction of stakeholders, the process needs to be strictly managed in order to constrain the amount of time it takes to implement it, individual stakeholders need to feel that their opinions have been heard and taken into account, and there need to be an overall improvement in ecosystem services. This can be achieved if the process itself is transparent, robust and trusted and should address issues raised by stakeholder in Figure 9.1, where possible.

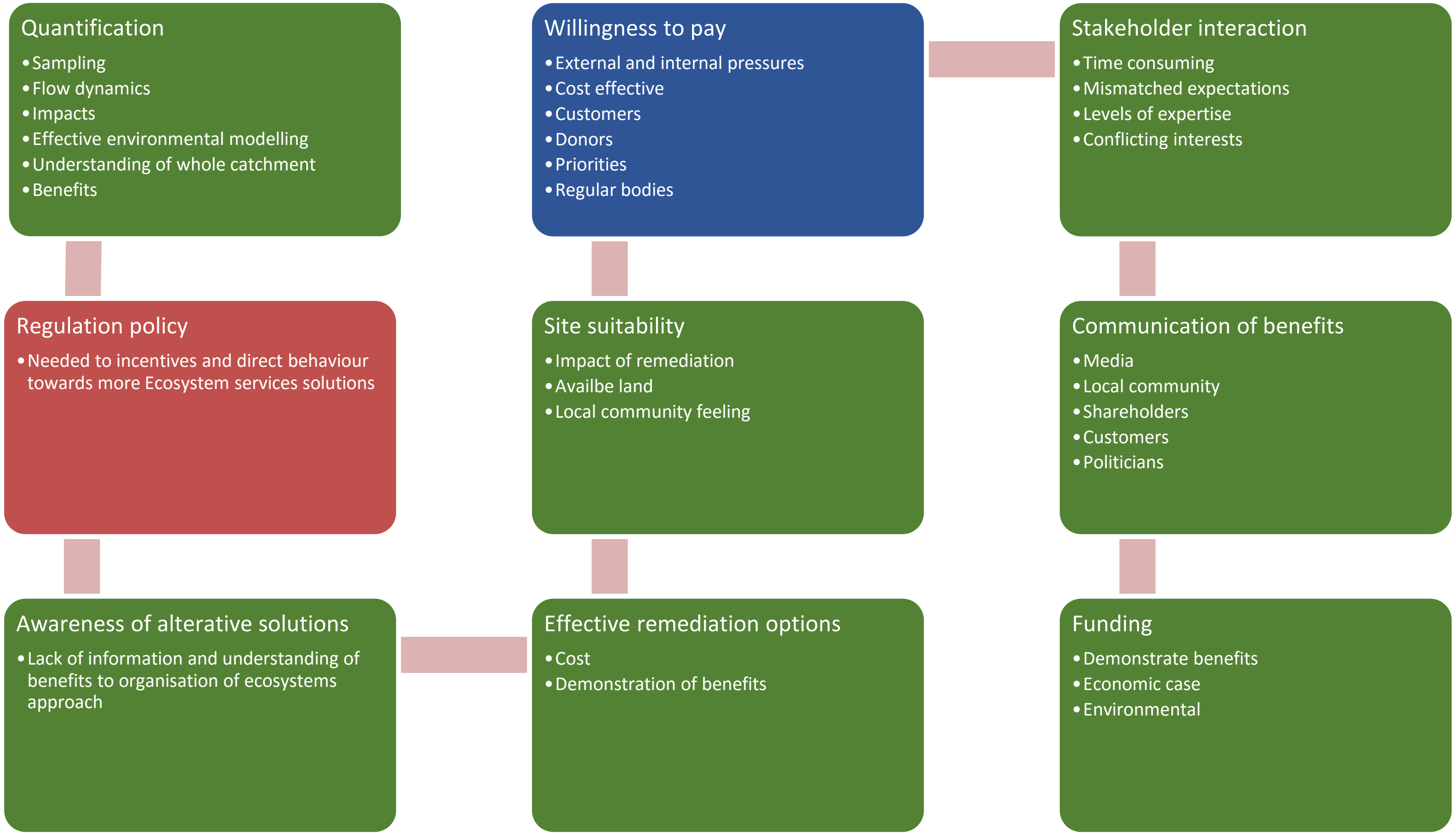


Figure 9.1: Difficulties directly identified by stakeholders that need to be tackled. Green indicates areas directly addressed by the framework developed (Figure 9.4). Red represents areas outside the influence of the framework. Blue represents areas which are influenced by the framework.

## 9.2 Initiating the Process

Any organisation, land owner or interested party could initiate the process to tackle and environmental problem which meet the criteria (Figure 9.2) that this framework has been developed to address.

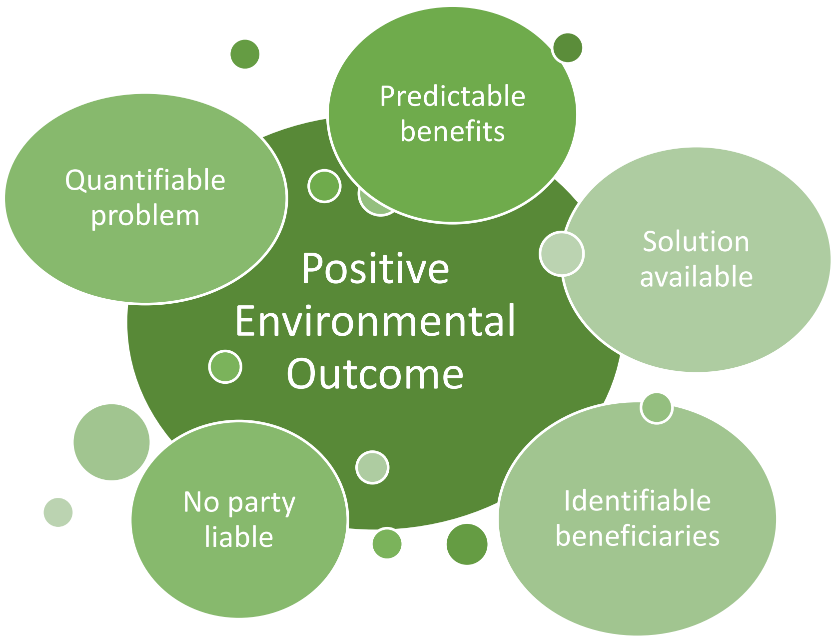


Figure 9.2: Criteria to be met for use of framework

Remediation of a particular abandoned mine site or multiple sites, using the process would be as outlined in Figure 9.4. The framework developed is comprehensive and far reaching as it incorporates a number of different elements that are not included in the Defra PES best practice guidelines (Smith, 2013). This is much more generic and does not include the wider benefits which sought to be captured by the LCSA element of the comprehensive quantification of the environmental issue being addressed and the wider benefits that could be potentially delivered. All of the stages required by the best practice guidelines (Figure 9.3) are incorporated into framework developed here (Figure 9.4).

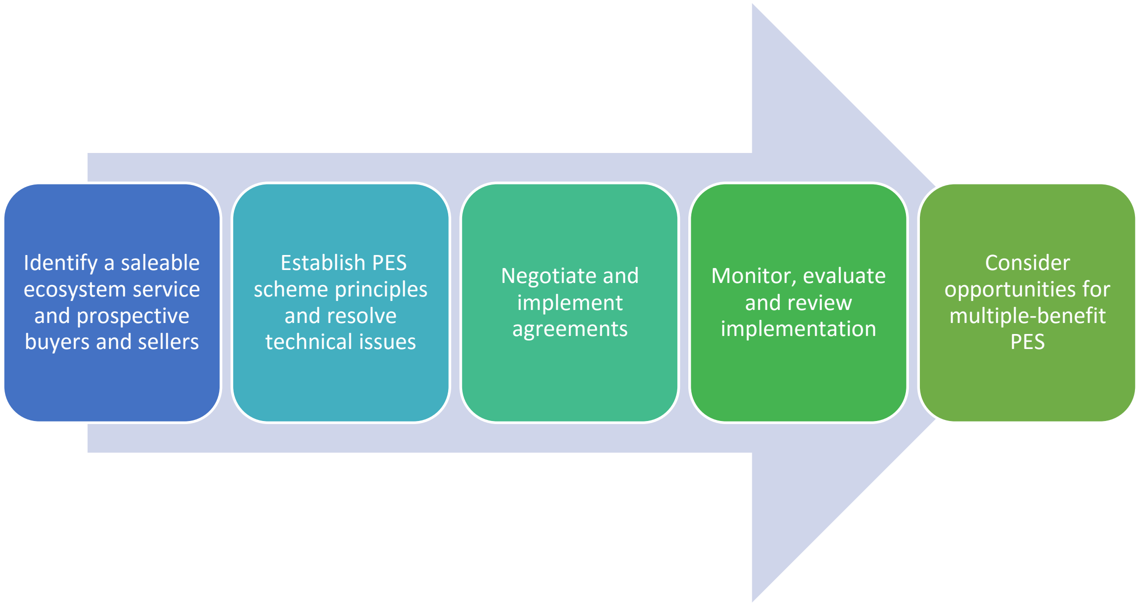


Figure 9.3: Five broad phases for designing and implementing a PES scheme, adapted from Defra PES; best practice guide (Smith, 2013)

Within the context of the framework developed here, Figure 9.4, the results of the research the generic process would be as follows.

Recognition that the pollution from the abandoned metal mine site is impacting upon the quality of local ecosystem services or preventing the water body meeting good ecological or chemical status. The interested party would contact other potential actors with the necessary means to instigate the second stage if they are not in a position to do this themselves. Given that abandoned metal mine sites are of particular interest to the Environment Agency and the Coal Authority these bodies are likely to become part of the process. The locations and discharges of abandoned metal mines have been researched extensively (Mayes et al., 2008, Mayes et al., 2009b, Mayes et al., 2010, Jarvis and Mayes, 2012, Jones et al., 2013, Mayes et al., 2013, Sawyer et al., Environment Agency, 2012b, Potter et al., 2012, Simpson et al., 2012, Environment Agency, 2014d, Jarvis et al., 2014a, Potter and Johnston, 2014). Other stakeholder organisations such as the National Trust, National Parks and AONBs, water companies, land owners and others would be brought into the process on a site-by-site basis. Early remedial planning work that the Environment Agency does aims to identify key stakeholders early on in proceedings (Mayes et al., 2009a).

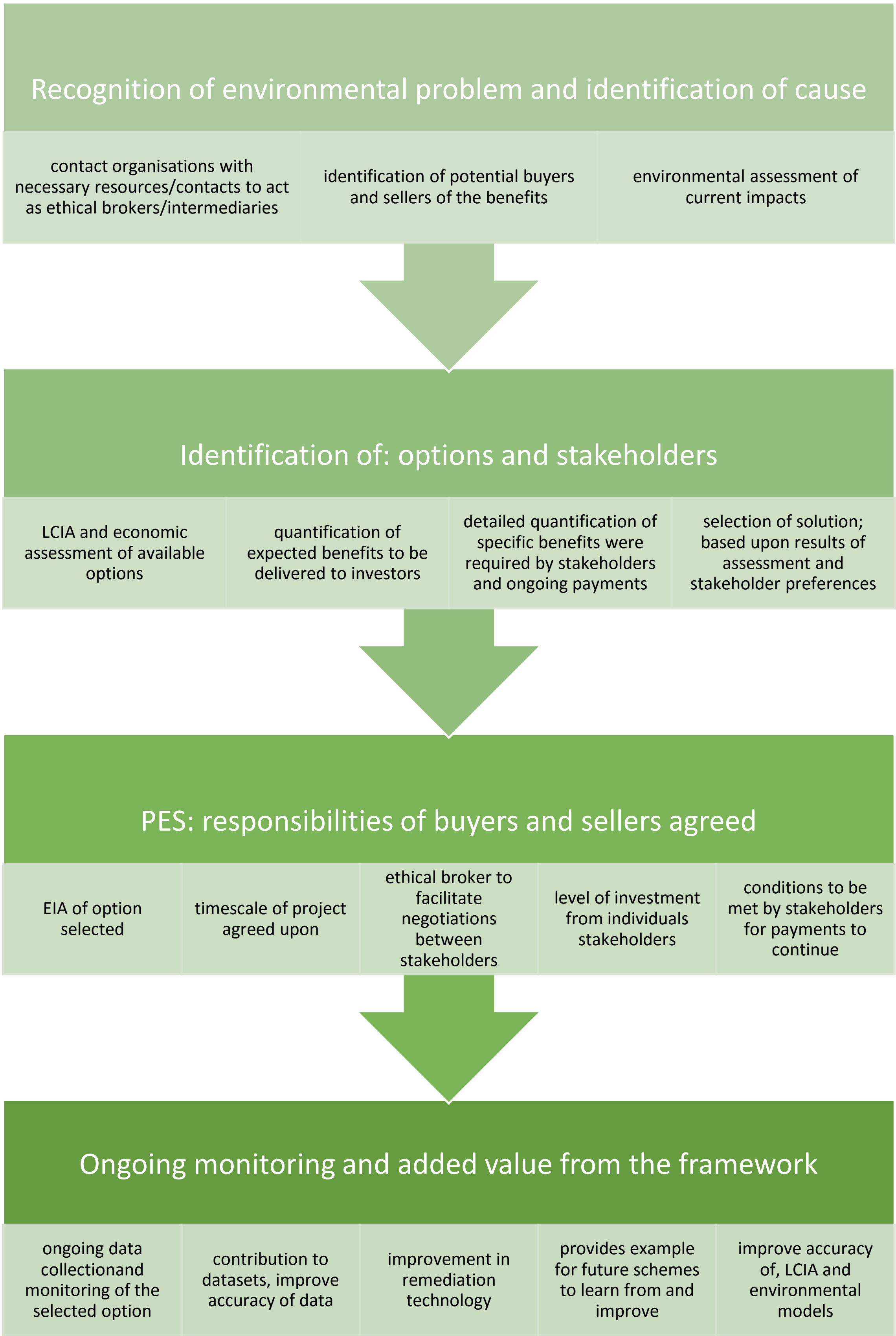


Figure 9.4: Generic stages of the framework process (authors own)

The goal of remediating the metals from the mine run-off and ensuring that this could be funded would be the primary purpose in implementing the framework. This would be built around catchment-scale management and improvements in the WFD status of individual water bodies. Utilising the best available modelling techniques and processes to assesses, on a balance of probabilities, the overall potential for a positive balance of benefits.

Assuming the major actors are in place, driving the process forward and that the case for remediating a group of sites or single site has been made, it then remains for the solution to be implemented within a reasonable timeframe and to the agreement of all stakeholders. Achieving this outcome relies upon:

- Trust
- Understanding
- Transparency
- Addressing concerns
- Negotiation
- Communication
- Perception and
- Robust science
- Accurate data

(Reed et al., 2013, Duraiappah et al., 2014, Iniesta-Arandia et al., 2014)

## 9.3 Managing the Process

The acceptance of decisions by individuals is based upon their perception that a process has been gone through which they perceived to be fair. This perception is enhanced if the decision is administered by a body that they trust which takes into account and listens to their opinions and concerns (vandenBos et al., 1997, Chan and Maubergne, 2003, Bianchi et al., 2015, Benson et al., 2014, Onkila, 2011, Feliciano et al., 2014). This applies to experts groups individuals and organisations equally and it has been found that decisions are more likely to be accepted if these criteria are met even if the outcome is not what the stakeholder wished (van Prooijen et al., 2002, Chan and Maubergne, 2003, Ruckelshaus et al., 2013, Kumar et al., 2012).

The framework itself is a process which has clear stages (Figure 9.4) that can be explained and understood. This is a transparent and understandable procedure in which stakeholders can trust. Bodies and organisations such as the North Pennines AONB, the National Trust, The Rivers Trust and even the Environment Agency to some extent are trusted by local communities in which they operate and the wider national population. This is evidenced by their membership numbers and in the case of the Environment Agency in involvement in projects which are well received in local areas. This was mentioned by a number of interviewees, trust is something that took time to create but was easily lost. Stewardship and special interest groups are in a strong position to act as "ethical brokers" in the framework. SICSO organisations often have experience of administrating environmental projects organising meetings with local communities and bringing together different groups and organisations. SICSO's experiences with different types of stakeholders, including businesses, statutory bodies, charitable organisations as well as members of the public was explained to interviewees. Of particular concern to many stakeholders was the amount of time that these meetings between bodies could take up and nothing was achieved. The framework addresses this area of concern by delivering clear quantifiable answers to specific areas of concern. Decisions are taken based upon clear processes, information disseminated and concerns listened to. This limits the amount of circularity which may occur if there is no structure to a process, while still enabling individuals to voice their organisations particular concerns. It is managing these potential conflicts to the satisfaction of stakeholders which is vital in order to prevent delays in the implementation of remediation.

### 9.3.1 **Managing Priorities**

Areas of conflict may arise between stakeholders or group of stakeholders who have different priorities. Managing different interests to reach a satisfactory result is fundamental to the process. If a pilot project is being undertaken which may result in further deployment of a technology it is important that all stakeholders feel engaged and satisfied by the process. This will facilitate future deployment and make the multiple deployment of remediation options more acceptable to stakeholders who have had a previous positive experience. Decisions need to be taken with objectivity based upon good science, not upon a power structure of whoever is paying the most gets the biggest say. However where statutory obligations have to be fulfilled this will influence the decisions taken. This does not mean that individual concerns stakeholders should be ignored but alternative solutions developed. An example of an obvious area of conflict is that of the metallophyte communities which rely upon the metals for their existence

(Whiting et al., 2004b, Lucassen et al., 2009, Baker et al., 2010, Bizoux et al., 2011, 2012). These communities often have conservation designations and there may be scope for integrating metallophyte communities into remediation, for example in phytoremediation of waste rock heaps or potentially in wetlands (Whiting et al., 2004a, Lucassen et al., 2009, Baker et al., 2010). This illustrates viewing the remediation in the wider context without dismissing other needs and priorities beyond the primary goal of reaching good chemical and ecological status for UK rivers as required by the WFD. Additionally by including land-use change in the LCIA (Canals et al., 2007, Reid et al., 2009, De Schryver et al., 2010, Hunt and Defra, 2011, de Baan et al., 2013, de Souza et al., 2013, Koellner et al., 2013b), it means that this aspect of the remediation project can be included in the same way as other aspects of remediation such as GHG emissions.

### 9.3.2 Stakeholder Interests

Of concern to organisations such as English Heritage are the historic sites which some of these abandoned mine sites represent. Protection and conservation of these sites is part of the process which needs to be managed. There are issues because many of these sites are located in areas of Outstanding National Beauty and National Parks. Rather than seeing this as an obstacle to remediation it can be used as a visitor attraction in its own right. These remediation projects, particularly the creation of settling ponds, actually recreate how the sites appeared while they were operating. Information boards about the remediation and about the history of the sites as well is the metallophyte communities can be an integral part of the projects. Talking to organisations and bodies before any work takes place to determine what modification they would be willing to accept and what should be emphasised and explained, would enable the project to move forward. Taking into account the scheduled national monuments, and sensitivities about their preservation, often remediation action preserved the industrial heritage in these areas. Creating an industrial heritage walk between the remediating side could also be a useful way to generate interest and acceptance of remediation generating income for local communities (Scarborough Tourism Economic Activity Monitor (STEAM), 2013) and contribute to cultural ecosystem services.

### 9.3.3 Compliance/Conditionality

Monitoring the remediation scheme to ensure that the agreed upon targets are being met is a necessary part of the framework. This cost has been included in the case study, ensuring that ongoing monitoring of the sites continues. This ongoing monitoring will provide data on, fluctuations in levels of metals overtime, determining the impact that these levels had and how this influenced EU EQS levels regulation. All stakeholders have a vested interest in ensuring that these regulations are realistic. This ongoing monitoring and research is potentially the most "valuable" aspect of this type of remediation project to the metal and mining industry (Bradford, 2014, Verdonck et al., 2014), validating EQS levels and helping industries developed approaches to minimise their environmental impacts. The contribution to research about the impact of metals on the environment and how ecosystems respond to them is a direct benefit of the framework. Ensuring that information and is effectively disseminated and used contributes to improving ecological models, understanding environmental responses, influencing policy, regulation and enhancing the effectiveness of future projects. The dissemination and use of this information will contribute to the national economy reinforcing the wider economic benefits. For stakeholders from industry the framework provides benefits such as information and data for their own research and improved public perception of businesses through engagement with environmental programs (Yorkshirewater, 2014) which corporations and industry recognise.

## 9.4 Communication

Communication of what is taking place and why is vital in order for public acceptance. Organisation of meetings and dissemination of information on websites and through letter drops is an effective way to communicate with the local communities and the public in general. Explaining the process listening to concerns and responding to those concerns is important for the acceptance of any decisions that are taken. This applies to the expert stakeholders and the investors in the framework as well as the general public, for example it is important that the ecologist and the metal industry talk and listen to each other, to resolve potential conflicts. Using LCSA to provide objective answers to questions such as, what is the overall environmental balance, economic balance and social balance of the impacts of taking action and not taking action, provides a starting point from which negotiation about priorities can take place beyond stakeholders' own vested interests.

Education on environmental issues and the impacts that they have on people's everyday lives and how the local environment impacts upon the local community, is part of the work of organisations such as the North Pennines AONB. This aspect of their work can be used by the framework to help with public acceptance and engage the local community with remediation projects. This should not be neglected in the application of the framework. Outreach to the media and the public is important in building the groundwork before any action is taken. Communication helps with acceptance that actions taken locally may provide benefits nationally and the framework demonstrates how the local community will also benefit.

## 9.5 Summary of Key Thesis Findings

Through quantifying PES-based assessments of the impacts of legacy pollution from abandoned mines, a robust estimate of the environmental costs of mine pollution can be formulated. This is critical for producing arguments for any potential remedial intervention. Subsequent integration of these baseline costs with LCSA of potential remedial actions can provide a robust way to inform decision making on the nature, scale and location of environmental management. Both PES and LSCA approaches are becoming increasingly adopted in the UK and further afield, but rarely have they been adopted in tandem (Baxter and Mayes, 2013, Raugei et al., 2014) for actual environmental problems.

Despite the growing use of PES in policy circles, the stakeholders interviewed showed inconsistency in understanding the terminology. There were disparities in stakeholder knowledge across all sectors. The investigation of the range of perceptions and opinions surrounding broader environmental management of abandoned mines revealed a common thread amongst those representing industry. There is considerable reticence to engage in PES-type schemes amongst active industry (e.g. water and metals industry) unless regulatory pressure is applied. At the same time some industrial representatives queried what they perceived to be overly-precautionary existing regulation on the water environment. A range of issues were raised by stakeholders of relevance to the practical implementation of a PES framework for mine remediation, these included;

- The mismatch between different stakeholders levels of knowledge and expertise
- The time-consuming nature of meetings where nothing is achieved and things do not move forward
- Conflicting priorities between stakeholders

The first issue that of the mismatch between different stakeholders can be addressed via rigorous use of the best available ecological models and scientific data which is then used in the LCIA. The results from the LCIA provides information about the different options being considered and the overall environmental benefit. The LCIA practitioner should be objective and impartial. Transparent application of the economic costs and quantification of predicted benefits using independent information about impacts, positive and negative, contributes to this process of communication. These assessments need to be conveyed in a way that is understood by all stakeholders regardless of their level of knowledge and expertise. Environmental assessment using expert knowledge and local knowledge can be used to resolve conflicts and ensure that concerns voiced are dressed so that the reasons why decisions can be understood.

The clear stages of the framework (Figure 9.4) ensures that the process maintains momentum and does not get “bogged down” in circular talking. The method of funding needs to place a value ecosystem services, this can be done using the TEEB framework which has a globally proven track record (Union, 2008, Ring et al., 2010, Van der Ploeg and de Groot, 2010) but is not universally accepted (Gowdy et al., 2012, Jax et al., 2013). There are problems with people’s willingness to pay for things which have previously been viewed as free. Equally there are issues surrounding the non-excludability from benefits that others have paid for. These issues are ongoing and cannot be resolved within the context of this framework. An awareness of their existence and an acceptance that these are aspects of the PES approach which will remain a problem and needs to be borne in mind when applying this framework to resolve environmental problems.

By applying the frameworks to the case study of Hebden Beck and investigating the different elements involved; environmental assessment, economic assessment, LCIA and PES, some useful conclusions were drawn about this specific case. It became apparent that the best option for remediating the catchment in which the Hebden Beck site was situated would be to deploy multiple small-scale remediation systems such as that proposed passive HFO filter media, rather than deploying larger scale systems at fewer sites. This was because the benefits derived would be maximised both environmentally and economically as each individual site would improve its immediate vicinity and the effects be felt downstream. This was particularly apparent when looking at the importance of these streams for salmonids and the overall health of fish stocks populations. Also the significance of population density in driving the relatively high value of these upland streams in the TEEB estimates. This is a vital source of revenue and as such would be maximised through this multiple small-scale deployment. Evident from the case study was the conflict which arose as a result of the impact that metal removal would have on the metallophyte communities which are present in the area.

The case study also illustrates the difficulty of economically quantifying the benefits of ecosystem services, derived not only in terms of their value to the economy, but also in predicting the future value of resources. The wide range of benefits and uncertainty associated with this was illustrated in the economics assessment. It has been shown there are economic benefits that do compensate for any costs incurred of the remediation action taken and also have an ongoing positive contribution in this specific case. It was revealing that the benefits of remediation to the water environment alone are enough to justify intervention in this case, given the uncertainties in assessing impacts beyond the water receptor (e.g. in plant/food chain metal uptake or the health effects of the release of fugitive dusts from spoil heaps:(Mayes et al., 2009b)).

Figure 9.5 shows those stakeholders who would see a direct economic benefit to their business or revenue stream resulting from reduction in levels of metals in the water course.

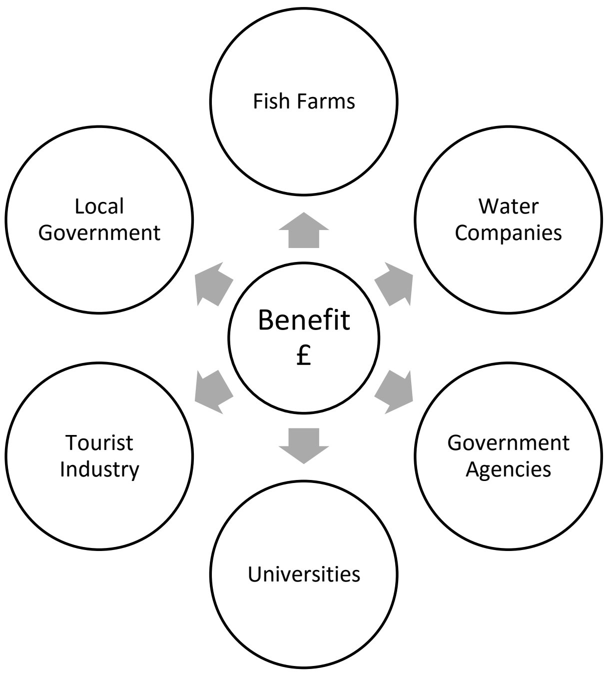


Figure 9.5: Examples of stakeholders who would receive direct economic benefit. From reduce costs to their business, increased productivity or revenue resulting directly from improvements in ecosystem services.

These benefits would be in the form of reduction costs to water treatment in the case of the water company (Clark et al., 2012), increase in revenue from Rod licenses for the Environment Agency and a reduction in costs for the fish farmers in addition to increased yield (Cefas, 2013). The universities would benefit from research activity and free access to data, local government and the tourist industry would experience increased revenue (Scarborough Tourism Economic Activity Monitor (STEAM), 2013). These same stakeholders are the potential investors in the remediation project and would invest in the scheme to receive a direct monetary benefit (Figure 9.5). The level of investment of individual stakeholders would be negotiated between the parties based upon the predictions made by the economic assessment and LCIA. Investors continuing contribution to the costs of maintaining the options selected would be dependent upon the ongoing operation of the remediation method being used and the continuing monitoring metal levels.

Because of the structured nature of the framework, and the necessity of stakeholders talking to each other and negotiating with each other, it allows any decisions that are made to be taken within the context of the best available information. This is assessed objectively using the proposed methodologies of LCIA and also the environmental assessment. Provided that the information is communicated effectively to the range of stakeholders this should ensure that decisions taken are acceptable to the stakeholders involved.

There are some problems with this framework's deployment, notably in terms of data availability for specific locations and processes. Existing models and data can be used to provide enough information to justify any decisions taken within the context of the framework. The framework provides a solution of how to fund the remediation of these abandoned historic mine sites where no single party is liable and can be applied to similar environmental problems. It is vital to illustrate to stakeholders the benefits that would accrue directly to them as a result of involvement in such a scheme, and means of communicating this effectively should be sought. The primary driver is the monetary benefit; there are additional, more nebulous benefits for example social corporate responsibility and goodwill within a community. These are assets that are of value to many organisations and increasingly recognised by the commercial world is a vital part of their company portfolio (TRUCOST Plc, 2013). It is often the avoidance of a cost which is being delivered to a stakeholder, the cost of not taking action resulting from catastrophic events (e.g. mine water breakout: (Mayes et al., 2011b, Sims and Bottenberg, 2008, McCarthy and Humphries, 2013, Safarzynska et al., 2013)) which would ultimately have a high monetary impact upon an affected party. These are counterfactual situations which need to be quantified and prevented from happening through management practices but often are a difficult to capture. Environmental issues and problems need to be included on a companies or organisations risk register so that a value can be derived from alternative management practices. This was a point that was strongly made by one of the interviewees with extensive experience in instigating PES schemes in the UK.

A further contribution that this framework enables is the ongoing monitoring of the remediation taking place, which contributes to developing our understanding of the impacts that environmental problems have. This collection of information will enable more accurate quantification of the benefits derived. Future projects will be more effective as the data collected from existing projects improves understanding of how different systems interact with one another, and how these projects impact within the systems in which they operate.

## 9.6 Future Research

To gain a deeper understanding of how this framework could potentially operate and be deployed in the most effective way research needs to be conducted in all the areas that comprise its component parts. Given the framework builds upon a range of disciplines there are a number of areas where future efforts could be directed to produce more robust management guidance (Table 9.1). The areas outlined in Table 9.1 are specialist disciplines which the framework could contribute to through providing data. All the pillars on which the framework is built are very dynamic individual research areas, key areas of future research focus should be on the way in which social, economic, and environmental components of the different methodologies interact with one another (Kumar et al., 2014, Flint et al., 2013, Péry et al., 2013, Thabrew and Ries, 2009).

An alternative way of investigating this proposed framework would be to construct a pilot project based upon the steps outlined in the framework (Figure 9.4). The first stage of this work would involve building the passive HFO system which was found to have the lowest costs and the lowest environmental impacts. Theoretically this option could also remove the levels of metals present in the Hebden Beck case study. This could be tested and monitored over the period of a year. The actual costs of building and installation of this pilot project could be used in the economic analysis of the framework. The levels of metals and the impact that the pilot scheme would have on the area could also be monitored. This real data could be used in the LCIA part of the framework. Building an actual system and monitoring its effects would provide information about the potential for this option to be deployed at multiple sites. Going through the process of building and installing a pilot of the passive HFO system in the field would present the opportunity to go through all the theoretical stages of the framework. This would necessitate interaction with local stakeholders and highlight any issues with planning and installation, as well as conducting an actual EIA of the pilot technology. The actual process itself would highlight any problems and benefits that cannot be theoretically predicted. An example of this was when suppliers were being contacted to get estimates for use in the cost benefit analysis, a number of them offered to supply materials at a discounted rate when they learned of the project. By actually going through the process and deploying one of the proposed remediation options, experience can be gained about how the framework would actually work in practice and how the technology would perform in the field. Lessons can be learned about the actual effects of deploying a pilot project and its effectiveness, which cannot be obtained in any other way. This would be a highly valuable process to go through and would also illustrate the attitudes to this kind of project from stakeholders in practice, when presented with a real installation rather than a theoretical one.

Table 9.1: Research needs that data collected from the remediation of environmental issues using the proposed framework could contribute to

| Research need | Research outcome |
|---|---|
| Environmental modelling<br>Improved EQS guidance based on biological metal availability / acclimation<br>refining and development of specific and generic CF for metals and other environmental contaminants<br>development of more accurate models and modelling software<br>more extensive environmental monitoring (temporally and geographically)<br>identification of key indicator species for specific contaminants | More robust basis for assessing impacts of mine discharges and requirement (or otherwise) for remediation<br>more accurate assessment of impacts<br>improved ability to predict ecosystem responses<br>early warning of environmental contamination |
| Environmental economics<br>Improved data on costs of sub-lethal metal pollution to river environment<br>quantification of public willingness to pay for environmental benefits<br>evaluation of ecosystem services contribution to markets<br>interaction between environment and human economic activity<br>identification of economic triggers to action | More realistic assessment of economic costs<br>more comprehensive risk registers<br>more integrated assessment of global economic impacts<br>improved ability to predict environmental impacts on the economy |
| Remediation systems<br>Full life cycle analysis of full scale treatment (i.e. including renovation and disposal costs)<br>comparison of pilot scale remediation systems using a range of reactive media and different configurations | More robust estimate of the full costs of management intervention<br>more accurate assessment of appropriate remediation system for specific geographic locations |
| Stakeholder engagement<br>Systematic analysis of stakeholders on a catchment basis at priority sites<br>investigation into different approaches to engage stakeholders<br>categorisation of different types of stakeholders | Fuller picture of key end-users who need to be consulted on potential PES schemes<br>identification of most effective ways to engage with stakeholders<br>identification of key stakeholders for most effective implementation of proposed project |
| Communication tools<br>Assessment of current methods of communication with different sectors<br>research into existing projects why they succeeded or failed<br>identify successful environmental campaigns, identify common elements | Development of communication techniques tailored to specific types of stakeholder<br>more effective generic communication techniques<br>more effective education of the public relating to issues associated with environmental pollution |

## 9.7 **Summary**

The Advantages of this framework are that it provides a fair and understandable process which can be built upon using organisations trusted to act as use of “ethical brokers” to enhance the acceptability of decisions to stakeholders. It involves communication and education which is an important part of building trust with local communities. It uses negotiation and expert knowledge which can contribute to solutions where conflicts between priorities may arise. LCSA can provide an objective assessment and comparison of proposed actions and solutions. The economic value of environmental assets is dependent upon “the willingness to pay” for that asset. It makes explicit the economic contribution that every aspect of the remediation can potentially deliver, enhances the likelihood that a project will move forward. It promotes ongoing monitoring is vital to maximise the benefits derived from remediation projects. It enables regulations can be used to ensure that environmental benefits are maximised and lets action take place rather than preventing action taking place (habitat offsetting and research into metallophyte communities). It gives the stakeholders the opportunity to voice their priorities and concerns, and decisions are made using objective and scientifically rigorous information. This framework is an ongoing and iterative process deriving benefits beyond the project is that it is applied to.

The disadvantages are that in order for it to be successful stakeholders have to be willing to invest in it and willing to continue with this investment over the lifetime of the project. Managing and negotiating different priorities between stakeholders may be difficult and it is possible that, despite information about the potential impacts and benefits of different options provided by the different assessment used within the framework, that stakeholders may be unable to reach an agreement about remediation of a site. However this framework does provide a way forward and strategies to negotiate these difficulties.

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# Appendix One **Stakeholder Survey and Interviews**

## 1.1 Purpose of Contacting Stakeholders

The purpose of sending out a questionnaire and interviewing a range of different stakeholders is to establish whether the "willingness to pay principle" is a valid assumption to make for the funding for the remediation of abandoned metal mines sites and what influences the calculations that individuals stakeholders make about the economic value of such a scheme. Thus gaining an evidence-based understanding of the overall balance of stakeholder's willingness to invest in the remediation of a specific site when offset against the actual costs of implementing and running such a project based upon the payments for environmental services model. This information will also enable a clearer understanding to be gained of the motivations and influences that affect individual stakeholders when considering whether or not to take part in a PES scheme. This information will be taken into account when assessing the way in which to present the overall framework for site remediation to potential future stakeholders in order to try to increase the likelihood that a stakeholder will commit financially to such an arrangement. Being informed about the sort of information stakeholders require before committing financially will give a better understanding of what aspects of the framework to highlight to different stakeholders to increase the probability of their taking part in the scheme. This aspect of the study will underpin assumptions about the economic viability of potential remediation programme.

How willing different types of organisation would be to purchase an ecosystem service and how they economically value individual services will influence the way in which different organisation types are approached

## 1.2 Email to Potential Interviewees

Dear company (water company/mining company/organisation)

I am a Ph.D. student based at the University of Hull as part of my research project I wish to find out about different companies and organisations attitudes towards taking part in environmental ‘clean-up’ schemes. I am specifically projects targeted at removing lead, zinc, copper and cadmium from UK rivers, which enters many river systems from abandoned non-coal mine sites. There are a range of options currently being considered by regulatory agencies to deal with this long-standing pollution problem, but one of the key issues that remain is how such schemes could be funded over the long term.

I am researching how viable it would be to sell the benefits derived from metal removal to potential beneficiaries as part of Payments for Ecosystem Services (PES) approaches that are currently being considered in many environmental management scenarios in the UK. Your opinions and perspectives on how your company/organisation would view such a proposal would be very much appreciated.

As such, I would be very grateful if you could spare a few minutes to assist me with my research. I have attached a questionnaire which you may wish to complete however I would very much like to interview you to gain a better understanding about how this sort of market-based approach would be viewed by your company. If you would be open to talking to me I would be very grateful for your help. We could arrange to conduct an interview via Skype or over the telephone at a time which is convenient to you. Please let me know what would work best for you.

Any information will be anonymous, only identifiable as the type of company that you represent and not made specific to your own organisation. If you wish a deeper level of anonymity I will respect that and ensure that neither you nor your organisation is identifiable.

If you would like any more information about this research or have any other question I would be most happy to answer them and can be contacted on this e-mail address; on the telephone during normal office hours,

Thank you for your time and I look forward to hearing from you.

Best wishes

Helen Baxter

## 1.3 Questionnaire

**Information about your organisation/business/company**

**Name of company/business/ organisation**

**Your name**

**Your role within the company/ business/organisation**

**How would you describe your business/ organisation/company?**

| | Yes | No | Would rather not say |
|---|---|---|---|
| Do you have links with local communities? | | | |

If you wish to, please describe what these links are.

How important is the public's perception of your organisation/business/company (please

| Very unimportant | Unimportant | Neither important or unimportant | Important | Very important |
|---|---|---|---|---|
| | | | | |

indicate appropriate level of importance below)

Does your company/business/organisation actively try to minimise its environmental impact/have environmental strategies in place, if so please briefly outline what they are below

**Knowledge about Ecosystem Services**

| | | | |
|---|---|---|---|
| Have you heard of either of the terms "environmental services or ecosystem services"? | Yes | Not sure | No |
| Do you understand what is meant by the term ecosystem services? | Yes | Not sure | No |

Ecosystem services are the ways in which ecosystems contribute to human well-being. Please tick the appropriate box to indicate how far you agree with the following statements;

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|---|
| It is important to look after the natural environment | | | | | |
| Areas which have been damaged by | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| human activity should be restored back to their original condition as far as possible | | | | | |

It is important the clean-up rivers, streams and lakes;

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|---|
| To make them look nice | | | | | |
| Because the pollutants may be harmful to human health | | | | | |
| To encourage wildlife | | | | | |
| Because of government legislation | | | | | |
| To improve the level and health of fish stocks | | | | | |
| Because it is our moral responsibility to look after the natural environment | | | | | |
| Because the pollutants harm wildlife and damage habitats | | | | | |
| It is not important to clean-up rivers, streams and lakes | | | | | |
| Communities benefit when local water bodies are cleaned up | | | | | |
| Local business benefits when local water bodies are cleaned up | | | | | |

Please add any additional comments about how you think the condition of local water bodies can improve an area:

- Socially
- Economically
- Environmentally

A range of benefits provided by Ecosystem Services contribute directly or indirectly to human well-being. The benefits listed below can be attributed to the improvement in "ecosystem services" which would result due to reduction of the levels of lead, cadmium, zinc and copper entering water bodies from abandoned non-coal mine sites. Please indicate on a scale of 1 to 10 where (1 is unimportant and 10 is very important) how important each of the individual benefits listed below are to you personally/your organisation or business

| | Important to me personally (scale of 1 to 10 where 1 is unimportant and 10 is very important) | Important to company/organisation/business (scale of 1 to 10 where 1 is unimportant and 10 is very important) |
|---|---|---|
| Increased levels of Biodiversity | | |
| Healthy fish stocks | | |
| Reduced health risks to humans | | |
| Improved water quality | | |
| The appearance the water is clearer | | |
| Healthier waterborne plants and animals populations | | |
| Increased abundance and health of local wildlife | | |
| Overall improvement in aesthetic appearance of the area due to better ecological health | | |

**Payment Ecosystem Services Schemes**

| | Yes | No | Unsure |
|---|---|---|---|
| Have you have heard of "Payments for Ecosystem/Environmental Services" (PES) schemes? | | | |
| Do you know what a payment for ecosystem/environmental services (PES) scheme is? | | Please skip to question 0 | Please skip to question 0 |

Please write a brief definition of what you understand a payment for ecosystem services (PES) scheme to be below

PES schemes work on the principle that a service provider should be compensated by the service user for the provision of that service. In the case of PES schemes it is the range of services resulting from the conservation and restoration of ecosystems. The service provider may be the landowner or another body or individual responsible for the management of a natural resource, for example a river or canal. The payment is made to the service provider for actions (Beyond What Would Occur in the Absence of Payment) that will guarantee an agreed upon level of ecosystem service provision. After having read the above explanation of PES schemes based on upon "the beneficiary pays principle" please indicate how far you agree or disagree with the following statements.

| | Strongly disagree | disagree | neither agree nor disagree | agree | strongly agree |
|---|---|---|---|---|---|
| Conservation and restoration of the natural environment contributes to the national and local economy | | | | | |
| A proportion of the economic benefits derived from ecosystems services should be invested in maintaining and enhancing ecosystem services | | | | | |
| Benefits derived from ecosystems services should be brought into the mainstream economy | | | | | |
| The cost of a service should be borne by the service user or users | | | | | |
| Placing an economic value on the environment devalues it | | | | | |

**Reasons for taking part in the scheme**

Reducing the levels of lead, cadmium, zinc and copper entering water bodies from abandoned mine sites would contribute to improving the ecological health of the habitats surrounding those water bodies as well as the water quality and health of the wildlife that depend upon them. The improvement in ecosystems results in enhanced benefit for human as well as the direct benefit of having reduced levels of these metals in the water bodies. Different ways of cleaning up this pollution exist and have been demonstrated to be effective, however these schemes need funding. One way to do this would be by selling the services provided by such a scheme to those that benefit.

Would your company/business/organisation consider taking part in a PES scheme?

| | |
|---|---|
| Yes | |
| No | |
| Would need more information | |
| Not sure | |

The following benefits have been shown to occur, in the area local to the clean-up scheme, as a result of metal removal from water bodies please indicate whether your organisation would be interested in purchasing such a service.

| | Not at all interested | neither interested nor uninterested | possibly interested | interested | very interested |
|---|---|---|---|---|---|
| The reduced levels of metals in the water; the levels of metals must be reduced to pre-arranged limits | | | | | |
| Increased numbers and heath of fish | | | | | |
| Increased variety in plant species | | | | | |
| Improved health in local vegetation | | | | | |
| Increase in numbers and heath of local wildlife | | | | | |
| Reduced human health risks from metal exposure | | | | | |

**Setting the price of ecosystem services**

Please indicate on a scale from 0 to 100 what proportion of the price paid by the service user should be based on the following factors:

| | 0 to 100 |
|---|---|
| The direct financial benefit gained by the service user | |
| The cost of providing the service to service provider | |
| The level of "use" of the service by the service user | |
| Economic value to society of maintaining that ecosystem service/services | |
| Value placed upon service provided by the service user (e.g. improved habitat/preservation of wildlife/protection of species) | |
| The number of users purchasing the service (the greater the number of service uses the lower the price to the purchaser) | |

Please make any further comment below, about setting the price of ecosystem services and what your organisation would consider when deciding whether or not a fair price had been set for an ecosystem service

Most ecosystem services are non-exclusionary (with the exception of provisioning service), that is for example, improved water quality is a universal benefit, the service user who is paying for the service to be provided is not the only beneficiary. How would this non-exclusionary aspect of ecosystem services influence your organisation/company's likelihood to take part in a PES scheme?

| | |
|---|---|
| Less likely to take part in a PES scheme | |
| More likely to take part in a PES scheme (the philanthropic value) | |
| Would not influence the organisation | |
| Would depend on the nature of the scheme | |
| Would depend upon the direct benefits to the company/organisation being purchased | |

Please indicate how far you agree or disagree with the following statements;

| | Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly agree |
|---|---|---|---|---|---|
| All service users should pay for the cost of the service being provided | | | | | |
| Service uses whom financially benefit from the service should contribute to providing the service | | | | | |
| There is value in doing something good for the environment for its own sake and organisations/companies have a responsibility to contribute | | | | | |
| Companies/organisations/businesses who operate in an area which has previously damaged the provision of ecosystem services have a moral responsibility to financially contribute to their restoration | | | | | |
| Everybody should contribute to the maintenance of ecosystem services through general taxation | | | | | |
| Philanthropic individuals and organisations should be asked to contribute to schemes to benefit the environment | | | | | |
| Charities and special interest groups should contribute to the funding of ecosystem services which benefit their cause/area of interest | | | | | |
| Local authorities should pay for the provision of ecosystem services which benefit the local population | | | | | |

Please make any further comment you wish to about what you think would influence your company or organisation's willingness to pay for ecosystem services below.

**Choice of Remediation Approach**

For the removal of metals from water there are a number of different remediation techniques available. These different techniques have different advantages and disadvantages, which need to be balance against one another when making the decision about which technology to deploy in a specific location for a PES scheme.

Please indicate below how important you think each of the following factors would be to your business/company/organisation in choice of remediation approach to be taken in a PES scheme that you were involved with.

| | Unimportant | Not a consideration | Important | Very important | Would alter the decision about whether or not to take part in PES scheme |
|---|---|---|---|---|---|
| Initial installation and setup costs | | | | | |
| Effectiveness of remediation method | | | | | |
| Impact on the local environment once installed and active | | | | | |
| Running costs | | | | | |
| Environmental impact of the production and installation of the remediation method (the environmentally friendliness of the remediation technology) | | | | | |

Please make any additional comments that you wish about the choice of remediation approach below.

**Role within the PES Scheme**

Payments for ecosystem services schemes when first being considered, present the opportunity for buyers and sellers of ecosystem services to negotiate with one another in order to determine what each party wishes to achieve. This can mean that service buyers have the opportunity to influence the way in which the scheme is put into practice, as well as negotiating about financial remuneration and initial upfront investment.

If your business/organisation/company were to be considering taking part in a PES scheme what level of involvement in the initial implementation of the scheme would you envisage? Please indicate which of the following statements would most apply to your company/business/organisation.

| | |
|---|---|
| None- would just wish to purchase the ecosystem service at an agreed price | |
| Some involvement- be informed about remediation methods and reasons for their choice | |
| Have some input into choice of remediation method and running of the scheme | |
| Would wish to have a large amount of influence over the choice of remediation method and how the scheme is implemented and run | |
| The level of involvement would depend upon the level of financial involvement of the company | |
| Not sure | |

Once the scheme was up and running what level of continuing involvement would your business/company/organisation require (please indicates which statement most applies)?

| | |
|---|---|
| No involvement, would expect to pay for ecosystem services as agreed provided the scheme was meeting its obligations | |
| No active involvement would expect to be updated on levels of service delivery and receive annual reports about how well scheme was providing the ecosystem services being purchased | |
| Minimal involvement would like to be consulted about any changes being made to the running of the scheme | |
| Active involvement in the continually running of the scheme | |
| Not sure | |
| Would depend upon the nature of the scheme | |

Please make any additional comments about the level of involvement you would envisage for your business/company/organisation.

Please make any additional comments about possible reasons for your business/company/organisation being more or less involved in setting up and running of a PES scheme.

**Compliance**

An important aspect of any PES scheme is that of compliance. That is ensuring that the provider of the ecosystem service or services sold is meeting their obligations as negotiated between the different stakeholders involved (buyers, sellers and intermediaries). In the case of metal removal from River systems this could involve monitoring levels of metal within the system to ensure that the remediation was working effectively. If the environmental service being sold was that of improvement to local wildlife it may also involve assessing the health of the local flora and fauna and the monitoring levels of fish stocks to ascertain whether or not ecosystem services were improving.

Monitoring is often difficult as the ecosystem services being sold may take time to improve, may be prone to seasonal variation and can be difficult to quantify. Systematic monitoring also increases the on-going running costs of a PES scheme. Not all schemes have a systematic monitoring approach in place. Payments are made on the basis of the continuation of the agreed upon remediation/land management approach taking place rather than on the monitoring the level of the improvement to the ecosystem service.

Please indicate how far you agree with the following statements relating aspects of compliance within a PES scheme.

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|---|
| Payment should be made long as remediation is taking place | | | | | |
| Levels of payment should vary depending on results from monitoring | | | | | |
| A fixed being made payment should be dependent upon meeting predefined criteria (maximum levels of metal allowable) | | | | | |
| Payment should be linked to results e.g. a proportion of revenue from fishing licenses in a specified area | | | | | |

Please add any additional comments about monitoring and compliance and how they would influence your company/business/organisation likelihood to participate in a PES scheme.

Thank you for your time and your opinions, they are very much appreciated.

# Appendix Two **Assessment of Conservation Designations Surrounding Metal Mine Sites in England and Wales.**

## 2.1 Method

Online searches for Sites of Special Scientific of Interest (SSSI) in Natural England and Natural Resources Wales (which now incorporates the Countryside Council for Wales) were undertaken to find any sites with "mine" in their title of notification documents. Additional searches for riverine SSSIs were undertaken (any SSSI with "river" in the notification document) to search for potential sites of interested relating to mining-derived calaminarian grassland (plant communities containing rare metal-tolerant "metallophytes" that colonise and develop on metal-contaminated spoil or floodplain sediments). Further searches on the JNCC website for Special Areas of Conservation (under the EU Habitats Directive) were undertaken to identify mining-related sites. In all cases, notification documents were reviewed and summary details on the primary reasons for designation were recorded along with site locations.

## 2.2 Distribution and Nature of Sites

A total of 61 SSSI were identified relating directly to abandoned non-coal mine sites. Figure A shows the primary reasons for notification of each site while the distribution of sites is shown in Figure 3. In some cases there were multiple primary reasons for notification, for example both geological interest and biological value. The majority of these sites (39) are notified for geological reasons, with the most common reason for citation relating to mineralogical specimens of particular rarity. These include rare double carbonate minerals in the north of England (Blagill and Fallowfield mines), Ba mineralisation in County Durham (Close House Mine) and Shropshire (Snailbeach and Huglith Mines) as well as uranium (amongst other) minerals in Cornwall (e.g. South Terras mine). The geological importance of abandoned non-coal mines also includes broader interests beyond mineral specimens such as exposure of structural features giving insight into orefield genesis as well as exposure of interesting fossil formations in country rock (e.g. Ordovician trilobite and graptolite fauna at Nant y Gadwen in Gwynedd).

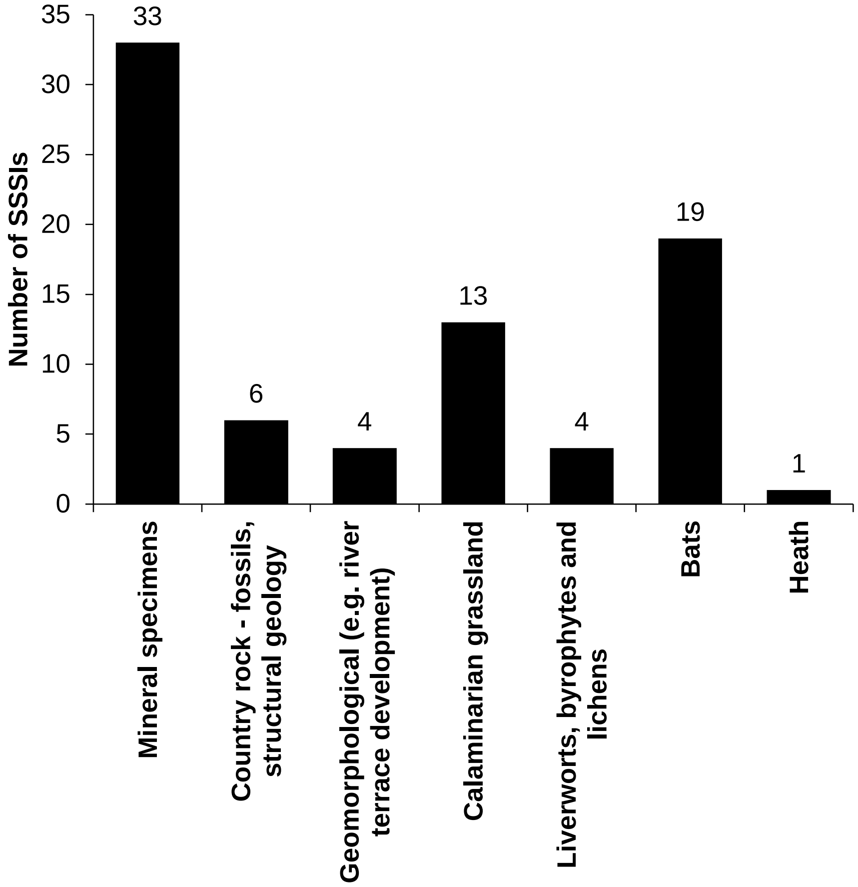


Figure A: Primary reasons for notification of SSSI sites in England and Wales relating to former non-coal mining

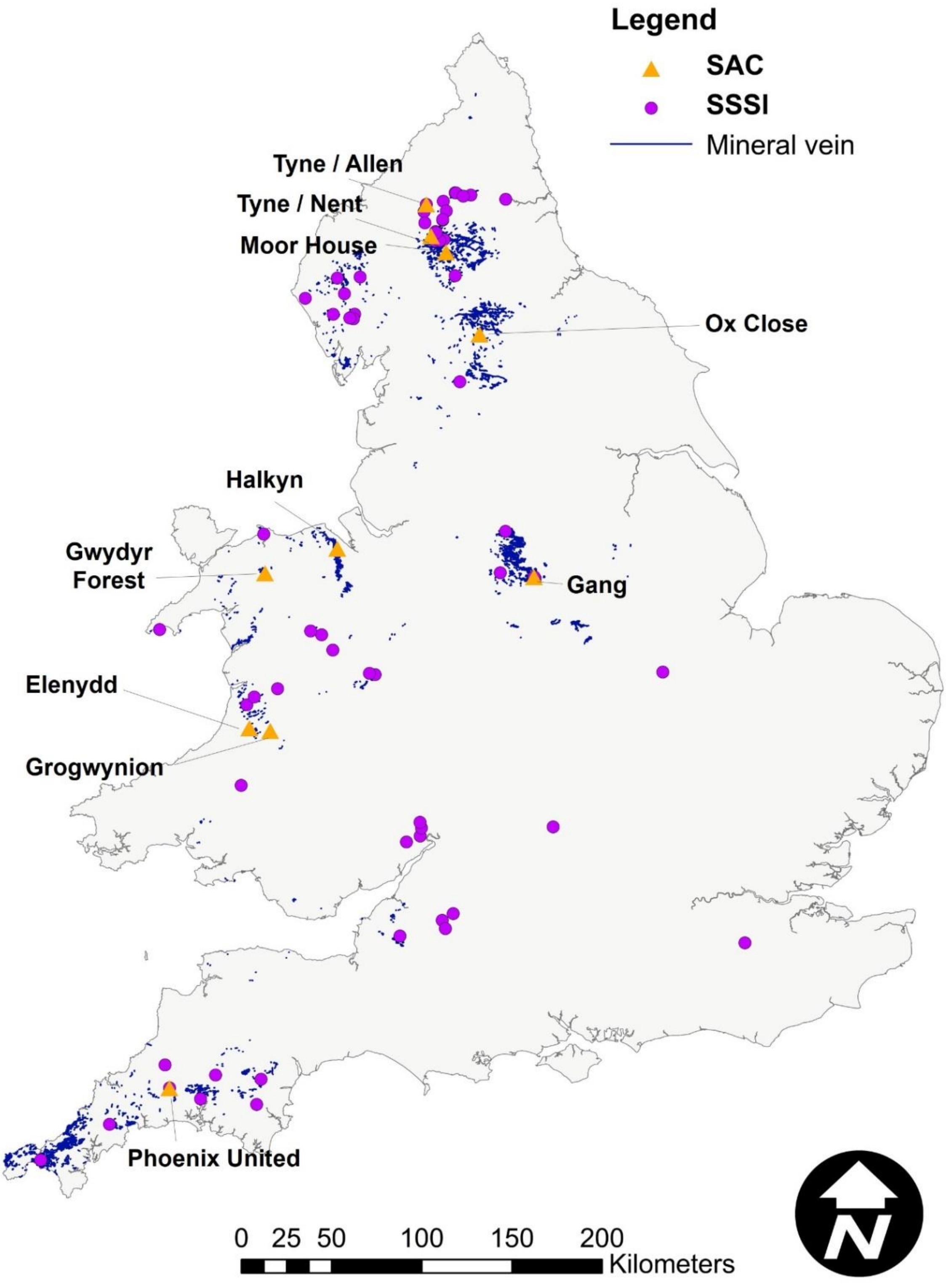


Figure B: Distribution of SSSIs and SACs relating to former non-coal mining in England and Wales. SAC sites are labelled.

Biological interest at the SSSIs is dominated by bats. In many cases citations are due to over-wintering or breeding populations of Greater Horsehoe Bat (*Rhinolophus ferrumequinum*) and / or Lesser Horsehoe Bat (*Rhinolophus hipposideros*) which account for 9 and 7 sites respectively. Three sites are notified due to a mixed assemblage of bats. Calaminarian grassland is the primary reason for notification at 13 SSSIs. Typical species present in these communities include spring sandwort (*Minuartia verna*) and alpine penny-cress (*Thlaspi caerulescens*). The high metal content of the soils leads to a generally low plant diversity, open sward and retarded succession (JNCC, 2014). These include sites in Derbyshire (Gang Mine), Cumbria (Whitesike Mine), Cornwall (Phoenix United Mine) and North Yorkshire (Pikedaw Calamine Caverns). However the most extensive notifications are in the South Tyne, Tyne and West Allen catchments where 9 SSSIs are notified for the metallophyte communities. These form a series of spoil and fluvial environments through the catchment that are also notified as Special Areas of Conservation (Tyne and Allen Gravels and Tyne and Nent SACs) highlighting their significance on a European scale. The other mining-related SACs notified with a primary designation for calaminarian grassland represent the best examples of the community from a broad geographic range (Figure B) including Cornwall (Phoenix United Mine), Western Wales (Elenydd and Grogwynion) through to North Wales (Gwydyr Forest Mines, Halkyn Mountain), Derbyshire (Gang Mine), North Yorkshire (Ox Close) and Cumbria (Moor House in the headwaters of the Tees). Some of the SSSIs affected by secondary mining pollution also have notification on the grounds of geomorphological interest, for example where metal contamination of floodplain sediments provide good marker horizons for dating terrace development and channel migration (River Nent at Blagill and River West Allen at Blackett Bridge). Additional biological interest in SSSI notifications concerns bryophytes, lichens, liverworts and ferns colonising spoil or in some cases around adit portals (4 sites). One site included the presence of juniper scrub (*Juniperus communis*) and bilberry (*Vaccinium myrtillus*) heath on spoil and adjacent land as part of the notification (Wanthwaite Mine, Cumbria).

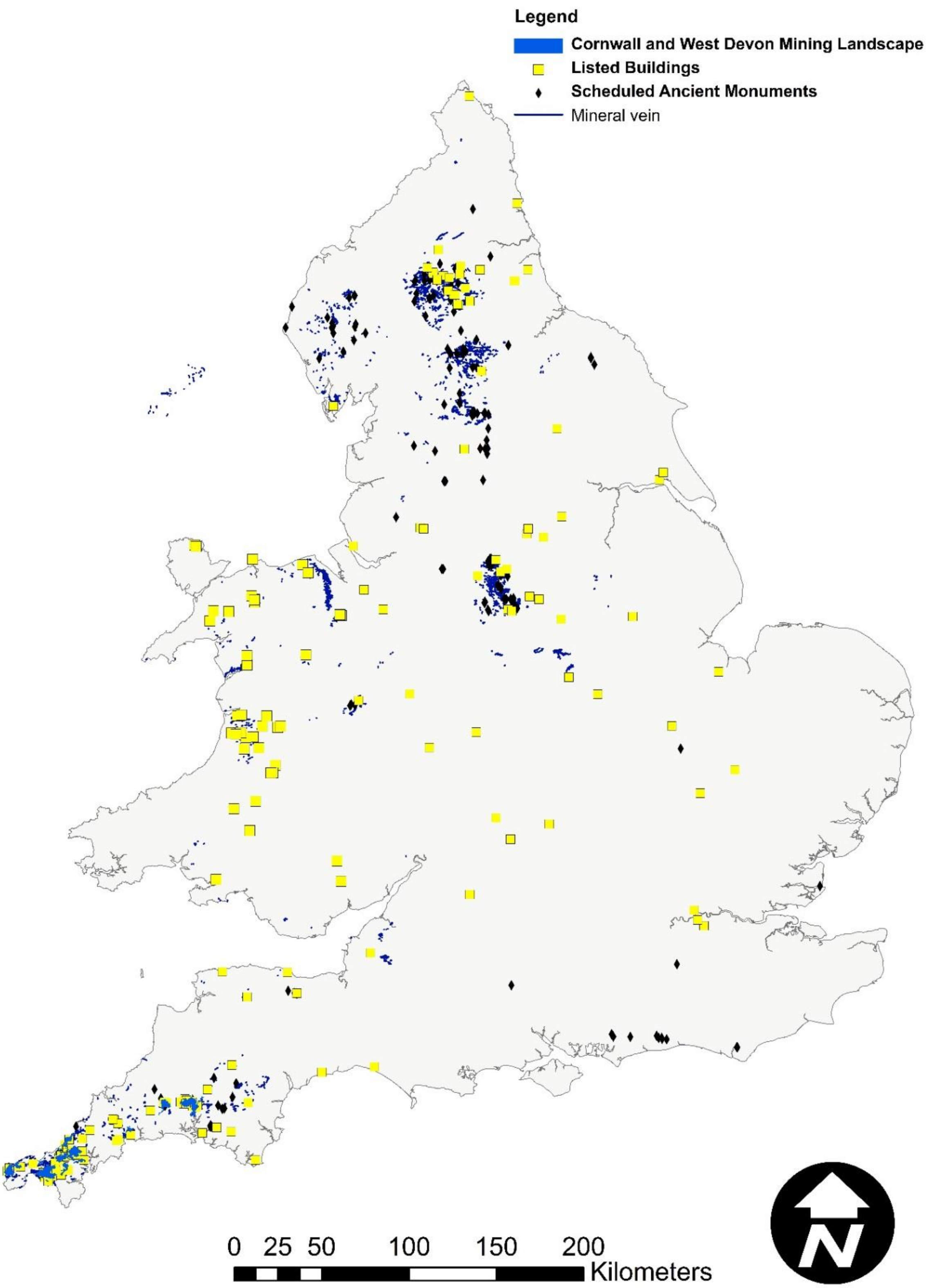


Figure C: Distribution of designated built environment features relating to abandoned non-coal mines in England and Wales

## 2.3 Built Environment

### 2.3.1 Method

English Heritage spatial databases for Scheduled Ancient Monuments (22402 sites in total) and Listed Buildings (363872 sites in total) were searched for sites containing "mine" in the name (Magic). The lists were then manually checked to ensure the designation was related to abandoned mining features.  Similar searches were undertaken using the Cadw online databases(Cadw, 2014a, Cadw, 2014b).

### 2.3.2 Distribution of Sites

Figure C shows the distribution of built environment abandoned mining features across England and Wales.  In total, 247 Scheduled Ancient Monuments were identified which typically cover entire mine sites, or large portions of mine sites and 229 Listed Buildings were identified.  These can vary from small, well-preserved structures such as adit portals through to smelt mills and washings floors. These features are broadly distributed across all the major orefields of England and Wales.  Of particular note, beyond national designations, is the World Heritage Site of Cornwall and West Devon Mining Landscape.  This area was notified as World Heritage Site in 2006 by the UNESCO on the basis of the mining technologies that were pioneered in the area that not only underpinned the Industrial Revolution, but were also subsequently exported to major global orefields in South Africa, North America and South America (Cornish Mining, 2014).

### 2.3.3 Summary

This mini-review of statutory protected sites relating to abandoned mine sites in England and Wales provides a revealing insight into the varied nature of biological, geological, geomorphological and archaeological interests that are preserved at these sites.  These provide a range of stakeholder interests when considering both the development and longer term impacts of mine site remediation.  There is considerable scope for potential conflict between longer term environmental ambitions and the scientific value inherent at these sites.  For example, the extensive calaminarian grassland that is apparent in all major orefields (and in cases designated at an EU level) is dependent on the metal-rich substrates present at the abandoned mine sites and in downstream fluvial sediments. The impacts of remedial efforts (for example capping spoil to prevent diffuse pollution of surface waters: (Gozzard et al., 2011)) could clearly conflict at least on a local level. Broader scale point mine water remediation (Jarvis and Mayes, 2012) could also lead to gradual reductions in sediment metal content over time (given most metals released from point discharges partitions onto downstream sediments) which could also negatively impact on the long term stability of these plant communities. For the built environment designations, the key issue for potential remediation is ensuring that any new features complement the existing natural and built environment. This could add significant cost on to remediation schemes but with careful planning may provide dual benefits, for example where remediation can make use of former mining features such as tailings ponds or settlement lagoons as is the case currently at Force Crag Mine in Cumbria (Riverwiki, 2014).

# Appendix Three **Tables EIA**

Table: Impacts zinc

| **Area of Concern** | **Receptor (the indicator being assessed and the current level of impact)** | | | | |
|---|---|---|---|---|---|
| **Zinc** | **Direct or indirect indicator of area being assessed** | **Sensitivity** | **Vulnerability** | **Recoverability** | **Significance** |
| Fish farming | Salmon/salmonids | Highly sensitive? | Reduction in size and numbers produced(Mebane et al., 2012) | Rapid recovery once pollution is removed | Significant to economic productivity of the area |
| Primary production | Algal biomass | Highly sensitive | Reduced biodiversity, reduced levels of biomass (Niyogi et al., 2002) | Rapid recovery dependent upon resilience of individual species/phase of life cycle and lifespan of species | Fundamental to resilience of overall ecosystem |
| Metallophyte communities | Variety of species/number of individuals/area colonised | Highly sensitive | Vulnerable to the loss of metal, little is known about requirements for their survival but it is assumed once metals are removed they will be unable to survive in a in an altered habitat(Lucassen et al., 2009, Whiting et al., 2004a) | Little is known about how long it takes to establish and develop such communities | Highly significant these are protected species and are very rare |

| | | | | | |
|---|---|---|---|---|---|
| Human health (NIH-USA and Office of dietary supplements, 2013) | Health effects resulting from exposure to zinc | Low level of sensitivity, Upper tolerance intake levels, 4 mg for young babies/40 mg for adults. | Exposure pathway through direct ingestion unlikely, Chronic toxicity development of headaches and reduced ability to take copper and iron, reduced immune function and reduction in high density lipoprotein also experienced headaches will stop zinc can also interfere with the functioning of some prescribed medications including antibiotics | Once exposure is reduced recovery is rapid. | Increase costs on health spending, days lost to ill health, reluctance to visit the area overall impact on well-being |
| Impact on sheep | Annual birth rate, growth of animals | Low impact at these levels | Some evidence of restricted growth and kidney damage (Ott et al., 1966, Harlett, 2012) | Once exposure is reduced recovery is rapid (any damage to kidneys permanent). | Reduced productivity limited significance |
| Visual of adit appearance | Subjective see photo (sticking cross-referenced to a picture of adit looking ugly) | Not significant enough to prevent walker from taking path. | Impact on immediate area's appearance | Immediate change once engineering works complete | Reduce visitor numbers impact on economy of local area |
| Water extraction | Direct measure of levels of zinc within the water | Dependent of end use of water | Very vulnerable dependant on levels being released and distance from point source pollution | Immediate effect But any re-suspension of contaminated sediment will have an effect | Additional cost to remove contaminants to water companies, may impact on animal health crop productivity where extraction is used for agricultural purposes |

| | | | | | |
|---|---|---|---|---|---|
| Downstream impact | Potential for increased levels of zinc to be re-suspended and transported further down the catchment | Very sensitive | Continuously redepositing contaminated sediment that adds anything to supply available for transportation down catchment and ultimately entering the oceans. | When you contaminated sediment is deposited on top of previously contaminated sediment will act as Over previously layers of contaminated sediment requiring a very high level of storm event to excavate down to previously contaminated levels thus reducing the levels of contaminated material being deposited further down the catchment and into the oceans. | Downstream ecological and economic impacts increase pollution in world oceans |

Table: Impacts lead

| **Area of Concern** | **Direct or indirect indicator of area being assessed** | **Receptor (the indicator being assessed and the current level of impact)** | | | |
|---|---|---|---|---|---|
| **Lead** | | **Sensitivity** | **Vulnerability** | **Recoverability** | **Significance** |
| Fish stocks | Salmon/salmonids | Highly sensitive | Reduction in fish population and size of fish (particularly at the larger swim up fry stage, fry becoming more sensitive at larger sizes (Mebane et al., 2012)) | New generations not impacted once led is removed affected populations have permanent damage, almost all may be impacted by contaminated sediment when still available | Significant due to issues around levels of lead for fish for human consumption, of significance to economic health of the area. |

| | | | | | |
|---|---|---|---|---|---|
| Primary production | Algal biomass | Sensitive | Reduction in growth rate, speciation of the Pb needs to be taken into account(De Schamphelaere et al., 2014)) | Rapid recovery, dependent on population turnover. | Important as fundamental to the resilience and functioning of the whole ecosystem |
| Metallophyte communities | Variety of species/number of individuals/area colonised | Highly sensitive | Vulnerable to the loss of metal, little is known about requirements for their survival but it is assumed once metals are removed they will be unable to survive in a in an altered habitat(Lucassen et al., 2009, Whiting et al., 2004a) | Little is known about how long it takes to establish and develop such communities | Highly significant these are protected species and are very rare |
| Human health | Health effects attributable to lead exposure | Highly sensitive | Wide range of reported health effects, a lowering of IQ has been reported at any exposure impact on the nervous system, kidneys and heart, reproductive organs and causing anaemia are widely reported organ systems affected by the lead[32]. It is now widely reported that there is no threshold of safe a level lead exposure. Children and babies are more sensitive to lead exposure than adults. | Damage caused by lead exposure is non-reversible. | Highly significance due to impact on economic outcomes resulting from lowering of IQ. Direct costs of health treatment. Costs of additional social impacts (late has been associated with higher crime rates (Mielke and Zahran, 2012) |

[32] http://www.chem.unep.ch/pops/pdf/lead/leadexp.pdf

| | | | | | |
|---|---|---|---|---|---|
| Impact on sheep | Annual birth rate, growth of animals | Highly Sensitive particularly during gestation and juveniles | Lowered birth-rate, liver damage, anaemia, brain damage, weakness, low growth rate(Pareja-Carrera et al., 2014) | Damage caused by chronic and acute lead exposure tends to be irreversible particularly if exposure occurs in uteri or at a young age | Lead is a highly toxic substance and any contamination has implications for the economics of the area in particular in relation to any meat intended for human consumption. |
| Visual appearance of adit | Subjective see photo (sticking cross-referenced to a picture of adit looking ugly) | Not significant enough to prevent walker from taking path. | Impact on immediate area's appearance | Immediate change once engineering works complete | Reduce visitor numbers impact on economy of local area |
| Water extraction | Direct measure of levels of lead | Dependent of end use of water | Very vulnerable dependant on levels being released and distance from point source pollution | Immediate effect But any re-suspension of contaminated sediment will have an effect | Additional cost to remove contaminants to water companies, may impact on animal health crop productivity where extraction is used for agricultural purposes |
| Downstream impact | Potential for increased levels of lead to be re-suspended and transported further down the catchment | Very sensitive | Continuously redepositing contaminated sediment that adds anything to supply available for transportation down catchment and ultimately entering the oceans. | When you contaminated sediment is deposited on top of previously contaminated sediment will act as Over previously layers of contaminated sediment requiring a very high level of storm event to excavate down to previously contaminated levels thus reducing the levels of contaminated material being redeposited further down the catchment and into the oceans. | Downstream ecological and economic impacts increase pollution in world oceans |

Table: Impacts copper

| **Area of Concern** | **Direct or indirect indicator of area being assessed** | **Receptor (the indicator being assessed in the current level of impact)** | | | |
|---|---|---|---|---|---|
| **Copper** | | **Sensitivity** | **Vulnerability** | **Recoverability** | **Significance** |
| Fish stocks | Reduction in growth rate and number of young. | Sensitive (DOC is a moderating factor in contest toxicity to aquatic organisms(Wood et al., 2011)) | Highly vulnerable, dependent on distance from source pollution | One source of pollution is removed stocks recover quickly | Economic impact on aquaculture also on "free range" and wild stocks, impact on functioning and resilience of the ecosystem |
| Primary production | Health and mass of primary producers (e.g. algae/biofilm/ duckweed) | Highly sensitive to levels as low as 2.5 µg/L(Donnachie et al., 2014) click | Highly vulnerable, dependent on distance from source pollution | Rapid recovery one source of pollution is removed and levels copper in the water are reduced to below effect levels. | Wider impact on the functioning and resilience of the ecosystem, transmitting copper through the food chain impacting on the highest species |
| Metallophyte communities | Variety of species/number of individuals/area colonised | Highly sensitive | Vulnerable to the loss of metal, little is known about requirements for their survival but it is assumed once metals are removed they will be unable to survive in a in an altered habitat(Lucassen et al., 2009, Whiting et al., 2004a) | Little is known about how long it takes to establish and develop such communities | Highly significant these are protected species and are very rare |

| | | | | | |
|---|---|---|---|---|---|
| Human health | Problems to human health directly attributable to overexposure to copper. | Some evidence to suggest that chronic exposure copper may lead to Alzheimer's disease, can lead to gastrointestinal blood and problems as well as liver more than 10 mg. (World Health Organisation, 2014) children are more susceptible to toxic effects of copper than adults | Not very vulnerable other than through direct source of drinking water that this should have been removed of water treatment centres and it is unlikely that people drinking directly from the contaminated water source | The bodies highly efficient and expelling toxic levels of copper and tends to maintain a steady quantity of copper which is required for normal physiological functions. Once damage has been done particularly in the case of Alzheimer's it is irreversible | Economic problems and people being unwilling to the mix to contaminated water however at these levels it is not of any significance to the tourist industry. |
| Impact on sheep | | Moderately sensitive (required nutrient for normal physiological processes) excess is levels of copper can lead to problems with liver kidneys and the blood (concentrations greater than 0.2 mg/L)(Zantopoulos et al., 1999) | Not very vulnerable due to alternative sources of drinking water for low concentrations of copper/sheep quite tolerant of high levels of copper in their diet.(Smith et al., 2009) | Damage caused by copper is permanent. | Economic impact of meat being unfit for human consumption due to levels of copper. |
| Visual appearance of adit | Subjective see photo (sticking cross-referenced to a picture of adit looking ugly) | Not significant enough to prevent walker from taking path. | Impact on immediate area's appearance | Immediate change once engineering works complete | Reduce visitor numbers impact on economy of local area |
| Water extraction | Direct measure of levels of copper | Dependent of end use of water | Very vulnerable dependant on levels being released and distance from point source pollution | Immediate effect But any re-suspension of contaminated sediment will have an effect | Additional cost to remove contaminants to water companies, may impact on animal health crop productivity where |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | extraction is used for agricultural purposes |
| Downstream impact | Potential for increased levels of copper to be re-suspended and transported further down the catchment | Very sensitive | Continuously redepositing contaminated sediment that add anything to supply available for transportation down catchment and ultimately entering the oceans. | When you contaminated sediment is deposited on top of previously contaminated sediment will act as Over previously layers of contaminated sediment requiring a very high level of storm event to excavate down to previously contaminated levels thus reducing the levels of contaminated material being redeposited further down the catchment and into the oceans. | Downstream ecological and economic impacts increase pollution in world oceans |

# Appendix Four **Information Component Parts**

Table: Information component parts passive HFO

| **Inputs Passive HFO** | | | | | | |
|---|---|---|---|---|---|---|
| Component Part | Additional Information/Description | Other Comments | Material | Mass kg | Number of Items/total requirements over life time | Total Mass |
| 3000 L fibreglass tank | | | Glass fibres and Resin | 30 | 2 | 60 |
| Pond liner 6 m³ pond | PVC http://www.dpiplastics.co.za/Green_Facts/ | Each pond requires 500m2 | Heavy Duty PVC, additional energy to produce 56MJ/Kg included in the LCA | 1200 | 2 | 2400 |
| Wood shavings | | | Wood shavings saw dust waste material | 768 | 1 | 768 |
| Limestone sand | Figures based on costs of limestone. | Replace this with LimeX? | In LCA Estimates about energy consumption for crushed have been made. | 1900.8 | 1 | 1900.8 |
| Alterative LimeX | | | LimeX | 1900.8 | 1 | 1900.8 |
| 168 L fibreglass tank | | | Glass fibres and Resin | 20 | 1 | 20 |
| PVC half pipe piping | | | PVC | 10 | 1 | 10 |
| HFO pellets (25% | 180 Approx. 140 HFO + 63 Portland Cement | Zero burden Assumption Applied to HFO, 2 scenario no replacement 1 | | 1 | 203 | 203 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Portland cement 75% HFO) | | replacement after 5 Years | | | | |
| Biodiversity habitat offsetting | Small additional reed bed | | 4 Reed trays | 200 | 1 | 200 |
| Earth excavation hydraulic excavator | Locally available Equipment | 2012 Bobcat E80 8 tonne zero tail swing excavator. Self-Drive - Operator additional £35 per day | Used over a week to excavate approximately 20m2 | 38000 | 1 | 3800 |

Table B: Costs component parts passive HFO

| **Inputs Passive HFO** | | | | | |
|---|---|---|---|---|---|
| Component Part | Source | Distance from Hebden Beck Km | Cost £ (Excluding VAT) | Delivery Cost £ | Source of Information |
| 3000 L fibreglass tank | Sheffield | 121 | £310.00 | £78.00 | Tanks Direct Ltd Channel House Mart Road Minehead Somerset TA24 5BJ http://www.draytontank.co.uk/ product_details_390.htm Sheffield |
| Pond liner 6 m³ pond | Sheffield | 121 | 1100 | 9 | Flexible Lining Products Limited ,Unit 37 Foxes Bridge Road, Forest Vale Industrial Estate, Cinderford, Glos GL14 2PQ. |
| Wood shavings | Local sourced | 10 | 768 | 0 | http://www.awjenkinson.co.uk/sales/ |
| Limestone sand | Tadcaster Building Limestone, Highmoor Quarry/Warren La, Tadcaster LS24 9NU, | 55 | 45.6192 | | (0.0072) approx. 2kWh/tonne http://www.sciencedirect.com/science/article/pii/S0892687507003603 |
| Alterative LimeX | British Sugar, Newark | 152 | 21.384 | 0 | British Sugar, Newark Sugar Factory, Great North Road, Newark NG24 1DL, |
| PVC half pipe piping | Sheffield | 121 | 28.35 | 9 | KC Plastic Pipes 94A Fairway Avenue West Drayton, Middlesex Country, UB7 7AW |
| PVC half pipe piping | Sheffield | 121 | 28.35 | 9 | KC Plastic Pipes 94A Fairway Avenue West Drayton, Middlesex Country, UB7 7AW |

| | | | | | |
|---|---|---|---|---|---|
| HFO pellets (25% Portland cement 75% HFO) | Whittle | 90 | 13 | 0 | http://www.wickes.co.uk/Lafarge-Blue-Circle-Cement-25kg/p/224661 |
| Biodiversity habitat offsetting | Aylesbury | 335 | 2000 | 50 | Kingspan Klargester College Road North, Aston Clinton, Aylesbury, Buckinghamshire, HP22 5EW |
| Earth excavation hydraulic excavator | Local equipment | 10 | 645 | 0 | Contact: Drew Graham Contracting Ltd (DGC Tree), Tambowie Farm. Milngavie, Glasgow, G62 7HD |
| Limestone | | | 480 | Free Delivery | HILLCREST, Wicker Lane, Guilden Sutton, Chester, CH3 7EL (Delivery free for N Yorkshire) |

Table: Information Semi-passive bio-reactor

| **Inputs Semi-passive bio reactor** | | | | | | |
|---|---|---|---|---|---|---|
| Component Part | Additional Information/Description | Other Comments | Material | Mass kg | Number of Items/total requirements over life time | Total Mass |
| PVC plastic tubing pressure control flow regulator | | | Plastic | 10 | | |
| Pond liners high-density polyurethane | Approx. 1000 $m^2$ Required for each pond | | PVC | 2400 | 2 | 4800 |
| Manure | Bulk density of manure http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex8875 | | Manure | 63797.76 | 2 | 127595.52 |
| Pass 100 compost | http://www.letsrecycle.com/prices/composting/organics-specifications/ | | Compost | 122688 | 2 | 245376 |
| Limestone and sand LimeX | http://www.clydeprocess.co.uk/sitefiles/clydeprocess/pdf/Clyde%20Tested%20Materials%20Index%20G%20to%20L.pdf | Can be sourced from British sugar waste product zero burden assumption | LimeX | 621880.93 | 2 | 1243761.869 |
| Straw | Bulk density of manure | | Straw | 24537.6 | 2 | 49075.2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex8875 | | | | | |
| Limestone gravel | Limestone, pulverized bulk density 1394 kg/m3 http://www.simetric.co.uk/si_materials.htm | | Lime stone | 77082.624 | 2 | 154165.248 |
| Perforated PVC plastic piping | Approx. 625m needed | | PVC | 1000 | 2 | 2000 |
| PVC plastic piping | | | PVC | 10 | 2 | 20 |

Table: Cost semi-passive bio-reactor

| **Inputs Semi-passive bio-reactor** | | | | | |
|---|---|---|---|---|---|
| Component Part | Source | Distance from Hebden Beck Km | Cost £ (Excluding VAT) | Delivery Cost £ | Source of Information |
| PVC plastic tubing pressure control flow regulator | Sheffield | | 28.35 | 0 | C Plastic Pipes 94A Fairway Avenue West Drayton, Middlesex Country, UB7 7AW |
| Pond liners high-density polyurethane | Sheffield | 121 | 44000 | 9 | Flexible Lining Products Limited ,Unit 37 Foxes Bridge Road, Forest Vale Industrial Estate, Cinderford, Glos GL14 2PQ. |
| Manure | Locally sourced | 10 | 23913.9524 | 0 | Woodfield’s Closes Farm, Atlow, Ashbourne, DE6 1PZ |
| Pass 100 compost | Locally sourced | 10 | 22083.84 | 0 | Green Vale products Old Holme Farm, Cemetery Lane , Burnley, Lancashire BB11 5QB |
| Limestone and sand LimeX | Peterborough | 232 | 13992.321 | 0 | http://www.britishsugar.co.uk/Careers/Working-With-Us/Locations.aspx |
| Straw | Locally sourced | 10 | 9815.04 | 0 | Colehay 21 The Croft South Zeal Nr Okehampton Devon EX20 2NZ |
| Limestone gravel | Tadcaster Building Limestone, | 55 | 3699.96595 | 0 | (0.0072) approx. 2kWh/tonne http://www.sciencedirect.com/science/article/pii/S0892687507003603 |

| | | | | | |
|---|---|---|---|---|---|
| | Highmoor Quarry/Warren La, Tadcaster LS24 9NU | | | | |
| Perforated PVC plastic piping | Sheffield | 121 | 5915.7 | 0 | KC Plastic Pipes 94A Fairway Avenue West Drayton, Middlesex Country, UB7 7AW |
| PVC plastic piping | Sheffield | 121 | 28.35 | 0 | KC Plastic Pipes 94A Fairway Avenue West Drayton, Middlesex Country, UB7 7AW |
| Plants for wetland | Aylesbury | 335 | 2000 | 50 | Kingspan Klargester College Road North, Aston Clinton, Aylesbury, Buckinghamshire, HP22 5EW |
| Biodiversity habitat offsetting | | | | | |
| Earth excavation using 500 kW hydraulic excavator | Local equipment | 10 | 645 | | Contact: Drew Graham Contracting Ltd (DGC Tree), Tambowie Farm. Milngavie, Glasgow, G62 7HD |

Table: Information lime dosing

| **Inputs Lime dosing system** | | | | | | |
|---|---|---|---|---|---|---|
| Component Part | Additional Information/ Description | Other Comments | Material | Mass kg Electricity kWh | Number of Items/total requirements over life time | Total Mass/Energy |
| 25 kW air blower | Tsurumi-100TRN424-Submersible-Aerator-400v-PT/100TRN424/3 | | Cast Iron | 470 | 1 | 470 |
| 1.1 kW motor | TEC IE2 Electric Motor 1.1kW 4 Pole Foot Mounted | | Aluminium | 12 | 1 | 12 |
| 1.5 kW pump | Pedrollo HFm70B - 1.5kW, Single Phase Centrifugal Water Pump (HF Series) | | Cast Iron | 25.5 | 1 | 25.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 kW pump | PEDROLLO HF 20A 4" Centrifugal High Flow Pump 4kW - 415v | | Cast Iron | 40 | 2 | 80 |
| 4 kW mixers | M300 Forced Action Mixer 4kW | | Steel | 289 | 2 | 578 |
| Bottom mounted vertical blade turbine | Turbine blade lime mixer vertical blade ACC.07031 | | Stainless steel | 33 | 1 | 33 |
| 55 m³ concrete reactor tank | 60000 Litre Concrete Tank | | Concrete 75mm thick, 3.13cu.m weight 2403kg/cum | 7958.73 | 2 | 15917.46 |
| 360 m³ sludge surplus tank | As above x 6 | | Concrete | 47752.41 | 1 | 47752.41 |
| Earth excavation hydraulic excavator | Excavated material used to create habitat | | | 893000 | 1 | 893000 |
| Ultra-fine lime stone for lime dosing | Material taken away for land filling once spent | Requirements of UFL a Year | UFL | 2421964.8 | 10 | 24219648 |
| Additional Energy | assumed Plant will be Running 24/7 50 Weeks a year allowance for 2weeks maintained | Electricity | | 299040 | 10 | 2990400 |
| Recovery of materials | | Assumed 5% is kept at site for habitat created also losses | Metals from UFL | 2300866.6 | 10 | 23008665.6 |
| Disposal of UFL | Hazardous material Land Fill £65 a tonne | Disposal of Spent UFL assumed truck bring new will take way spent | UFL | 2300866.6 | 10 | 23008665.6 |
| Limestone | HILLCREST, Wicker Lane, Guilden Sutton, Chester, CH3 7EL | Limestone | 20tonnes | 480 | Plus VAT | Free Delivery from Local Quarry for North Yorkshire |

Table: Costs lime dosing

| Inputs Lime dosing system | | | | | |
|---|---|---|---|---|---|
| Component Part | Source | Distance from Hebden Beck Km | Cost £ (Excluding VAT) | Delivery Cost £ | Source of Information |
| 25 kW air blower | Brentwood | 356 | 12375 | Delivery Free | All Pumps Direct Ltd 2 The Brambles, Pilgrims Lane, Coxtie Green Brentwood Essex, CM14 5PR United Kingdom |
| 1.1 kW motor | Rackheath | 342 | 90 | Delivery Free | Bearing Boys Ltd. Unit 8, Mission Road, Rackheath, Norfolk, NR13 6PL |
| 1.5 kW pump | Deeside | 183 | 571.17 | Delivery Free | Collister and Glover, Tenth Avenue, Zone 3, Deeside Industrial Park, Deeside, Flintshire, Ch5 2UA |
| 4 kW pump | Deeside | 183 | 899.78 | Delivery Free | Collister and Glover, Tenth Avenue, Zone 3, Deeside Industrial Park, Deeside, Flintshire, Ch5 2UA |
| 4 kW mixers | Salisbury | 434 | 4140 | 50 | Lime Stuff, Unit 12, Glendale Farm Southampton Road Whiteparish Salisbury, Wilts SP5 2QW |
| Bottom mounted vertical blade turbine | Northampton | 262 | 450 | 75 | Belmar Group 3 Brunel Close Drayton Fields Daventry Northamptonshire NN11 8RB |
| 55 m³ concrete reactor tank | Retford | 126 | 7612.5 | 950 | Direct Water Tanks (Kingfisher Direct Ltd) Retford Enterprise Centre, Retford, Nottinghamshire, DN22 7GR |
| 360 m³ sludge surplus tank | Retford | 126 | 45675 | 2700 | See above |
| Earth excavation hydraulic excavator | Site | 0 | 0 | | |
| Ultra-fine lime stone for lime dosing | Tadcaster | 55 | 581271.552 | to be negotiated | HILLCREST, Wicker Lane, Guilden Sutton, Chester, CH3 7EL |
| Additional Energy | | | 28409675 | | http://www.businesselectricityprices.org.uk/cost-per-kwh/#my-rates |
| Recovery of materials | Leeds | 40 | -161060.66 | | http://www.wrap.org.uk/sites/files/wrap/Gate_Fees_Report_2013_h%20(2).pdf https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/246485/0555.pdf |
| Disposal of UFL | Silverwoods | 50 | 149556326 | 0 | http://www.wrap.org.uk/sites/files/wrap/Gate_Fees_Report |

| | | | | | |
|---|---|---|---|---|---|
| | Waste Management Ltd<br>12 Beverley Dr Clitheroe BB7 1HY | | | | _2013_h%20(2).pdf silverwoodsltd.co.uk |

# Appendix Five **Metals Data**

Table: Ecotoxicity of metals Hebden Beck

| | kg a day from Hebden | HB EU Ave/day | HB EU Geo/day | HB EU Wt/day | HB EU Cent/day | CTU HB EU Wt/Year |
|---|---|---|---|---|---|---|
| Cd | 8.00E-03 | 1.28E+04 | 1.04E+04 | 1.28E+04 | 1.12E+04 | 4.67E+06 |
| Cu | 2.40E-03 | 3.12E+03 | 6.96E+02 | 1.80E+03 | 3.60E+02 | 6.57E+05 |
| Pb | 3.51E-02 | 1.30E+01 | 1.09E+01 | 1.05E+01 | 1.86E+01 | 3.84E+03 |
| Zn | 1.16E+00 | 1.06E+05 | 8.35E+04 | 9.51E+04 | 7.77E+04 | 3.47E+07 |
| Total metals | 1.21E+00 | 1.22E+05 | 9.46E+04 | 1.10E+05 | 8.93E+04 | 4.01E+07 |
| Eco Toxicity 1HFO | | | | | | 1317.93 |
| Eco Toxicity 8 HFO | | | | | | 10543.44 |

Table: Ecotoxicity of Zn, in catchment local to Hebden Beck

| | | Flow L/s | mg/l | Load kg/day | Zinc Ecotoxicity CTUe |
|---|---|---|---|---|---|
| Site | | | Zn | Zn | EU Wt/day |
| Wonderful Level | | 8.90E-01 | 8.11E-01 | 6.23E-02 | 5.11E+03 |
| York Level | | 3.15E+00 | 2.81E-01 | 7.65E-02 | 6.27E+03 |
| Cock Hill Level | | 5.16E+00 | 1.35E-01 | 6.02E-02 | 4.94E+03 |
| Gilfield Level | | 5.40E-01 | 6.31E-02 | 2.94E-03 | 2.41E+02 |
| Eagle Level | | 5.40E+01 | 9.43E-02 | 4.40E-01 | 3.61E+04 |
| Blackhill Level | | 1.18E+01 | 1.02E-01 | 1.04E-01 | 8.53E+03 |
| Perserverance Level | | 4.40E+00 | 7.81E-02 | 2.97E-02 | 2.43E+03 |
| Jackass Level | | 1.10E+00 | 5.02E-02 | 4.77E-03 | 3.91E+02 |
| Devis Hole Level | | 3.12E+01 | 1.12E-01 | 3.02E-01 | 2.48E+04 |
| How Lead Level | | 1.96E+00 | 2.46E-01 | 4.16E-02 | 3.42E+03 |
| Ray Gill Level | | 3.69E+01 | 6.53E-03 | 2.08E-02 | 1.71E+03 |
| Sir Francis Level | | 1.24E+01 | 2.00E+00 | 2.15E+00 | 1.76E+05 |
| Bunton (Bunting) Level | | 2.00E+00 | 1.29E+00 | 2.22E-01 | 1.82E+04 |
| Gunnerside Gill discharge | | 1.00E-01 | 6.79E-01 | 5.86E-03 | 4.81E+02 |
| Spence Level | | 1.09E+00 | 7.38E-02 | 6.95E-03 | 5.70E+02 |
| Hard Level | | 1.22E+01 | 5.41E-01 | 5.68E-01 | 4.66E+04 |
| Victoria Level | | 1.00E-01 | 9.30E-03 | 8.04E-05 | 6.59E+00 |
| Crackpot Level | | 1.00E-01 | 2.91E+00 | 2.52E-02 | 2.06E+03 |
| Billybank Level | | 2.00E-01 | 7.38E-02 | 1.28E-03 | 1.05E+02 |
| Parkes Level | | 4.50E+00 | 9.51E-01 | 3.70E-01 | 3.03E+04 |
| Bolton Gill Level | Hebden | 1.20E+00 | 2.10E+00 | 2.18E-01 | 1.79E+04 |
| Sunken Level | Hebden | 1.00E-01 | 4.55E-01 | 3.93E-03 | 3.22E+02 |
| Yarnbury | Hebden | 8.00E-01 | 6.56E-01 | 4.53E-02 | 3.72E+03 |
| Duke's Level | Hebden | 2.40E+01 | 9.59E-01 | 1.99E+00 | 1.63E+05 |
| Lanshaw Level | Hebden | 1.43E+00 | 5.93E-02 | 7.32E-03 | 6.00E+02 |

# Appendix Six **Additional Information LCIA**

Table: Midpoint Impacts

| LCIA category | Bioreactor | Normalised Bioreactor | HFO | Normalised HFO | UFLS | Normalised UFLS | Unit |
|---|---|---|---|---|---|---|---|
| Acidification | 1.82E+03 | 5.00E-01 | 1.10E+02 | 3.02E-02 | 1.78E+04 | 4.87E+01 | Mole H+ eq. |
| Climate change | 2.83E+05 | 7.76E+01 | 1.68E+04 | 4.59E+00 | 3.66E+06 | 1.00E+04 | kg CO2 eq. |
| Freshwater ecotoxicity | 1.32E+04 | 3.62E+00 | 1.32E+03 | 3.61E-01 | 2.75E+05 | 7.53E+02 | CTUe |
| Freshwater eutrophication | 6.36E-01 | 1.74E-04 | 7.68E-03 | 2.10E-06 | 6.90E+00 | 1.89E-02 | kg P eq. |
| Human toxicity - carcinogenics | 7.54E-02 | 2.07E-05 | 1.38E-02 | 3.78E-06 | 1.20E-03 | 3.29E-06 | CTUh |
| Human toxicity - non-carcinogenics | 4.11E-03 | 1.13E-06 | 6.41E-04 | 1.76E-07 | 7.47E-02 | 2.05E-04 | CTUh |
| Ionizing radiation - ecosystems | 1.37E-01 | 3.76E-05 | 5.01E-02 | 1.37E-05 | 8.77E+02 | 2.40E+00 | CTUe |
| Ionizing radiation - human health | 1.39E+04 | 3.80E+00 | 2.39E+03 | 6.55E-01 | 6.59E+05 | 1.80E+03 | kg U235 eq. |
| Marine eutrophication | 6.41E+02 | 1.76E-01 | 1.35E+01 | 3.70E-03 | 7.10E+03 | 1.94E+01 | kg N eq. |
| Ozone depletion | 1.15E-02 | 3.14E-06 | 1.96E-03 | 5.38E-07 | 1.28E-01 | 3.50E-04 | kg CFC-11 eq. |
| Particulate matter/Respiratory inorganics | 7.79E+01 | 2.13E-02 | 5.90E+00 | 1.62E-03 | 7.12E+02 | 1.95E+00 | kg PM2.5 eq. |
| Photochemical ozone formation | 1.81E+03 | 4.96E-01 | 4.40E+01 | 1.21E-02 | 2.08E+04 | 5.71E+01 | kg C2H4 eq. |
| Resource depletion - mineral, fossils and renewables | 2.86E-01 | 7.82E-05 | 4.36E-02 | 1.19E-05 | 7.38E-01 | 2.02E-03 | kg Sb eq. |
| Terrestrial eutrophication | 7.05E+03 | 1.93E+00 | 1.52E+02 | 4.16E-02 | 7.80E+04 | 2.14E+02 | Mole N eq. |

Table: Endpoint impacts

| ILCD 2011, endpoint<br>Impact category | Semi passive Bioreactor | Normalised Semi passive bioreactor | Passive HFO system | Normalised Passive HFO | UFL for 1 Year Active Lime Dosing | Normalised UFLS for 1 Year | Reference unit |
|---|---|---|---|---|---|---|---|
| Ecosystems - Acidification | 8.04E-06 | 2.20E-09 | 4.89E-07 | 1.34E-10 | 2.49E-05 | 6.81E-08 | PNOF |
| Ecosystems - Climate change | 2.25E-03 | 6.16E-07 | 1.33E-04 | 3.65E-08 | 1.43E-02 | 3.91E-05 | PDF |
| Ecosystems - Eutrophication freshwater | 2.79E-08 | 7.66E-12 | 3.37E-10 | 9.24E-14 | 4.41E-08 | 1.21E-10 | PDF |
| Ecosystems - total | 2.26E-03 | 6.18E-07 | 1.34E-04 | 3.66E-08 | 1.43E-02 | 3.92E-05 | species*year |
| Human health - total | 1.42E+00 | 3.88E-04 | 1.95E-01 | 5.33E-05 | 3.05E+00 | 8.37E-03 | DALY |
| Human health - Climate change | 3.97E-01 | 1.09E-04 | 2.35E-02 | 6.44E-06 | 2.52E+00 | 6.91E-03 | DALY |
| Human health - Human toxicity, carcinogenics | 8.67E-01 | 2.38E-04 | 1.59E-01 | 4.35E-05 | 2.66E-03 | 7.29E-06 | DALY |
| Human health - Human toxicity, non-carcinogenics | 1.11E-02 | 3.04E-06 | 1.73E-03 | 4.74E-07 | 1.86E-01 | 5.09E-04 | DALY |
| Human health - Ionizing radiation | 2.28E-04 | 6.23E-08 | 3.92E-05 | 1.07E-08 | 1.07E-02 | 2.94E-05 | DALY |
| Human health - Ozone depletion | 2.03E-05 | 5.55E-09 | 3.47E-06 | 9.52E-10 | 3.27E-04 | 8.97E-07 | DALY |
| Human health - Particulate matter/Respiratory inorganics | 1.40E-01 | 3.84E-05 | 1.06E-02 | 2.91E-06 | 3.34E-01 | 9.14E-04 | DALY |
| Human health - Photochemical ozone formation | 7.06E-05 | 1.94E-08 | 1.72E-06 | 4.72E-10 | 1.85E-04 | 5.06E-07 | DALY |
| Resource depletion - Mineral, fossils and renewables | 1.42E+06 | 3.90E+02 | 7.53E+04 | 2.06E+01 | 1.14E+07 | 3.13E+04 | $ |
| Resource depletion - total | 1.42E+06 | 3.90E+02 | 7.53E+04 | 2.06E+01 | 1.14E+07 | 3.13E+04 | $ |

# Appendix Seven **Economic Quantification Additional Information**

Table: Expected economic benefits from remediation of Hebden Beck site only for passive HFO system and the semi-passive bioreactor derived from Environment Agency assessments (Environment Agency, 2014c, Environment Agency, 2014f, Shamier et al., 2014)

| **Environment Agency Assessment (Environment Agency, 2014c, Environment Agency, 2014f, Shamier et al., 2014)** | **Low Passive HFO Use Values only** | **Medium passive HFO Use Values Only** | **High passive HFO Use Values Only** | **Low Semi-Passive Bioreactor Use Values only** | **Medium Semi-Passive Bioreactor Use Values only** | **High Semi-Passive Bioreactor Use Values only** |
|---|---|---|---|---|---|---|
| **Hebden site only** | **Passive HFO** | | | **Semi-Passive Bioreactor** | | |
| Initial upfront costs of materials and installation | 5425 | 5425 | 5425 | 126185 | 126185 | 126185 |
| Scoping, feasibility, project management | 895000 | 895000 | 895000 | 895000 | 895000 | 895000 |
| Ongoing costs of monitoring (PV) per annum | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 |
| Reactive media replacement after 5 years | 850 | 850 | 850 | 0 | 0 | 0 |
| Total Cost Year 1 | -913275 | -913275 | -913275 | -1033185 | -1033185 | -1033185 |
| Benefits derived economic value (PV) per annum approximate | 360000 | 680000 | 1000000 | 360000 | 680000 | 1000000 |
| Total Benefit | 360001 | 680001 | 1000001 | 360001 | 680001 | 1000001 |
| Hebden Beck scenario one | -553274 | -233274 | 86726 | -673184 | -353184 | -33184 |
| Year 2 | 354961.02 | 681361.02 | 1007761.02 | 354961.02 | 681361.02 | 1007761.02 |
| Year 3 | 362060.2404 | 694988.2404 | 1027916.24 | 362060.2404 | 694988.2404 | 1027916.24 |
| Year 4 | 369301.4452 | 708888.0052 | 1048474.565 | 369301.4452 | 708888.0052 | 1048474.565 |
| Year 5 | 376687.4741 | 723065.7653 | 1069444.057 | 376687.4741 | 723065.7653 | 1069444.057 |
| Year 6 | 384221.2236 | 737527.0806 | 1090832.938 | 384221.2236 | 737527.0806 | 1090832.938 |
| Year 7 | 391905.6481 | 752277.6222 | 1112649.596 | 391905.6481 | 752277.6222 | 1112649.596 |
| Year 8 | 399743.761 | 767323.1747 | 1134902.588 | 399743.761 | 767323.1747 | 1134902.588 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Year 9 | 407738.6362 | 782669.6382 | 1157600.64 | 407738.6362 | 782669.6382 | 1157600.64 |
| Year 10 | 415893.409 | 798323.0309 | 1180752.653 | 415893.409 | 798323.0309 | 1180752.653 |
| **Total Benefit** | **£2909238.858** | **£6413149.578** | **£9917060.297** | **£2789328.858** | **£6293239.578** | **£9797150.297** |

Table: NWEBS (Environment Agency, 2013) value for remediating the 8 impacted sites over 10 years

| **Passive HFO System**<br>**NWEBS (Environment Agency, 2013)** | **Total NWEBS Low**<br>**Eight Catchments Impacted**<br>**£** | **Total NWEBS Medium**<br>**Eight Catchments Impacted**<br>**£** | **Total NWEBS High**<br>**Eight Catchments Impacted**<br>**£** |
|---|---|---|---|
| **Year 1** | -1049348.943 | 324507.1307 | 1714916.699 |
| **Year 2** | 6284068.078 | 7685401.273 | 9103619.033 |
| **Year 3** | 6409749.44 | 7839109.299 | 9285691.414 |
| **Year 4** | 6537944.429 | 7995891.485 | 9471405.242 |
| **Year 5** | 6668703.317 | 8155809.314 | 9660833.347 |
| **Year 6** | 6802077.384 | 8318925.501 | 9854050.014 |
| **Year 7** | 6938118.931 | 8485304.011 | 10051131.01 |
| **Year 8** | 7076881.31 | 8655010.091 | 10252153.63 |
| **Year 9** | 7218418.936 | 8828110.293 | 10457196.71 |
| **Year 10** | 7362787.315 | 9004672.499 | 10666340.64 |
| **Total Benefit** | **£ 60251909.06** | **£ 75295800.43** | **£ 90520954.58** |

Table: Total benefit expected over 10 years for the Hebden Beck site and for remediation of 8 impacted sites based on Environment Agency assessment (Environment Agency, 2014b, Environment Agency, 2014c, Environment Agency, 2014d, Environment Agency, 2014e)

| Environment Agency Assessment (Environment Agency, 2014b, Environment Agency, 2014c, Environment Agency, 2014d, Environment Agency, 2014e) | Low Passive HFO | Medium Passive HFO | High Passive HFO | Eight Sites Remediated Low | Eight Sites Remediated Medium | Eight Sites Remediated High |
|---|---|---|---|---|---|---|
| **Initial upfront costs of materials and installation** | £5,425.00 | £5,425.00 | £5,425.00 | £43400 | £43400 | £43400 |
| **Scoping, feasibility, project management** | £895,000.00 | £895,000.00 | £895,000.00 | £7160000 | £7160000 | £7160000 |
| **Ongoing costs of monitoring (PV) per annum** | £12,000.00 | £12,000.00 | £12,000.00 | £96000 | £96000 | £96000 |
| **Reactive media replacement after 5 years** | £850.00 | £850.00 | £850.00 | £6800 | £6800 | £6800 |
| **Total Cost Year 1** | -£913,275.00 | -£913,275.00 | -£913,275.00 | -£7306200 | -£7306200 | -£7306200 |
| **Benefits derived economic value (PV) per annum approximate** | £360,000.00 | £680,000.00 | £1,000,000.00 | £2880000 | £5440000 | £8000000 |
| **Total Benefit** | £360,000.00 | £680,000.00 | £1,000,000.00 | £2880000 | £5440000 | £8000000 |
| **Year 1** | -£553,274.00 | -£233,274.00 | £86,726.00 | -£4426192 | -£1866192 | £693808 |
| **Year 2** | £354,961.02 | £681,361.02 | £1,007,761.02 | £2839688.16 | £5450888.16 | £8062088.16 |
| **Year 3** | £362,060.24 | £694,988.24 | £1,027,916.24 | £2896481.923 | £5559905.923 | £8223329.923 |
| **Year 4** | £369,301.45 | £708,888.01 | £1,048,474.57 | £2954411.562 | £5671104.042 | £8387796.522 |
| **Year 5** | £376,687.47 | £723,065.77 | £1,069,444.06 | £3013499.793 | £5784526.122 | £8555552.452 |
| **Year 6** | £384,221.22 | £737,527.08 | £1,090,832.94 | £3073769.789 | £5900216.645 | £8726663.501 |
| **Year 7** | £391,905.65 | £752,277.62 | £1,112,649.60 | £3135245.185 | £6018220.978 | £8901196.771 |
| **Year 8** | £399,743.76 | £767,323.17 | £1,134,902.59 | £3197950.088 | £6138585.397 | £9079220.707 |
| **Year 9** | £407,738.64 | £782,669.64 | £1,157,600.64 | £3261909.09 | £6261357.105 | £9260805.121 |
| **Year 10** | £415,893.41 | £798,323.03 | £1,180,752.65 | £3327147.272 | £6386584.247 | £9446021.223 |
| **Total Benefit** | **£2,909,238.86** | **£6,413,149.58** | **£9,917,060.30** | **£23273910.86** | **£51305196.62** | **£79336482.38** |

Table: Benefits from each 8 selected individual catchment based on Environment Agency assessment (Environment Agency, 2014b, Environment Agency, 2014c, Environment Agency, 2014d, Environment Agency, 2014e)

| **Total Benefit per Catchment (PV)** | | | |
|---|---|---|---|
| **Catchment Name** | **Low** | **Medium** | **High** |
| Gunnerside Gill (Swale) | -546388.4251 | -224876.2936 | 96654.05641 |
| Barney Beck / Hard Level Gill (Swale) | -536281.5215 | -212550.1492 | 111226.1794 |
| Ashfold Side Beck (Nidd) | -493488.5328 | -160360.8164 | 172925.0652 |
| Nidd (Ashfold to Birstwith) | -216065.8468 | 177977.4329 | 572912.8002 |
| Hebden Beck (Wharfe) | -550767.1334 | -230216.4643 | 90340.83943 |
| Wharfe (Barben to Hundwith) | 476490.0684 | 1022602.504 | 1571439.186 |
| Washburn Beck (Wharfe) | -448330.1699 | -105286.7284 | 238034.345 |
| Easton to Worth | 48260771 | 58898131 | 67833247 |
| **Total Benefit** | **£45945939.44** | **£59165420.49** | **£70686779.47** |

# Appendix Eight **Conference Abstracts**

## 8.1 Conference paper abstract; SETAC Europe Glasgow 2013

Integrating Payment for Ecosystem Services into Life Cycle Analysis: Metal Removal from Abandoned Mine Sites

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### 8.1.1 Introduction

Payment for Ecosystem Services (PES) schemes are becoming an ever more popular way in which to encourage responsible land management practices in order to maintain and restore ecosystems for the benefit of humanity [1,2]. Within the UK a best practice guide has been published by the Department for Environment Food and Rural Affairs (DEFRA) based on the principle that a service provider should be compensated for providing a service by those that receive the benefit from that service [3]. This is being used as one strategy to help maintain and restore different UK habitat types of which approximately 30% have been found to be in decline and others in a state of degradation according to be UK National Ecosystem Assessment (NEA) [4]. These habitats provide essential ecosystem services (ES) which, it is being increasingly recognised, need to be actively maintained. Targets have been proposed to restore habitats by bodies such as the European Union in an effort to maintain and prevent the further degradation of vital ES [5].

When designing a PES scheme associated with a contaminated site it is often in response to local risk, or the *primary impacts*. By deploying life cycle assessment (LCA) methodology to determine the *secondary impacts* associated with the production, deployment, use and disposal of different methods of remediation it is possible to determine whether the secondary impacts outweigh the benefits derived from remediating a contaminated site. Through this approach comparisons can be made with alternative methods of remediation to assess which would be most effective locally while also assessing the secondary impacts to determine which method has the lowest impact globally when balanced against benefits achieved by remediating the site and hence protecting local habitat.

### 8.1.2 Approach and Method

Abandoned mines pose interesting environmental challenges given longevity of water pollution and absent or unclear liabilities for remediation in many parts of the world. In the UK, Defra is currently assessing ways to tackle pollution from abandoned metal mines to meet targets associated with major European legislation such as the Water Framework Directive. Given the limited remedial budgets and the remote nature of many discharges, low cost, "passive treatment" (i.e. using only natural energy sources such as gravity, photosynthesis and microbial activity) approaches are being advocated in most situations to deal with the long-standing metal (principally zinc, cadmium and lead) pollution sources. To evaluate the potential suitability of remediation in individual cases, we need to identify (1) the key pollutant sources at a catchment scale, (2) the length of river that can be remediated through investment in treatment at a site, (3) the potential benefits in terms of environmental services and quality improvements that would accrue from such investment and (4) the costs (both monetary and environmental) of installing and managing treatment systems (e.g. in terms of maintenance, handling and disposal of metal-rich solids etc.). This study provides a framework by which we can integrate PES methodologies to assess the benefits of remediation with full LCA for remedial systems. Case studies of two mine-impacted catchments in North Yorkshire will be made based upon current knowledge and research.

1. methods for the removal of metals from waste water
2. the impact of metals on human health
3. the impacts metals have upon different habitats and individual species

Through establishing the ESs, identification of potential purchasers of these services is then viable, enabling a linking of potential purchasers for the ES with those who will be providing the service. Negotiations between these stakeholders to determine how much value each places upon the benefit derived imposes a market value upon the range of services which result from actions needed to remove the metal from the wastewater.

Regulation such as the Water Framework Directive (WFD) also affect the identification of possible stakeholders who would benefit from metal removal from mine sites (e.g. angling groups, local communities). These legal requirements impose a duty upon actors, such as water companies, to comply with these regulations. The cost of compliance with these regulations may be reduced if upstream decontamination is taking place (in minimising potable water treatment for example), giving a quantifiable value to reducing the levels of metal that they are exposed to.

LCA techniques will determine the impacts of implementing the remedial practices identify potential purchasers and provide information for negotiations between the parties about appropriate levels of monetary remuneration and realistic expectations of what can be achieved by the service provider.

### 8.1.3 Results and Discussion

By using LCA techniques to determine the impacts of different remediation methods for specific sites in North Yorkshire integrating PES methodology, for the use phase of the LCA, to identify the potential monetary benefits that can be derived from remediation the specific size is being undertaken so that a determination can be made about;

1. the benefits derived from site remediation outweighed the impacts which result from the production, deployment, and use of different remediation techniques
2. the potential for recovery of the upfront investment and continuing costs related to the remediation method deployed
3. the additional economic value derived from metal removal provided by improvement in the four categories of environmental services (provisioning, regulating, auditing/habitat and cultural services
4. Conclusions

PES provide a useful tool for determining the value of ecosystem services locally to individual stakeholders based upon their willingness to pay. This information can be used to inform cost benefit analyses and life cycle analysis practitioners when assessing the potential for internalising environmental costs associated with specific human activities. This can then give rise to more realistic assessment of different stakeholders' willingness to pay for the different benefits derived from the provision of specific ecosystem services.

Additionally, the monitoring required in order to establish whether or not conditions have been met by the service provider in order to receive payments from the beneficiary will provide an opportunity to improve future LCA models and determine the levels of uncertainty and error present by comparison with a predictive LCA used for a specific PES scheme.

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## 8.2 Conference paper abstract; SETAC Europe Basel 2014

Taking account of expert stakeholder knowledge: constructing a framework to meet WFD requirements using LCSA and PES for metal removal at abandoned non-coal mine sites.

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### 8.2.1 Introduction

A major contributing factor to some UK surface waters failing to meet good ecological and chemical status is pollution (notably Zn, Cd, Cu and Pb) arising from abandoned non-coal mine sites [1]. A requirement of article 4 (1) of the Water Framework Directive (WFD) (2000/60/EC) are the specific targets created for member states to protect and restore aquatic ecosystems. The comprehensive nature of the WFD specifies that member states have to consider the environmental, economic and social ramifications of any actions taken to achieve this improvement, hence ensuring that sustainable water resource management is achieved. Options for addressing legacy sources of pollution can be costly and contentious. Stakeholders who have an interest in a specific site may have conflicting interests and different priorities. In addition, the costs of site remediation are not attributable to any specific party due to a loophole in the UK legislation which means that any metal mine site closed before 1999 does not have any lasting legal liability for environmental clean-up associated with it.

This set of circumstances requires that before site remediation can go forward a number of problems need to be resolved, including; (a) sources of funding for site remediation are identified, (b) sustainable remediation technologies are developed, (c) implications of remediation are determined and effectively communicated to stakeholders (e.g. in terms of length of stream improved, or sentinel species which re-establish), (d) all stakeholders are able to access a feedback mechanism so that their requirements, priorities and opinions can be expressed, and (e) the overall sustainability of the options over their whole life cycle established.

We have developed a framework which integrates life cycle sustainability assessment (LCSA) with payments for ecosystem services (PES) specifically for the task of funding and managing the remediation of abandoned non-coal mine sites, so the affected water bodies are able to achieve a minimum of good ecological and chemical status. During the development of this framework a range of expert stakeholders were interviewed to discover what in their opinion, the requirements and problems that such a framework would need to address, based upon their experiences of mine pollution, stakeholder engagement or broader water resource policy and management. Stakeholders were questioned about what drivers are already in place which prompts their organisation to seek solutions for abandoned mine pollution and what additional measures could be further implemented to induce their organisation to act.

### 8.2.2 Materials and Methods

Stakeholders were identified based upon their sector's interest in or links with, water or metal mining. Stakeholders interviewed were drawn from 3 main areas; industry, government agencies and special interest/conservation/stewardship organisations.

These organisations were contacted initially by e-mail inviting them to take part in this research, of the 38 organisations contacted 12 agreed to a phone interview. Interviewees where asked for their consent for the interview to be recorded, not all interviewees did give permission in which case notes were taken. Interviews varied in length depending upon the interviewees time constraints from 20 min to over an hour. The initial part of the interview established how familiar the participant was with the concept of ecosystem services, the extent of their knowledge and awareness PES schemes and whether they had been involved in any PES schemes. After these points had been established the individual interviews continued, there was a variety of different perspectives, priorities and scope of knowledge depending upon the interviewees own area of expertise, sector and experience.

Interviews were transcribed and these transcripts and notes made from the interviews were analysed looking for similarities, differences, key points, areas of conflict, roadblocks, issues, suggestion and needs, relevant to the framework. This range of opinions and stories, knowledge and experience has been used to construct a list of requirements that the framework needed to tackle in order to be successfully implemented fulfilling the requirements of "*operating within safe planetary boundaries*", sustainably.

### 8.2.3 Results and Discussion

a. Overview

The range of interviews revealed that 3 different sectors, industry, government agencies, and special interest organisations highlighted the different approaches and priorities of each sector. The language used by the different sectors was markedly different, industry for example where preoccupied with effectiveness and efficiency, results and costings. Government agencies tended to use expressions such as benefits, wider catchment, regulation and targets. While the special interest/conservation/stewardship organisations language was around terms such as "conversation" ethical brokers, and liaison.

However, although the priorities of each of the sectors were different it was clear that when asked about what was required in order to move forward with this kind of ecosystem services approach, the majority of the interviewees said that a consistent and reliable framework was needed. Policy was consistently mentioned, as well and the need to educate the public about ecosystem services.

b. Key Points

The industry sector had a pragmatic cost benefit analysis attitude and were very concerned about shareholders, regulatory bodies and complying with external regulation as well as their perceived customer image. It was noticeable that a number of interviewees from this sector mentioned that their customers willingness to pay for perceived environmental measures, even if proven to be more cost efficient, was a definite constraint to their ability to take part in such a scheme. Liaising with other organisations and government bodies was also seen as highly time-consuming, the perception was that this would impinge upon the company's ability to fulfil its primary purpose.

Interviewees from government agencies were very aware of their image and relationships with those organisations and individuals with whom they had to enforce regulation. Often this was seen as a problematic interaction, as they felt that they were viewed negatively and that this attitude got in the way when trying to set up new projects.

The special interest/conservation/stewardship organisations were by far the most diverse group of expert stakeholders. A common characteristic was that they were very focused on a goal, be that preservation of the specific species or improving the environment. Some respondents from this group saw themselves as facilities and ethical brokers, bringing together different sectors for their mutual benefit. This group of stakeholders, overall, felt that they had a good public image. Another characteristic of this group was their wide and varied network of contacts. These contacts came from government, other special interest groups, regulatory bodies, local communities, landowners and industry. Most interviewees felt that they could talk to these different groups and had good relationships with them. One striking comment was that trust was hard-won and once this has been established it is vitally important not to jeopardise it. It may be in the case of mine remediation, such stewardship organisations are best-placed to bring-together and mediate the varied stakeholder interests better than, for example, a governmental regulator where entrenched opinions may limit stakeholder buy-in (e.g. from agricultural land owners).

### 8.2.4 Conclusions

All stakeholders saw the requirement for a clear and rigorous framework to address the problem of remediating abandoned non-coalmine sites. It was acknowledged that applying LCSA methodologies would be vital in order to illustrate what the benefits and consequences of different approaches would potentially be. It was striking how all interviewees recognised the importance of policy and legislation in fact seemed to want more legislation in order to direct their actions towards more sustainable practices.

This shows that there is a need and a desire for LCSA in the real word and that the interaction of legislation and policy is a vital driver towards "*operating within safe planetary boundaries*". This something that LCSA practitioners can take advantage of. By listening to the experiences of experts from different sectors their needs can be taken into account when selecting indicators and approaches so ultimately enabling a more effective communication of results.

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