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A national strategy for identification, prioritisation and management of pollution from abandoned non-coal mine sites in England and Wales. I. Methodology development and initial results

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Abstract

In regions affected by historic non-coal (principally metal) mining activity, government agencies are often faced with the challenge of deploying limited remedial resources at abandoned mine sites to achieve maximum improvements in the chemical and ecological quality of impacted ground and surface waters. As such, strategies for the defensible allocation of public funds require comprehensive and systematic frameworks by which to identify and prioritise polluting sites for remediation. This paper describes the development and initial findings of such a national initiative in England and Wales which allies catchment-scale environmental impact assessments using existing public archive data, with recognition of the uncertainty in impact appraisals arising from disparities in data availability between sites and regions. The methodology identifies polluting sites and takes account not only of the chemical and ecological impacts of mine water discharges on receiving watercourses, but also of socio-economic factors such as conservation and heritage concerns, which can both impede or complement efforts to remediate mine sites. Using a Geographic Information System database and a suite of spatial analyses employing Boolean operators, both the extent of the pollution problem from abandoned non-coal mines in England and Wales (6% of 7815 surface water bodies are affected nationally) and the insight that can be gleaned from systematic analyses of existing archive data are highlighted. The results of the nationwide survey can be used as a dynamic database to inform future remedial planning, in terms of prioritising impacted river basins and abandoned non-coal mine sites themselves for either remediation or future monitoring efforts. As the assessment framework is built upon existing water quality and ecological data and mine site / geological data, there is considerable scope for the approach to be applied elsewhere where the legacy of historic mining persists through the widespread pollution of the aquatic environment.

Keywords: metal mine, pollution, impact assessment, remediation, mine water, catchment

1. Introduction

Drainage from abandoned non-coal (principally metal) mines can be an acute and persistent form of aquatic pollution. The microbially-mediated oxidative dissolution of hitherto unexposed mineral strata (primarily metal sulphides) during and after mining leads to the release of potentially ecotoxic contaminants into surface and ground waters (e.g. Younger et al., 2002; Wolkersdorfer, 2008). These include metals and metalloids such as arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), nickel (Ni), manganese (Mn), lead (Pb) and zinc (Zn) in addition to problems associated with high sulphate concentrations and acidification of water courses where there is insufficient chemical buffering by host strata. In high enough concentrations these contaminants can be of significance to freshwater (e.g. Armitage et al., 2007) and downstream estuarine ecosystems (e.g. Morillo et al., 2008), water resources (e.g. abstractions and water supply infrastructure: e.g. Pawlak et al., 2008), amenity value and in extreme cases public health concerns due to exposure of local populations to contaminant metals (e.g. Garavan et al., 2008). As such, the nature, management and remediation of polluting metal mine drainage has received considerable research attention in recent decades (see Younger et al., 2002; Younger and Wolkersdorfer, 2004 and Wolkersdorfer, 2008 for detailed reviews). In regions where the bulk of the extraction of metalliferous ores was historic in nature, environmental managers are often faced with long-standing pollution problems from sites with unclear or absent legal liabilities for clean-up costs. This is the case in many of the orefields of North America (where there are in the region of 35000 abandoned metal mine sites in the USA and 10000 abandoned mines in Canada), Japan (>5500 abandoned mines), western Europe (e.g. Sweden has at least 1000 abandoned mines; Ireland >100 coal and metal mines: Fields, 2003; Garavan et al., 2008; Wolkersdorfer, 2008), and is certainly the case in the United Kingdom (>10000 coal and metal mines) where the cost burden of remediation often falls with local or national government (Environment Agency, 2008a). Strategies for the systematic identification and prioritisation of polluting sites for remediation based on robust scientific evidence are therefore essential for the effective, defensible deployment of public funds.

This paper presents the method and initial results from a national desktop assessment exercise in England and Wales to identify polluting abandoned non-coal mine sites and prioritise impacted water bodies (river reaches) for remediation planning. Pollution from abandoned coal mines in the UK has been subject to an extensive rolling programme of remediation undertaken by the UK Government's Coal Authority which took on the remit for clean-up from the predominantly nationalised coal mining industry in 1994 (Johnston et al., 2007). However, pollution from non-coal mines (which hereafter refers primarily to base metal and ironstone mines) has until now not been subject to central Government remedial programmes largely due to the fragmented private ownership of the many metal mining operations and the generally much longer timescales since abandonment. Indeed there are very few operational non-coal mine water remediation schemes in the UK, despite the long history of base metal and ironstone mining in the UK and although metal mines were recognised as causing serious pollution as early as the 1874 River Pollution Commissioners report (Palumbo-Roe et al., 2009). The main *loci* of historic non-coal mining activity in England and Wales are portrayed in Figure 1.

The identification and prioritisation exercise reported here is underpinned by recent European Union legislation, the Water Framework Directive (European Commission, 2000), which demands programmes of measures for addressing sources of pollution to achieve long-term improvements in the chemical and ecological quality of both surface and groundwaters (European Commission, 2000). The prioritisation methodology uses archive data to perform a two-stage impact assessment:

(1) national-level data collection and GIS screening to appraise instream pollution in areas of former mining followed by

(2) collation of existing evidence and expert local opinion to assess the nature and extent of pollution impacts by non-coal mines on a range of ecological and water resource receptors.

The assessment framework places great emphasis on the level of confidence these data provide in being able to link polluting abandoned mines with instream water quality pollution. This approach permits prioritisation of river catchments for remediation planning (where there is a sufficient body of information to accurately define the impacts) or further data collection (where additional data is needed to verify the extent and nature of impacts at a site). While some individual metal mine sites (e.g. Wheal Jane: Whitehead et al., 2005), mine-impacted catchments (e.g. River Nent, Cumbria: Nuttall & Younger, 1999 and River Tamar, Cornwall: Mighanetara et al., 2008) and indeed regions in the UK (e.g. Wales: Environment Agency Wales, 2002) have been subject to intensive investigations and data collation exercises, there are clear disparities between data availability in different River Basin Districts (RBD; Figure 1). Since there are limited public funds for monitoring and remediation, the impacted rivers must be prioritised so that an overarching national strategy for addressing the problem can be developed to reap maximum improvements in environmental quality.

Site inventories and assessments of environmental impact have been applied to mine water pollution at the catchment-scale in many parts of the world (e.g. Kimball et al., 1999; Fuchs et al., 2002; USGS, 2004; Younger and Wolkersdorfer, 2004; Clark et al., 2008), however river basin scale and national strategies for such targeted remediation of metal mine sites have been reported in only a few cases (e.g. Neitzel et al., 2002; Hurst et al., 2005). National impact assessment and prioritisation strategies have been previously described for abandoned coal mine drainage (e.g. Davies et al., 1997; Jarvis and Younger, 2000). These integrate a suite of chemical and ecological indices while putting great emphasis on the visual impact of the discharges (e.g. survey of the length of water course impacted by Fe precipitates). Significantly, however, the impact assessment and prioritisation exercise undertaken in the UK for coal mine drainage did not assess *all* coal mine water discharges (Environment Agency, 2008b). Rather, expert opinion was used to select a fraction of discharges in each geographical region of the UK which were considered to be most damaging to the environment. Thus, a manageable subset of all discharges was subject to more detailed investigation of impacts and subsequently prioritisation. Furthermore, the visual discoloration evident below many coal mine water discharges, which formed the crux of the prioritisation methodology for coal mine waters, cannot be invoked for discharges from abandoned non-coal mines, since the visual impact can often be minimal or absent where the mineral veins are poor in pyrite. Thus, in the case of abandoned metal mines a more sophisticated impact assessment procedure is required, with the capability of objectively evaluating impacts on water quality and ecology from all known mine sites, and without relying on physical discolouration.

Approaches to environmental impact assessment typically focus on individual sites, and rely upon assessment of that sites' impact by comparison to regional, national or international standards i.e. comparison of actual contaminant concentrations against regulatory standards in the case of water pollution. As Troldborg et al. (2008) point out, this is useful for assessing whether a particular contaminated source poses a risk to a specific receptor, but traditional site impact assessment approaches are typically too confined in scale to a single relevant downstream receptor. As such, it does not permit prioritisation of sites across catchments because they have each been assessed separately with different definitions of receptors. In assessing and prioritising the impacts to groundwater resources by contaminated sites Troldborg et al. (2008) therefore propose impact assessment at catchment scale to prioritise individual sites, one of the key motivations for which being that limited resources need to be wisely apportioned, and therefore targeted appropriately. In the case of abandoned non-coal mine sites similar resource limitations exist, and therefore the need for prioritisation is the same. Previous studies such as the Metal Mine Strategy for Wales (Environment Agency, 2002) have identified all abandoned mine sites and in the absence of data on their environmental impact, these mines have been ranked on the basis of size of ore production and similar criteria. Identifying all abandoned mine sites in a country where mineral extraction has taken place over 2000 years is not trivial, yet it does not help identify the sites which are causing the greatest environmental impact. Therefore for this project we wished to go one step further and perform the impact assessment at a national scale to prioritise individual catchments, and then identify the main culprit mine sites within those catchments.

Inevitably as the geographical scale of impact assessment increases the resolution of the assessment can be compromised. Therefore, a key objective in developing a methodology for the prioritisation of abandoned non-coal mines was to use sufficiently detailed information in the assessment to enable a ranking of affected sub-catchments that was of suitable resolution to be operationally useful i.e. it should be possible to make distinctions between water bodies in terms of the level of impact. Furthermore, to ensure that the impacts in different water bodies were directly comparable, the basis of impact assessment had to be nationally consistent. For this reason the categories of impact used in the methodology are operationally defined, as discussed in detail below.

In addition, while impact-based decision making, informed by robust scientific insight, is typically employed in environmental management, socio-economic factors can be an overriding driver for remedial efforts (e.g. Jarvis and Younger 2000). For example, Younger et al. (2005) document the basis for remedial works at the former Wheal Jane tin mine in Cornwall, England following a major mine water outbreak in 1992. While scientific investigation into the nature of the impacts was necessary to inform remediation planning, the principal remedial driver was found to be the public perception of a negative effect of the outbreak on local commercial seaweed harvesting due to discolouration of the receiving Fal Estuary waters by iron in the mine water. This perception existed despite scientific evidence suggesting the integrity of the seaweed was not affected by the mine water release, although there was a significant impact on water quality until the discharge was treated. Furthermore, there can be important heritage issues associated with former mining areas that may also have a strong influence on approaches to remediation and limit remedial options. These can range from national built environment designations (e.g. listed buildings and scheduled ancient monuments) up to international designations (e.g. Cornwall and West Devon Tin Mining district UNESCO World Heritage Site, UK) which may have a bearing on any site remediation civil engineering works. Any natural environment designations can be an equally important consideration for remediation. For example, a downstream protected estuarine ecosystem (e.g. Ramsar or Natura 2000 site) may be adversely impacted by ongoing metal input from upstream mining areas and thus a converging force for upstream remediation, whereas the colonisation of leachateproducing waste rock heaps by rare bryophytes (e.g. Pearce, 1993) may prevent capping of the spoil. As a result it was necessary for the second part of the assessment exercise to collate information on stakeholder issues at abandoned mine sites, and identify where these are convergent or divergent with potential remediation initiatives. This provides environmental managers with a list of priority water bodies, while garnishing them with sufficient mine site specific information that is crucial in underpinning site remediation.

2. Method

2.1. Phase 1 – national identification of non-coal mine pollution

The first phase of the methodology comprises a precautionary assessment of all surface water bodies across England and Wales with regard to former non-coal mining activity and current metal pollution problems (Figure 2). This took place in a Geographic Information System (MapInfo v9.51) and used a number of Boolean operators to describe mining history, water quality impacts and their spatial inter-relation. Resultant categories were then defined to describe the impact of the water pollution problem being associated with former non-coal mining activity. There are 7815 water bodies (or sub-catchments) across England and Wales that form the basic management and reporting units for the WFD, ranging in area from 0.01 km^2 (a small number of minor catchments discharging directly to the sea) to 249 km^2 with a mean catchment area of 19.5 km^2. Across these sub-catchments there are 4222 ambient water quality monitoring stations maintained by the national environmental regulator: the Environment Agency of England and Wales for legislative compliance and reporting purposes, in addition to data from numerous (>50000) spot sample locations that are held on the Environment Agency national water quality archive over the period 1999-2004. As such there is a good geographic coverage of instream water quality data across much of England and Wales by which to identify the potential signal of non-coal mine pollution.

The first stage of the spatial analyses identified water bodies within which there was a potential for or evidence of former non-coal mining activity. Evidence of potential for, or former mining encompasses::

(1) a database of known abandoned non-coal mine sites collated by the Environment Agency from various regional mining assessment exercises and public archive data listing the co-ordinates of 4706 sites which were screened against location within each of the water body polygon using a spatial join procedure
(2) a shapefile of mineral veins from 1:50000 scale British Geological Survey (BGS) base maps and
(3) relevant economic geological strata from BGS base maps. Geological strata that were deemed relevant include metalliferous minerals, ironstone, Greensand (workings with known metal problems in discharge waters), and other strata listed as economically exploited in the BGS memoirs.

Where one or more of the above three features was present within the boundary of a water body, the water body was thereafter delineated a former “mining area” (see Figure 2).

These mining areas were then screened against statutory surface water quality failures (Environmental Quality Standards – EQS) of 8 metals/metalloids commonly associated with metal mine drainage (As, Cd, Cu, Fe, Pb, Ni, Mn, and Zn – Table 1) both within the host water body and in the immediately downstream water body. The screening for the presence of water quality failures in downstream water bodies serves as a spatial buffer to link recorded pollution issues with mining areas where there is no water quality data from the upstream water body. The downstream water body screening was chosen as opposed to a set buffer zone (e.g. failure within a 10 km radius of water body boundary or mine site: Environment Agency, 2008a) as it has a firmer physical basis in linking downstream receptors than the buffer radius approach which could inappropriately link a mine site with a water quality failure in an adjacent, hydrologically unconnected catchment.

The impact categories produced from this screening of metal pollution and non-coal mining activity grade from Impacted where water quality failures are coincident in a water body with former mine sites to catchments where the quality failures are either not associated with any former mining areas, or there are no reported water quality issues (Not Impacted sites). The impact categories prefixed "probably" are there to indicate uncertainty in the nature and extent of the link between mining and pollution. A Probably Impacted site describes a water body where there is a pollution problem but uncertainty persists as to whether the mining activity and downstream pollution issue are explicitly connected, either due to distance between source and receptor, or where there are no recorded mine sites in a former mining area. For example elevated metal concentrations could be due to industrial effluent discharges or occur through the release of metals from atmospheric fallout (e.g. Rothwell et al., 2007). Probably

Not Impacted water bodies are those in mining areas where there is no water quality concern either in the host or downstream water body. The upper portion (Phase 1) of Figure 2 presents a schematic depiction and conditions required for the formulation of these impact categories.

A crucial component of the prioritisation exercise is that it is designed to be dynamic, not least because no additional data collection or site visits were possible within the budgetary and time constraints of the project during which this strategy was developed. There is therefore no assumption of completeness of any of the datasets being used, and data addition during phase 2 (and beyond) will permit future changes in impact category. For example, the addition of a mine site from hitherto un-consulted mining records, or the addition of a new water quality failure as a result of more targeted monitoring regimes, could lead to an adjustment of impact category. Equally, as phase 1 is designed to be precautionary (to ensure data-poor regions are not eliminated from the prioritisation), phase 2 integrates local expert knowledge to permit down-grading of impact status to Probably Not Impacted if the pollution issue is known for certain to be associated with a source other than abandoned non-coal mines (Figure 2).

2.2. Phase 2 – validation and prioritisation of impacted water bodies

After the identification of water bodies that may be impacted by pollution from abandoned non-coal mines, and division of them into the 4 impact categories described above, phase 2 of the methodology integrates an array of archive data with expert local opinion from contaminated land specialists, aquatic ecologists and hydrogeologists in each of the 11 RBDs in England and Wales to validate and weight the severity of the mine-related pollution in each impacted water body. Only sites which fall within the Impacted and Probably Impacted categories are carried forward for this phase of prioritisation. A scoring system was devised based on four key indices (which are discussed in more detail below):

(1) the severity and number of concurrent EQS breaches
(2) impacts on ecology
(3) impacts on groundwater quality and
(4) any higher impact (e.g. abstractions, recreational or commercial fisheries).

In addition, the second phase collates existing summary information on mine sites and discharges into a single national database as a prelude to future remedial scoping studies.

An internet-hosted questionnaire was used as the medium for obtaining the responses from regional experts at the Environment Agency in a consistent format which was then converted to a numeric score. These regional experts encompassed environmental scientists, hydrogeologists, chemists and biologist/ecologists who undertake day to day investigations of river quality and health and know local catchment pressures intimately (Table 1). The bulk of these respondents were in RBDs that were centres of former non-coal mining, with the largest number in the large Humber RBD where sub-regional divisions in geographical management units led to numerous respondents. Additionally, specialists with knowledge of mining impacts who are present in all of the main former mining regions were identified before the questionnaires were sent out which maximised the likelihood of gathering accurate data on the impacts of non-coal mines on water quality and ecology. The questions posed were designed to accommodate limited responses (e.g. question: “Do you know of any discharges from abandoned mines in this water body?” responses: “Yes,” “No”, “Suspected” or “Unknown”), with criteria clearly given to ensure consistent response between users (Table 3). Adjacent text fields were provided next to each question for citation of reference sources or further information, all of which is held in the geodatabase for future reference. The questionnaire also provided an avenue for any hitherto unidentified impacted water bodies, that the geological screening and mine site assessments may have overlooked, to be identified by local experts. As the geological screening was precautionary in identifying all potentially economic non-coal mineral strata in the UK, there was only one case nationally where a water body was incorrectly categorised as Not Impacted, until the regional surveys highlighted pollution from a small band of worked ironstone that was not represented on the 1:50000 digital geological maps due to issues of scale.

2.2.1. EQS failure

The database detailing all the statutory failures of Environmental Quality Standards (EQS) for eight metals / metalloids over the period 1999 to 2004 provides a detailed account of the location and average contaminant concentrations at sites in breach of aquatic-life standards. While these data do not represent the full range of contaminants arising from abandoned non-coal mines (e.g. Al, Hg, Mo, S, Sb and H^+ may affect receiving streams), they do cover the most commonly encountered metals / metalloids at sites in the UK and crucially those for which data are routinely collected and for which EQS are prescribed. For example analyses of Sb and Mo are not routinely undertaken so such datasets are of little value in a systematic national assessment. Furthermore, in the isolated cases where elements such as Hg are present (only one site in the UK is known to the authors where it was used for gold extraction) many of the assessed contaminants are present and are of greater concern. In the rare occasions where pollution from non-coal mines may not be characterised by metal / metalloid release (e.g. a gypsum mine may produce elevated sulphate loadings in site drainage) the regional assessment provided the opportunity for local experts to highlight any anomalous situations that may have been systematically overlooked by the national screening exercises.

A scoring system was devised to convert the extent of any EQS breach (after adjustment for the relative hardness of the waters where appropriate) and number of concurrent failures in an impacted water body into a simple numeric score. The extent of the breach was scored by the order of magnitude of the failure in three bandings (concentration: >1×, >2×, >5× EQS), which gives a maximum possible score of 24 for a water body failing all 8 metal EQS by at least a factor of 5 (Table 1). The highest EQS score of 19 was recorded in 3 water bodies in the Western Wales RBD where there were concurrent and considerable failures of all EQS except As. These EQS scores are subsequently converted to a classified EQS score to be used in combination with other categories of impact to generate an overall score. This is discussed further in the Mining Impact Score below.

2.2.2. Ecological Impact

Systematic ecological assessment of surface waters across England and Wales is undertaken by the Environment Agency under the auspices of the General Quality Assessment (GQA) for biology. There are 5979 GQA monitoring points across

England and Wales which employ the River Invertebrate Prediction and Classification System (RIVPACS) to assess the macro-invertebrate assemblage at a point over time and assess the deviance in this community away from a reference, unpolluted site of similar hydro-morphic condition (Wright et al., 1993). While this method is designed primarily to identify ecological perturbation in response to organic pollution, where there are wholesale changes in aquatic ecosystems owing to metal pollution, the RIVPACS tool is sensitive to identify such changes (e.g. Armitage et al., 2007). The GQA biological assessment gives a grade for each sample site from 'a' (very good) to 'f' (bad). In the abandoned non-coal mine national screening described here, Impacted and Probably Impacted water bodies which scored less than 'c' (fairly good) were given a "Suspected" classification with regard ecological impact of mine pollution (Table 3). Given the research efforts required to determine causality between metal pollution and ecological response in catchments where there may be multifarious sources of pollution (most notably agricultural pollution in the upland settings that many of the former metal mining regions are located), only where there was firm evidence of mining-induced ecological impact from intensive local surveys was ecological impact graded as "Yes" in priority water bodies. This ecological impact can encompass a range of factors, from absence of salmonids in rivers with suitable spawning habitats, to changes in physical characteristics of stream substrates due to release of fines from mine sites.

2.2.3. Groundwater Impact

Contaminant impacts on groundwater are a crucial component of reporting for the WFD. However, one feature of the initial delineation of groundwater bodies for WFD reporting purposes in England and Wales has been that they are very large and traverse many surface water bodies. Whilst this delineation is effective for relatively homogenous aquifers, groundwater bodies in most non-coal mining areas contain multiple geological units, each of which may exhibit distinct baseline quality. In addition, groundwater quality in metal mining areas is spatially very heterogeneous due to the localised influence of the mining activities. Therefore spot sample data from individual boreholes may not be truly representative of the heterogeneity of water quality across a groundwater management unit. Previous WFD mining characterisation exercises in England and Wales (Environment Agency, 2008b; Johnston et al., 2007) have used EQS failures of metal contaminants in mine waters at point of surface discharge as an indicator of poor status of the host groundwater body. For consistency, a similar approach was adopted here; groundwater impact acquired an affirmative response if there were EQS failures in point mine water discharges (Table 3). However, given that this failure at discharge point may not be representative of water quality across larger geological units, the maximum weighting attached to groundwater impact was lower than other categories of impact, as discussed in section 2.2.5. In addition, the EQS of one or more contaminants can be exceeded in groundwaters of undisturbed mineralized geology whereas the primary pollution concern is in the metal load from groundwater discharge to surface waters and not the metal concentration.

2.2.4. Higher Impact

The Higher Impact parameter covers various other issues and potential receptors of non-coal mine pollution. These receptors typically have some economic value, such as downstream ground and surface water abstractions (as distinct from deterioration of groundwater quality *per se*, which is covered by Groundwater Impact – section

2.2.3) or recreational and commercial fisheries. National screening exercises were performed to highlight impacted water bodies in which there were known abstractions or Source Protection Zones (SPZs) which are areas delineated by the Environment Agency to protect potable water supplies against polluting impacts of human activity. The regional assessment exercise also yielded a range of responses from local environmental managers as to particular sensitivities in impacted water bodies which also fed into scoring the catchments. These included downstream impacts on industrial abstractions, aesthetic impacts of shoreline ochre staining in coastal areas of high amenity value, impacted fisheries and the presence of downstream sensitive, designated conservation sites (e.g. Ramsar wetlands). The responses were again limited to the Yes-Suspected-Unknown-No choices with opportunity to populate data sources and details in an adjacent open text column.

2.2.5. Mining Impact score

Evaluation of the above criteria gives a range of alpha-numeric responses for each impacted water body: a score between 1 and 24 for EQS failure, and a Yes-Suspected-Unknown-No response for each of the other three criteria. To attain a single overall summed value to represent Mining Impact on the various receptors, an approach for converting these responses into a single numeric score was devised. In any impact assessment exercise weighting of an individual criterion ahead of others can contain a degree of subjectivity between observers and thus requires systematic justification. Of the four criteria assessed, the statutory failures for the eight metals listed above (EQS failures) are the main driver for identifying and prioritising polluting sites and thus greater weight in the final priority is assigned to it. There are three reasons for this:

(1) while EQS failure in a stream does not necessarily guarantee impacted aquatic biota (given differing sensitivities and exposure of receptors between sites), the EQS dataset is very comprehensive and provides the best coverage of all the national datasets at spatial scales relevant to the individual water body management units, i.e. there are very few situations where there is not water quality data across any given two linked water bodies (hence the downstream impact assessment in phase 1)

(2) the instream water quality monitoring points are typically near the outlets of sub-catchments at scales in the order of 10-30 km^2 –if there is an EQS failure in such relatively large streams then it implies a significant contaminant flux must be entering upstream for dilution / instream attenuation effects to have not sufficiently lowered contaminant concentrations below EQS thresholds, and

(3) with the ecological, groundwater and higher impact criteria, in most cases there exists some uncertainty of the nature, scale and source of the impact, e.g. ecological surveys will reflect a complex array of environmental variables to which mining pollution may contribute, whereas the EQS data provide evidence of an actual impact on the chemical quality of a water body that is known to be mining related since non-mining related pollution will have been identified via responses on the internet-hosted questionnaire (see Section 2.2). Equally, the presence of an abstraction may elevate Higher Impact scores but it is more indicative of potential sensitivities, as opposed to certain impact on a particular receptor.

Given these factors, a higher weighting for impact scores in the EQS data was given than in the other three categories (Table 4). The maximum EQS failure score is given double the weight of the maximum ecological and higher impact criteria, and over three times the weight of the maximum groundwater impact. The sum total of the scores is used to produce a ranked list by which to prioritise impacted water bodies for remediation planning.

2.2.6. Mine site information

During the regional assessment stage of phase 2, a suite of relevant mine site information was collated from end-users at the Environment Agency via the online questionnaire and literature review. The form and extent of data requested is presented in Table 5. While some subjectivity in response is inherent in such data collation exercises, efforts to minimise this were ensured by constraining response categories (e.g. “Yes”, “”Suspected”, “Unknown” and “No”) and through providing example criteria for each case. This information covers multifarious issues associated with mine site pollution from the impacts on the water environment which are the main focus of this study, to issues of airborne pollutants and geotechnical hazards associated with waste rock heaps. A crucial component of the methodology is linking the catchment or water body scale screenings with identification of the polluting mine sites within them. The information provided in Table 5 provides this connection through obtaining basic mine site details, summary water quality data, and highlighting whether there are likely to be issues of diffuse mine-related pollution (e.g. direct groundwater-surface water discharges, spoil heap runoff, contaminated fluvial sediments that can be remobilised: see Mayes et al., 2008; Environment Agency, 2008c) that may constrain the effectiveness of point discharge remediation. This information also extends to whether there are known stability issues at the mine site, or risk of mine water outbreak (in this work ‘outbreak’ refers to mine sites at which a sudden release of (polluted) water may occur, typically because a large volume of water has built up behind a blockage in the abandoned workings; failure of the blockage could result in sudden release of the head of water to the surface environment). Some of the solid waste inventories gathered as part of this project will also assist in meeting the demands of the EU Mining Waste Directive (European Commission, 2006).

3. Initial Results and Discussion

3.1. Phase 1 – national screening

Figure 3 shows the categories assigned to each of the water bodies in England and Wales with regard to impact of abandoned non-coal mine pollution resulting in non-compliance of surface water quality standards. In total, 224 water bodies fall within the Impacted category, with 241 in the Probably Impacted category. The main *loci* of these priority water bodies are in the mining areas of the south west of England, North and Western Wales, the Lake District and the Pennine orefields (Figure 3). The Western Wales RBD reports the highest number of Impacted water bodies with 70, followed by the South West (58), then the Severn (31) and Northumbria RBDs (27). A significant number of Impacted water bodies are also present in the Lake District area of the North West RBD (14), the Yorkshire and South Pennine Orefields of the Humber RBD (13) and in the Minera-Halkyn area of the Dee RBD (8).

Table 6 displays the overall impact scores and presents summary information from the top 30 Impacted water bodies in the prioritisation. An encouraging validation of the methodology is that many of the well-studied and notorious polluting non-coal mine sites in the UK occur towards the top of the prioritised list. A large number of the top priority water bodies are situated within Wales, where 10% and 15% of water bodies in Western Wales and Dee RBDs respectively fall within the top two impact categories.

Table 7 displays summary water body information and scores for the top 30 Probably Impacted water bodies. These are again situated predominantly in the orefields of Western Wales, the Pennines and the South West, but with a far greater representation by those in the Northumbria, Humber and Severn RBDs. The solitary Probably Impacted water body in the Anglian region is associated with drainage from an ironstone mine in Northampton in the River Ise catchment. It is also apparent that many of the top priority Probably Impacted water bodies score similar scores to those in the Impacted category. One of the scenarios for discriminating between these two categories is the certainty regarding the link between former mining activity and current instream water pollution issues. In many cases for Probably Impacted water bodies it is known that abandoned non-coal mines are present but not if they are the specific cause of the downstream pollution. The large numbers of Probably Impacted water bodies in some upland mining settings may in large part be an artefact of the density of the monitoring network. Ambient water quality monitoring is limited in extent due to economic constraints at environmental regulators, with the focus for monitoring often being on 2nd, 3rd or even higher order channels. As a result many headwater catchments in mining areas with known mine sites (some of which are known to be polluting) do not have instream monitoring points and so are classed as Probably Impacted due to the water quality failures being reported in a downstream water body. The Northumbria region illustrates the point, with the average catchment area of the Impacted water bodies (53 km^2) being far greater than that of the Probably Impacted water bodies (20 km^2) which include many small headwaters that are not routinely monitored. Indeed there are several tributaries of one of the main drainage streams from the North Pennine orefield, the River Wear, which are Probably Impacted (e.g. Middlehope, Stanhope and Burnhope Burns), contain known polluting sites but no instream monitoring data, suggesting that more targeted monitoring may be required to assess the severity of any pollution in the mined headwaters. This serves as a good illustration of why the prioritisation approach must be dynamic, allowing for amendments to the categorisation as more targeted future data become available. It also demonstrates how the prioritisation results can be useful to environmental managers when allocating scarce monitoring resources.

Figure 3 also shows a large number of Probably Not Impacted water bodies along the ironstone formations from eastern to central England and the Upper and Lower Greensand Formations of the London Valley, where pollution issues have been found to not be mining-related given the predominance of urban areas (and their associated metal sources such as urban / highways runoff and sewage discharges).

3.2. Phase 2: Mine sites

The exercise identified an additional 202 mine sites reported by respondents via the online questionnaire to the 4706 listed in the original mine site database. Of this total of 4908, there are 257 mine sites at which the Environment Agency has documented the presence of a water discharge containing elevated (above EQS) concentrations, with an additional 81 sites where polluting discharges from mines are suspected to exist. Table 5 provides summary mine site details that fall within selected priority Impacted water bodies. This provides crucial data to link impacted water bodies with mine discharges themselves. An important note here is that for some of the high priority Impacted water bodies there are multiple mine sites and discharges for which data have been collected. For example, in the top priority Rheidol catchment there are 22 discharges for which summary information has been added to the database. A selection of this information for the Cwm Rheidol site is presented in Table 5. In most of the top ranked Impacted water bodies numerous mine discharges have been identified and are in some cases well-characterised in terms of water quality and flow rates.

A range of useful information is also compiled in the mine site data which will assist in focussing remediation planning and future monitoring design. For example, there are 187 mine sites which reported a “Suspected” or “Yes” for the possible impacts of diffuse metal pollution in their vicinity, which primarily centred around large expanses of riparian waste rock that are actively eroding. Of the solid waste and outbreak issues, there are 79 mine sites nationally that returned a ‘Yes’ or ‘Suspected’ response for whether there was a suspected threat of mine water outbreak, there are 384 sites where airborne pollution was cited to be a possible concern, and 75 sites where there is thought to at least some likelihood of geotechnical hazards predominantly associated with adit or spoil heap collapse. Unfortunately for the vast majority of these mine site hazards there is insufficient technical information available at present to be able to carry out conventional risk assessment of the hazards (i.e. impact and likelihood of an event such as minewater outbreak or tailings collapse). As such, this exercise served as an inventory of sites where there were concerns about the various abandoned mine hazards to inform future more detailed site specific studies and do not feed directly into the current scoring system. Stakeholder issues were also highlighted as a concern at 75 mine sites. Where detailed responses were received it was observed that at 16 of these sites, stakeholder concerns were detailed to be explicitly diverging, largely due to mining heritage issues and metallophyte-based nature conservation sites. Eight sites had issues that were explicitly converging to remedial efforts (e.g. sensitive downstream ecosystems, amenity value was impacted, or site landowners were keen for remedial efforts) and at least 5 sites had a mix of both converging and diverging issues. In addition, there were 32 sites where the environmental regulator had received public complaints about the mine discharge.

3.3. Utility of prioritisation method to inform environmental management

This combination of systematic analyses of extensive environmental archives coupled with local expert knowledge and documented impacts of mining-related pollution on a range of receptors provides a national assessment of which watercourses are most severely impacted by pollution from abandoned metal mines. Approaches to the remediation of hard rock mine sites in some parts of the world have demonstrated that detailed characterisation of mining impacts at the catchment (watershed) scale is very expensive and can be unsuccessful if detailed site investigations and remediation are carried out without a clear understanding of which individual mine sites are most polluting (e.g. USGS, 2004). Very limited resources are available for monitoring investigations and remediation at abandoned mine sites in the UK (and many other mining regions around the world) and there are disparities in data availability and resolution to accurately describe mine pollution impact on a site specific basis. Through implementation of the impact assessment framework presented here, a more cost-effective approach is offered to objectively determine the water courses that are most impacted, at scales at which environmental archives are sufficiently detailed to overcome site-specific data discrepancies and at the scales at which river basin management is typically conducted. The impact categories formulated also offer environmental managers clearly defined objectives for future management efforts. For the large number of Probably Impacted catchments, the uncertainty between linking abandoned mines and instream pollution needs resolving. Therefore the priority in the higher scoring Probably Impacted catchments would be to confirm the sources of metals, and if necessary, collect additional water quality data. Collecting new metal concentration data in these rivers where abandoned mines were present would allow water bodies to be re-categorised either to Probably Not Impacted (if no EQS failures are identified) or to Impacted (if EQS are exceeded) categories by environmental managers. The facility for data addition and re-running the prioritisation method is essential not just for targeted monitoring in Probably Impacted catchments but also to account for any other changes over time in water quality or ecology (e.g. more EQS failures of dissolved metals in some areas if waters become more acidic, updated routine ecological surveys).

Even for the case of the priority Impacted water bodies, with very few exceptions, there is not sufficient available monitoring data in any water bodies to allow remediation measures to be immediately designed and implemented. The top ranked Impacted water bodies are therefore recommended for scoping and feasibility studies to identify remedial options. These should include more targeted catchment monitoring programmes, such as the loadings-based exercises detailed by Kimball et al. (2005) and Mayes et al. (2006; 2008). Such approaches are able to discern the primary contaminant sources of instream metal loading at which to target remedial efforts and can also ascertain the relative contribution of point and diffuse pollution as well as other non-mining sources to instream pollution.

At the stage of catchment scoping studies and subsequent treatment feasibility assessments, the range of information collected in the database becomes crucial to environmental managers. Stakeholder engagement is essential when considering the form of remedial scheme (e.g. large chemical treatment plants may be unsuited to remote upland sites with multiple conservation and heritage issues), while an awareness of the multifarious mine site details collated in the database may highlight potentially converging forces to remediation and greater cost-effectiveness. For example, at some tailings facilities and waste rock dumps there may be multiple benefits of reclamation in terms of minimising geotechnical hazards, diffuse pollution input from metal-rich fines in addition to preventing infiltration through the mounds and the generation of polluting mine drainage. The range of issues collated in the database therefore arm environmental managers with a range of site-specific data that can be assimilated to ultimately inform cost-effective remedial action.

4. Conclusions

Drainage from abandoned metal mines is a widespread form of water pollution in England and Wales. The outcomes of this work have provided the UK Government, environmental regulator, and other concerned groups with the most definitive objective assessment of the scale of this problem in England and Wales to date. Particularly because of the absent or unclear liabilities associated with abandoned metal mines, pollution from them is likely to become an increasingly limiting factor to legislative compliance with statutory water quality standards as other pollutant sources are addressed (e.g. sewer discharges). The systematic analyses of national instream and groundwater data overcomes the disparities in quality and availability of data that exist when focussing solely on data from polluting mine sites themselves. This approach also highlights where there is insufficient available information and prioritises catchments for further investigations. An initial national assessment has revealed some 465 water bodies out of 7815 across England and Wales that appear to be impacted by pollution from non-coal mines. Of these, 224 fall within the top Impacted category where, due to coincidence of former mine sites and instream metal pollution in relatively small catchments and the lack of other known major sources of metal pollution, there exists a high degree of confidence that mining activity is significantly contributing to the instream pollution. A larger number of water bodies (241 in total) fall within the Probably Impacted category, which reflects the greater degree of uncertainty that instream pollution and former mining activity are related; this is due either to spatial separation of polluted stream reaches and mining areas or incomplete mining records in remote locations. A total of 4908 former non-coal mine sites are recorded in England and Wales, of which 338 are known or suspected to discharge polluting waters. A scoring system based on the recorded chemical, ecological, groundwater and higher impact in affected water bodies showed many of the top ranking rivers to be located in the main metal mining orefields of Western Wales, South West England and Northumbria. The methodology is founded on commonly held archive data and as such could be transferable to many other geographic locations, particularly those in Europe where there are similar water quality monitoring and reporting demands under the WFD. The approach described in this paper could be applicable equally where there is reasonable spatial coverage in ambient and compliance water quality monitoring (and could also incorporate modified contaminant datasets depending on any specific local contaminant concerns and data availability) coupled with mining inventories (which in their simplest form can be based on geological maps). The results of this exercise are already proving valuable to inform environmental managers where to allocate funds for remediation planning in England and Wales and with regular future updates will continue to provide a basis on which to direct a national strategy for the management of pollution from abandoned non-coal mines.

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Table 1. Bandings for Environmental Quality Standard (EQS) failure score in water bodies. All values in µg/L. The bandings are listed to 2 decimal places and represent the magnitude of EQS breach from 1-2× breach (band 1); 2-5× EQS breach (band 2) and >5× EQS breach (band 3). The EQS values were chosen based on discussions with the EA in 2007 about the standards expected to be in use for the WFD, and were deliberately precautionary; not all of these new EQS have been introduced. Some EQS values were hardness-related (Cd, Cu); this was taken into account when screening EA data.

Metal	**Band 1 (1-2× EQS breach)**	**Band 2 (2-5× EQS breach)**	**Band 3 (>5× EQS breach)**
As	50 – < 100	100 – < 250	≥ 250
Cd	0.25 – < 0.50	0.50 – < 1.25	≥ 1.25
Cu	1 – < 2	2 – < 5	≥ 5
Fe	1000 – < 2000	2000 – < 5000	≥ 5000
Mn	7 – < 14	14 – < 35	≥ 35
Ni	20 – < 40	40 – < 100	≥ 100
Pb	7.20 – < 14.4	14.40 – < 36	≥ 36
Zn	7.80 – < 15.6	15.60 – < 39	≥ 39

Table 2. Summary of geographical region of Environment Agency questionnaire respondents. Note: the respondents for the North West RBD also provided data return for the Solway Tweed RBD.

RBD	**Number of Environment Agency respondents**
Anglian	2
Dee	7
Humber	21
North West	8
Northumbria	5
Severn	8
South East	1
South West	5
Thames	1
Western Wales	6
National	2

Table 3. Conditions for impact response for the ecological, groundwater and higher impact categories.

Response	**Ecological Impact criteria**	**Groundwater Impact**	**Higher impact**
Yes	Documented evidence of impact to ecology (e.g. flora, invertebrates and fish) **confirmed** due to abandoned non-coal mining (e.g. published papers/ EA reports or investigations)	Metal EQS breach in any mine water discharge within the water body. **OR** Metal EQS breach in groundwater quality network confirmed due to mining.	Source Protection Zone within water body. **OR** Surface abstraction within water body **OR** Other confirmed impact (e.g. on fisheries / domestic water abstraction confirmed by local EA office)
Suspected	Biological GQA grade C or less in "mining area" water	Metal EQS breach in groundwater quality	Surface abstraction in immediately downstream

	body **OR** Biological GQA grade C or less in downstream water body to a "mining area" water body. **OR** Documented evidence of impact to ecology **unconfirmed** due to mining (e.g. published papers/ EA reports)	network in mining area- unconfirmed due to mining.	water body **OR** Other unproven anecdotal evidence (e.g. higher impact suspected by community / angling group)
Unknown	No data	No data	No data
No	Grade A or B in host water body to mine **OR** confirmed no ecological impacts	Confirmed no groundwater impacts	Confirmed no higher impacts

Table 4. Scoring matrix used to transpose responses from the four impact criteria into a single mining impact score.

Response	**Classified EQS Score**	**Ecological Impact**	**Groundwater Impact**	**Higher Impact**
EQS Score 21-24	10	-	-	-
EQS Score 17-20	9	-	-	-
EQS Score 13-16	8	-	-	-
EQS Score 9-12	7	-	-	-
EQS Score 5-8	6	-	-	-
Yes or EQS Score 1-4	5	5	3	5
Suspected	-	2	2	2
Unknown	-	1	1	1
No	-	0	0	0

Table 5. Summary mine site details for 5 selected mine sites across different RBDs within the top 30 priority Impacted water bodies.

Water Body	**Rheidol**		**Clywedog**				**Carnon River**	**Newlands Beck**		**West Allen**
RBD	Western Wales		Dee				South West	North West		Northumbria
Example mine site	Cwm Rheidol		Minera complex				Wheal Andrew / various	Force Crag		Barneycraig
Discharges	Adit 6	Adit 9	Lagoon 1	Lag. 2	Lag. 3	Stryt y Scweiar Dingle	County Adit	Adit 0	Adit 1	Barneycraig
Diffuse pollution	Suspected – disappearing streams, mass balance discrepancies		Unknown				Yes – exposed spoil on site	Yes – spoil runoff / erosion, leachate from tailings, disappearing stream in spoil		Yes – riparian spoil actively eroding into West Allen
Visual impact	Yes – ochre staining along 10m reach of River Rheidol		Yes				Yes – ochre staining 4km downstream	Yes – ochre staining 50m downstream of adit 1		No
Stakeholder issues	Yes – fairly convergent: work supported by stakeholders but with reservations about ecological disturbance and visual impact		Unknown				Suspected	Yes – converging: site owners wish to prevent outbreak		Yes – adit portal is listed building, downstream Site of Special Scientific Interest
Public Complaints	No		Unknown				Yes	No		No
Mean flow rate (L/s)	11	3	-	-	-	-	454	2	10	20
Mean concentrations	Adit 6	Adit 9	Lag 1	Lag 2	Lag 3	SSD		Adit 0	Adit 1	
As (mg/L)	-	-	-	0.01	-	0.0004	0.19	0.001	0.003	-
Cd (mg/L)	0.03	0.09	-	0.02	-	0.001	0.004	0.0005	0.02	0.004
Cu (mg/L)	-	-	-	-	-	-	0.06	0.001	0.008	-
Fe (mg/L)	9.0	13.4	0.17	1.5	-	0.001	9.8	0.3	0.3	0.1
Mn (mg/L)	0.7	3.3	0.009	0.42	-	0.001	0.8	0.08	0.5	-
Ni (mg/L)	-	-	-	0.0006	-	0.0008	0.08	0.005	0.009	-
Pb (mg/L)	0.75	0.02	0.02	0.04	-	0.0008	0.005	0.003	0.06	0.003
Zn (mg/L)	13.8	69.3	0.18	9.8	-	0.02	2.4	0.14	3.5	4.0
Airborne pollution risk	No		No				Suspected – exposed spoil	No		Yes – exposed spoil
Stability Issues	Yes – steeply sloping spoil heaps, now revegetating however after livestock exclusion		No				Suspected	Yes – see outbreak risk		Yes – spoil undercutting may lead to collapse
Safety Concerns	No		No				Suspected	Yes – see outbreak risk		Yes – see above
Outbreak Risk	Yes – adit 9 unless it is drained down, adit 6 if stream breaks in to workings		No				No	Yes – Adit 0 blocked and overflowing crown hole 10m up steep hillside		No

Table 6. Top 30 Impacted water bodies. EQS^1: raw EQS score, EQS^2: classified EQS score (from Table 3), Eco: ecological impact, HI: higher impact, GW: groundwater impact. Total column: sum of EQS^2, Eco, Hi and GW.

Rank	RBD	Water body name	EQS^1	EQS^2	Eco	HI	GW	Total	Known polluting mine discharges
1	Western Wales	Rheidol	18	8	5	5	3	21	Cwm Rheidol Adit 6 & 9, Tynyfron,
1	Western Wales	Tywi	17	8	5	5	3	21	Nant Y Mwyn Upper and Lower Boat Adit
3	Western Wales	Gain	19	9	2	5	3	19	Afon Gain, Gelli Gain, Level Moel Yr Wden, Bwlch Y Fford
3	Western Wales	Goch Amlwch	19	9	2	5	3	19	Mynydd Parys: Dyffryn Adda Adit, Morfa Ddu Adit.
3	Dee	Clywedog	12	6	5	5	3	19	Minera complex: Park Day and Deep Day Levels
3	Western Wales	Melindwr	10	6	5	5	3	19	Melindwr: Bwlch Adit, Goginan drainage.
3	Western Wales	Llechwedd-Mawr	10	6	5	5	3	19	Llechwedd-Mawr: Copper shaft Adit A & B, East Level
8	Western Wales	Mawddach	19	9	1	5	3	18	Gwynfynydd Gold mine
8	South West	Carnon River	17	8	2	5	3	18	County Adit, Wheal Maid Tailings Dam
8	Western Wales	Meurig	12	6	5	5	2	18	Esgair Mwyn Tailings, Esgair Mwyn Adit, Nant Garw, Llwynllwyd Adit
11	Western Wales	Goch Dulas	15	7	2	5	3	17	Dyffryn Coch, Mona Adit, Mona / Henwaith Ponds, Southern Lagoon
11	Western Wales	Twymyn	14	7	5	5	0	17	Dylife
11	South West	Hayle	6	4	5	5	3	17	Hayle
11	Western Wales	Teifi	6	4	5	5	3	17	Cwm Mawr Adit, Cwm Mawr Stream, Abbey Consoles Stream 1 & 2
11	Northumbria	Saltburn Gill	6	4	5	5	3	17	Saltburn Borehole and Tributary discharges
11	Western Wales	Bow Street Brook	5	4	5	5	3	17	Mynydd Gorddu
11	North West	Newlands Beck	5	4	5	5	3	17	Force Crag Adit 0 & 1
11	South West	Lanivet Stream	4	4	5	5	3	17	
11	Humber	Loxley / Hobson Moss	4	4	5	5	3	17	Loxley Bottom, Ughill, Stubbing, Storrs Bridge, Low Matlock, Studfield, Wisewood
11	North West	Crake (Yewdale Beck)	4	4	5	5	3	17	Coniston Mines
21	Northumbria	Wear	13	7	1	5	3	16	Cambokeels, upstream mines in Middlehope Burn and Killhope Burn
21	Northumbria	Nent	12	6	2	5	3	16	Nent Force Level, Caplecleugh, Rampgill, Haggs, Croft, Nenthead
21	Western Wales	Ystwyth	10	6	2	5	3	16	Level Fawr, Frongoch Stream
21	Western Wales	Conwy	10	6	2	5	3	16	Parc Mine, Gwaenllifon Adit, Pwl Adit
21	Northumbria	Rookhope Burn	10	6	2	5	3	16	Grove Rake, Frazers Hush, Rispey, Bolts Burn Level, Tail Race Level
21	Dee	Alyn	3	3	5	5	3	16	Alyn
21	Northumbria	West Allen	3	3	5	5	3	16	Barneycraig, Low Barneycraig, Coalcleugh, Scraithole
28	South West	Perranwell Stream	17	8	2	5	0	15	South Crofty
28	Western Wales	Dwyryd / Goedol	15	7	2	5	1	15	Llwyn y Gell, Lord’s Street
28	Northumbria	South Tyne	13	7	0	5	3	15	Upstream Nent & Tynehead mines

Table 7. Top 30 Probably Impacted water bodies. EQS^1: raw EQS score, EQS^2: classified EQS score (from Table 3), Eco: ecological impact, HI: higher impact, GW: groundwater impact. Total column: sum of EQS^2, Eco, Hi and GW.

Rank	RBD	Water body name	EQS^1	EQS^2	Eco	HI	GW	Total
1	Northumbria	Leven	4	4	5	5	3	17
1	Western Wales	Mynach	18	8	1	5	2	16
3	Northumbria	Newbrough Burn	10	6	1	5	3	15
3	Northumbria	Middlehope Burn	5	4	1	5	3	13
3	North West	Glenderaterra Beck	4	4	2	5	2	13
3	North West	Glenderamackin (Greta)	2	3	2	5	3	13
3	Northumbria	Burnhope Burn	11	6	1	5	0	12
8	Western Wales	Ystwyth	10	6	1	5	0	12
8	Severn	Sundorne Brook	7	5	2	5	0	12
8	Northumbria	Horsleyhope Burn	11	6	0	5	0	11
11	Western Wales	Ddu	10	6	0	5	0	11
11	North West	Sabden Brook	8	5	1	5	0	11
11	South West	Withey Stream	7	5	1	5	0	11
11	Severn	Nant Clun	4	4	2	5	0	11
11	Severn	Elan Reservoirs	4	4	2	5	0	11
11	Severn	Clywedog	4	4	2	5	0	11
11	North West	Mearley Brook	4	4	2	5	0	11
11	Northumbria	Hudeshope Beck	4	4	1	5	1	11
11	Western Wales	Gwenffrwd	17	8	2	0	0	10
11	South West	Bourne	8	5	0	5	0	10
21	Western Wales	Dwyryd	8	5	0	5	0	10
21	South West	Inny	7	5	0	5	0	10
21	Northumbria	Erring Burn	7	5	0	5	0	10
21	Northumbria	Stocksfield Burn	7	5	0	5	0	10
21	Northumbria	March Burn	7	5	0	5	0	10
21	Dee	Alyn	6	4	1	5	0	10
21	Humber	Lathkill	5	4	1	5	0	10
28	Humber	Birdforth/Green's Brooks	5	4	1	5	0	10
28	Humber	Cod Beck	5	4	1	5	0	10
28	South West	Ruthern	4	4	1	5	0	10

FIGURES

Fig 1. Location map of the main former non-coal mining districts of the UK. The main orefields are labelled in italics and Water Framework Directive River Basin Districts (RBD) labelled in non-italic.

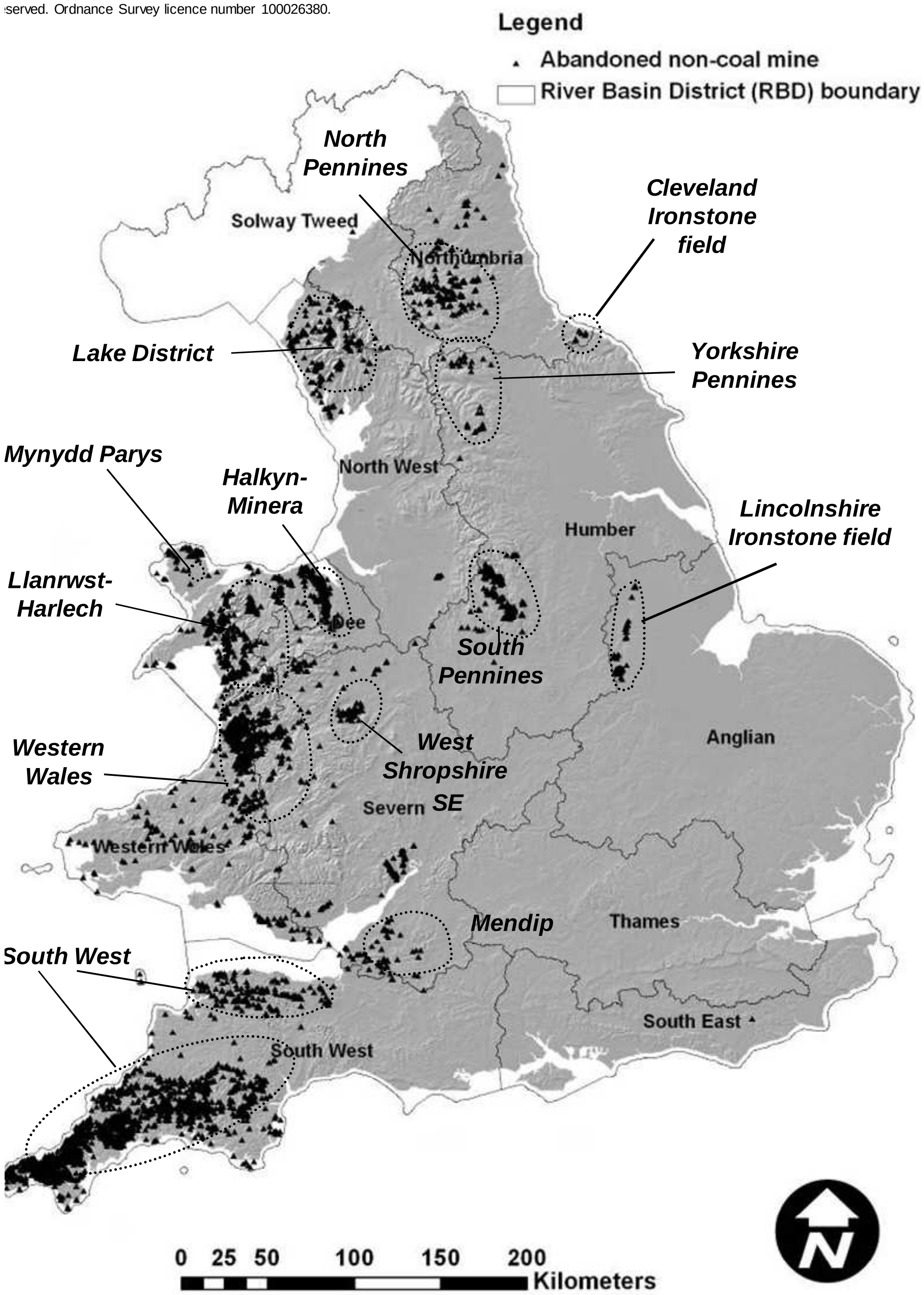
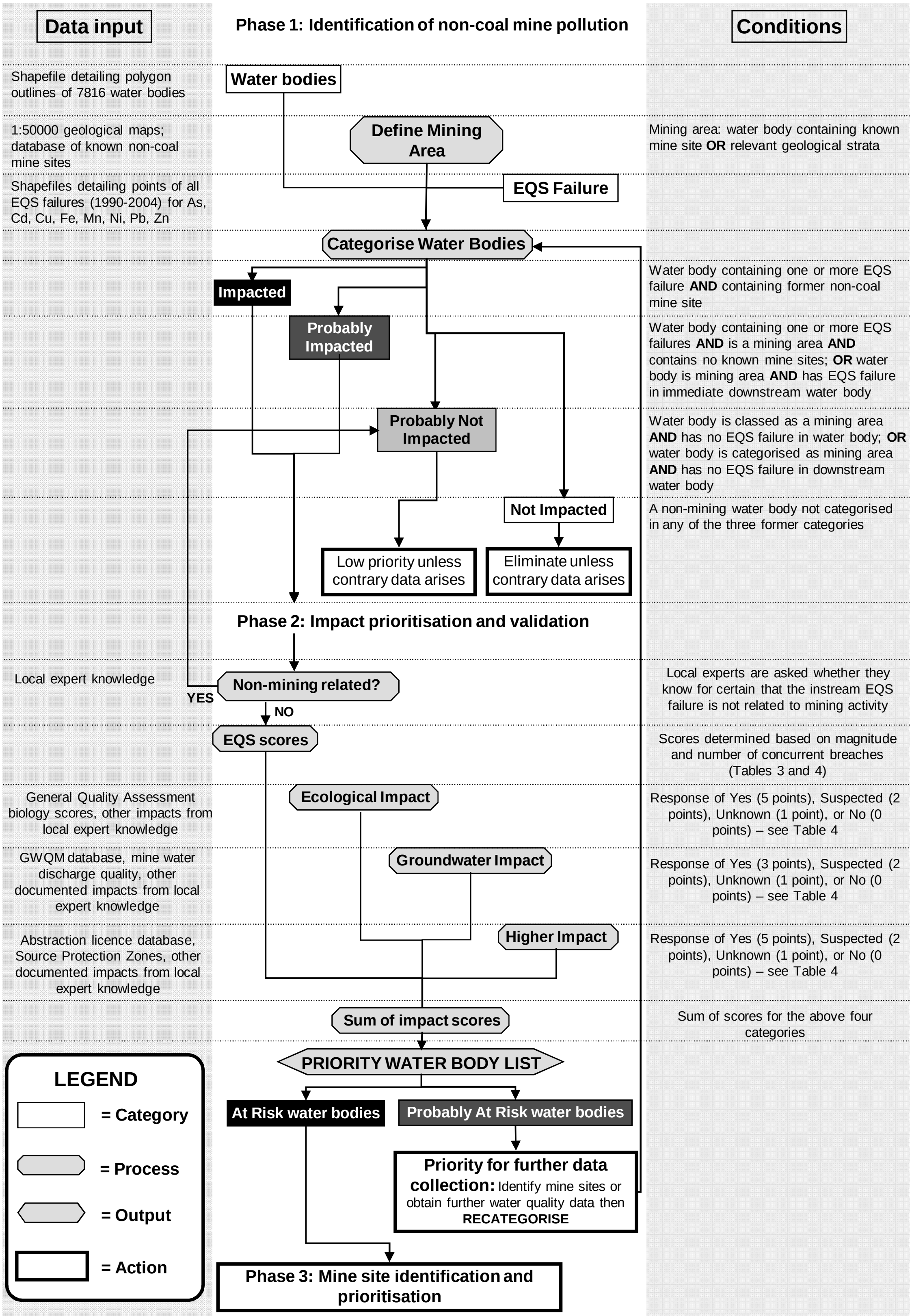


Figure 2. Schematic diagram depicting the methodology for identifying and prioritising abandoned non-coal mine sites.



Shapefile detailing polygon outlines of 7816 water bodies

1:50000 geological maps; database of known non-coal mine sites

Mining area: water body containing known mine site **OR** relevant geological strata

Shapefiles detailing points of all EQS failures (1990-2004) for As, Cd, Cu, Fe, Mn, Ni, Pb, Zn

Water body containing one or more EQS failure **AND** containing former non-coal mine site

Water body containing one or more EQS failures **AND** is a mining area **AND** contains no known mine sites; **OR** water body is mining area **AND** has EQS failure in immediate downstream water body

Water body is classed as a mining area **AND** has no EQS failure in water body; **OR** water body is categorised as mining area **AND** has no EQS failure in downstream water body

A non-mining water body not categorised in any of the three former categories

Local expert knowledge

Local experts are asked whether they know for certain that the instream EQS failure is not related to mining activity

Scores determined based on magnitude and number of concurrent breaches (Tables 3 and 4)

General Quality Assessment biology scores, other impacts from local expert knowledge

Response of Yes (5 points), Suspected (2 points), Unknown (1 point), or No (0 points) – see Table 4

GWQM database, mine water discharge quality, other documented impacts from local expert knowledge

Response of Yes (3 points), Suspected (2 points), Unknown (1 point), or No (0 points) – see Table 4

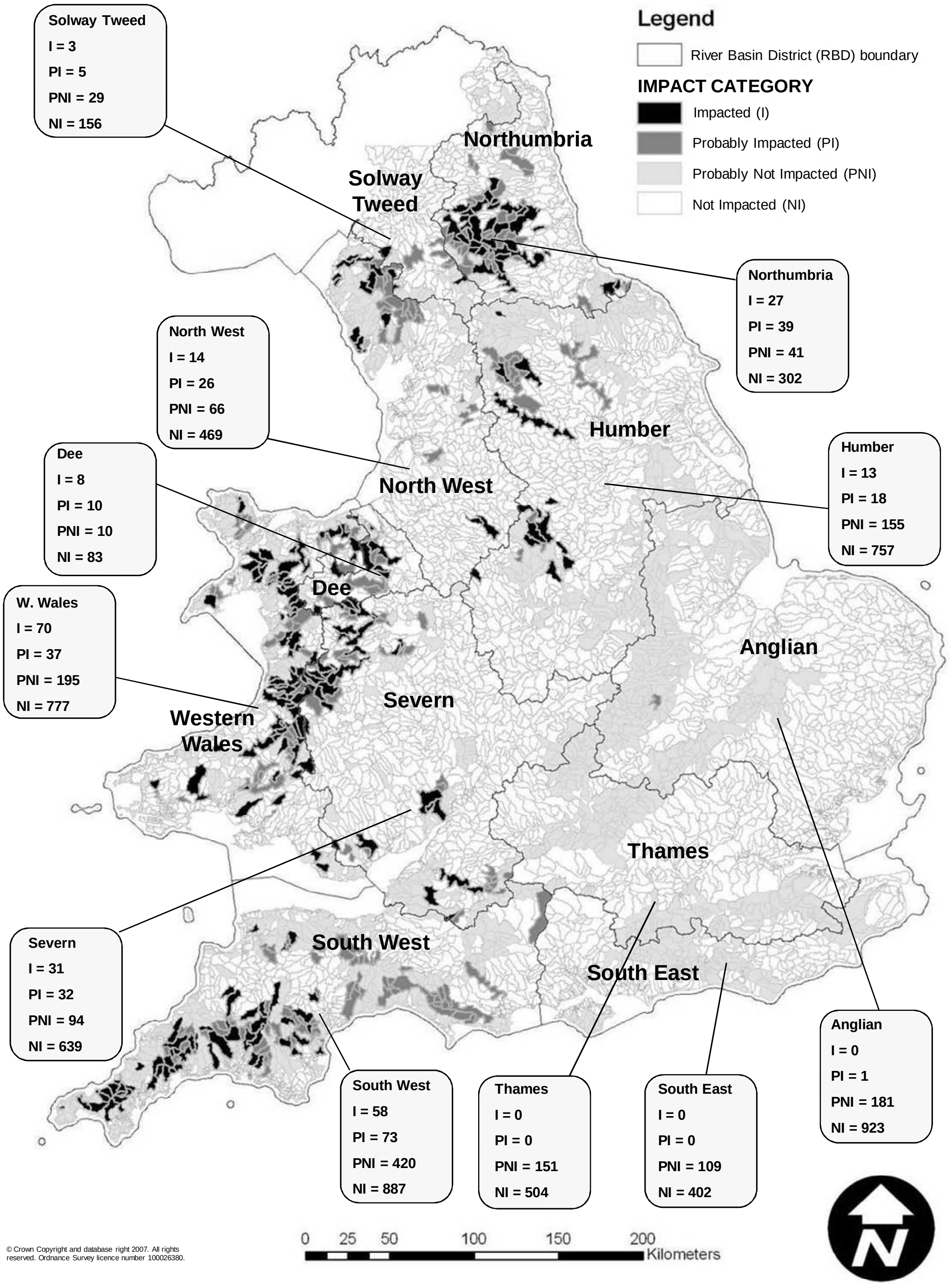
Abstraction licence database, Source Protection Zones, other documented impacts from local expert knowledge

Response of Yes (5 points), Suspected (2 points), Unknown (1 point), or No (0 points) – see Table 4

Sum of scores for the above four categories

Priority for further data collection: Identify mine sites or obtain further water quality data then RECATEGORISE

Figure 3. Impact status of all water bodies in England and Wales with regard failure to meet statutory environmental legislation due to pollution impact from abandoned non-coal mines. I: Impacted, PI: Probably Impacted, PNI: Probably Not Impacted, NI: Not Impacted



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