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# Broadening the scope of mine water environmental impact assessment: a UK perspective

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**Abstract**

Mine water pollution is one of the most severe forms of aquatic pollution in the UK, and it is a widespread problem internationally. The impacts of mine waters and current methodologies for quantifying these impacts are detailed. Current EIA methods take little account of the socioeconomic effects of these discharges, which can be severe. Local public interest and concern may constitute a major driving force towards remedial action. A number of benefits are associated with involving local communities in mine water EIA and remediation. Thus, some provision for incorporating these issues into mine water EIA is recommended. There is also a pressing need to develop predictive EIA strategies for future mine water discharges. While predictions of the pollution risks associated with a cessation of deep mining are now possible, the accuracy and precision of the latest techniques still falls short of what is needed to allow rational cost–benefit analysis of future environmental management options for redundant mine workings. 

*Keywords:* Environmental impact assessment; Mine drainage; Water pollution

## 1. Introduction

Pollution of surface streams and rivers due to discharge of contaminated water from mines and spoil heaps is one of the severest and most widespread causes of aquatic pollution in the United Kingdom (UK) [1,2]. Current estimates suggest that more than 700 km of the UK's streams and rivers

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are detrimentally affected. Internationally, too, the phenomenon is significant in any area of current or abandoned mining. In northern Appalachia, United States of America (USA), for example, some 3000 km of streams and rivers are currently affected [3]. Mine water pollution is also widespread across many other countries in Europe, Africa, and Asia (e.g., [4,5]). Elevated concentrations of iron, manganese, zinc, aluminum and sulfate are typical in receiving watercourses, and low pH conditions are not uncommon (e.g., [6]). Detailed summaries of the chemical reactions and hydrological changes involved in the generation of mine waters are provided by Banks et al. [6], Barnes and Romberger [7], and Younger [8], amongst others.

The impact of these metalliferous discharges on receiving streams invariably is detrimental. Aquatic flora and fauna are highly impoverished. For example, benthic macroinvertebrate communities are severely restricted (e.g., [9–13]), and this has a knock-on-effect for higher organisms, especially fish. In addition, a number of socioeconomic impacts are associated with mine waters. Clearly, deposition of bright orange, iron-rich precipitates on stream beds has a devastating aesthetic impact. Apart from aesthetics, mine waters rising through deep mines (usually following mine closure) may result in flooding, subsidence, corrosion of foundations, and emissions of carbon dioxide and methane gases at the surface [14]. These are current problems in many areas of the UK and USA and impending issues in other parts of the world, such as Poland and the Czech Republic, where coal mines are closing [5]. Furthermore, severe mine water discharges threaten water supply in many areas of the UK.

The severity of mine water pollution and its multifarious impacts dictate that a thorough methodology for environmental impact assessment (EIA) be adopted. The following discussion outlines the methodologies for mine water impact assessment used in the UK. At present, these methodologies are almost wholly focused on quantification of existing impacts, rather than prediction of impacts in advance of a change in land-use, which would be the more usual focus of general EIA [15]. In this paper, we present suggestions for both improving existing impact quantification techniques and developing a predictive EIA capability for application during the planning of mine closures.

## 2. Quantifying mine water impacts

Despite the numerous factors involved in mine water pollution it is proving increasingly important to be able to quantify these impacts, at least to some degree. This is principally because, as other sources of aquatic pollution (principally sewerage) are addressed, contaminated mine waters will increasingly become the limiting factor to further riverine quality improvements. This problem is exacerbated by the unusual legislative situation regarding discharges from abandoned mines in the UK [16]. Because the national regulator for England and Wales, the Environment Agency, has limited powers to enforce pollution control by former mine operators, inadequate financial support is available for remediation measures. Similarly in the USA, mine owners who abandoned operations prior to 1970 are not liable for subsequent water pollution [3]. The nature of mine water discharges is such that they are invariably sources of prolonged environmental degradation. As a consequence, the burden of responsibility for any treatment works is a long-term undertaking, which will rarely be accepted voluntarily.

Thus, in the unusual situation of all of these obstacles being overcome and remediation measures being implemented, it is vital that treatment of the selected mine water result in significant environmental quality improvements. Hence, the significance of environmental impact assessment as a first step.

Methods of environmental impact assessment for mine waters have focused to date on quantifying existing impacts via chemical, ecological, and visual characterization. In terms of chemical variables, extensive research has focused on metal fate in streams receiving acid mine drainage (e.g., [17–19]. Simultaneously, computer modeling techniques have been developed to simulate the fate of metals and the impact of mine water discharges in receiving watercourses (e.g., [20–22]). Such computer models have not yet been refined sufficiently to allow using the results of these chemical simulations for predicting ecological and aesthetic impacts, but they may nevertheless constitute a useful tool in mine water EIA in some instances.

Of the other techniques available, the most widely applied method of impact assessment has been that devised by the UK National Rivers Authority (NRA; now the Environment Agency). To the authors' knowledge, this type of EIA system is unique to the UK. First used in South Wales [23], the method is divided into two distinct phases.

*Phase I*: Initially, the impact of mine waters on the receiving watercourse is assessed by physicochemical means. The severity of impact is measured sequentially in six categories:

1. Area affected (by deposition of metal precipitates; assessed visually) ($m^2$)
2. Length affected (m)
3. Substrate quality for salmonid reproduction
4. Iron deposition (the intensity of discoloration, assessed visually)
5. Total iron concentration (mg/l)
6. pH, dissolved oxygen concentration (mg/l), aluminum concentration (mg/l)

These categories are listed in what is perceived to be a decreasing order of importance. Each category is subdivided to indicate the severity of impact measured, as illustrated in Table 1.

In its first application, for mine waters in South Wales, this method was

Table 1
Grading of impacts via physicochemical impacts [25].

| Physicochemical parameter (in decreasing order of importance) | Impact on receiving waters | | | | | |
|---|---|---|---|---|---|---|
| | High (A) | | Medium (B) | | Low (C) | No (D) |
| Area affected ($m^2$) | A1 | A2 | B1 | B2 | | |
| | >10,000 | 2,501–10,000 | 1,001–2,500 | 10–1,000 | <10 | — |
| Length affected (m) | >0.50 | | 0.01–0.50 | | <0.01 | — |
| Substrate quality for salmonid reproduction | rocks/stones/gravel | | bedrock/boulders/rocks | | artificial channel/sand/silt | — |
| Iron deposition (visual) | High | | Medium | | Low | — |
| Total iron (mg/l) | >3 | | 2–3 | | <2 | — |
| pH,[a] DO (%),[b] total aluminum (mg/l)[c] | 3 failures | | 2 failures | | 1 failure | None |

[a] pH values less than 7.
[b] Dissolved oxygen (DO) value less than 70% saturation.
[c] Total aluminum concentration downstream of discharge greater than 1 mg/l.

effectively used as a screening tool for selecting a cluster of the worst mine waters in the region, which were then carried forward to the second phase of impact assessment [24].

*Phase II*: Benthic macroinvertebrates are used in the second phase of the impact assessment, which is based almost exclusively on the impact of mine water on these organisms. Essentially, receiving watercourses are assessed by the decrease in the abundance and diversity of invertebrates downstream of a discharge, and by the area of streambed downstream affected by the discharge (calculated by finding the point downstream at which ecological integrity returns to the abundance and diversity found at an upstream, unaffected site). A less significant, third category is also included, which assesses the fisheries' potential of a receiving watercourse [25].

This system, which effectively ranks mine waters according to their severity of impact, has been applied in the Wales [23,24], Yorkshire and Northumbria [25], and North West regions of the Environment Agency. Subsequent to these impact assessments, the worst mine waters have been the focus of attention for potential installation of treatment schemes, some of which have been implemented recently by the UK Coal Authority (a regulatory agency).

The environmental impact assessment detailed above is unique, inasmuch as it is the only current method that accounts for both chemical and biological impacts. More typical are assessment techniques that utilize either chemical or ecological data. For example, Gray [26] has developed an index method of impact assessment based solely on the concentrations of key chemical contaminants typical of mine drainage (pH, $SO_4$, Fe, Zn, Al, Cu, Cd), which he then applied to the Avoca mining district in Ireland. In addition to this Acid Mine Drainage Index (AMDI), a second method, employing a qualitative visual assessment, has also been proposed [27]. This latter system of assessment is based on a visual interpretation of metal precipitate deposition and floc formation on the substrate of receiving watercourses. Both of these factors may prove to correlate well with the biological impacts of discharges, in which case they could serve as inexpensive proxy measures in place of full biosurveys. Further research is needed to establish whether this is indeed feasible. Notwithstanding the outcome of such research, the method of Gray [27] already has potential application as a screening tool for comparing impacts of different discharges, perhaps coupled with an assessment of the area affected by ochre deposition, as used by the NRA [23].

Many investigations of stream and river ecological quality have made use of one or more of the plethora of biological indices now available. The one most commonly applied in the UK to assessment of the impacts of mine water pollution in recent years is the Biological Monitoring Working Party (BMWP) score (e.g., [25,13,24]). This system, like many other biological indices, makes use of benthic macroinvertebrate communities. This particular group of organisms has been used as indicators of pollution world-wide [28], although ecological impact assessments based on benthic macroinvertebrates are not without problems. In particular, specific groups may not respond to certain types of pollution, and other factors may influence their distribution (e.g., physical habitat, climate) [29]. Fewer studies make use of aquatic floral communities, although Vinyard [30], for example, details a reasonably straightforward method of ecological impact assessment based upon primary production of periphyton.

## 3. Missing elements of mine water EIA

The impacts of mine waters on aquatic environments clearly are wide-ranging, but often include the following:

1. Chemical degradation, usually with elevated metal concentrations and low pH as a minimum
2. Ecological impoverishment, in some cases rendering receiving watercourses lifeless
3. Aesthetic impacts, often resulting in reduced amenity value, due to deposition of iron-rich ochre
4. Water supplies threatened, where discharges are upstream of abstraction points

The impacts just summarized consider the surface environment alone, and therefore do not account for environmental impacts resulting from the mining operation itself, or the potential difficulties associated with groundwater rebound. In the UK, the latter issue will in part be resolved with the introduction of new legislative controls in 1999 that will require mine operators to provide detailed closure plans and to provide for long-term treatment of any post-closure polluting discharges [16]. Sadly, it may be that this new legislation will serve only to precipitate the demise of small, privately owned mines, which will not be able to carry the financial burden of such a requirement. Certainly the spate of deep mine closures announced in the first weeks of 1999 (e.g., Frazer's Hush Fluorspar Mine, County Durham; Annesley-Bentinck Colliery, Nottinghamshire; Dolacouthi Gold Mine, N Wales) is consistent with this hypothesis.

Such closures highlight one of the principal elements missing from current mine water EIA methodologies: a technique for predicting future mine water pollution impacts that may arise from proposed mine closures. The flooding of previously dewatered deep mine voids has the potential to provoke a deterioration in water quality, as acid-generating mineral salts are leached from previously dry areas (e.g., [31,32]). In the worst case, such as occurred at Wheal Jane Mine in Cornwall in 1991–1992 [6,31], the water that eventually flows from the mine may have a very low pH and as much as 2500 mg/l total iron, thus totally devastating the natural watercourse that receives the mine drainage. However, the range of possibilities extends from this upper extreme to (albeit rarely) innocuous discharges that are actually beneficial to the receiving watercourse. Predicting where on this wide scale the future discharge from a given abandoned mine will fall is a very difficult task, requiring the application of state-of-the-art hydrogeological and geochemical modeling techniques [33–35]. Such predictive techniques are especially vital for regions where mine closures are imminent or have occurred recently, such as in parts of Eastern Europe [5]. However, for all of the efforts that have gone into developing such techniques over the last few years, the bounds of uncertainty associated with their output remain wide. It is thus difficult (though by no means impossible) to make confident predictions of future mine water impacts to the degree of precision necessary for stringent cost–benefit analysis of alternative options (see [36]). In some cases, the sensitivity of the future receiving watercourse is so great that even the best-quality mine water would give cause for concern if it were discharged untreated. For instance, when Whittle Colliery in Northumberland closed in April 1997, water levels in the old workings began to rise rapidly, threatening to give rise to an uncontrolled discharge into the River Coquet as early as January 2000. Although debate over the likely quality of the future discharge has been lively, even those who predict a future discharge only moderately contaminated with iron have accepted that the environmental damage that a discharge could cause is far more costly than the installation and operation of a preventive pump-and-treat scheme. The reason this case was so unequivocal is that the entire channel of the Coquet is a designated Site of Special Scientific Interest (SSSI), which supports one of the finest salmon fisheries in the UK. Furthermore, a long-standing public water supply abstraction from the Coquet at Warkworth lies downstream of the mine. With the case for pollution prevention so strong, the UK government announced in September 1998 that a treatment scheme would be implemented by the year 2000 to prevent pollution. There are many other cases, however, where the target watercourse is not so highly prized as the Coquet, and in such cases the predictive EIA for mine abandonment will be subject to more protracted debate.

No single investigation has attempted to quantify the actual or potential impacts of a mine water discharge, or series of discharges, on the water abstraction needs of an entire catchment (whether it be an abstraction for agriculture, industry, or water supply). However, the loss of water supply to BP Chemicals' Baglan Bay Works, due to the Ynysarwed mine water discharge, South Wales, was one of the key factors leading to the development of a treatment scheme at this site [37]. Similarly, the River Wear, County Durham, has been the focus of extensive research due to the potential threat of rising mine waters to Lumley water treatment works [36].

A further shortcoming of both predictive and post-event impact assessments of mine waters lies in the weakness of methods for taking aesthetic impacts into account (e.g., the visual intrusion of ochre staining in watercourses that have recreational value). Among the myriad of chemical and/

or biological survey techniques used in mine water EIA to date (e.g., [25,23,26,38]), the only common measurement which gives any real indication of possible aesthetic impacts is the quantification of the area or length affected by ochre deposition [25,23,27]. However, even this measure cannot readily be equated with a loss in amenity value in a given area. Recent work undertaken by the Environment Agency in relation to the Wheal Jane mine in Cornwall has demonstrated the feasibility of using surveys of visitor numbers to sites in and around rivers affected by visible ochre deposition to quantify the loss of willingness-to-pay for recreational value arising from mine water pollution. Nevertheless, the results obtained to date will remain equivocal until a much more concerted effort is made to undertake such surveys in a range of areas affected by visible mine water pollution.

The examples above illustrate that factors such as sustenance of water supply and protection of amenity value, which are not addressed in current mine water EIA strategies, may be highly significant. Attempting to encompass all of these disparate impacts in a single EIA methodology is not a problem unique to mine water pollution. Effective EIA for water pollution control has proved difficult, if not impossible, in many settings [39]. To a point, the current emphasis on assessing chemical and ecological impacts is understandable, since these impacts are always reflected in receiving watercourses to some degree, whereas aesthetic and water resource impacts may not always be relevant. Nevertheless, recent events have shown that other factors can play a key role in influencing the selection of discharges for treatment.

One final element that should be considered during mine water EIA is public opinion/community pressure. An acidic, ferruginous, and aluminum-rich discharge into the Stanley Burn, near the village of Quaking Houses, County Durham, became the focus of a treatment feasibility study in 1995 [40] because of persistent lobbying of the Environment Agency by local residents. Charitable funding subsequently enabled the construction of one of the most successful full-scale wetlands for mine water treatment in the UK [41], which recently won a prestigious national conservation award, due largely to the involvement of the local community. The authors currently are involved with two other community groups (in Tyne and Wear, and Yorkshire) who also wish to see their local mine water treated, even though neither is deemed a national priority for remediation. Awareness of the level of community concern regarding pollution, and involvement of such groups in EIA and remediation, brings with it a range of benefits.

1. Local knowledge can provide an invaluable insight into the origins of mine water pollution and its historical nature and severity.
2. Correctly instructed, local community members may assist with sample collection and EIA.
3. In the experience of the authors, a collaboration of professional engi-

neers and local community is an attractive proposition to potential funding bodies.
4. Local communities can assist with construction of remediation schemes, and perhaps more significantly can ensure day-to-day maintenance of such facilities (such is the case at the Quaking Houses wetland).

Thus, there is a strong argument for incorporating some facility for assessing local interest in, and anxiety about, aquatic pollution during mine water EIA. We have found, this interest to be common, particularly where some of the residents of the villages adjacent to polluted streams worked in the offending mine prior to its closure. Simply creating a database of public complaints to the Environment Agency would provide such information in the first instance.

Thus, while ranked lists such as those produced by the Environment Agency (England and Wales) undoubtedly serve as useful yardsticks of pollution severity, it is important to supplement these technical data with local information, such as proximity to residential areas and impacts on amenity value, as well as actual and potential impacts on water abstraction and/or supply, even if knitting this information into a semiquantitative EIA format is not possible in the short term. Strong public opinion may serve as one of the most powerful tools for attracting financial backing for any treatment initiative.

## 4. Summary

1. Pollution from mines and spoil heaps typically imparts elevated concentrations of iron, aluminum, and acidity on receiving watercourses. Current estimates suggest that more than 700 km of streams and rivers in England, Scotland, and Wales are affected. Mine waters are therefore one of the most serious causes of aquatic pollution in the UK.
2. Receiving watercourses are invariably impoverished with respect to their flora and fauna. In addition rising water tables following mine closure can lead to subsidence problems, chemical attack of foundations, and gas emissions at the surface. Contamination of groundwater and surface water resources threatens water supply in some areas.
3. Impact assessment for mine water pollution has focused on the use of chemical, ecological and visual measures of degradation associated with existing discharges. The methodology of the Environment Agency (England and Wales) has been most widely applied [23–25], although Byrne and Gray [38] and Gray [26,27] have developed alternative approaches.
4. Predictive EIA techniques applicable to situations in which mines are

scheduled for abandonment have undergone rapid development in recent years [33], though the precision and accuracy of predictions still requires substantial improvement.

5. Incorporation of the socio-economic impacts of mine water pollution into an EIA is clearly a complex process, and has not been attempted to date. However, a number of examples illustrate that amenity value concerns and water supply/abstraction needs can be of critical importance. Furthermore, recent experience suggests that public pressure may well be the most effective catalyst for initiating mine water treatment schemes. Involving local communities in mine water EIA and remediation has a number of benefits. Thus, it may be advisable for mine water EIAs to include some measure of local interest/concern, even if this is achieved only in a qualitative manner.

## References

[1] NRA. Abandoned mines and the water environment. Report of the National Rivers Authority. Water Qual Ser 14. 1994.
[2] Younger PL. Mine water pollution in Scotland: nature, extent and preventative strategies. Sci Total Environ (In review).
[3] Hedin RS. Passive mine water treatment in the eastern United States. In: Minewater Treatment Using Wetlands, Younger PL, editor. Proceedings of a national conference held 5th September 1997, at the University of Newcastle, UK. London: Chartered Institution of Water and Environment Management, 1997, pp. 1–15.
[4] Kempe JO. Review of water pollution problems and control strategies in the South African mining industry. Water Sci Technol 1983;15(2):27–58.
[5] Norton PJ. Mine closure and associated hydrological effects on the environment: some case studies. In: Minerals, Metals and the Environment II. The Institution of Mining and Metallurgy, 1996, pp. 263–70.
[6] Banks D, Younger PL, Arnesen RT, Iversen ER, Banks SB. Mine-water chemistry: the good, the bad, and the ugly. Environ Geol 1997;32(3):157–74.
[7] Barnes HL, Romberger SB. The chemical aspects of acid mine drainage. J Water Pollut Control Fed 1968;40:371–84.
[8] Younger PL. Hydrogeochemistry of minewaters flowing from abandoned coal workings in County Durham. Q J Eng Geol 1995;28:S101–S13.
[9] Armitage PD. The effects of mine drainage and organic enrichment on benthos in the River Nent system, North Pennines. Hydrobiologia 1980;74:119–28.
[10] Dills G, Rogers DT. Macroinvertebrate community structure as an indicator of acid mine pollution. Environ Pollut 1974;6:239–62.
[11] Scullion J, Edwards RW. The effect of coal industry pollutants on the macroinvertebrate fauna of a small river in the South Wales coalfield. Freshwater Biol 1980;10:141–62.
[12] Kelly M. Mining and the freshwater environment. London: Elsevier Applied Science, 1988.
[13] Jarvis AP, Younger PL. Dominating factors in mine water induced impoverishment of the invertebrate fauna of two streams in the Durham coalfield, UK. Chem Ecol 1997;13:249–70.
[14] Younger PL. Possible environmental impact of the closure of two collieries in County Durham. J Inst Water Environ Manage 1993;7(5):521–31.

[15] Glasson J, Therivel R, Chadwick A. Introduction of Environmental Impact Assessment, 2nd ed. London: UCL Press, 1999.
[16] Jarvis AP, Younger PL. The 1995 Environment Act and Mine Water Pollution: Implications and Consequences. Geogr J 1999 (in press)
[17] Chapman BM, Jones DR, Jung RF. Processes controlling metal ion attenuation in acid mine drainage streams. Geochim Cosmochim Acta 1983;47:1957–73.
[18] McKnight DM, Bencala KE. The chemistry of iron, aluminum, and dissolved organic material in three acidic, metal-enriched, mountain streams, as controlled by watershed and in-stream processes. Water Resour Res 1990;26(12):3087–100.
[19] Broshears RE, Runkel RL, Kimball BA, McKnight DM, Bencala KE. Reactive Solute Transport in an Acidic Stream: Experimental pH Increase and Simulation of Controls on pH, Aluminum, and Iron. Environ Sci Technol 1996;30(10):3016–24.
[20] Whitehead PG, McCartney MP, Williams RJ, Ishemo CAL, Thomas R. A method to simulate the impact of acid mine drainage on river systems. J Chartered Inst Water Environ Manage 1995;9:119–31.
[21] Runkel RL, Bencala KE, Broshears RE. Reactive solute transport in streams. 1. development of an equilibrium-based model. Water Resour Res 1996;32(2):409–18.
[22] James A, Elliott DJ, Younger PL. Computer aided design of passive treatment systems for minewaters. In: Minewater Treatment Using Wetlands, Younger PL, editor. Proceedings of a national conference held 5th September 1997, at the University of Newcastle, UK. London: Chartered Institution of Water and Environmental Management, 1997, pp. 57–64.
[23] NRA. A survey of ferruginous minewater impacts in the Welsh coalfields. NRA Welsh Office Contract (No. WEP 100/138/11). 1994.
[24] Davies G, Butler D, Mills M, Williams D. A survey of ferruginous minewater impacts in the Welsh coalfields. J Chartered Inst Water Environ Manage 1997;11(2):140–6.
[25] NRA. Environmental assessment of selected abandoned minewaters. Report of the National Rivers Authority, Northumbria & Yorkshire Region. 1996.
[26] Gray NF. The use of an objective index for the assessment of the contamination of surface water and groundwater by acid mine drainage. J Chartered Inst Water Environ Manage 1996;10:332–40.
[27] Gray NF. A substrate classification index for the visual assessment of the impact of acid mine drainage in lotic systems. Water Res 1996;30(6):1551–4.
[28] Cairns J Jr, Pratt JR. A history of biological monitoring using benthic macroinvertebrates. In: Freshwater Biomonitoring and Benthic Macroinvertebrates, Rosenberg DM, Resh VH, editors. New York: Chapman & Hall, 1993, pp. 10–27.
[29] Rosenberg DM, Resh VH. Introduction to freshwater biomonitoring and benthic macroinvertebrates. In: Freshwater Biomonitoring and Benthic Macroinvertebrates, Rosenberg DM, Resh VH, editors. New York: Chapman & Hall, 1993, pp. 1–9.
[30] Vinyard GL. A chemical and biological assessment of water quality impacts from acid mine drainage in a first order mountain stream, and a comparison of two bioassay techniques. Environ Technol 1996;17:272–81.
[31] Younger PL. The longevity of minewater pollution: A basis for decision-making. Sci Total Environ (In review).
[32] Younger PL. Coalfield abandonment: geochemical processes and hydrochemical products. In: Energy and the Environment. Geochemistry of Fossil, Nuclear and Renewable Resources, Nicholson K, editor. Society for Environmental Geochemistry and Health. Aberdeenshire: McGregor Science, 1998. pp. 1–24.
[33] Sherwood JM. Modelling Mine Water Flow and Quality Changes after Coalfield Closure. Unpublished PhD thesis, University of Newcastle, UK, 1997.
[34] Younger PL, Barbour MH, Sherwood JM. Predicting the consequences of ceasing pumping from the Frances and Michael collieries, Fife. In: Proceedings of the Fifth National Hydrology Symposium, Edinburgh, 4-7th September 1995. Black AR, Johnson RC, editors. British Hydrological Society. 1995. pp. 2.25–.33.

[35] Younger PL, Adams R. Predicting Mine Water Rebound. A Practical Guide for Hydrogeologists. Bristol, UK: Environment Agency R&D Tech Rep W179. 1999.
[36] Younger PL, Harbourne KJ. "To pump or not to pump": Cost-benefit analysis of future environmental management options for the abandoned Durham coalfield. J Chartered Inst Water Environ Manage 1995;9(4):405–15.
[37] Ranson CM, Edwards PJ. The Ynysarwed experience: active intervention, passive treatment and wider aspects. In: Minewater Treatment Using Wetlands, Younger PL, editor. Proceedings of a National Conference held 5th September 1997, at the University of Newcastle, UK. London: Chartered Institution of Water and Environmental Management, 1997, pp. 151–64.
[38] Byrne C, Gray NF. Field acute toxicity method for the assessment of acid mine drainage using macro-invertebrates. Fresenius Environ 1995;4:583–8.
[39] Lumbers JP. Environmental impact assessment in water pollution control. In: Water and Environment (Environmental Topics Volume 3), Rose J, editor. Philadelphia: Gordon & Breach Science Publishers. 1991.
[40] Younger PL, Curtis TP, Jarvis AP, Pennell R. Effective passive treatment of aluminium-rich, acidic colliery spoil drainage using a compost wetland at Quaking Houses, County Durham. J Chartered Inst Water Environ Manage 1997;11:200–8.
[41] Jarvis AP, Younger PL. Design, construction and performance of a full-scale compost wetland from mine spoil drainage treatment, Quaking Houses, UK. J Chartered Inst Water Environ Manage 1999 (in press).