A Survey of Ferruginous Minewater Impacts in the Welsh Coalfields

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Abstract

The aim of this study was to locate all ferruginous discharges within the Welsh coalfield areas and to assess their impact upon receiving watercourses. The project was undertaken in two stages. In the first stage, visual assessments were carried out on an area of river bed affected by iron hydroxide deposition. Chemical samples of the discharges and the receiving watercourse were analysed for a suite of physico-chemical determinands. Ninety discharges were located impacting upon 59.4 km of river, and an area of 22 ha was affected by iron hydroxide deposits.

A ranking method, incorporating the physical/ chemical determinands, was developed to assess the comparative impact which discharges were having on receiving watercourses. A total of 33 of the top ranked discharges (20 to classified watercourses and 13 to unclassified watercourses) having the highest environmental impact were selected; chemical, biological and fisheries impact assessments were then carried out on these discharges in the second stage of the project. The sites were then ranked on the basis of biological and fisheries impact. A list of the highest impacted sites was produced, and some of these were further investigated for remediation options and associated costs.

Key words: **BMWP; coalfields; ferruginous; HABSCORE; invertebrates; minewater; ranking; remediation; RIVPACS; salmonids.**

Introduction

Ferruginous minewater discharges from abandoned coal mines in the South and North Wales coalfields have been causing problems to receiving watercourses for many decades. Also during recent years, the spate of mine closures has resulted in several new ferruginous discharges to a number of rivers, and their effects on the aquatic environment are of growing public concern. Because the extent of the ferruginous minewater problem in Wales was not fully known, a joint NRA/Welsh Office study was undertaken between October 1992 and October 1993.

This paper was presented at a joint meeting of CIWEM's Scientific Group and Welsh Branch on 7 December 1995.

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Methodology

The Welsh coalfield areas covered by the study were determined from geological maps and marked on OS 1:10 000 maps. Rivers, tributaries, mines, collieries, shafts, and levels were identified within these area. Sites on all the main rivers and tributaries were surveyed visually to assess the presence or absence of ferruginous deposits, and rivers were inspected at a minimum frequency of one site every kilometre (along their length) within the coalfield area. All tributaries were inspected at a minimum of one site, within 1 km of the confluence with the main river, and at additional sites on larger tributaries.

At ferruginous sites, field assessments were made of the dilution of the ferruginous input (e.g. 10:1, 100:1, 1000:1). The width, length and % bed affected by the ochreous deposit were assessed, and the total surface area affected was calculated by multiplying the three parameters. A subjective measurement of colour intensity and degree of flocculant deposit was recorded. Field measurements and chemical samples were taken upstream, downstream and of the discharge itself. A Grant YSI multi-parameter hand-held meter was used to measure pH, temperature, dissolved oxygen (mg/l and % saturation) and conductivity (μS). At the NRA's† laboratory, in Llanelli, chemical samples were analysed for suspended solids, total alkalinity, dissolved sulphate, total and dissolved iron, and total and dissolved aluminium.

Study: Stage 1

Within the Welsh coalfields, 1065 sites were visited, 90 ferruginous sites were identified, and 59.4 km of river were found to be affected by ferruginous minewater, resulting in a total area of 22 ha which was visually affected (Table 1).

At present, 25% of classified river stretches in South Wales fail to meet their long-term water-quality objectives. A proportion of these stretches are affected by ferruginous minewater discharges; therefore they are an important factor in the NRA's river recovery programme.

Ranking of Minewaters Located in First Stage of Study

The data collected in stage 1 of the survey were reviewed and assessed, and a ranking method for the impact of minewater discharges on rivers was developed. Table 2

†Now the Environment Agency

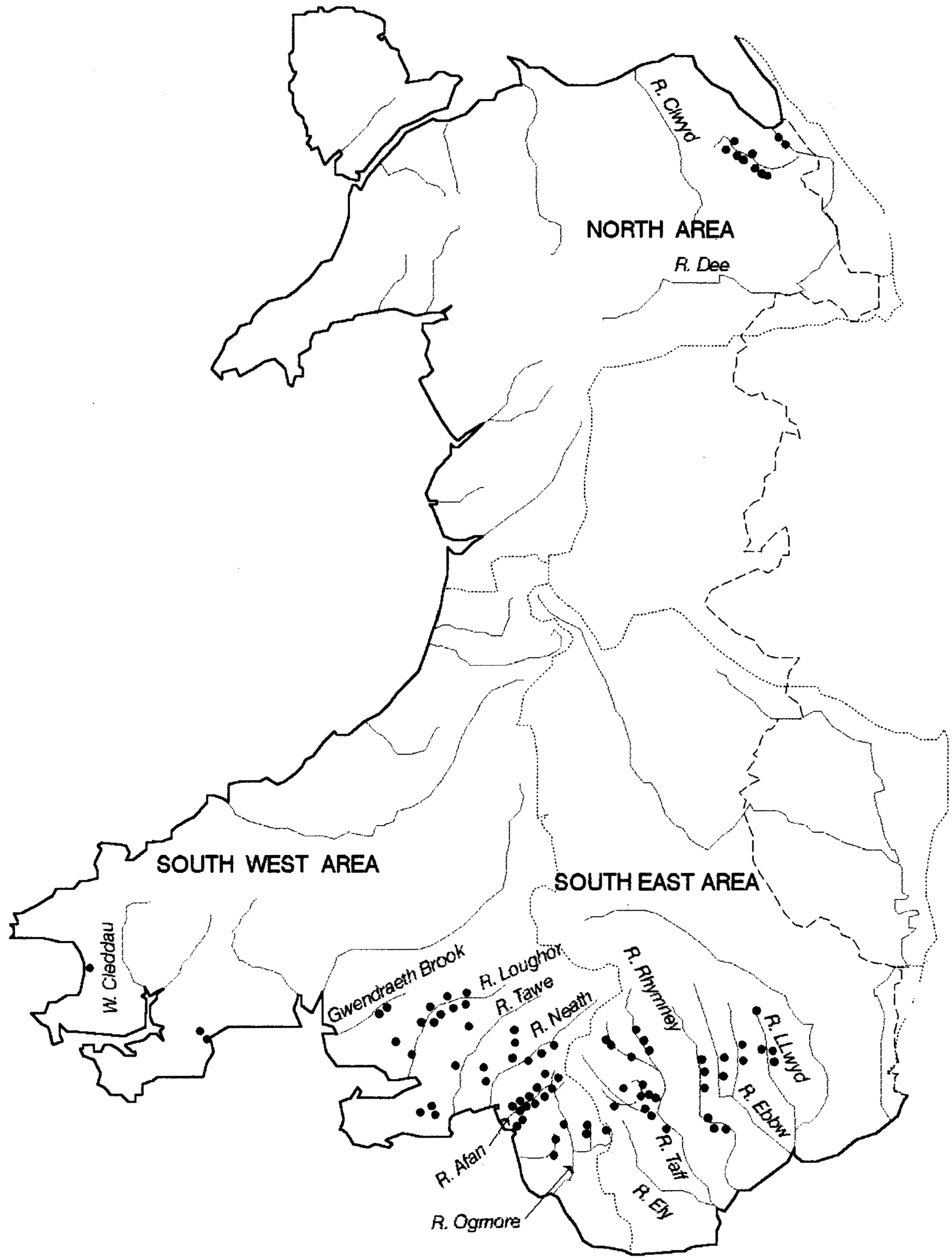

Fig. 1. Minewater discharges in Welsh Coalfields

lists the criteria (in order of importance as indicators of environmental impact) to describe the effect of ferruginous minewater discharges on receiving waters. Each impact criterion was graded high, medium or low, based either on absolute ranges or distributionally derived ranges.

The ranking was performed in order so that rivers and streams which received an A rating appeared at the top of the list, followed by all those receiving a B rating etc. to give three main groups. These were then ranked according to the second criterion, i.e. length of river affected, to give three sub-groups in each main group. Each sub-group was then ranked according to quality of substrate (and so on) for the remaining parameters. For

Table 1. Number and occurrence by catchment of ferruginous sites in Wales

Catchments surveyed	No. of ferruginous sites		Length of river affected (km)	Surface area of river bed affected (× 1000m²)
	Found	Sampled		
Llwyd	4	4	3.2	13.8
Sirhowy	2	2	2.2	17.4
Ebbw	2	2	2.4	10.8
Rhymney	6	5	2.4	38.3
Taff	15	15	6.8	21.9
Ely	–	–	–	–
Ogmore	5	5	4.4	10.6
A. Cynffig	2	2	4.5	13.5
Afan/Pelenna	13	13	16.1	52.4
Neath	9	6	3.3	14.8
Tawe	2	2	1.5	3.2
Loughor	11	11	8.9	18.3
Gwendraeth Fawr	2	2	0.3	0.3
Gower	3	3	0.6	4.0
Pembrokeshire	3	3	0.6	0.6
Dee/Alyn	11	8	0.4	0.4
Total	90	82	59.4	220.3

Table 2. Grading of physicochemical data

Impact criteria	High (A)	Medium (B)	Low (C)	No impact (D)
(In decreasing order of importance)				
1. Area affected (m²)	>2500	10–2500	<10	–
2. Length affected (km)	>0.5	0.01–0.5	<0.1	–
3. Substrate quality for salmonid reproduction	Rocks/ stones/ gravel	Bedrock/ boulders/ rocks	Artificial channel sand/silt	–
4. Iron deposition (visual)	High	Medium	Low	–
5. Total iron (mg/l)	>3.0	2–3	<2.0	–
6. pH, DO(%), total Al (mg/l)	3 failures	2 failures	1 failure	No failures

example, a site with an A rating for area affected but B rating for all other parameters appears in the ranking above a site with a B rating for area affected and A rating for all other parameters. This dichotomous method of ranking was derived, following a series of trials with various scoring techniques, as the best assessment of the data. The discharges were ranked separately for classified and unclassified stretches so that the most severe cases could be identified for each of the two types according to the number of A, B, and C ratings. There was a spread of sites showing high (A), medium (B), and low (C) impact.

Discharges to both classified and unclassified rivers were selected for the second-stage assessment because it was considered important to assess ferruginous minewater impacts on headwater streams as well as on main rivers. A total of 33 discharges were selected, which included the top 19 discharges to classified waters, the top 10 discharges to unclassified waters, and 4 additional sites on the Afan/Pelenna. This gave a realistic number of sites to survey whilst ensuring that discharges throughout the coalfield measures were studied.

Full Assessment Methodology

Biological assessments were carried out at each site by taking (a) upstream, (b) immediate downstream, and (c) subsequent downstream samples (at short intervals) to a point where the visible effects of iron deposition had ended. The final sampling point was considered to represent a point of recovery. Biological sampling produced a total of 112 samples from the 33 sites. These samples were obtained using the standard Institute of Freshwater Ecology (IFE) 3-min kick sampling methodology and were processed in the laboratory to give a 'biological monitoring working party' (BMWP) score for each sample. This involves identifying invertebrates to family level and then allocating each family a score between 0 and 10 according to its sensitivity to pollution. Those with the greatest sensitivity scored 10. The BMWP score is designed particularly for organic pollution, but it is also sensitive to other types. The scores for each taxon were totalled to give the BMWP score which provides a numerical estimate of biological quality.

The abundance of invertebrate taxa was also estimated on a logarithmic scale.

The impact of a minewater discharge was considered to be significant when a reduction in BMWP score of ≥40% occurred between the upstream and immediate downstream sites. Additionally, a reduction in $\log_{10}$ abundance of 4 or more high-scoring families (i.e. ≥6) was used to reflect more subtle changes in species abundance. A combination of these two criteria was used to grade the biological impact as follows:

High impact (A). A reduction in BMWP score ≥40% between the upstream and immediate downstream site *and* a reduction in $\log_{10}$ abundance between the upstream and downstream sites of 4 or more families scoring ≥6 on the BMWP system.
Medium impact (B). Either: A reduction in BMWP score ≥40% between upstream and downstream site; or a reduction in $\log_{10}$ abundance between the upstream and downstream site of 4 or more families scoring ≥6 on the BMWP system.
Low impact (C). Neither of the criteria in A or B.

Biological data were also used to indicate the area of river bed impacted by a minewater discharge by measuring the surface area of bed affected between the discharge and the first point downstream at which the biological quality (C) was the same or better than upstream from the discharge. The affected area was graded into high (A), medium (B), or low (C) impact categories using the same band sizes as applied in the stage 1 ranking (Table 3).

Quantitative electrofishing surveys were carried out upstream and immediately downstream from the minewater discharges at 19 sites. A number of sites were not electrofished for a variety of practical reasons, e.g. the Tawe tributary (33) and Broughton brook (34) had very low flows upstream from the discharge and were considered to be unsuitable for salmonids.

Fisheries data were initially assessed according to the method used by the NRA for the 'regional juvenile salmonid monitoring programme' (RJSMP). Fish densities for fry (0+) and parr (>0+) (< 1 year old) age groups are divided into five categories (Table 4). These abundance categories are then combined to give a classification matrix (Table 5).

Reductions in RJSMP class between the upstream and downstream sites were used as a measure of the impact of minewaters on fisheries as follows:

A reduction of 2 classes between u/s and d/s = A (High impact)
A reduction of 1 class between u/s and d/s = B (Medium impact)
No change in class between u/s and d/s = C (No impact)

HABSCORE is a computer model which predicts the numbers of fry (0+) and parr (>0+) (which are both stages of growth <1year old) at a site, based upon the physical characteristics of unpolluted sites in Wales[1]. HABSCORE was used to quantify the potential of the fishery habitat, called the 'habitat quality score' (HQS) and the 'habitat utilization index' (HUI). The HABSCORE indices (HQS and HUI) were also used in the interpretation of significant changes and to determine where habitat quality was more limiting than water quality.

All 33 sites were sampled chemically a second time when the biological surveys were carried out, and a third time during the fishery surveys using the same methods and for the same parameters as before. The minewater discharges were gauged using standard flow-gauging methods.

Table 3. Impact categories

	Impact	Area affected (m²)
High	A	>2500
Medium	B	10–2500
Low	C	<10

Table 4. Abundance categories (number per (100m²) for juvenile salmonids for quantitative runs

	Fry (0+)	Parr (0+)
Excellent	>100	>25
Good	50–100	15–25
Moderate	25–50	5–15
Poor	0.0–25	0.01–5
Absent	0	0

Table 5. Classification matrix for juvenile salmonids

		(Fry+)				
		Excellent	Good	Moderate	Poor	Absent
Parr (>0+)	Excellent	A	A	A	B	C
	Good	A	A	B	B	C
	Moderate	A	B	B	C	D
	Poor	B	B	C	D	D
	Absent	C	C	D	D	E

Physical/Chemical Impacts

A low pH is often associated with mine drainage, and such discharges are frequently referred to as acid mine drainage. However, the results of sampling ferruginous minewaters in the South and North Wales coalfields demonstrate that most of these discharges were not particularly acidic. Only four of the 33 discharges had a mean pH less than 6.0. It is assumed that most minewaters had been neutralized by the limestone which is associated with the South Wales coal measures, especially in the eastern area, before they emerged to the surface. As a result, precipitation of iron hydroxide occurred quickly at or near the point of entry to the watercourse. Where the pH of the minewater discharge and the receiving watercourse were more acidic, the rate of precipitation was slower. Generally, rivers and minewaters in the western part of the coalfield were more acidic than in the eastern area. However, where problems of low pH were noted at some upstream sites, the acidic discharges to these streams exacerbated the pH problems downstream. The near neutral pH values, which were found at many sites in the study, reduced the potentially harmful effects of dissolved aluminium as, in freshwater, at a pH value of 6-8 aluminium is least soluble and has a low toxicity to the biota. As the pH decreases, the amount of dissolved aluminium increases, causing a subsequent increase in the toxicity. It was found that aluminium did not exceed the 'environmental quality standard' (EQS) of 1 mg/l at pH 6-8 at any of these sites receiving full impact assessment[2].

The single most important chemical component of the discharges impacting on the fauna was iron, because deposition of ferric hydroxide onto the substrate has a highly deleterious impact. The EQS of 2 mg/l total iron[3] was exceeded on at least one sampling occasion for 11 of the 33 sites selected for impact assessment in stage 2. Downstream from the discharge to the River Morlais (30) the maximum concentration of iron was 26.4 mg/l. Failure of the EQS for iron has implications in meeting long-term water quality objectives and hinders the long-term improvement of water quality of a number of rivers in South Wales.

Before they discharge, minewaters can be low in dissolved oxygen due to the oxidation of pyrites below ground. Further rapid oxidation to iron hydroxide, which precipitates in the receiving watercourse, also requires oxygen.

Suspended solids at concentrations of less than 25 mg/l are considered to have no direct impact upon freshwater fisheries[4]. In general, the concentrations of suspended solids downstream from most minewater discharges remained below 25 mg/l. The results for mean temperature indicated that, in all cases, there was little difference between the discharge and the receiving watercourse. However, the discharge temperatures tended to be fairly constant throughout the year so that during the winter period they were approximately 2°C higher than the temperature of the receiving water. Small increases in temperature were observed at many downstream sites, although these increases are not considered to be high enough to significantly affect the biota.

Mine drainage may contain high concentrations of sulphates due to the oxidation of pyrites. In 32 of the 33 sites sampled, on more than one occasion it was found that downstream sulphate concentrations were increased, often by as much as several hundred percent.

Biological Impacts

A high (A) biological impact was shown at ten sites, which included the three most significant discharges to classified waters and the top two discharges to unclassified waters. This indicates a correlation between physical/chemical impact and biological impact.

Greatest biological impact occurred below the discharge from Morlais colliery, Llanelli. This discharge drains minewater from the old Brynlliw colliery and discharges to the River Morlais close to its confluence with the River Loughor. The site is near to the tidal limit of the Loughor estuary. A riffle site was sampled downstream from the discharge, which showed a substantial impact on the fauna with an 82% reduction in BMWP score. The number of taxa scoring ≥6 in the BMWP score, decreased from 9 at the upstream site to 1 at the downstream site. The degree of deposition of iron hydroxide at the site was very high, and the downstream iron concentration (26.4 mg/l) was the highest of the 33 sites studied and well in excess of the EQS for total iron. Such a high iron loading had a highly deleterious impact upon the invertebrate fauna, causing a complete loss of 14 families and a reduction of 3 families at that site.

A total of 13 discharges were found to cause a medium biological impact and, of these, 8 discharges caused a medium impact over a large area (Table 3). At some sites, upstream biological quality was relatively poor, as indicated by the RIVPACS EQI, and difficulty was experienced in assessing the true impact of the ferruginous discharges.

Discharges to a total of 9 sites were shown to have no biological impact. In the case of a discharge to the River Rhondda, the upstream fauna were affected by poor water quality, probably as a result of storm-sewer overflow discharges. However, the reduction in BMWP score of 30% between the upstream and downstream site suggests that the minewater was affecting the invertebrate fauna.

Across the region, a total of 12 families were apparently eliminated from the immediate downstream sties by iron hydroxide deposition. They included the mayfly Leptophlebiidae, cased caddis larvae of the taxa Goeridae, Odontoceridae and Lepidostomatidae, Helodidae, Dryopidae, Lymnaeidae, Planorbiidae and Sphaeriidae. Some of these taxa are known to show a degree of tolerance to organic pollution. Minewater discharges do not organically enrich the receiving watercourse, but the blanketing of substrate by iron hydroxide and possible direct toxicity of some discharges explains why these taxa were absent below discharges. Where taxa were present at a reasonable number of upstream sites (i.e. >5), they were considered to be ubiquitous in the rivers surveyed, and complete loss and/or reductions in abundance of these taxa suggests that they are particularly sensitive to ferruginous minewaters. On this basis, the following taxa are deemed to be sensitive to minewater discharges: Perlodidae, Chloroperlidae, Sericostomatidae, Cordulegasteridae, Philopotamidae, Limnephilidae, Hydroptilidae, Dytiscidae, Hydrobiidae and Erpopdellidae. These taxa score at all levels in the BMWP index, suggesting that the blanketing and binding of substrate by iron hydroxide is highly deleterious to a wide range of invertebrate taxa. The above taxa could be used as indicators of the impact of ferruginous minewaters either in addition to the BMWP scoring system or as an alternative.

Fisheries Impacts

The upstream fishery quality of most sites was moderate (C) to poor (D). This suggests that either the habitats are unsuitable for salmonid populations or the upstream water quality may be limiting the success of salmonids. However, at some sites populations were excellent (A) (Llynfi tributary (15)) or good (B) (River Cathan (29), Nant Melyn (32) and the River Llwyd at Abersychan (1)).

No fish were caught on the Gwenffrwd (26), in the Pelenna catchment, either upstream or downstream from the discharge. The low pH, which was observed upstream and downstream from the minewater discharge, is believed to be detrimental to salmonids, contributing to their absence in this site. No fish were caught at site (18) on the River Corrwg Fechan, which is also in an upland afforested area. At eleven sites there was no reduction in RJSMP class due to the minewater discharges. Of these, three sites had better fish population downstream from the discharge (than upstream) due to poor upstream quality masking the true effects of the minewaters on the fish populations of the receiving watercourses. In the case of the River Sirhowy (6) and the River Rhymney (7), this may be due to intermittent discharges of storm-sewage overflows. Ideally, an upstream 'control' site should support a good population of salmonids so that any impact of a minewater would be readily detected at the downstream site. The reduction of two RJSMP classes indicated high (A) fisheries impact at three sites. In each case the discharges impacted on the fry or juvenile salmonid population. The blanketing effect of iron hydroxide precipitation is believed to be detrimental to the success of salmonids by affecting the spawning, the survival of fry, and consequently the size of juvenile populations.

Reductions of one RJSMP class, from good (B) to moderate (C) were noted below two discharges and from moderate (C) to poor (D) at three sites. HABSCORE was applied to 17 of the 19 sites which were electrofished. The HUIs correlated well with the RJSMP classifications and indicated that, at many upstream sites, a perturbed fishery exists, i.e. poor to moderate. They also showed that, at sites where an excellent or good fishery existed, the quality of the fish populations could be even better. The 'habitat quality scores' show that some sites had low to median quality habitats, upstream and downstream from the discharge. This indicates that, despite under-utilization of some sites, the relatively poor quality of the habitat explains, in part, the low numbers of fish caught. In cases where the habitat quality scores indicated high-

Table 6. Stage 2 ranking results using override

Table of ranked minewaters		Stage 2 impact criteria					
Rank	Site	Biology	Area biol. impacted	Fisheries	Stage 1 orig. rank	Class	U/S RIVPAC EQI
1	30 A. Morias	A	A	A	2	C	0.78
2	16 N. Craig yr Aber	A	A	B	6	C	0.80
3	19 N. Gwynfi	A	A	C	10	C	0.59
4	25 N. Blaenpelenna	A	A	C	1	C	0.62
5	26 Gwenffrwd	A	A	C	3	C	0.53
6	10 R. Llwyd Blaenavon	A	A	–	19	C	1.33
7	33 Tawe Trib.	A	A	–	2	U	0.98
8	31 R. Clyne	A	B	C	1	U	0.88
9	2 R. Llwyd Pontnewydd	A	B	–	13	C	0.86
10	12 Y Ffrwd Clydach trib	A	B	–	4	U	0.99
11	17 A. Corrwg	B	A	B	10	U	0.44
12	29 R. Cathan	B	A	B	3	U	0.91
13	18 A. Corrwg Fechan	B	A	C	15	C	0.38
14	6 R. Sirhowy Pontlanf.	B	A	C	15	C	0.61
15	7 R. Rhymney Hengoed	B	A	C	9	C	0.64
16	4 R. Ebbw Newbridge	B	A	–	11	C	0.49
17	5 R. Sirhowy B'Wood	B	A	–	4	C	0.77
18	3 R. Llwyd Pontypool	B	A	–	14	C	0.82
19	15 Lynfi Trib	B	B	A	5	U	1.06
20	1 R. Llwyd Abersychan	[B]	[B]	B	7	C	0.69
21	11 R. Clydach Trib.	B	B	C	9	U	0.84
22	24 N. Blaenpelenna	B	B	–	–	–	0.54
23	34 Broughton Brook	B	B	–	17	C	0.31
24	32 Nant Melyn	C	C	A	19	U	0.79
25	21 A. Corrwg W.D.A. Site	C	C	B	12	C	0.81
26	23 Ffrwd Wyllt Goytre	C	C	C	8	C	1.15
27	27 Trib. of Nant Cregan	C	C	C	27	U	1.33
28	28 Nant y Fedw	C	C	C	14	U	1.22
29	9 R. Dare trib.	C	C	–	18	C	1.10
30	13 R. Rhondda	C	C	–	16	C	0.48
31	20 R. Afan	C	C	–	25	C	0.86
32	22 Ffrwd Wyllt Bryn	C	C	–	20	C	1.31
33	14 Ogwr Fach	No upstream flow so not ranked.					

[ ] ranked according to override rules.
Those sites where fisheries surveys were not carried out are denoted by a dashed line.

quality habitats upstream and downstream from the discharge, the effects of poor upstream water quality often masked the effects of the minewater discharge.

In conclusion, the impact of minewater discharges on fish populations was only fully demonstrated at sites where upstream water quality, habitat and therefore background fish populations were good (e.g. R. Llynfi (15)).

Ranking Method for Full Impact Assessment Data and Results

A ranking method to provide an overall assessment of the impact of the 33 minewaters on the biological and fisheries quality of the receiving waters has been developed.

The method is based on three components: (i) a measurable biological impact between the upstream and immediate downstream site (which is the most important component); (ii) the area of river bed biologically affected; and (iii) the impact on fisheries. Sites have been ranked against each of the three components (in turn) as high (a), medium (B), or low/no impact (C) as described previously.

After an initial ranking exercise, it was felt that a number of sites which were ranked as having a significant physical/water quality impact in stage 1 of the study, but did not have measurable biological or fisheries impacts in stage 2 because of poor upstream biological quality, were erroneously placed (e.g. the River Llwyd at Abersychan (1)). To overcome this, the 'river invertebrate prediction and classification system' (RIVPACS) was used. RIVPACS is a computer model developed by the Institute of Freshwater Ecology to predict the invertebrate fauna which would be expected in a variety of natural river types under pristine water quality conditions[5]. The ratio of the observed to the RIVPACS expected BMWP scores can be used as an 'environmental quality index' (EQI). A biological override when the EQI was less than 0.7, was applied.

Sites which were ranked in the top 15 in the stage 1 ranking and which had no measurable biological impact (i.e. scored C) in stage 2, but which had an upstream EQI value of <0.7, have been re-ranked on the assumption that there would have been a moderate biological impact, had the upstream quality been better. Such sites have been given a subjective (B,B) for biological impact and biological area affected (Table 6).

Developments

A second phase of the project was carried out in 1994, and the top 16 discharges identified in this study were assessed to (a) identify the underlying causes of the discharges, (b) propose the most favourable remedial options, and (c) provide budget costings[6]. This work was jointly funded between the NRA and Welsh Office. Recently, Welsh Region has provided its 'top ten' list of abandoned mines requiring remediation to the Coal Authority, who are appointing consultants to investigate about 30 abandoned mines in England and Scotland, similar to phase 2 described above. Other regions will use the minewater impact assessment ranking described in this paper to produce a National (England and Wales) ranked list.

Conclusions

1. The deposition of iron hydroxide from ninety ferruginous minewater discharges affected a total length of 59.4 km of river and an area of 22 ha of river bed in the Welsh coalfield areas. Of the 33 most deleterious discharges selected for full assessment, the impacts ranged from mainly aesthetic effects to impacts on water quality, biology and fisheries status downstream.
2. The minewater discharges were found to be generally mildly acidic, and the neutralization of minewaters by locally occurring limestone, prior to discharge to surface waters, may explain this fact.
3. The concentrations of dissolved aluminium in the discharges were not sufficiently high to cause failure of the EQS of 1 mg/l aluminium at pH 6-8 in the receiving watercourses.
4. The deposition of iron hydroxides onto the substrate caused blanketing and binding of substrate, loss of habitat, and reduction in the epilithon – all of which are essential for a diverse and abundant invertebrate fauna. In ten cases, considerable losses and reductions in abundance of taxa were demonstrated below discharges to both pristine quality waters and poor-quality watercourses.
5. The impact of minewater discharges on fisheries was not readily demonstrated where the receiving watercourse was already of poor quality. In such cases the impact was partly masked by the poor receiving water quality, caused, for example, by intermittent discharges from combined sewer overflows.

Acknowlegements

The NRA would like to acknowledge funding received for both phases of the project from the Welsh Office and wish to thank Dr Havard Prosser for his contributions. The authors are grateful to Doryn Foolchand and Gillian Bourn who both assisted on the project, to NRA Llanelli Laboratory staff, to NRA Pollution Control and Environment Appraisal staff for their practical assistance.

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