November 1996

Environmental Assessment of Selected Abandoned Minewaters in the North East Region

ENVIRONMENT AGENCY

EXECUTIVE SUMMARY

1. The deleterious impact of abandoned minewater discharges on watercourses within the Durham and Yorkshire coalfields has been recognised, and to a large degree tolerated, for many decades. Many discharges are associated with mines which were abandoned before the industry was nationalised. The extent of the problem has never been properly quantified. Previous work has primarily been on a site specific basis such as at Bullhouse and Sheephouse minewater discharges. However, there is very little information relating to the issue on a national or regional basis. Further to the Memorandum of Understanding between the NRA and the Coal Authority (1995), the Coal Authority are addressing the issue of abandoned minewater discharges and are currently exploring the possibility of obtaining funding for minewater remediation schemes. This report is intended both to assist with the Coal Authority's bid for funds and also to aid in the prioritisation of resources.

2. This report details the procedures, results and conclusions of a project undertaken by the NRA Northumbria and Yorkshire Region to assess the environmental impacts of 19 minewaters considered to be amongst the most damaging in the region.

3. The impact assessment was based on both physicochemical and biological parameters. The strategy used to rank the minewaters is based largely upon the methodology designed by the NRA Welsh Region in 1994, as this approach proved relatively successful. Also this ensures consistency in the methods used by different regions of the NRA and will allow comparison of results on a national basis.

4. Chemical analyses of both the minewaters and the receiving watercourses were repeated three times between September and November 1995. Samples were taken from the minewaters themselves, and from the receiving watercourses, both upstream and downstream of the polluting discharge. Benthic macroinvertebrate samples were also taken on one occasion at these sites, in September 1995.

5. Results indicate that the minewater discharges have a deleterious impact on both the water quality and the invertebrate fauna of receiving watercourses. It would appear that the highly elevated iron concentrations in these minewaters (5.5 mg/l - 124.3 mg/l) are largely responsible for damage to the fauna and for the reduction in water quality.

6. The data collected are used to generate a ranked list of the minewaters. This has been achieved by utilising the Welsh methodology, which is based largely on the magnitude of the biological impact downstream of a minewater discharge and the area affected, both physicochemically and biologically. Other categories used in the ranking strategy are, the fisheries potential of a receiving watercourse, the length of receiving watercourse visually affected by deposition of orange iron precipitates, together with various chemical parameters (pH, iron and aluminium concentration, and dissolved oxygen saturation in the receiving water).

7. On the basis of this investigation, the five minewaters in Northumbria and Yorkshire with the highest environmental impact are, in order, as follows:

1. Bullhouse Minewater, Upper Don Catchment.

=2. Fender Minewater, Rother Catchment.

=2. Edmondsley Minewater, Lower Wear Catchment.

4. Clough Foot Minewater, Upper Calder Catchment.

5. Lambley Minewater, Tyne Catchment.

This list is not intended to be used in isolation and is designed only as a precursor to a full cost-benefit analysis.

8. Should future work of this nature be carried out it is recommended that the following areas are considered:

(i) Categorising fisheries potential has mainly been achieved on an essentially subjective basis in this report, but ideally quantitative data should be made available for a more accurate and robust assessment.

(ii) Only 19 minewaters have been assessed. If a greater number are investigated it will probably be necessary to subdivide the various categories of assessment further, in order to avoid groups of minewaters being assigned the same rank.

(iii) The biological impact category is critical in determining the final ranking of these minewaters. It is felt uncertain whether the emphasis on this category is justified, and whether its importance is greater than area affected. The heavy reliance on biological impact in assigning a ranked position to a minewater should be borne in mind when carrying out work of this nature in the future.

CONTENTS

SECTION **PAGE**

GLOSSARY OF ACRONYMS

AMD	-	Acid Minewater Drainage
AMP	-	Asset Management Plan
ASPT	-	Average Score Per Taxa
AQC	-	Analytical Quality Control
BMWP	-	Biological Monitoring Working Party System
DO	-	Dissolved Oxygen
EIFAC	-	European Inland Fisheries Advisory Commission
EQI	-	Environmental Quality Index
EQS	-	Environmental Quality Standard
GQA	-	General Quality Assessment
HABSCORE	-	Habitat Quality Score System
NRA	-	National Rivers Authority
NAMAS	-	National Measurement Accreditation Service
RIVPACS	-	River Invertebrate Prediction And Classification System
STW	-	Sewage Treatment Works

1.0 INTRODUCTION

In July 1995, the NRA Northumbria and Yorkshire Region undertook a detailed study to assess the impact of abandoned (or uncontrolled) minewaters on watercourses throughout the region. In many areas within the region such discharges are responsible for significant pollution problems. The recent large scale run down of the coal industry and the possibility of this resulting in the emergence of new uncontrolled discharges (following cessation of active mine dewatering) has brought the issue back into focus. The NRA has identified the problem as a top priority for action in its corporate plan 1995-'96. Memoranda of Understanding have recently been agreed between the NRA and both the Coal Authority and mine operators RJB Mining (UK) Ltd. Emphasis has been placed on the development of a strategy in partnership with the Coal Authority to deal with abandoned minewaters. The immediate task for the NRA is to produce evidence to show which discharges are having the most severe impact, to assist in the process of effective targeting of funds which the Coal Authority hope to secure from the Government for remediation. In order to ensure consistency of approach throughout the NRA regions, Sue Slack (Regional Technical Manager) was identified as National Coordinator for the issue and it was decided that a methodology developed in a Welsh region impact study (1994) would be used in similar impact studies throughout the other NRA regions.

This report presents the results of the project which assesses the impact of 19 'high priority' abandoned minewater discharges and is intended as a follow on to the NRA report "Abandoned Mines And The Water Environment", (1994). These 'high priority' discharges were selected on the basis of the limited impact data already possessed within the region and because the Coal Authority required a list of the worst minewaters within the region by early 1996. Within this timescale it would have been impossible to effectively evaluate all the discharges within the region. Survey work commenced in late August 1995 and was completed by the end of October 1995.

1.1 Background

There are approximately fifty abandoned minewater discharges within Yorkshire. These mainly affect the Rivers Don, Rother and Calder and their tributaries.

There are approximately one hundred abandoned minewater discharges within Northumbria, mainly affecting the Rivers Tyne and Wear and their tributaries.

In Yorkshire most of the discharges are associated with long abandoned shallow workings towards the western edge of the catchment. These minewaters typically affect upland, fast flowing otherwise unpolluted watercourses which might be expected to contain healthy salmonid populations. Few of the minewaters discharge to lower lying, slow flowing watercourses.

In Northumbria almost all of the discharges are to be found in the western part of the exposed coalfield. Further to the east drainage from interconnected workings is primarily influenced by dewatering operations carried out at nine pumping sites by the Coal Authority. As in Yorkshire those watercourses impacted are typically unaffected by other significant sources of pollution.

The deleterious impact of abandoned minewater discharges on watercourses within the Durham and Yorkshire coalfields has been recognised, and to a large degree tolerated, for many decades. Many discharges are associated with mines which were abandoned before the industry was nationalised. The extent of the problem has never been properly quantified. Previous work has primarily been on a site specific basis such as at Bullhouse and Sheephouse minewater discharges. For many abandoned minewaters, impact data is sketchy or non existent. Before the work carried out for this project it would not have been possible to determine which of the regions' minewaters were having the greatest overall deleterious impact on the receiving watercourses.

As the NRA strives to meet its statutory obligation of improving river water quality by regulating discharges from industry and water undertakers, abandoned minewaters will progressively become the limiting factor to improvements on affected watercourses unless action is taken to remediate them.

The NRA has lacked a legislative framework with which to deal with pollution from abandoned mines. This legal loophole will be closed by the provisions of the new Environment Act which received royal assent in July 1995. The new legislation will allow the Environment Agency to require mine owners to undertake remedial schemes to mitigate pollution where mines are abandoned after 1999. The discharges associated with long abandoned workings and indeed, any associated with mine closure before 1999 will remain exempt.

Further to the Memorandum of Understanding, the Coal Authority are addressing the issue of abandoned minewater discharges. They have already let a contract to engineering consultants Scott, Wilson Kirkpatrick to look closely at possible remediation options on approximately thirty polluting discharges throughout the north of England and Scotland (including fifteen in Northumbria and Yorkshire). They also hope to secure funding to implement some of the remediation schemes recommended. It is essential that finite resources secured are targeted effectively to ensure maximum environmental benefit. The NRA has a role to play in this process by producing evidence to show which discharges are having the greatest impact. The Coal Authority would like this information in the form of an impact ranked list and such a list will be the main product of this project.

When the NRA was approached by the Coal Authority early in 1995 to produce a ranked list of abandoned minewaters, it was impossible to do so because vital information required to do the assessments was lacking. To satisfy the Coal Authority's urgent requirement for information, it was agreed to nominate the regions' worst minewaters. A list of nineteen 'high priority' minewaters was produced based on the experience and professional judgement of field staff and the limited impact data already possessed. The project covered by this report has looked at these nineteen 'high priority' abandoned minewaters.

1.2 Chemistry Of Minewater Generation

A brief description of the chemical reactions and conditions leading to the formation of minewaters is given below. Only the salient points are highlighted here, as numerous other sources discuss the chemistry of minewater generation in more detail (e.g. Barnes and Romberger, 1968; Singer and Stumm, 1970).

The formation of ferruginous, and sometimes acidic, discharges is a result of the oxidation and hydrolysis of the mineral pyrite (iron disulphide, FeS_2). Pyrite occurs widely in coal seams, and is exposed during mining operations. Lowering of water tables, to enable access to deeper coal seams, facilitates the oxidation of pyrite, a reaction which is catalysed by the action of iron oxidizing bacteria such as *Thiobacillus*. Subsequent rebound of water tables, often as a result of the cessation of dewatering activities following mine closure, enables these oxidation residues to be washed into solution. The composite equation below illustrates that this series of reactions results in minewaters being characterized by high iron and sulphate concentrations, and elevated acidity concentrations, since 4 moles of acidity are released for each mole of pyrite.

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 16H^+ + 8SO_4^{2-}$$

(From Barnes and Romberger, 1968)

Further rebound eventually leads to water tables adopting their natural level, and minewaters may then emanate at the surface, via adits, springs, seepages, or even stream beds. Receiving streams are often thickly coated with orange iron hydroxide and related compounds, which are precipitated out of solution in the oxidizing environment of surface streams. These deposits are collectively known as 'ochre'. Discharges into these receiving waters may also be highly acidic ($pH < 2$ in some examples) as a result of sulphuric acid generation. However, where minewaters have percolated through calcareous material discharges at the surface may approach neutrality. In instances where the discharges are acidic other heavy metals, in particular manganese and aluminium, may also be present at elevated concentrations, as a result of their increased solubility at low pH. Minewaters generated from coal spoil heaps may have even higher acidity levels, and greater heavy metal concentrations, as there may be greater potential for pyrite oxidation, and water percolation through the spoil heap.

1.3 Aims

The principle aim of this interim report is to produce a ranked list of the 19 preselected minewater discharges within Yorkshire and Northumbria according to their ecological impact on the receiving waters. In addition to the ranked list, this report aims to:-

- Provide supporting data and information for the development of remediation options;
- Facilitate the prioritisation of resource input into remediation treatments; and
- Act as a precursor for further assessment of the minewater discharges within Yorkshire and Northumbria.

1.4 Ranking Strategy

The strategy used to rank minewater discharges, according to their environmental impact on the receiving waters, is based on the methodology developed by the NRA Welsh Region, which is detailed in the report "A Survey of Ferruginous Minewater Impacts in the Welsh Coalfields" (NRA Welsh Region, 1994). The ranking strategy adopts a two stage approach. Stage one provides a preliminary ranked list based on the physicochemical impact of the minewater discharge on the receiving water. Those minewaters which have the severest physicochemical impact are selected for progression to stage two. This provides a final ranked list based on the biological impact of the minewater discharge on the receiving water.

For the purpose of this report, however, nineteen minewater discharges have been preselected for physicochemical and biological assessment based on the experience and professional judgement of the NRA Northumbria and Yorkshire Region.

The collection and processing of data required for stage one and stage two of the ranking methodology is detailed in Section 3.0.

1.4.1 Stage 1 Ranking Strategy - Physicochemical Data

Parameters used in Stage 1 ranking

Table 1 details the physicochemical factors and impact criteria used to provisionally rank the minewaters. The area and length of the river bed visually affected by iron hydroxide deposits provides an indication of the potential loss of aquatic habitat. The area affected is calculated by:

$$\underset{(m^2)}{\text{Area Affected}} = \underset{\text{Visually Affected (m)}}{\text{Length of River}} \times \underset{\text{Width (m)}}{\text{Average Channel}} \times \underset{\text{Iron Deposits}}{\text{\% Bed Covered With}}$$

Substrate is classified according to its potential to support diverse fauna and salmonid reproduction. The substrate categories detailed in Table 1 are based upon the criteria used for the Habitat Quality Score (HABSCORE), which quantifies the fisheries potential of the habitat, and the River Invertebrate Prediction and Classification System (RIVPACS) computer models.

The visual iron deposition impact category indicates the degree of blanketing and binding of the substrate by iron hydroxide precipitation. Photographs illustrating high, low and medium impact are used for comparison purposes to reduce the element of subjectivity in assigning the level of impact (Plates I, II and III). The impact of the iron concentration, in the mixing zone downstream of the minewater discharge, is based on a proposed Environmental Quality Standard of 2 mg/l (Total Annual Average of Iron) for surface waters supporting salmonids (Mance and Campbell, 1988).

PLATE I

High Visual Impact Standard

PLATE II

Low Visual Impact Standard

PLATE III

Medium Visual Impact Standard

The standards set for pH, dissolved oxygen (DO) and Total Aluminium concentration are based on their potential to cause harm to fisheries. The values equating to a failure of that standard are described below:

pH	-	< 7
DO	-	< 70% saturation
Total [Al]	-	> Environmental Quality Standard (EQS) 1 mg/l

TABLE 1: GRADING OF PHYSICOCHEMICAL IMPACT

PHYSICOCHEMICAL PARAMETER (In Decreasing Order of Importance)	IMPACT ON RECEIVING WATERS					
	HIGH (A)		MEDIUM (B)		LOW (C)	NO (D)
AREA AFFECTED (m²)	A1	A2	B1	B2	< 10	-
	> 10,000	2,501 - 10,000	1,001 - 2,500	10 - 1,000		
LENGTH AFFECTED (km)	> 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) [1]	> 3		2 - 3		< 2	-
PH [2], DO (%) [3], TOTAL ALUMINIUM (mg/l) [4]	3 Failures		2 Failures		1 Failure	No Failures

[1] Iron concentration ranges based on a proposed Environmental Quality Standard of 2 mg/l ; annual average of total iron for surface waters supporting salmonids (Mance and Campbell, 1988).
[2] pH values less than 7.
[3] Dissolved Oxygen (DO) values less than 70% saturation.
[4] Total Aluminium (Al) concentration downstream of discharge greater than the EQS of 1 mg/l (European Inland Fisheries Advisory Commission (EIFAC) for surface waters of pH 6-8).

Ranking Strategy

Using the categories outlined above, a dichotomous method is used to rank the minewaters. This is carried out using the physicochemical parameters in decreasing order of importance. For example, watercourses receiving an 'A' rating for the area of river bed affected appear at the top of the list followed by those receiving a 'B' rating and 'C' rating respectively. These are then ranked according to the second criterion, length of river affected, giving three sub-groups per main group. Each sub-group is then ranked according to the quality of substrate. This procedure is carried out for the remaining parameters. A minewater with an 'A' rating for area affected but a 'B' rating for all the other parameters appears above a site with a 'B' rating for area affected and an 'A' rating for all other parameters.

The high and medium impact categories for the area visually affected by the minewater have been subdivided in order to provide a greater sensitivity to the ranking procedure. This will allow better separation of the minewater discharges according to their physicochemical impact. It should be noted that this approach differs from the Welsh Ranking Strategy which does not use subcategories. Although the categories have been subdivided, the areas defined within each category remain the same.

1.4.2 Stage 2 Ranking Strategy - Biological Data

Table 2 details the biological parameters and impact criteria used to produce a final ranked list of the minewaters. Details of the three parameters used in this stage of ranking are given below.

Biological Impact Criteria

The Biological Monitoring Working Party (BMWP) system is a recognised biological tool which may be used to assess the biological impact of the minewater discharge on the receiving water. The BMWP system is based on the differing sensitivity of benthic macroinvertebrate families to primarily organic pollution, but can also be used to infer toxic pollution. The most sensitive families are allocated scores of 10 and the least sensitive 1. A series of intermediate scores, 2-8, are allocated for those organisms in between. The BMWP score is the sum of the individual scores of the invertebrate families present in the sample. It should be noted that families are only counted once.

Comparison of BMWP scores between the upstream and the immediate downstream site from the minewater discharge provides an indication of the biological impact. A reduction in the BMWP score of greater or equal to 40% between the two sites is considered to be significant.

The change in BMWP score is used in conjunction with changes in abundance of the high scoring families, i.e. those with an index value greater or equal to 6. Changes in taxa abundance, like the BMWP score, provides an indication of the impact of the minewater discharge. The abundance of sensitive families will decrease with increasing impact from the minewater discharge. The impact is considered significant when there is a reduction in the $\log_{10}$ abundance of four or more families with an index value greater or equal to 6 on the BMWP system between the upstream and immediate downstream site.

RIVPACS is used to indicate those upstream sites which are affected by other sources of pollution, such as discharges from sewage treatment works (STWs), which act to lower the BMWP score and average score per taxa (ASPT) . This in turn masks the actual impact the minewater discharge is having on the receiving water. The RIVPACS system is used to predict the optimum BMWP, ASPT and number of taxa for the upstream sites. The ratio of observed to expected scores, known as the Environmental Quality Index (EQI), gives a measure of the actual biological quality of the receiving water relative to its potential quality. To make an accurate prediction RIVPACS requires environmental data from three seasons (spring, summer and autumn). Predictions used for this report have been made based on one seasons environmental data therefore the EQIs of the ASPT and number of taxa are used to indicate those upstream sites affected by other sources of environmental stress. ASPT is less prone to influences caused by season, sample size and sampling effort (Armitage *et al*, 1983). Where an

EQI of the ASPT is less than 0.7 and/or the number of taxa is less than 0.5 the macroinvertebrates may be considered to be influenced by 'poor' water quality. In these situations, the assigned level of biological impact of the minewater discharge is increased by one (e.g. from category C to B). Where the biological impact is already high (A) the new impact category A^+ is assigned.

The criteria used to assign the impact category are exactly the same as those employed by the NRA Welsh Region. The C category, however, has been renamed from 'no impact' to ' low biological impact' in order to take into account situations where there is a low biological impact affecting a large area.

TABLE 2 : GRADING OF BIOLOGICAL IMPACT

BIOLOGICAL PARAMETER (In Decreasing Order of Importance)	IMPACT ON RECEIVING WATERS			
	HIGH (A)	**MEDIUM (B)**		**LOW (C)**
BIOLOGICAL IMPACT	Reduction in BMWP score ≥ 40% **AND** a reduction in $\log_{10}$ abundance of ≥ 4 families with an index score of ≥ 6 between the upstream and immediate downstream site.	**EITHER** a reduction in BMWP score ≥ 40% **OR** a reduction in $\log_{10}$ abundance or ≥ 4 families with an index score of ≥ 6 between the upstream and immediate downstream site.		Neither the criteria of high or medium impact.
AREA BIOLOGICALLY AFFECTED (m^2)	> 2, 500	10 - 2, 500		< 10
FISHERIES POTENTIAL		**B1**	**B2**	
	Presence of riffle and deep pool sites, rock/stone/gravel substrate, meanders and overhanging bankside vegetation. Capable of supporting a self sustaining salmonid fisheries.	Similar to (A) but on a smaller scale.	Similar to (B1) but physical habitat not as suitable, ie. lack of spawning medium, pooled areas limited and/or poor overhanging vegetation.	No fisheries potential essentially due to size restriction; narrow /shallow channel.

The override system employed to upgrade the assigned biological impact category differs from that used in the Welsh Ranking Strategy. The BMWP EQI has been substituted with that of the ASPT and number of taxa. It is considered that the use of a predicted BMWP based on one seasons data to calculate the EQI is less reliable than the use of a predicted ASPT and number of taxa to indicate water quality. ASPT is inherently less variable than BMWP and is therefore substituted as an indicator of water quality. ASPT, however, is essentially a function of organic pollution. To compensate for this, the EQI of the number of taxa is also included to indicate those sites which may be affected by heavy metal pollution or acidification, conditions which act to reduce the number of taxa (Stoner *et al*, 1984). The threshold values used, 0.7 EQI ASPT and 0.5 EQI number of taxa, are the provisional values to be used in the quinquennial General Quality Assessment (GQA)survey of the NRA.

Area Affected Biologically

The area of the river bed affected biologically by the minewater discharge provides a measure of the biological impact that the minewater discharge is exerting on the receiving aquatic habitat. The area affected is taken from the discharge point to the first point downstream at which the biological quality is the same or better than upstream of the discharge.

Fisheries Potential

A fisheries potential parameter has replaced the fisheries impact assessment used as part of the Welsh Ranking Strategy. The decision to modify this was based primarily on the limited timescales involved.

An assessment of the fisheries potential of a watercourse indicates the grade of fisheries which may be established if the impact from the minewater discharge is removed. This does not however take into account the impact of other discharges which may exert additional impacts on the fisheries.

This assessment identifies those locations where the fisheries potential would be habitat restricted.

Final ranked list

The final ranked list is that determined by use of the biological data. The same dichotomous ranking strategy used for physicochemical ranking is adopted here. Thus, those mine waters having a category A biological impact appear at the top of the list (see Table 5).

LOCATION OF MINEWATERS STUDIED IN NORTHUMBRIA & YORKSHIRE

Figure 1

2.0 SURVEY AREA

The survey area is within the NRA's Northumbria and Yorkshire Region and centres around the location of 19 pre-selected 'high priority' abandoned minewaters (7 in Northumbria and 12 in Yorkshire). Refer to Figure 1 and Table 3 for the minewater locations.

The selected Northumbria minewaters of this survey are located along the western edge of the Durham Coalfield, most being beyond the influence of dewatering carried out in the east. All the discharges except Helmington Row arise from old coal mineworkings. Helmington Row discharge is thought to arise from a coal spoil heap.

Five of the Northumbrian minewaters affect the River Wear and its tributaries and two affect the River Tyne and its tributaries. Generally, the discharges occur in the head water regions of the catchments. Exceptions to this are Bishop's Park and Lowlands.

The majority of the selected Yorkshire minewaters are located in South Yorkshire along the western edge of the Yorkshire Coalfield. All except Morton Clay arise from old coal mineworkings whose discharge results from clay mineworkings.

TABLE 3: NATIONAL GRID REFERENCES OF THE MINEWATERS

MINEWATER	NGR	MINEWATER	NGR
Bullhouse	SE 215 028	Unstone No. 1	SK 373 744
Fender	SK 366 751	Lowlands	NZ 134 251
Edmondsley	NZ 231 494	Summerley No.1	SK 365 780
Clough Foot	SD 905 238	Jackson Bridge	SE 164 074
Lambley	NY 673 596	Craggs Moor	SD 895 262
Acomb	NY 927 662	Limb Brook	SK 318 818
Helmington Row	NZ 185 357	Morton Clay	SE 104 323
Stony Heap	NZ 148 515	Sheephouse Wood	SK 253 992
Loxley Bottom	SK 323 894	Bishop's Park	NZ 217 301

Seven of the Yorkshire minewaters affect the River Don and its tributaries. Three affect the Rother sub-catchment, three affect the Calder catchment and one the Aire catchment. Conversely to the Northumbrian minewaters, the majority of the Yorkshire ones are located in the mid-reaches of the watercourse, and many are situated on the periphery of Sheffield.

3.0 METHODOLOGY

3.1 Site Selection Criteria

To collect sufficient data to meet the requirements of the ranking methodology broad decisions on sample areas were made prior to site visits. The following areas are essential sampling points:

1. Upstream of the minewater.
2. The minewater itself.
3. The mixing zone of the receiving water.
4. Downstream of the ochre limit in the receiving water.

Limits were inevitably imposed on the precise location at which samples were taken due to on site factors, such as:

1. Restricted/dangerous access.
2. Other influential discharges into the receiving watercourse.
3. Man-made stream beds/culverts.

Biological samples were taken across riffle zones at each watercourse, following the procedures outlined in the documents given in section 3.2.2, below. Chemical samples were taken immediately upstream of the area of biological sampling wherever possible.

At some minewaters, such as Stony Heap, it was not possible to obtain an upstream sample, as the minewater itself was the source of the stream. In these instances an adjacent stream within the catchment was selected. The following characteristics were looked for when selecting these proxy upstream sites:

1. Similar flow rate to the watercourse receiving the minewater.
2. Similar height and aspect.
3. Comparable width and depth.

3.2 Sampling Procedure

3.2.1 Physicochemical

Temperature, pH, electrical conductivity, dissolved oxygen concentration (as a percentage) and alkalinity were measured, in the field, using the following equipment:

-Temperature and pH with a Palintest digital probe (Microcomputer 900 model).

- Electrical Conductivity with a Palintest digital probe.
- Dissolved oxygen with a WTW Oxi 320 Oximeter.
- Alkalinity with a Hach alkalinity test kit.

The general guidelines given in the NRA National Sampling Procedures Manual, section ES021("Field measurements"), were followed throughout. Further, numerous NRA guideline documents relating to specific measurements were adhered to. These are listed in the References at the back of this document.

A number of physical site characteristics are required for the calculation of ranking variables. These parameters, and the method in which they were measured are listed below:

1. Length of watercourse affected: Measured either by pacing the length, or alternatively by making a note of the point at which the impact ceases, and then calculating the distance from an O.S. 1:50 000 scale map.
2. Wetted width of watercourse: Measured by tape measure to the nearest 10 cm.
3. Depth of watercourse: Measured with a metre ruler at 0.25, 0.5 and 0.75 width from the right hand bank.
4. Altitude: Calculated from O.S. 1:50 000 map.

5. Slope: Again, calculated by measuring the distance between two relevant contours on an O.S. 1:50 000 map.

Discharge values for each of the minewaters were collected using a single point measurement taken at 60% of the depth. The full details of this standard procedure are given in BS 3680. Where this was not possible, usually due to the narrow width of a watercourse, the guidelines in ISO 9002 were followed.

3.2.2 Biological Sampling

Benthic macroinvertebrate samples were taken at every site where it was practicable to do so. 3 minute kick samples were taken, together with a 1 minute manual stone search of the site. Samples were taken from riffle zones in the particular reach of interest. They were stored in labelled plastic bags for transport to the laboratory. Field identification of invertebrates in each sample was not undertaken. More detailed information on the procedures that were followed throughout sampling are given in:

BT001 "Procedure for collecting and analysing river macro-invertebrate samples for RIVPACS application".

3.3 Laboratory Procedure

3.3.1 Chemical

Determinands analysed for, in the NAMAS accredited NRA laboratory, were as follows:

Metals: Dissolved and/or total Iron, Aluminium, Lead, Copper, Zinc, Arsenic and Nickel. Manganese concentration was determined only for the last of the three surveys.

Anions: Sulphate and Chloride.

Other: Total Particulate Solids at 105° C.
Alkalinity (in mg/l as $CaCO_3$).

3.3.2 Biological

Samples were preserved, in a laboratory, on the day of collection using 4% Formaldehyde solution. Samples were then stored, in the same plastic bags in which they were collected, until sorting and identification proceeded. Full training was provided for the field staff involved.

3.4 Sorting And Identification Procedure

Sorting and identification procedures used are detailed in BT001, "Procedure for collecting and analysing river macro-invertebrate samples for RIVPACS application" (pp. 59-62). Full Analytical Quality Control (AQC) procedures were adhered to throughout sorting and identification.

3.5 Assessment Of Fisheries Potential

With regards to fisheries impact the equivalent Welsh NRA survey, "A survey of ferruginous minewater impacts in the Welsh Coalfields" (1994), on which this project is largely based, undertook quantitative electrofishing surveys. However, given the limited time available such a survey was not deemed possible here. An alternative category was therefore designed for this survey, known as 'Fisheries potential'.

The method is a subjective assessment of the stream/river habitat upstream and downstream of the minewater discharge. Each receiving water was assigned one of the following four categories:

A - Capable of supporting a self sustaining salmonid fishery, with habitat capable of holding significant numbers of fish above 30cm.

B1 - An important salmonid spawning and nursery tributary adding support to stocks in larger streams/rivers. Contains good spawning and fish holding areas.

B2 - Still likely to be a spawning and nursery stream but not so important as B1. Physical habitat lacking in some respect. i.e. lack of spawning medium, pooled areas limited, poor overhanging vegetation.

C - Identified as having very little or no fisheries potential.

Features used in this categorisation included substrate quality, watercourse size, the presence/absence of pools and riffles, and the nature of bankside vegetation.

4.0 RESULTS

4.1 Introduction

A substantial quantity of both chemical and biological data were collected during the course of the three month survey period. Only general trends and unusual results are discussed here. Full documentation of the chemical and biological data collected are available from the NRA, Hexthorpe, however.

Additionally, data was collected relating to flow rates and iron loadings of both mine water discharges and receiving watercourses. These data are not included here, as they are not considered of direct relevance to this discussion. Such data are of more significance when investigating possible remediation options. Again, however, all these data are available from the NRA in Hexthorpe.

4.2 The Ranked List Based On Physicochemical Impact (Table 4)

The first, and consequently the most important, stage of ranking on a physicochemical basis is by the area affected by ochre staining. Bullhouse, Loxley Bottom and Clough Foot minewaters are ranked highest through this categorisation (26 950 m^2; 14 668 m^2 and 21 925 m^2 respectively). Bishop's Park minewater is ranked eighteenth (39 m^2).

Fourteen of the eighteen minewaters fall into category A for length affected, the second phase of ranking. Category A is given to all those receiving watercourses which are affected for a length greater than 0.5 km. Sheephouse Wood, Lambley, Morton Clay and Bishop's Park are the only ones which are affected for less than 0.5 km.

Substrate quality is category A for all minewaters except Craggs Moor, which is category B/C.

The intensity of discolouration due to iron deposition, for which the categories are defined by the Plates in Section 1.4.1, is high (category A) for fifteen of the minewaters. Unstone No.1 and Bishop's Park are medium intensity, and Sheephouse Wood is low intensity.

Eleven of the receiving watercourses have an iron concentration immediately downstream of the discharge greater than 3.0 mg/l, and thus fall into category A. Helmington Row has the highest concentration, 53.4 mg/l.

Only Helmington Row falls into category A for the final ranking phase, which accounts for the combined parameters of pH, dissolved oxygen saturation and aluminium concentration. The majority of the minewaters fall into category D, which indicates that the receiving waters do not fail the threshold values for any of the three parameters. The result of this physicochemical ranking strategy is given in Table 4.

TABLE 4 : RANKED LIST BASED ON PHYSICOCHEMICAL IMPACT

RANK	MINEWATER DISCHARGE	AREA AFFECTED (m^2)	LENGTH AFFECTED (km)	SUBSTRATE QUALITY	IRON PPT.	TOTAL IRON (mg/l)	PH, DO %, TOT [Al] (mg/l)
1	CLOUGH FOOT	21,925[1] (A1)	6.30 (A)	A	A	16.20 (A)	7.0, 90%, [0.25] (D)
2	BULLHOUSE	26,950 (A1)	3.85 (A)	A	A	2.36 (B)	7.1, 92%, [0.15] (D)
3	LOXLEY BOTTOM	14,668 (A1)	1.93 (A)	A	A	1.22 (C)	7.0, 90%, [0.10] (D)
4 =	FENDER	3,045 (A2)	0.87 (A)	A	A	4.85 (A)	7.0, 74%, [0.02] (D)
4 =	JACKSON BRIDGE	4,300 (A2)	1.72 (A)	A	A	3.33 (A)	7.5, 81%, [0.06] (D)
6	UNSTONE 1	3,036 (A2)	0.92 (A)	A	B	3.53 (A)	6.7, 43%, [0.07] (B)
7	CRAGGS MOOR	2,856 (A2)	2.45 (A)	B/C	A	15.83 (A)	5.8, 85%, [1.41] (B)
8	SHEEPHOUSE WOOD	2,828 (A2)	0.39 (B)	A	C	1.71 (C)	7.4, 82%, [0.24] (D)
9	LIMB BROOK	1,400 (B1)	0.80 (A)	A	A	5.02 (A)	6.3, 91%, [0.14] (C)
10 =	SUMMERLEY 1	2,295 (B1)	0.85 (A)	A	A	4.82 (A)	7.3, 84%, < [0.01] (D)
10 =	ACOMB	1,500 (B1)	1.00 (A)	A	A	32.5 (A)	7.2, 69%, [0.06] (C)
12	EDMONDSLEY	1,950 (B1)	0.65 (A)	A	A	8.35 (A)	7.2, 77%, [0.03] (D)
13	LOWLANDS	2,250 (B1)	0.60 (A)	A	A	2.00 (B)	7.1, 78%, [0.06] (D)
14	LAMBLEY	1,925 (B1)	0.35 (B)	A	A	3.32 (A)	6.6, 44%, [0.05] (B)
15	HELMINGTON ROW	525 (B2)	0.60 (A)	A	A	53.4 (A)	3.2, 51%, [47.4] (A)
16	STONY HEAP	400 (B2)	0.80 (A)	A	A	5.78 (A)	7.7, 80%, <[0.01] (D)
17	MORTON CLAY	330 (B2)	0.28 (B)	A	A	2.59 (B)	7.3, 77%, [0.09] (D)
18	BISHOP'S PARK	39 (B2)	0.03 (B)	A	B	0.73 (C)	7.5, 68%, <[0.01] (C)

NOTE: [1] Heavy rainfall on day of survey.

TABLE 5 : FINAL RANKED LIST BASED ON BIOLOGICAL IMPACT

RANK	MINEWATER DISCHARGE	BIOLOGICAL IMPACT (% Redn. BMWP, Δ Log $_{10}$ Abund.)	AREA AFFECTED BIOLOGICALLY (m^2)	FISHERIES POTENTIAL	UPSTREAM EQI	
					No. OF TAXA	ASPT
1	BULLHOUSE	59.8%, 8 (A)	> 28,875 (A)	A	1.08	0.84
2 =	FENDER	78.9%, 5 (A)	> 3,045 (A)	B1	0.71	0.85
2 =	EDMONDSLEY	57.7%, 6 (A)	15,000[1] (A)	B1	0.82	0.92
4	CLOUGH FOOT	86.9%, 4 (A)	2,535 (A)	B2	0.52	0.88
5	LAMBLEY	61.2%, 9 (A)	325 (B)	A	1.27	0.95
6	ACOMB	97.1%, 7 (A)	1,500 (B)	B1	0.86	0.93
7 =	HELMINGTON ROW [2]	87.3%, 4 (A)	1,300 (B)	C	0.81	0.82
7 =	STONY HEAP	78.5%, 11 (A)	>675 (B)	C	1.08	1.07
9	LOXLEY BOTTOM	16.5%, 6 (B)	16,568 (A)	A	0.71	0.90
10 =	UNSTONE 1	[23.5%], 0 (C)-->(B)	4,356 (A)	B1	0.25	0.47
10 =	LOWLANDS	37.3%, 8 (B)	6,750 (A)	B1	1.01	1.00
10 =	SUMMERLEY 1	15.4%, 0 (C)-->(B)	2,768 (A)	B1	0.39	0.49
13	JACKSON BRIDGE	44.4%, 3 (B)	> 4,394 (A)	B2	0.91	0.78
14	CRAGGS MOOR	27%, 3 (C)-->(B)	2,870 (A)	C	0.39	0.83
15 =	LIMB BROOK	14.5%, 5 (B)	725 (B)	B2	1.12	0.88
15 =	MORTON CLAY	34.1%, 6 (B)	600 (B)	B2	1.12	0.86
17	SHEEPHOUSE WOOD	[9.3%], 2 (C)	725 (B)	B1	0.73	0.84
18	BISHOPS PARK	[9.1%], 3 (C)	0 (C)	A	0.95	1.03

NOTE: [1] Area affectecd biologically - overestimated

4.3 The Final Ranked List Based On Biological Impact (Table 5)

Eight of the minewaters under investigation exert a high biological impact. The highest reduction in BMWP score is between the upstream and immediately downstream sites of Acomb minewater discharge, where there is a 97.1% decrease. There is a reduction in $\log_{10}$ abundance of 11 families between the upstream and downstream sites at Stony Heap minewater. This is the highest number recorded.

Ten of the minewaters biologically affect an area greater than 2500 m^2. Bullhouse minewater affects the largest area biologically being in excess of 28 000m^2.

After the second stage of ranking the four top minewaters have tied ranks. It is only by applying the third stage of biological ranking that these four can be split. The third category of ranking is fisheries potential, the details of which are explained in section 3.5. Only Bullhouse, Lambley and Bishop's Park are placed in category A. As a result of this Bullhouse minewater is ranked one. Edmondsley and Fender are both given a category B1 for fisheries potential, and hence they are ranked equal second. As with the physicochemical ranking, Bishop's Park minewater comes at the bottom of the list.

4.4 Chemical Data

Seasonally, minewater temperatures remain comparatively constant, as they are not as susceptible to fluctuations in ambient air temperatures as receiving waters. During the sampling period (September - November 1995) minewaters averaged 9.5 - 12.0° C and, with the exception of Edmondsley minewater, were in the order of 1° C less than receiving watercourses.

The phenomenon of minewater drainage is often, somewhat misleadingly, known as "Acid Mine Drainage". Most of the minewaters in this investigation have a pH of approximately 6.5, usually only slightly lower than the receiving watercourse. Only three of the eighteen discharges can truly be described as acidic: Limb Brook (pH 5.7), Loxley Bottom No.1 (pH 4.9), and Helmington Row No.2 (pH 4.1).

At the point of first emergence the minewaters have suppressed dissolved oxygen saturations (11% - 67%), with the exceptions of Craggs Moor (88%) and Clough Foot (86%). The effects of this only appear to persist to any degree in the receiving watercourses at Unstone, Lambley and Helmington Row.

Conductivity values, a general measure of an aliquot's total ion concentration, is invariably high for minewaters (approximately 600 - 3000 μS/cm). This is due mainly to the presence of certain ions, detailed below, being present in exceptionally high concentrations.

At seven sites alkalinity is low (less than 100 mg/l as $CaCO_3$). As expected this includes the low pH sites highlighted above. Of the others only Bishop's Park has an exceptionally high alkalinity. Here, the minewater itself has a mean alkalinity of 571 mg/l as $CaCO_3$, and the receiving watercourse has an alkalinity in excess of 300 mg/l as $CaCO_3$.

Sulphate concentrations are variable. Given a knowledge of the chemistry of minewater generation, high levels would be expected. This is reflected at 15 sites, where sulphate concentrations are well in excess of upstream values. At these sites sulphate concentrations range from 173 mg/l (Craggs Moor) to 1933 mg/l (Helmington Row No.2). Generally these high concentrations are reflected in elevated levels in receiving watercourses downstream of the discharge. Sites where sulphate concentrations are not high, or do not exceed background levels, are Summerley, Unstone and Lambley.

The overriding characteristic of the metallic ion concentrations in all of the minewaters is the elevated iron concentration. Total iron concentrations range from 5.5 mg/l (Lambley) to 124.3 mg/l (Helmington Row No.2) at the point of first emergence. In the receiving watercourses, immediately downstream of the minewater discharges, total iron concentrations range from 0.45 mg/l (Limb Brook) to 53.4 mg/l (Helmington Row No.2). Only two of the receiving watercourses, Limb Brook and Bishop's Park, have iron concentrations below the EQS level of 1.0 mg/l immediately downstream of the discharge. In general other metallic ion concentrations do not warrant attention here, with some noteworthy exceptions. Helmington Row is the most outstanding of the sites in terms of metallic ion concentrations. Not only is total iron concentration the highest measured (124.3 mg/l), but also total concentrations of aluminium (72.7 mg/l), manganese (16.9 mg/l), zinc (3.03 mg/l) and nickel (0.68 mg/l) are amongst the highest recorded. Concentrations remain high 50 m downstream, but decrease rapidly beyond this point. Other notable points are elevated concentrations of manganese at Bullhouse, Loxley Bottom, Summerley, Jackson Bridge and Stony Heap (1.9 - 13.0 mg/l), and also high aluminium concentrations at Craggs Moor and Clough Foot (1.55 mg/l and 0.62 mg/l respectively). These examples seem to have little or no impact on the receiving watercourses, however.

4.5 Invertebrate Abundance & Diversity Data

Of primary importance are the BMWP scores, as these are used in the final ranking strategy. Abundance is also used to categorise the impacts of the minewaters, however. This factor is indicated by the number of individuals present in a sample. In general the BMWP score is significantly lower at sites along the receiving watercourses just below the minewater discharge. Exceptions to this, such as Craggs Moor, are almost certainly due to pollution occuring above the upstream site. The override system is designed to account for this in the final ranking. The lowest BMWP score recorded is 3, 50 m downstream of the Acomb minewater. The highest BMWP score recorded immediately downstream of a minewater discharge is 106, at Limb Brook. The highest score recorded for all sites is 169, several kilometres below the Lowlands minewater discharge, in Northumbria.

General comments can be made about the specific families of invertebrates present at the various sites. Those sites most acutely affected by the minewater discharge are invariably impoverished. As a result high scoring taxa, such as the stoneflies, are largely absent. The larvae Tipulidae (cranefly) and Simuliidae (blackfly) are often present at these sites. Hydrobiidae (snails) also appear to be common. However, by far the most abundant families at these sites are the Chironomidae (midges) and Oligochaeta (worms). Indeed, at the most impoverished sites these taxa appear to be the only ones that can adapt to the conditions. Interestingly, Leuctridae (a stonefly which scores a maximum 10 for the BMWP score, and hence is considered pollution intolerant) is found at many of the moderately affected sites, implying that it may have developed some tolerance to the effects of mine water pollution, or that it is simply not affected by it. Only at sites that are either upstream of the minewater discharges, or are well below the influence of them, do other high scoring taxa begin to appear. Examples include Heptageniidae (mayfly), Leptoceridae and Lepidostomatidae (caddisfly).

Figure 3

BIOLOGICAL RESULTS OF THE MINEWATER DISCHARGES WITHIN THE TYNE & WEAR CATCHMENTS

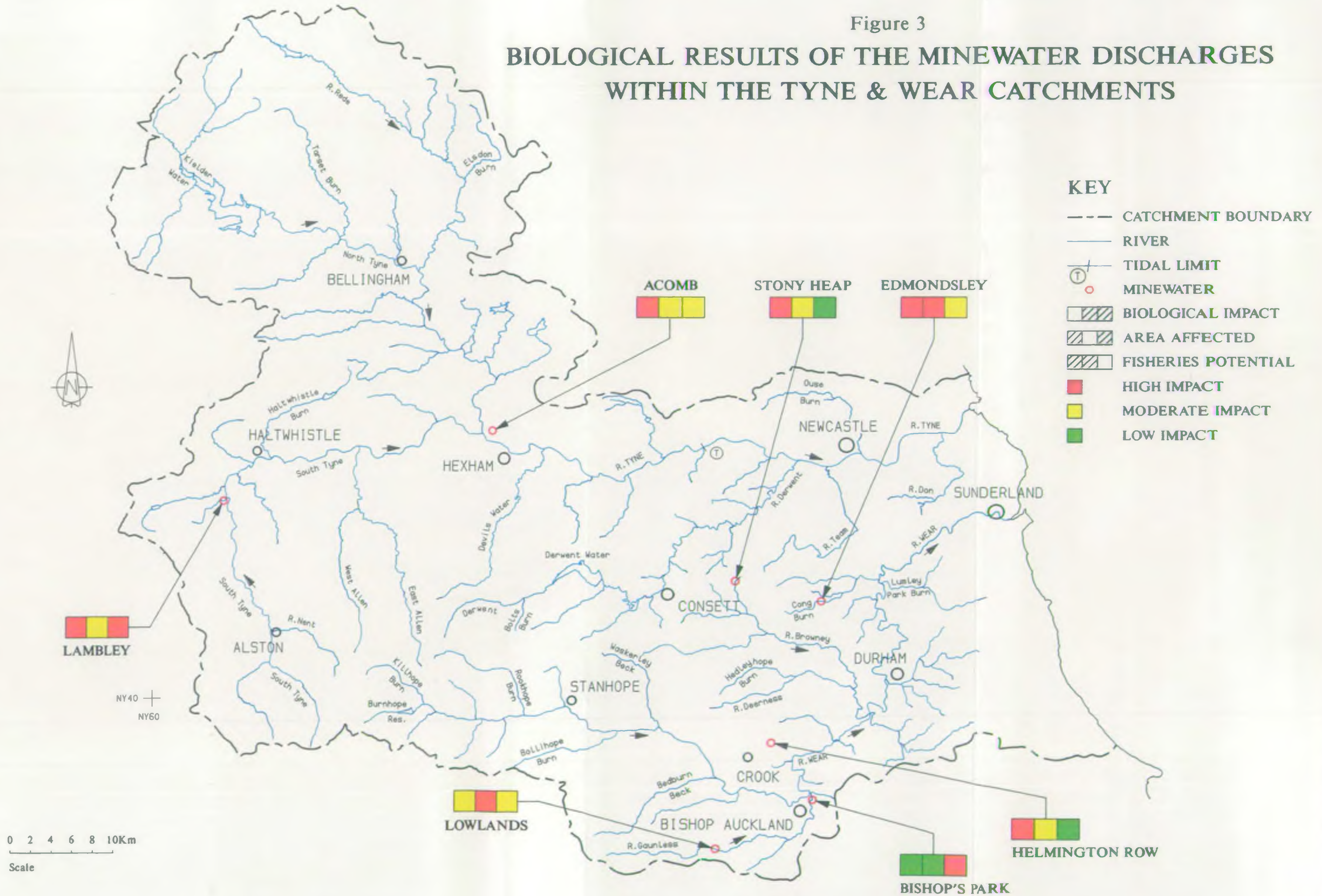
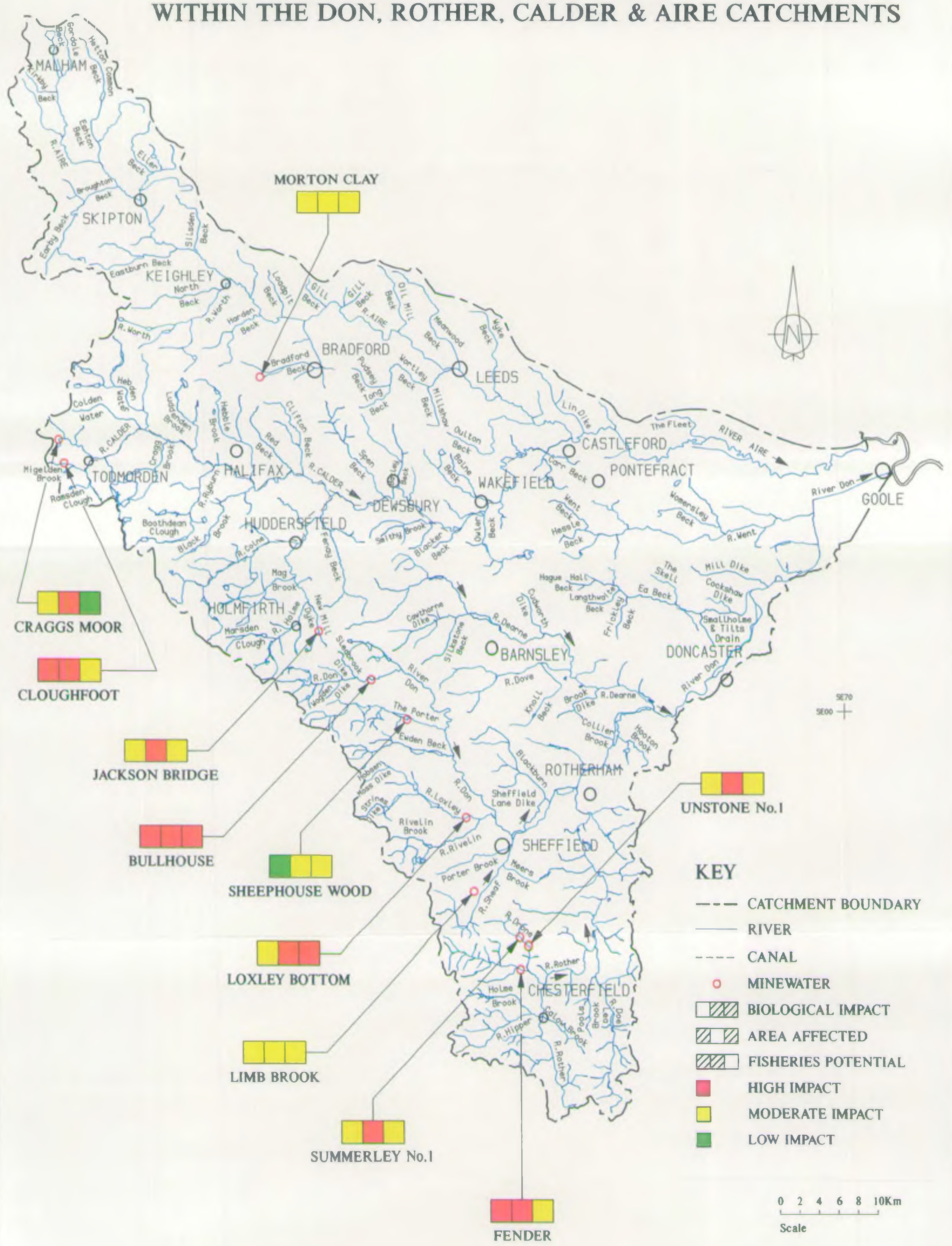


Figure 2

BIOLOGICAL RESULTS OF THE MINEWATER DISCHARGES WITHIN THE DON, ROTHER, CALDER & AIRE CATCHMENTS



5.0 DISCUSSION

The ranked list of minewater discharges presented in Section 4.0 is based on their observed environmental impact on the receiving waters. The list is not intended to be used in isolation. It is designed to play an integral part in facilitating the prioritisation of resource input into remediation schemes and should be used in conjunction with site specific details. It is important that a holistic approach is taken to ensure that appropriate remediation techniques are adopted. Evaluation of the benefits to be gained by ameliorating the impact of the minewater discharge should be addressed in the context of the relevant catchment management plan. The effects of minewater on the receiving water may restrict other initiatives aimed at improving water quality and the environment. Remediation of minewater impacts may serve as a catalyst for other projects so that the associated costs and benefits are optimised.

This section presents a general overview of the physicochemical and biological results detailing common elements and differences between the minewaters. It should be borne in mind when assimilating the results that the sampling was undertaken during the drought conditions of 1995. The majority of the minewater flows were below their annual average to varying degrees. For example, Sheephouse Wood and Bullhouse minewater were both approximately a third of 'normal' flow, based on limited historical data. This may well influence the degree of impact the minewater exerts on the receiving watercourse.

5.1 General Overview

In order to interpret the results it is first necessary to discuss the standards used by the NRA to assess and protect water and environmental quality. The parameters used will be assessed with regard to the water quality objective, i.e. the intended end use of the water course. For the purpose of this survey the water quality objective is the protection of sensitive aquatic life such as salmonid fish.

5.1.1 Suspended Solids

The concentration of inert suspended solids (SS) may cause direct and indirect effects on the biota. Indirect effects include blanketing of the stream bed which may affect food availability, spawning and reduction in light penetration. Direct effects include siltation of gills (Mainstone and Gulson, 1990). The Freshwater Fisheries Directive (78/659/EEC) states a guideline value of less than or equal to 25 mg/l inert suspended solids annual average for the protection of EC designated salmonid fisheries. This is supported by the work of Alabaster and Lloyd (1980) who proposed the categories outlined below:

- < 25 mg/l SS - no effect on fisheries
- 25-80 mg/l SS - support good or moderate fisheries
- >80 mg/l SS - unlikely to support good fisheries

It should be borne in mind that the categories proposed are based on annual averages and therefore can only be used as a guideline for the interpretation of the results. In addition, due to the limited sampling events, the results obtained will be influenced by the prevailing weather conditions. Comparisons with the annual average values should be interpreted with care. For example, sampling at the time of heavy rain may give rise to a high suspended solids value.

The majority of minewaters have a suspended solids content less than 25 mg/l at the immediate downstream sites. Exceptions to this are Clough Foot (26 mg/l), Edmondsley (33 mg/l) and Acomb (75 mg/l). Based on the categories of Alabaster and Lloyd (1980), however, it is only Acomb that is considered to have a suspended solids content that may be detrimental to the survival of salmonids.

5.1.2 Temperature

Standards for temperature variation and tolerance limits for the protection of salmonid fisheries are presented in the Freshwater Fisheries Directive, (78/659/EEC) and are concerned with thermal pollution, such as an elevation in ambient temperature from upstream values. In general, the acute toxic effects of pollutants such as zinc, copper and lead, increase with temperature (Felts and Heath, 1984; Mason, 1991). The Directive states that the temperature measured downstream of a point of discharge at the edge of a mixing zone must not exceed the unaffected temperature by more than 1.5 °C or exceed 21.5 °C during the breeding season (Mainstone and Gulson, 1990).

The minewater discharges, however, generally have a lower and less variable temperature than the receiving waters. The maximum decrease in mean ambient temperature was 2.1 °C, recorded at Summerley No. 1. The majority of the minewaters caused a decrease in ambient temperature of less than 1 °C. The exception to this is Acomb minewater which has a temperature 0.6 °C higher than the ambient temperature upstream and causes a 0.7 °C increase in the receiving water. It should be noted that this is based on data from three sampling events which took place in Autumn and does not take account of diurnal fluctuation within the river. Full seasonal data would be required to establish the annual variation, as in winter it is likely that the minewaters will cause an elevation in ambient temperature.

Based on the available data, the small decrease in ambient temperatures of the downstream sites are not considered to have a significant impact on the biota.

5.1.3 Dissolved Oxygen (% Saturation)

A value of 65% saturation of dissolved oxygen is considered the minimum value for the survival of a salmonid population. A value of 75%, however, is the proposed guideline (Hunt, 1986).

The dissolved oxygen concentrations of the minewaters are lower than those of the receiving water. Generally, the Northumbrian minewaters have a lower concentration than those in the Yorkshire area. For example, four of the seven Northumbrian minewaters have a dissolved oxygen saturation of less than 20 %, the other three being less than 60%. All eleven of the Yorkshire minewaters have a dissolved oxygen content greater than 20%, five being greater than 60%. Despite these low dissolved oxygen concentrations the majority of the minewaters have no significant effect on the dissolved oxygen of the receiving waters. Exceptions to this are Fender, Helmington Row, Acomb and Lambley. It is only Lambley and Helmington Row, however, that cause a decline to below the 65% threshold and therefore it is considered that these watercourses may not be able to sustain a salmonid population.

5.1.4 pH

A pH value in the range of 6 to 8 is considered by the EIFAC to be suitable for the survival of salmonid fish. This range is based on the direct physiological effects pH has on salmonids and the influence pH has on heavy metal speciation, availability, rate of uptake and toxicity. To a great extent the proposed pH range is based on the relationship between aluminium and pH. Within the pH range 6-8 aluminium is least soluble and therefore has low toxicity to the biota (Howells, 1984). It is difficult to generalise the relationship between pH and metal toxicity as it differs with metal type and other factors such as water hardness and the presence of chelating agents (Kelly, 1988).

Minewater discharges are commonly referred to as acid mine drainage (AMD) due to the acidifying hydrolysis reactions occurring underground. The majority of the minewaters covered in this survey, however, were found to have circumneutral (6-8) pH values. Their impact on the receiving waters with regards to pH are therefore considered to have a negligible impact. The exception to this is Helmington Row which causes a reduction in the ambient pH from 7.6 to 3.3.

The generation of minewaters, detailed in section 1.2, suggests that minewaters should be acidic unless they come into contact with calcareous material during their passage to the surface. However, particularly in the Durham coalfield, there is no evidence of carbonate mineralogy. An alternative explanation for the circumneutral nature of some of these minewaters is given by Younger (1995), who provides hydrochemical evidence supporting "...incipient microbial sulphate reduction..." in close proximity to the surface, as a possible source of alkalinity.

5.1.5 Heavy Metals

Table 6 details the Environmental Quality Standards (EQS) for the measured List II substances as detailed in the NRA Consents Manual (1994) and in accordance with those substances identified in the Dangerous Substances Framework Directive (1976) and subsequent Daughter Directives. The values presented below are based on the water quality objective for the protection of sensitive aquatic life.

TABLE 6: EQS VALUES FOR MEASURED LIST II SUBSTANCES

<table>
<tr><th>TOTAL HARDNESS (mg/l $CaCO_3$)</th><th>IRON (µg/l)</th><th>LEAD (µg/l)</th><th>ZINC (µg/l)</th><th>COPPER (µg/l)</th><th>NICKEL (µg/l)</th><th>ARSENIC (µg/l)</th></tr>
<tr><td>0 - 50</td><td rowspan="6">1000 AD</td><td>4 AD</td><td>8 AT (30)P</td><td>1 AD (5)P</td><td>50 AD</td><td rowspan="6">50 AD</td></tr>
<tr><td>50 - 100</td><td rowspan="2">10 AD</td><td>50 AT (200)P</td><td>6 AD (22)P</td><td>100 AD</td></tr>
<tr><td>100 - 150</td><td rowspan="3">75 AT (300)P</td><td rowspan="3">10 AD (40)P</td><td rowspan="2">150 AD</td></tr>
<tr><td>150 - 200</td><td rowspan="3">20 AD</td></tr>
<tr><td>200 - 250</td><td rowspan="2">200 AD</td></tr>
<tr><td>250 +</td><td>125 AT (500)P</td><td>28 AD (112)P</td></tr>
</table>

NOTE: A = Annual Average
P = 95% of samples
D = Dissolved
T = Total

In addition to the values identified in Table 6, the EQS for total aluminum is 1000 µg/l (EIFAC) for surface waters of pH 6-8.

It should be noted that EQSs are annual averages determined from a minimum of twelve samples, (one per month), from a designated sampling site. For the purpose of this survey they are used as a guideline and exceedence of EQSs can therefore only be inferred, as it is based on a maximum of three sampling events rather than the recommended minimum of twelve. In addition, EQSs refer to the receiving waters beyond the discharge mixing zone and cannot be applied to the minewater discharge itself.

The EQS for iron is based on the dissolved concentration rather than the total. Minewater discharges in general will have high concentrations of both dissolved and total iron. It is therefore necessary to assess both factions in order to determine the possible impact on the biota. Warnick and Bell (1969) observed an LC_{50} (lethal concentration at which 50% of the population die) in mayfly and caddisfly at total iron concentrations of 0.32 mg/l. The United States Environmental Protection Agency (US EPA, 1986), however, propose a standard of 1 mg/l total iron concentration for the protection of fresh water aquatic life. For the purpose of this survey the US EPA value of 1 mg/l will be used as the EQS for total iron.

To allow interpretation of the results Table 7 details the hardness values of the watercourses receiving the minewater discharges.

TABLE 7: TOTAL HARDNESS VALUES OF THE RECEIVING WATERCOURSES

MINEWATER	HARDNESS (mg/l $CaCO_3$)	MINEWATER	HARDNESS (mg/l $CaCO_3$)
Bullhouse	107	Unstone No. 1	225
Fender	192	Lowlands	236
Edmondsley[1]	409	Summerley No. 1	236
Clough Foot	83	Jackson Bridge	192
Lambley	104	Craggs Moor	74
Acomb	89	Limb Brook	125
Helmington Row	231	Morton Clay	150
Stony Heap	181	Sheephouse Wood	64
Loxley Bottom	101	Bishop's Park[2]	649

[1] Reading from 2.10.95 [2] Average value February 1995 - September 1995

All other values are annual averages. (Yorkshire: January 1991 - November 1994; Northumbria: November 1993 - November 1995)

Above:

PLATE IV

Ochreous Plume Of
Bullhouse Minewater
At The
Point of Discharge
Into The River Don.

Left:

PLATE V

Edmondlsey
Minewater
At The
Discharge Point
Into The Cong Burn.

All the minewaters have a total iron concentration above 1 mg/l, the majority occurring within the range of 10 mg/l to 30 mg/l. This is repeated for the dissolved iron concentration except for Sheephouse Wood minewater (87 µg/l average dissolved iron).

The low dissolved iron concentration recorded for Sheephouse Wood may be explained by the fact that the minewater discharge point is 3 km from its source. During this distance the conversion of dissolved iron (Fe^{2+}) to iron hydroxide precipitate (Fe^{3+}) occurs due to adequate aeration. Work undertaken by Robin Perry, Imperial College London (in prep), however, has shown that the leat almost provides complete treatment in summer , (at the time of sampling), but very little in winter. The increased reaction rate observed in summer is probably a combination of high temperature and low flow. It is reasonable to assume, therefore, that the impact of Sheephouse Wood minewater on the Little Don is less than would be expected if sampling was undertaken in Winter.

The EQSs for lead, zinc, copper, nickel, aluminium and arsenic are not exceeded at any of the downstream sites from the minewater discharges except for Helmington Row. The EQSs for total and dissolved iron are exceeded at the majority of immediate downstream sites. The exceptions to this are Loxley Bottom, Jackson Bridge, Sheephouse Wood, and Acomb, where the dissolved iron concentration is less than 1 mg/l, and at Bishop's Park where both the total and dissolved iron concentrations are below 1 mg/l. It can therefore be concluded that the environmental impact due to heavy metal concentration appears to be a result of elevated iron concentrations in the minewaters and the receiving rivers. At Helmington Row, however, other heavy metals such as copper, zinc, aluminium and nickel all greatly exceed their EQS and are therefore instrumental in the overall impact as well as iron.

An intraregional difference is apparent with regards to the change in total and dissolved iron concentration in the receiving waters with distance downstream from the minewater discharge point. Generally, the Northumbrian sites have total and dissolved iron concentrations in excess of 1 mg/l at the first downstream sampling location falling to background levels of around 0.5 mg/l further downstream. The majority of Yorkshire sites do not exhibit this relatively rapid decrease to background levels; the total iron concentration, and to a lesser extent the dissolved iron concentration, remain above 1 mg/l for the majority of downstream sites. This occurrence is reflected by the area and length of river visually affected by iron deposition and the area affected biologically, which is greater for the Yorkshire sites. This intraregional difference suggests that the iron precipitates out and deposits more rapidly at the Northumbria sites relative to those in the Yorkshire area. In order to ascertain the exact cause for this difference further investigation would be required. Possible explanations could be related to pH, geochemistry and/or flow regimes.

Thick iron deposits observed at many of the immediate downstream sites in Northumbria may be a function of the rapid deposition of iron, as well as its absolute concentration. The biological impact (% reduction in BMWP and change in $\log_{10}$ abundance) tends to be greater for the Northumbria minewaters compared to the biological impact of the Yorkshire minewaters. The thick iron deposits may be the causal factor behind this difference.

5.1.6 Sulphate, Alkalinity and Conductivity

Sulphate has been shown to cause a biological impact at concentrations of 2500 mg/l or greater (Kelly, 1988). The majority of the minewaters do not approach this value except for Bishop's Park (1789 mg/l) and Helmington Row discharge No. 2 (1933 mg/l). With regards to the effect on the receiving water it is only Helmington Row (discharge No. 2) that causes a significant increase in the ambient sulphate concentration. A mean concentration of 1664 mg/l was recorded at the immediate downstream site. Based on the results, sulphate is not considered directly relevant to the environmental impact of the minewaters and is therefore not assessed in this context.

Strong odours of hydrogen sulphide (H_2S) were apparent in close proximity to certain minewater outfalls, particularly those at which the water discharges to the surface at full bore. This implies that sulphate is being reduced at some point below the surface, and adds support to the hypothesis, discussed in section 5.1.4, that sulphate reduction may be a mechanism by which the alkalinity of these minewaters is increased.

Alkalinity is a measure of a watercourse's capacity to neutralise acidic inputs. pH values less than 4.2 can destroy this buffer system by conversion of carbonate and bicarbonate into carbonic acid, which readily dissociates to water and free carbon dioxide which may be lost to the atmosphere (Kelly, 1988). This has important implications for the biota. Once destroyed, the rate of recovery for alkalinity is dependent on source replenishment rate which is ultimately dictated by the catchment geology, atmospheric transfer of carbon dioxide and flow regime of the river. Parsons (1977) recorded a recovery period of three and a half months after a river received a pulse of acidity from a minewater discharge.

The minewater discharges are considered to have negligible effect on the alkalinity of the receiving waters. The exception to this is Helmington Row where the alkalinity decreases to below 10 mg/l as $CaCO_3$ at the immediate downstream sampling site from the minewater discharge. This reflects the impact characteristics the minewater pH exerts on the receiving waters, Helmington Row being the only discharge causing a 'significant' pH change.

Measurement of sulphate and alkalinity enable the hydrogeological properties of the mines and minewater quality to be defined, serving as a precursor to developing remediation schemes and for predicting future water quality problems.

Conductivity is an indirect measure of the ionic salt concentration and is a product of the catchment geology combined with the activities of mining. Apart from its role in locating minewater discharges (Younger and Bradley, 1994) it has limited use both in the development of remediation options and biological assessment. It does, however, become biologically significant at 'high' concentrations, when physiological disruptions may occur. A value of 1000 $\mu S/cm$ tends to be used by the NRA but is dependent on background values.

There is a clear division between the Yorkshire and Northumbrian conductivity values for both the minewaters and their receiving waters. In general the Northumbrian minewaters and the receiving waters have a conductivity value exceeding 1,000 μS/cm, whereas the Yorkshire sites have values typically in the range of 700 to 900 μS/cm. The differences between the two regions are most likely to be a function of the geology.

5.1.7 BMWP & ASPT

A reduction in BMWP and ASPT scores have been shown to reflect a deterioration in water quality but may also reflect a change in the physical properties of the habitat (Armitage *et al*, 1983). The selection of riffle sites as the sampling locations reduces the influence habitat structure has on the invertebrate community composition. Refer to Section 3.0.

All the minewaters except Unstone, Sheephouse Wood and Bishop's Park cause a lowering of the BMWP score between the upstream and immediate downstream sites. In addition, the majority of minewaters caused a loss of pollution sensitive invertebrate families. The main reason for this occurrence is probably due to the observed increase in iron concentrations in the receiving watercourse below the minewater discharge point (Section 5.1.5).

The maximum reduction in BMWP was observed at Acomb (97.1%). The main cause for this high biological impact is probably due to the minimal dilution of Acomb's high total iron concentration (48.4 mg/l) as it enters the Red Burn. In addition, Acomb minewater differs from many of the others investigated, in that the high iron load imparted on the Red Burn largely remains in suspension for approximately 1 km until its confluence with the South Tyne (Plate VII). This occurrence is likely to cause a reduction in light penetration in addition to the smothering impact from iron hydroxide and oxyhydroxide precipitation, the latter occurring at the majority of sites to varying degrees. This combined effect is likely to be the main reason for the sustained impoverishment of the macroinvertebrate benthic community observed along the length of the Red Burn.

PLATE VI
Visual Impact Of Clough Foot Minewater
On The Midgelden Brook At Gauxholme.

PLATE VII
The Red Burn Downstream Of Acomb Minewater Discharge
Illustrating The High Degree Of Iron In Suspension

The EQS for total iron is 1 mg/l. Warnick and Bell (1969), however, have demonstrated the low tolerance of mayfly and caddisfly to total iron concentrations of 0.32 mg/l. Further to this, Bullhouse minewater impacts the macroinvertebrate benthic community of the River Don for 4.2 km, beyond the limit of EQS compliance. This suggests that the EQS for iron may not be providing adequate protection for sensitive aquatic life.

The pollution sensitive stonefly, Leuctridae appear to exhibit some resistance to the effects of the minewater as they are present at both the upstream and immediate downstream sites for half of the minewaters. In some instances the abundance of Leuctridae increased, for example at Jackson Bridge and Lowlands. This increase cannot be accounted for by their high tolerance of acidic waters as the majority of minewaters and hence receiving waters are around circumneutral. Their presence, however, may be due to the removal of inter-taxa competition or predation.

Five of the minewaters impact a greater area visually than biologically. This indicates that the presence of a visual impact may not always exert a biological one.

5.1.8 Influence Of Other Discharges

The impact assessment for several of the minewaters surveyed were complicated by the influence of other discharges both upstream and downstream of the minewater discharge points. Any marked deterioration in water quality upstream of the minewater discharge, which would mask the impact of the minewater, is compensated for by the override factor contained within the ranking strategy (Section 1.4.2). This compensation mechanism was employed in the assessment of Craggs Moor, Summerley No. 1 and Unstone No.1.

Upstream of Craggs Moor the low pH of 3.9 and high concentrations of heavy metals are probably the main causes of the impoverished macroinvertebrate benthic community. Further investigation would, however, be required to establish their source.

The poor water quality upstream of Unstone No. 1 is a combination of the input from Summerley No. 1 and the discharge from Dronfield STW.

Upstream of Summerley No. 1, the poor water quality inferred by the low BMWP score may be due to surface run-off from the nearby industrial estate and/or input from the Chesterfield Road South sewage pumping station. Due to the dry weather conditions at the time of sampling, input from both of these sources would not be expected to be significant.

The override procedure only takes into account the influence of upstream discharges having a significant effect and does not consider the influence of downstream discharges, or in fact upstream discharges which may be having a more subtle effect. The minewaters which fall into this category are Fender, Lowlands and Bishops Park.

Approximately 0.9 km downstream of Fender minewater discharge is an industrial discharge from GKN Sheepbridge Stokes consisting of site drainage. In this instance, the impact from Fender may mask the effect of the industrial discharge. The similarity in BMWP and ASPT scores both upstream and downstream of the industrial discharge infers there are no additive or synergistic effects with the minewater.

The River Gaunless, which both Lowlands and Bishop's Park minewaters discharge into, has a number of sewage and industrial discharge inputs which may act to mask or exacerbate the effects of the minewaters.

The full influence of these other discharges is beyond the scope of this report but should be bome in mind when interpreting the results.

6.0 CONCLUSIONS

Based on the ranking strategy and methodology employed the following conclusions can be drawn from this investigation:

1. The nineteen preselected minewaters are ranked in the following order, according to the severity of their environmental impact:

1.	Bullhouse minewater, Upper Don Catchment
=2.	Fender minewater, Rother Catchment
=2.	Edmondsley minewater, Lower Wear Catchment
4.	Clough Foot minewater, Upper Calder Catchment
5.	Lambley minewater, Tyne Catchment
6.	Acomb minewater, Tyne Catchment
=7.	Helmington Row minewater, Upper Wear Catchment
=7.	Stony Heap minewater, Lower Wear Catchment
9.	Loxley Bottom minewater, Upper Don Catchment
=10.	Unstone No.1 minewater, Rother Catchment
=10.	Lowlands minewater, Upper Wear Catchment
=10.	Summerley No.1 minewater, Rother Catchment
13.	Jackson Bridge minewater, Upper Calder Catchment
14.	Craggs Moor, Upper Calder Catchment
=15.	Limb Brook minewater, Upper Don Catchment
=15.	Morton Clay minewater, Aire Catchment
17.	Sheephouse Wood minewater, Upper Don Catchment
18.	Bishop's Park minewater, Upper Wear Catchment

The nineteenth minewater, Silkstone, was not included in the ranking as there was no flow from it during the period of the survey.

2. Bullhouse minewater exhibits the greatest impact on its receiving watercourse. Both the area affected visually and biologicaly, 26 950 m^2 and 28 875 m^2 respectively, exceed those of the other minewaters. Bullhouse is followed by Edmondsley and Fender, which are equal second.

3. The following generalizations can be drawn regarding the chemical nature of the minewater discharges and their receiving watercourses:

- Iron concentrations are very high in all of the minewaters (5.5 mg/l - 124 mg/l). In the receiving watercourse, immediately downstream of the minewater discharges, iron concentrations are greater than the EQS of 1.0 mg/l at seventeen of the sites investigated. Bishop's Park minewater is the exception.
- With the exception of three, the minewaters are circumneutral (pH 6 - 8) at their point of first emergence. As a result, as the minewaters enter the receiving watercourses, they generally appear to have a minimal impact in terms of pH.
- Other metallic ion concentrations are only notably elevated in minewaters with a low pH. The outstanding example of this is Helmington Row minewater, which has very high concentrations of aluminium, zinc, copper and nickel.
- As the minewaters emerge from the ground they have characteristically low dissolved oxygen saturations (approximately 10% - 65%). However, this does not appear to have any substantial impact on the receiving watercourses.
- Sulphate concentrations, whilst high, do not seem to have a direct deleterious impact on the receiving watercourse. However, sulphate concentrations may require consideration prior to certain types of treatment, should remediation measures be taken.

4. The receiving watercourses downstream of the minewater discharges are invariably impoverished in terms of invertebrate abundance and diversity. This is demonstrated by lower BMWP scores in the receiving watercourses downstream of the minewaters, when compared to upstream sites. The magnitude of the impact, and the area over which it persists, varies greatly between sites. It is this variation which is fundamental in determining the order of the minewaters on the final ranked list.

5. The iron concentration (and the associated iron load) is considered to be of paramount importance in determining the severity of the environmental impact. The deposition of iron precipitates is thought to be the main cause of faunal impoverishment. Generally, the Northumbrian minewater discharges tend to exert a greater biological impact, over a more localised area, compared to those of Yorkshire. This is thought to be a function of the rate of deposition of iron precipitates, which appears to be more rapid at the Northumbrian sites.

6. With minor alterations the NRA Welsh region approach to ranking minewaters has been successfully applied in the NRA Northumbria and Yorkshire region. The ranked list given above is a valuable addition to the growing database of information regarding pollution from abandoned mineworkings, and will be of considerable use should resources be made available for remediation of selected minewaters. However, on a cautionary note, the list should not be viewed in isolation, or without consideration of factors beyond the scope of this report. It should be used primarily as a precursor to a full cost-benefit analysis of specific sites. Given the short time in which these nineteen minewaters were selected, it should also be noted that the list is by no means exhaustive, and that other minewaters may subsequently appear in prominent positions on a more complete ranked list.

7.0 RECOMMENDATIONS

This project has been successfully conducted, and completed within a relatively short space of time. Inevitably, however, during the course of any project, various areas in which improvements could be made become apparent. Since an important objective of this study was to maintain consistency with the Welsh region approach to ranking minewaters, it would have been unwise to implement any such improvements during the course of this project. However, it is felt important to outline the areas in which members of the project team feel minor adjustments may benefit future work of this nature. The recommendations given here in no way undermine the validity of either this or previous reports of this type. Rather, they are suggestions that will either 'fine tune' the accuracy of ranking lists or, given more time, enable the data collected to be used for other applications, such as the design of remediation techniques. These recommendations are outlined below:

- Although it would not have been possible, given the timescale of this particular project, data pertaining to both the chemistry and ecology of watercourses affected by minewaters should ideally be collected over three seasons. The natural progression from this report is to design remediation measures for selected minewaters. For this to be done adequately it is strongly advisable to be aware of the nature and magnitude of seasonal variations in both water quality and deleterious effects. It would perhaps be necessary, in this context, for relevant sites to be routinely monitored, both chemically and biologically, by the NRA. To a degree routine monitoring of sites has already been implemented.

- The categories used in the NRA Welsh region approach, to define area affected (physicochemical), have been subdivided in this report to enable differentiation between minewaters which have similar impacts. Should all the minewaters in the Northumbria and Yorkshire region be assessed and ranked it may be necessary, and important, to subdivide other categories as well as this one.

- It has become apparent during this work that 'Biological Impact' is critical in defining the final ranking position of the minewaters. It is uncertain whether the emphasis on this category in isolation is justifiable, and whether its importance is so much greater than the area affected biologically category. It is unclear how this problem may be resolved, but it should certainly be borne in mind when carrying out work of this nature,in the future.

- The fisheries potential category is a subjective assessment. As a result there is a danger that different workers would interpret data in different ways, and hence there could be inconsistency in results. Where possible it would have been preferable to use quantitative data. Unfortunately such data was not available for the Yorkshire region during the study period, and time constraints precluded its collection. It is recommended that any future work should have quantitative data made available where possible. Where electrofishing is not possible the use of a predictive model (the Welsh NRA report used HABSCORE) is suggested.

8.0 REFERENCES

ALABASTER, J.S. and LLOYD, R. (1980). Water Quality Criteria For Freshwater Fish. Butterworths.

ARMITAGE. P.D., *et al.* (1983). The performance of a new biological quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Res.*, **17**, 333-347.

BARNES, H.L. and ROMBERGER, S.B. (1968). The Chemical Aspects of Acid Mine Drainage, *Journal of the Water Pollution Control Federation*, **40**, 371-384.

BRINCKHURST, R.O. (1971). A guide for the identification of British aquatic Oligochaeta. 2nd edition. *Sci. Plbl. Freshw. Biol. Ass.*, **22**, 1-55.

DoE (1995) The Environment Act, 1995. HMSO.

FELTS, P.A. and HEATH, A.G. (1984). Interactions of temperature and sublethal environmental copper exposure on the energy metabolism of bluegill, *Lepomis macrochirus* Rafinewque. *J. Fish Biol.*. **25**, 445-453.

HOWELLS, G.D. (1984). Fishery decline: mechanisms and predictions. *Philosophical Transactions of the Royal Society of London, B* **305**, 529-547.

HUNT, D.T.E. (1986). Trace metal speciation and toxicity to aquatic organisms - a review. TR 247. Water Research Council.

KELLY, M. (1988). Mining and the Freshwater Environment. Elsevier Applied Science.

MAINSTONE, C.P. and GULSON, J. (1990). The Effects Of Water Quality On Freshwater Fish Populations - Final Report. Report No. PRS 2481 - M/1. NRA.

MANCE, G. and CAMPBELL, J.A. (1988). Proposed Environmental Quality Standards for List II Substances in Water - Iron. TR 258: Water Research Centre - Environmental Strategy, Standards and Legislation Unit.

MASON, C.F. (1991). Biology Of Freshwater Pollution. Second ed. Longman Scientific & Technical.

NRA Welsh Region (1994). A Survey Of Ferruginous Minewater Impacts In The Welsh Coalfields. Welsh Office Contract (No. WEP 100/138/11).

NRA (1994). Abandoned Mines And The Water Environment. Water Quality Series No. 14. HMSO.

NRA (1994). Discharge Consents Manual. Vol 024B.

NRA (1994). National Sampling Procedures Manual. Vol 025. Quality Management System For Environmental Sampling.

NRA National Sampling Procedures Manual, sections:

Field Measurements (ES021)

Field Measurements using Dissolved Oxygen Meters (ES018)

Field Measurements using pH Meters (ES019)

Field Measurements using Conductivity Meters (ES020)

Test Kits (ES021)

Special Sampling Procedure (ES002)

Quality Control Checks for Sampling Equipment (ES011)

Prevention Measures for Contamination (ES012)

Sampling Waters Directly into Bottles (ES013)

Sample Filtration (ES016)

Procedure for Collecting and Analysing River Macro-invertebrate Samples for RIVPACS Application (BT001)

PARSONS, J.D. (1977). Effects of acid mine wastes on aquatic ecosystems. *Water, Air, & Soil Pollution,* **7**, 333-54.

SINGER, P.C. and STUMM, W. (1970) Acidic mine drainage: The rate-determining step. *Science,* **167**, 1121-1123.

STONER, J.H *et al.* (1984). The effects of acidification on the ecology of streams in the upper Tywi catchment in West Wales. *Environ. Pollut. (A)*, **35**, 125 - 157.

US EPA (1986). Quality Criteria For Water. Washington DC.

WARNICK, S.L. and BELL, H.L. (1969). The acute toxicity of some heavy metals to different species of aquatic insect. *Journal of the Water Pollution Control Federation,* **41**, 280-284.

YOUNGER, P.L. and BRADLEY, K.F. (1994). Application of Geochemical Mineral Exploration Techniques to the Cataloguing of Problematic Discharges from Abandoned Mines in North-East England. *Proceedings of the 5th International Minewater Congress,* Nottingham, UK. Volume 2, pp 857 - 871.

YOUNGER, P.L. (1995) Hydrogeochemistry of Minewaters Flowing from Abandoned Coal Workings in County Durham. *Quarterly Journal of Engineering Geology* (in press).