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Investigations into the status of fisheries, biological and water quality in the River Pelenna catchment, prior to the treatment of discharges from abandoned coal mines.

NATIONAL RIVERS AUTHORITY
WELSH REGION
SOUTH WEST AREA

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Background

The River Pelenna catchment has been affected by ferruginous discharges from abandoned coal mines for more than 25 years (see Fig.1). As well as affecting water quality in their receiving rivers, these discharges have caused a major aesthetic impact in the catchment, due to the settlement of an orange-coloured precipitate known as ochre (iron hydroxide). It was suspected that the minewater discharges were responsible for the impoverished status of fish populations and macroinvertebrate communities in the catchment.

In a joint venture, the NRA and West Glamorgan County Council are undertaking a large scale demonstration project to ameliorate the impact of minewater pollution in the catchment using wetland treatment systems. The project is partly funded by the LIFE fund (the European Community's Financial Instrument for the Environment) and the Welsh Development Agency's Land Reclamation Programme. The scheme, which commenced in March 1995, will involve the treatment of five key discharges over a period of 4 years.

Extensive investigations have been carried out by the NRA in the last three years, to provide baseline information on the status of fish and macroinvertebrate populations and water quality in the Pelenna catchment. This information will provide a basis for monitoring improvements resulting from the installation of treatment systems.

Methods

Water quality sampling was carried out on a regular basis from seven minewater discharges, as well as their receiving rivers, using spot sampling techniques involving the use of hand-held meters and laboratory analyses (see Fig.4). Automatic water samplers and continuous water quality loggers have also been deployed for limited periods to monitor the influence of rainfall episodes.

Extensive biological surveys were carried out in 1993 and 1994, in spring and summer, to assess the status of macroinvertebrate communities in the Pelenna catchment. Routine biological monitoring has also been carried out at four sites in the catchment since 1990. Samples were processed to determine Biological Monitoring Working Party (BMWP) scores and taxon richness. The RIVPACS (River inVertebrate Prediction and Classification System) computer model was used to compare the observed macroinvertebrate fauna with that which may be expected under pristine water quality conditions.

An acid indicator key was used in winter/spring 1994, to assess the impact of acidification on macroinvertebrate fauna in the headwaters of the catchment.

Quantitative electrofishing surveys were carried out in the summers of 1993 and 1994. Densities of trout fry and parr were calculated, and classified according to the Regional Juvenile Salmonid Monitoring Programme (RJSMP) system. The HABSCORE computer model was used to determine whether available habitats were being fully utilised by salmonids.

Fish and egg survival experiments were carried out in the winter and early spring of 1994. Brown trout eggs were buried within the river gravel in mesh boxes to monitor egg and alevin survival, while parr survival was assessed by keeping fish in submerged cages.

Results/Discussion

Minewater discharges entering the Blaenpelenna (ie. Garth Tonmawr) and the Gwenffrwd (ie. Whitworth lagoon, Gwenffrwd discharge and Whitworth no.1) were found to cause elevated concentrations of iron in these rivers. Water quality and aesthetic impacts were demonstrated on the River Pelenna as far downstream as its confluence with the River Afan.

Upstream of the minewater discharges on both the Gwenffrwd and Blaenpelenna, an additional water quality problem was identified. The headwaters of the catchment were found to be subject to episodes of extreme acidity ($pH<4.5$) corresponding with high flow conditions. High concentrations of aluminium ($>2mg/l$), which is known to have harmful effects on fish and macroinvertebrates in acidic streams, were also observed in high flow conditions. The acidification problem is probably due to the atmospheric deposition of airborne pollutants, the effects of which are exacerbated by conifer afforestation, fast catchment run-off rates and base-poor underlying geology.

Juvenile trout populations and macroinvertebrate assemblages were found to be impoverished both upstream and downstream of the minewater discharges on the Gwenffrwd and Blaenpelenna, and to a lesser extent on the River Pelenna. Macroinvertebrate assemblages in the headwaters of the catchment were typical of acidified streams, while communities downstream of the major minewater discharges were even more impoverished. Poor survival rates of brown trout eggs, alevins and parr were observed in the Blaenpelenna and Gwenffrwd, particularly downstream of the minewater discharges.

The combined toxic effects of low pH and high aluminium concentrations may be responsible for the poor status of fish and invertebrate communities upstream of the minewater discharges. An additional impact may have occurred downstream of these discharges, as a result of toxic effects of metals contained in the minewater and smothering effects of precipitated iron hydroxide. Salmonid eggs in particular may suffocate if excessive sedimentation occurs on the gravel in which they are laid.

The effects of acidification and minewater pollution became less pronounced further downstream on the River Pelenna, due to increased dilution of toxic metals, scouring of sediments and buffering of acidity. No significant impacts on fish or invertebrate populations or water quality, from either acidification or minewater pollution, were identified on the Fforch-dwm, a tributary of the Blaenpelenna which was used as a control, or at sites on the main River Afan.

A feasibility study was carried out by ACER Environmental, from January to March 1995, to investigate methods of ameliorating surface water acidification in the headwaters of the Pelena catchment. This study confirmed the NRA's findings regarding the existence and the likely causes of an acidification problem in the headwaters of the Pelenna catchment. The report indicated that the most feasible options for alleviation of the acidification problem would involve the application of limestone to the affected streams, either by direct dosing or by using lime wells.

Further studies were carried out by the NRA from January to March 1995, to assess the aesthetic impact of minewater pollution in the Pelenna catchment and to quantitatively measure the amount of iron deposited on and within the gravel substrates. The findings of these studies will be reported at a later date.

Recommendations

(i) It is recommended that the findings of this report, as well as the findings from the aesthetic and sediment studies carried out this year, are used as a basis for assessing improvements to the River Pelenna catchment following the installation of wetland treatment systems.

(ii) Discrete monitoring of the water quality of minewater discharges and river sites should be continued on a monthly basis. The suite of determinands to be included in these analyses should be modified to enable a greater understanding of the chemical processes occurring in the minewater discharges and in their receiving rivers. This information is necessary for the design of effective treatment systems as well as for monitoring improvements resulting from their installation.

(iii) The occurrence of acute acidic episodes in the upper reaches of the Pelenna catchment is likely to reduce the potential for recovery of fish and invertebrate populations and water quality, following the installation of wetland treatment systems. It is therefore recommended that the findings of the liming feasibility study carried out by ACER Environmental are considered, with a view to alleviating the acidification problem.

1. INTRODUCTION

1.1. Background to the problem.

The River Pelenna catchment has been adversely affected by pollution associated with abandoned coal mines for a period of more than 25 years. A recent report published by the NRA (Butler *et al*, 1994) identified this catchment as the worst affected by this type of pollution in the Welsh Region. Acidic minewater discharges, containing high concentrations of iron compounds, have affected populations of fish and invertebrates, as well as causing severe discolouration of the River Pelenna down to its confluence with the River Afan.

The combination of poorly buffered peat soils, fast catchment run-off rates and enhanced atmospheric pollutant loads scavenged by conifer forestry may also influence base water quality in the catchment. As a result of these characteristics, the headwaters of the Pelenna catchment may be subject to acid episodes.

1.2. Nature of the problem

A common feature of mines in the South Wales coalfield is the presence of iron pyrites (FeS_2) which, upon exposure to air and water, becomes oxidised to form ferrous sulphate and sulphuric acid. This process may be catalysed by the presence of chemosynthetic bacteria. In active mines, groundwater is pumped away from the coal faces and released in a controlled manner into receiving watercourses, thus minimising pollution. However, when a coal mine is abandoned, pumping operations often cease, and the mine becomes flooded. As a result, acidic discharges containing ferrous sulphate eventually find their way into receiving watercourses.

Further oxidation and hydrolysis reactions in the receiving watercourse result in the formation of ferric hydroxide, which eventually precipitates out as an orange deposit, causing discolouration of the river bed. As well as being directly toxic to aquatic life, these deposits can smother the gravel substrate and hence interfere with the reproduction and feeding of fish and invertebrates.

1.3. Proposed remedial actions

In a joint venture, the NRA and West Glamorgan County Council are undertaking a large scale demonstration project to ameliorate the impact of minewater pollution in the catchment using wetland treatment systems. These systems promote the removal of iron by precipitation of iron compounds and anaerobic bacterial sulphate reduction. The project is partly funded by the LIFE fund (the European Community's Financial Instrument for the Environment) and the Welsh Development Agency's Land Reclamation Programme. The scheme, which commenced in March 1995, will involve the treatment of five key discharges over a period of 4 years. The aims of the project, as specified in the LIFE application (West Glamorgan County Council *et al*, 1993), are as follows:

1. To create a large scale demonstration wetland treatment system capable of improving watercourses contaminated by coal mine effluent.

2. To evaluate water purification and therefore rehabilitation of contaminated watercourses.

3. To assess and develop opportunities to enhance the conservation aspects of such a treatment system.

4. To produce comprehensive data to contribute to the information base on minewater treatment and its applicability to the European Community, including dissemination of that information.

1.4. Catchment information

The River Pelenna is a tributary of the River Afan, which flows into the sea at Port Talbot in West Glamorgan. The Pelenna derives from the Nant Gwenffrwd and the Nant Blaenpelenna (Fig 1). The Blaenpelenna rises at 300m above OD and is 7km long, with a catchment area of $10km^2$. The Gwenffrwd is 5km long with a catchment area of $6km^2$. The Fforch-dwm drains from a steep catchment into the Blaenpelenna to form the River Pelenna below this confluence. The Pelenna catchment receives high annual rainfall and is subject to pronounced spates.

1.4.1. Land use

Much of the lower Pelenna catchment is urbanised, with the main populations centered around Pontrhydyfen, Efail Fach and Tonmawr. The Blaenpelenna and

Gwenffrwd catchments are predominantly conifer afforested at their sources with a greater proportion of upland moor in their lower reaches (Fig.2). Approximately half of the Fforch-dwm catchment is conifer afforested, the remainder being upland moor.

1.4.2. Geology

The solid geology of the Pelenna catchment is Pennant series sandstone, which covers a large number of coal measures. Soil type and drift geology differs between each of the Pelenna tributary catchments (Fig.3). The Blaenpelenna catchment is dominated by hill peat, with a considerable amount of sandstone in its lower reaches, while the Fforch-dwm, Gwenffrwd and the River Pelenna flow through large areas of boulder clay (Higham, 1994).

1.4.3. Minewater discharges

The Nant Gwenffrwd currently receives minewater effluent from three main sources, namely Whitworth Lagoon, Gwenffrwd discharge and Whitworth no.1. (Fig.1). Whitworth lagoon itself receives minewater from two inlets, namely Whitworth A (north inlet) and Whitworth B (south inlet).

The most significant minewater discharge on the Blaenpelenna is Garth Tonmawr, although another smaller discharge, known as Middle Mine, enters the watercourse further upstream.

Wetland treatment systems will be constructed to treat the Whitworth No.1, Garth Tonmawr, Gwenffrwd, Whitworth A and Whitworth B discharges, in that order, over a five year period from 1995.

1.5. Objectives of this study

During the last three years, extensive investigations have been carried out by the NRA, to provide baseline information on the status of fish and macroinvertebrate populations and water quality in the Pelenna catchment. This information will be essential to enable a valid assessment of the effectiveness of the wetland treatment systems in relation to the restoration of the River Pelenna catchment. The aim of this report is to summarise the methodology and the findings of these investigations and to discuss the nature and extent of the problems affecting the Pelenna catchment.

Further studies were carried out from January to March 1995, to assess the aesthetic impact of minewater pollution in the Pelenna catchment and to quantitatively measure the amount of iron deposited on and within the gravel substrates. The findings of these studies will be reported at a later date.

2. METHODS

2.1. Water quality assessment

2.1.1. Discrete monitoring

Routine monthly water quality samples have been collected from 4 river sites within the Pelenna catchment throughout the study period (1990-1994). In 1992, the number of sites sampled on a monthly basis was increased to 8. An additional control site, on the Fforch-dwm, was added to the monthly sampling route in 1994. Routine sampling points are also located on the River Afan, both upstream and downstream of the Pelenna confluence (tables 1 & 2, Fig.4).

Monthly sampling of 5 minewater discharges (Middle Mine, Garth Tonmawr, Whitworth Lagoon, Gwenffrwd discharge and Whitworth no.1) has been carried out since February 1992. The discharges entering Whitworth Lagoon (ie. Whitworth A & B) were added to the sampling route in 1993.

Up until February 1994, all water samples collected from the Pelenna catchment were analysed for pH and concentrations of total iron and aluminium. Selected samples were also analysed for Biochemical Oxygen Demand (BOD). In February 1994, the suite of determinands was increased to include alkalinity, hardness, conductivity, dissolved metals (iron, aluminium, zinc, calcium and magnesium), total zinc, sulphate and sulphide, and dissolved oxygen.

A hand-held meter (Grant YSI 3800) was used in conjunction with the collection of spot samples in 1994, in order to provide additional (field) measurements of pH, conductivity and dissolved oxygen.

Water samples were collected in conjunction with the biological acidification survey in February 1994 (see section 2.2.2) and the fish survival experiments in February/March 1994 (see section 2.3.2). These samples were analysed for pH, conductivity and concentrations of ammonia (as N), total organic nitrogen, nitrite, hardness, chloride, orthophosphate, silica and dissolved organic carbon, as well as total and dissolved concentrations of sulphate, sodium, potassium, magnesium, calcium, zinc, aluminium, manganese and iron.

2.1.2. Continuous monitoring

Continuous water quality data loggers (Datasonde 3) were deployed at sites BP4, on the Blaenpelenna, and G3, on the Gwenffrwd, in February and March 1994. Values of pH and conductivity (in mS/cm^3) were logged at intervals of 15 minutes throughout most of this period.

2.1.3. Rainfall episode monitoring

From January to March 1992, automatic water samplers (Rock & Taylor QMP) were deployed at 4 of the minewater discharges (Garth Tonmawr, Whitworth lagoon, Gwenffrwd discharge and Whitworth no.1) and at sites on the Blaenpelenna and Gwenffrwd, upstream and downstream of these discharges (Table 2). The autosamplers were triggered manually during rainfall events and samples were collected at hourly intervals over periods of up to 29 hours.

The water samples were analysed for pH and total concentrations of sulphate, iron, aluminium and manganese.

2.2. <u>Biological Quality Assessment</u>

2.2.1. Macroinvertebrate sampling

Routine biological samples have been collected in spring and summer at 4 sites in the Pelenna catchment (Table 2) since 1990, as part of the NRA River Quality Survey (RQS). In 1990 and 1991, samples were also collected at these sites in autumn.

More extensive biological surveys were carried out in 1993 and 1994, in spring and summer. In 1993, samples were collected at a total of 11 sites in the Pelenna catchment (Table 2). In 1994, the number of sites sampled was increased to 12, to include a control site on the Fforch-dwm.

Macroinvertebrate samples were collected using the standard Institute of Freshwater Ecology (IFE) methodology, involving a three minute kick/sweep sample. These samples were preserved in 4% formaldehyde. All the invertebrates collected were identified to family level (for routine samples) or species level (for 1993 and 1994 surveys) and a Biological Monitoring Working Party (BMWP) score was determined for each sample (Appendix 1). This system provides a rapid measure of the impact of pollution on the invertebrate community.

Although the BMWP system is normally used to assess the impact of organic pollution, it is also a good indicator of other forms of riverine pollution (Chesters, 1980). Invertebrate taxon richness (number of families present) was used as an additional indicator of biological quality.

The RIVPACS II model (Cox *et al*, 1991) was used to predict the invertebrate assemblages which could be expected at each site under pristine water quality conditions. The model uses probabilities of taxon occurrence, predicted from catchment and habitat features, to calculate a predicted BMWP score and a predicted number of taxa (families) for each site. Predicted values were compared with observed BMWP scores and the observed number of taxa present at each site, to assess whether water quality or sedimentation were limiting biological quality.

Only habitat and geographical features were used when running the RIVPACS model. Water quality variables such as alkalinity and hardness, which are optional for the model, were not selected. These determinands are affected both by surface-water acidification and by the minewater discharges; therefore predictions of faunas which are based on these determinands may not be representative of faunas occurring under pristine water quality conditions.

2.2.2. Acidification survey

A biological acid indicator key (Rutt *et al*, 1990; Appendix 2) was used to assess the impact of acidification on macroinvertebrate assemblages in the headwaters of the Pelenna catchment. This survey was carried out in February 1994, using a one-minute kick sampling technique at 14 sites (Table 2).

2.3. Fisheries investigations

2.3.1. Fish population assessment

Quantitative electrofishing surveys were carried out in July/August 1993 at 10 sites in the Pelenna Catchment. This survey was repeated in July 1994, with an additional (control) site on the Fforch-dwm (Table 2).

The quantitative technique used involved performing 2-3 electrofishing runs over a section of river (30m) enclosed with stop nets. A third run was carried out if the number of either fry or parr caught in the second run was greater than 50% of the respective number caught in the first run.

Densities of trout fry (0+) and parr (>0+) were calculated per $100m^2$ using the catch depletion formulae of Seber le Cren (1967), where 2 runs were performed, or Zippin (1958), where 3 runs were performed. Trout fry and parr densities were classified according to the Regional Juvenile Salmonid Monitoring Programme (RJSMP) classification (NRA, Welsh Region, 1991a).

The HABSCORE model (Milner *et al*, 1991; NRA, Welsh Region, 1991b) was applied to each electrofishing site to determine whether the habitat was being fully utilised by salmonids. This model is based on empirical data from unpolluted streams in Wales and relates predicted fish populations (species and age specific) to observed habitat variables. A significantly low observed density ($P<0.05$), compared with the predicted density, indicates that the site is being impacted by factors other than habitat suitability.

2.3.2. Fish and egg survival experiments

The survival of brown trout eggs and alevins was assessed at six sites in the Pelenna catchment in February and March 1994 (Table 2). Eyed brown trout eggs from a commercial hatchery in West Wales were buried in gravel-filled plastic mesh boxes at each of the sites, approximately 25cm beneath the surface of the gravel. Eight boxes were planted at each of the sites, each box containing 100 eggs. Half of the egg boxes were recovered 14 days after being planted and the percentage of survival to hatching was determined. The remaining boxes were recovered after a further 28 days to determine the percentage of alevin survival.

Survival of hatchery reared brown trout parr was assessed at 7 sites in the Pelenna catchment in February and March 1994, including a control site on the Fforch-dwm (Table 2). The fish were kept in secured cages and percentage survival was assessed after 24 and 48 hours. Moribund fish were also noted.

Samples of blood plasma and gill tissue were removed from fish from each of the cages after 24 and 48 hours. Blood plasma samples were analysed for concentrations of chloride, sodium, potassium, manganese, calcium and iron. Gill tissue samples were rinsed in distilled water and analysed for concentrations of zinc, aluminium, manganese and iron (expressed as mg/kg dry weight). Control samples of gill tissue and blood plasma were taken from fish at the hatchery before the experiments, and from fish held in freshwater tanks for the duration of the experiment.

2.3.3. Economic benefit analysis

A calculation was made to assess the potential increase in the capital value of the River Afan migratory salmonid fishery, resulting from improvements in the quality of water and substrates in the Pelenna catchment. These calculations, which are based on observed and predicted numbers of trout parr in the area impacted by minewater pollution, are shown in Appendix 3.

3. RESULTS

3.1. Water quality assessment

3.1.1. Discrete monitoring

(i) pH

Values of pH in the Blaenpelenna and Gwenffrwd were highly variable, especially in the upper reaches of these watercourses, where values as low as 4.4 and 4.2 were recorded at sites BP3 and G3 respectively (Fig.5, Appendix.4). Further downstream, pH values were generally less variable, although a minimum value of 4.5 was recorded on the Gwenffrwd as far downstream as the confluence with the River Pelenna. Median pH values were between 5.2 and 6.2 at all sampling sites on the Blaenpelenna and Gwenffrwd and 90 percentile pH values at these sites were below the European Inland Fisheries Advisory Council (EIFAC) standard of water quality for sustaining salmonid fisheries. This directive stipulates that 90 percentile pH values for salmonid fisheries should be between 6 and 9.

On the River Pelenna, below the confluence with the Gwenffrwd, pH values became more stable with increasing distance downstream. Median pH values at sites on the Fforch-dwm, River Afan and lower River Pelenna were in the range 6.3 to 7.4. At these sites, 90 percentile values generally appeared to be within the range of values which meet the EIFAC class 1 standard for sustaining high class salmonid fisheries, although there is insufficient data to confirm compliance with these standards.

Of the 5 minewater discharges entering the Blaenpelenna and Gwenffrwd, only Garth Tonmawr, Whitworth Lagoon and the Gwenffrwd discharge had median pH values lower than those of their respective receiving watercourses. The Gwenffrwd was found to be the most acidic discharge with a median pH value of 3.9 and a range of pH from 3.4 to 6.8 (Fig. 6, Appendix 5). Middle Mine and Whitworth no.1 were the least acidic of all the minewater discharges and these two discharges also had the highest median alkalinity values.

(ii) Iron

Upstream of the minewater discharges, concentrations of total iron on the Gwenffrwd were similar to those observed on the Blaenpelenna, and were all in the range 0.06 to 4.53mg/l, with median concentrations of 0.23 and 0.21 at sites BP3 and G3 respectively (Fig.7, Appendix 4).

Middle Mine discharge only appeared to cause a slight increase in the iron concentration of the Blaenpelenna: site BP4, downstream of this discharge, had a median iron concentration of 0.41mg/l. However, a noticeable increase in iron concentrations occurred downstream of the Garth Tonmawr discharge: a median iron concentration of 1.40mg/l was recorded at site BP5. The mean concentration of dissolved iron at BP5 (1.45mg/l) exceeds the maximum EIFAC standard of 1mg/l, below which salmonid fisheries may be sustained.

At sites G4 to G6, downstream of the minewater discharges on the Gwenffrwd, median total iron concentrations ranged from 1.96 to 2.63mg/l. Again, the mean dissolved iron concentrations at these sites (from 1.43 to 1.82mg/l) exceeded the EIFAC standard for salmonid fisheries.

Median total iron concentrations in the River Pelenna ranged from 0.39 to 0.80 mg/l, with the highest median concentration recorded at site P2, downstream of the Gwenffrwd confluence. The median total iron concentration on the River Afan at A3, downstream of the Pelenna confluence, was 0.16mg/l, which was slightly higher than at site A2, upstream of the Pelenna confluence, where a median concentration of 0.11mg/l was recorded.

Concentrations of iron vary considerably between minewater discharges entering watercourses in the Pelenna catchment (Fig.8, Appendix 5). The most heavily contaminated discharge in this respect is Whitworth lagoon, which had a median iron concentration of 42.5mg/l, followed by Garth Tonmawr, with a median concentration of 26.4mg/l, and Whitworth no.1, which had a median concentration of 25.6mg/l. The Gwenffrwd discharge was found to have a median iron concentration of 10.8mg/l, while the Middle Mine discharge is far less significant, with a median concentration of only 0.9mg/l.

Iron concentrations are extremely variable in all of the minewater discharges, especially in the Whitworth A discharge, where recorded iron concentrations ranged from 0.9 to 98.9 mg/l.

The most significant discharge in terms of iron loading (iron concentration x flow) is Garth Tonmawr, from which approximately 66.5 kg of iron is discharged into the Blaenpelenna each day (Table 3). Whitworth lagoon was found to discharge approximately 45.3 kg/day into the Nant Gwenffrwd, of which the vast majority is derived from the Whitworth A discharge, which had more iron as well as having a higher flow than Whitworth B. The Gwenffrwd and Whitworth no.1 discharges were found to discharge 11.9 and 6.8 kg/day respectively into the Nant Gwenffrwd. Flow data is not currently available for the Middle Mine discharge.

(iii) Aluminium

The highest concentrations of total aluminium recorded in the Pelenna catchment were in the Blaenpelenna and Gwenffrwd catchments, where median concentrations ranged from 0.36 to 0.68mg/l (Fig.9, Appendix 4). Aluminium concentrations were generally higher upstream of the main minewater discharges, although the highest median aluminium concentration was recorded at site G6, downstream of all the discharges on the Gwenffrwd.

Aluminium concentrations in the minewater discharges were generally no greater than those recorded in their respective receiving rivers, with the exception of the Middle Mine discharge, with a median total aluminium concentration of 0.76mg/l, and the Gwenffrwd discharge, which had a median concentration of 1.65mg/l (Appendix 5).

3.1.2. **Continuous monitoring**

At site BP4 on the Blaenpelenna, pH values between the 7th and 22nd of March 1994 ranged from 4.1 to 6.8, while conductivity ranged from 57 to 105ms/cm^3 (Fig 10a).

At site G3 on the Gwenffrwd, pH values between the 8th of February and 10th March 1994 ranged from 4.3 to 6.9, while conductivity ranged from 72-142ms/cm^3 (Fig 10b).

A strong positive correlation was apparent between pH and conductivity at both the continuous monitoring sites. Increases or decreases in conductivity were invariably followed almost immediately by corresponding changes in pH.

Sharp decreases in both pH and conductivity were found to occur following episodes of high rainfall in both the Blaenpelenna and Gwenffrwd. This trend was demonstrated particularly well on 8th March 1994, at BP4 and G3 (Fig.10).

3.1.3. Storm event chemistry

Episodes of high rainfall in the upper reaches of the Pelenna catchment invariably caused an overall decrease in pH for a period of at least 24 hours. Minimum pH values fell to below 4.5 during such episodes in both the Blaenpelenna and Gwenffrwd. These decreases in pH generally corresponded with increases in concentrations of total aluminium, up to a maximum recorded concentration of 1.9mg/l (Fig.11).

Downstream of the minewater discharges, at sites G5 and BP5, decreases in pH following rainfall episodes were generally less severe (Appendix 6). Dilution of the minewater discharges under these conditions may have caused overall reductions in concentrations of sulphate and metals, although occasional peaks in metal concentrations may have resulted from scouring and flushing of sediments.

Although it appears unlikely that rainfall events are responsible for immediate changes in the chemistry of the discharges themselves, these investigations did highlight possible relationships between chemical determinands in the minewaters (Appendix 7).

3.2. <u>Biological quality assessment</u>

3.2.1. Macroinvertebrate communities

(i) Routine monitoring, 1990-1994

BMWP scores at all 4 routine monitoring sites were found to be well below RIVPACS predicted scores in each of the last 5 years. No obvious trends in biological quality are apparent between these years (Fig.12a). Observed values for taxon richness were also generally well below those predicted by the RIVPACS model (Fig.12b).

(ii) Status of macroinvertebrate communities in 1993 and 1994

BMWP scores were lower than RIVPACS predictions at all 11 sites sampled in 1993 and at all 12 sites sampled in 1994 (Table 4, figs. 13 & 14). Similarly, at the majority of sites sampled in the Pelenna catchment, the observed number of taxa was lower than that predicted by the RIVPACS model. The only exceptions to this rule were at sites on the River Afan in 1994 (Table 4, figs. 15 & 16).

Species abundance and taxon richness were relatively impoverished at sites on the Blaenpelenna and Gwenffrwd, compared with the rest of the catchment. This pattern was reflected by the observed BMWP scores. Upstream of the minewater discharges on these watercourses, taxon richness and BMWP scores were low compared to sites on the Fforch-dwm, lower Pelenna and River Afan. However, the most impoverished faunas in the 1993 and 1994 surveys were identified immediately downstream of the minewater discharges on the Blaenpelenna and Gwenffrwd, with gradual recovery of the communities occurring with increasing distance downstream of the discharges.

A comparison of spring samples collected in 1993 and 1994 shows an overall improvement in biological quality between these two years, with 10 of the 11 sites sampled in spring and summer having increased taxon richness in 1994 compared with 1993.

Detailed information about the abundance and distribution of species identified in the 1994 survey is shown in Appendix 8.

3.2.2. **Acidification survey**

A survey carried out in February 1994, using a biological acid indicator key, clearly demonstrated that the upper reaches of the Gwenffrwd and Blaenpelenna contained impoverished macroinvertebrate communities typical of acidified streams (Table 5, Fig.17). This survey also provided evidence of acidification in the Twynpumerw, Sychnant and the Blaengwenffrwd. The Nant-y-Cywian, Fforch-dwm and Cwm-y-Pant were all classified in group 2, indicating that, although macroinvertebrate taxon richness was less than optimal, the faunas present were not typical of acidic streams.

At the times when invertebrate samples were collected, sites which fell into the group 4 category (the most acidic) were found to have pH values in the range 4.3 to 6.5, with dissolved calcium concentrations ranging from 2.2 to 7.7 and dissolved aluminium concentrations in the range 0.02 to 0.89 (Table 5). The catchment at site S1 was very steep and this may have caused the site to fall into the group 4 category, despite the apparent good water quality. Sites which fell into the group 2 category were found to have pH values in the range 5.8 to 7.1, dissolved calcium concentrations in the range 3.0 to 4.7, and dissolved aluminium concentrations in the range 0.08 to 0.17.

3.3. Fisheries Investigations

3.3.1. Status of fish populations

According to the HABSCORE model, densities of trout fry and parr were below the predicted densities at all 9 of the sites sampled in the Pelenna catchment in 1993 and at all 10 of the sites sampled in 1994 (figs. 18 & 19). Differences between observed and predicted densities were found to be significant at the $P<0.001$ level at all the sites in the Blaenpelenna and Gwenffrwd, with the exception of site BP4, where trout parr densities were found to be significantly low at the $P<0.05$ level (Table 6). In the lower Pelenna, at sites P2 and P3, and in the Fforch-dwm, at site FD3, differences between observed and predicted densities were not found to be significant.

Trout fry and parr were virtually absent in the Gwenffrwd catchment, with only 2 parr caught in the 1994 survey and none caught in 1993 (Table 6). Trout densities were classified as poor at all sites on the Blaenpelenna in 1993 and 1994, according to the Regional Juvenile Salmonid Monitoring Programme (RJSMP) system, while trout densities in the River Pelenna ranged from Poor to Moderate in 1993, and from Moderate to Good in 1994. Site FD3, on the Fforch-dwm, was classified as Excellent in 1994. Overall, trout densities appeared to have improved between 1993 and 1994, with 3 of the sites (G5, P1 and P3) increasing their RJSMP status by one class.

3.3.2. Trout egg/alevin survival

Percentage survival to hatching was found to be lowest at sites BP5 (40%) and G6 (36%), downstream of the minewater discharges on the Blaenpelenna and Gwenffrwd respectively. At the other 6 sites in the Pelenna Catchment, percentage survival to hatching ranged from 60 to 68% (Fig.20).

No alevins were found to be alive at G6 after 42 days, while only 1% of the alevins had survived during this period at BP5 (Fig.21). Elsewhere in the catchment alevin survival ranged from 11%, at site G3, to 43%, at site BP4. Egg boxes were however not recovered after this period at site P1 or at the control site FD3, where the highest egg survival had occurred. It is likely that these boxes were flushed out of the gravel under high flow conditions.

3.3.3. Trout parr survival

After 24 hours in cages, dramatic differences in parr survival were observed between different sites in the catchment (Table 7, Fig.22). At the control site on the Fforch-dwm (FD3), and at site P1 on the Pelenna, 100% survival was observed after 24 hours. In contrast, no fish survived this period at site BP5, downstream of Garth Tonmawr discharge, or at either of the sites on the Gwenffrwd. A survival rate of 25% was observed after 24 hours at site BP4, upstream of Garth Tonmawr discharge, and at site P2, on the Pelenna downstream of the Gwenffrwd confluence.

After 48 hours, no parr had survived at any of the sites, with the exception of site FD3, where no mortalities had occurred (Table 7).

After 24 hours and 48 hours, gills removed from fish caged at site FD3, where 100% survival was observed, were found to contain lower concentrations of aluminium (mean = 79mg/kg after 48 hours), manganese (mean = 7mg/kg after 48 hours) and iron (mean = 152 mg/kg after 48 hours), than gills taken from fish kept at any of the other 6 sites (Table 7). Fish which died during these experiments at site P1 were found to have accumulated up to 375mg/kg of aluminium, up to 19mg/kg manganese and up to 909mg/kg iron in their gills after 48 hours in cages.

Blood plasma could only be collected from fish which were recovered alive and therefore only a limited amount of information about blood plasma content is presented in Table 7. After 24 hours, concentrations of chloride and sodium in the plasma of fish kept at site FD3 were similar to those observed in the controls. However, chloride and sodium concentrations in the plasma of fish kept at sites BP4, P1 and P2 were found to be lower after 24 hours than in the controls. After 48 hours, chloride and sodium concentrations in the plasma of fish kept at site FD3 were lower than those observed in the controls and a further reduction in chloride and sodium concentrations had occurred in the plasma of fish kept at site P1.

4. DISCUSSION

4.1. Water quality assessment

The main purpose of the proposed wetland treatment systems is to reduce the quantity of iron entering watercourses in the Pelenna catchment. Analysis of water samples showed that three minewater discharges in particular, namely Garth Tonmawr, Whitworth lagoon and Whitworth no.1, caused elevated concentrations of iron in their receiving watercourses. As a result, at least 1.5km of the Blaenpelenna and Gwenffrwd contained mean dissolved iron concentrations in excess of the EIFAC standard for salmonid fisheries (ie. >1mg/l). These river sections, as well as the entire length of the River Pelenna (approximately 5km), have also been affected by precipitation of iron hydroxide, which has caused a major aesthetic problem and affected the feeding and reproduction of fish and invertebrates.

Another common problem associated with discharges from abandoned coal mines is that of acidity, resulting from free protons (low pH) and from dissolved metals, which can undergo hydrolysis reactions forming hydrogen ions (Hedin, *et al*, 1994). With the exception of the Gwenffrwd discharge, minewater discharges in the Pelenna catchment do not appear to cause an immediate impact in this way, as they generally have a higher pH than their receiving rivers. However, hydrogen ions may be produced in the receiving river as iron hydroxide precipitates out of solution. This may partially counteract the buffering of acidity further downstream.

Acidification of the headwaters in the catchment is likely to be the result of atmospheric deposition of airborne pollutants, the effects of which are exacerbated by conifer afforestation and base-poor catchment geology. Following periods of high rainfall in particular, low pH values and high concentrations of aluminium were recorded upstream of the minewater discharges on the Blaenpelenna and Gwenffrwd. Rainfall episodes in the upper Pelenna catchment increase the deposition of airborne acidic compounds, which then greatly exceed the buffering capacity of the receiving watercourses. Under the resulting extreme low pH conditions, excess amounts of toxic metals, such as aluminium, are leached from the surrounding soils.

As well as causing extremes in metal concentrations and pH, episodes of high rainfall resulted in corresponding decreases in conductivity. This indicates that during the period of continuous monitoring (February-March 1994) the headwaters of the Pelenna catchment were not affected by sea salt episodes, which have been found to exacerbate acid stream conditions in some catchments, particularly those in coastal areas (Bird *et al*, 1990). Rainfall episodes may also have diluting and scouring effects, thus temporarily reducing metal contamination of water and sediments immediately downstream of the minewater discharges.

The only substantial watercourse in the Pelenna catchment which appears to be unaffected by either acidification or minewater pollution is the Fforch-dwm. The geology of this sub-catchment is predominantly boulder clay, which has a higher buffering capacity than the sand, gravel and hill peat which surrounds the majority of the headwaters of the Blaenpelenna and Gwenffrwd.

All classified reaches in the River Pelenna catchment failed to comply with NRA (Rivers Ecosystem) water quality objectives during routine monitoring in 1994. All of the classified reaches of the Blaenpelenna and Gwenffrwd, and the majority of the River Pelenna, failed to meet NRA objectives for pH, while approximately 1km of the River Pelenna downstream of Tonmawr failed to meet objectives for BOD (Fig.23). The BOD failure was caused by a combined sewer overflow discharging downstream of the Gwenffrwd/Pelenna confluence. Recent improvements to this sewerage system should however ensure that this objective is met in future. An insufficient number of water samples were analysed for metal concentrations in 1994 to allow testing for compliance with List 2 Metals (General Ecosystem) objectives.

4.2. <u>Biological quality assessment</u>

Biological studies carried out in the Pelenna catchment indicated that macroinvertebrate communities were impoverished at all sites in the Gwenffrwd, Blaenpelenna and River Pelenna. Upstream of the minewater discharges on the Gwenffrwd and Blaenpelenna, and on most of the minor tributaries, macroinvertebrate assemblages were typical of those occurring in acidified streams. Below the minewater discharges, macroinvertebrate faunas were even more impoverished, with a gradual recovery occurring further downstream.

Episodes of low pH and corresponding high aluminium concentrations in the headwaters of the catchment, with the exception of the Fforch-dwm, are probably largely responsible for the impoverished status of macroinvertebrate communities upstream of the minewater discharges. Taxon richness was found to be far greater in the Fforch-dwm, where recorded pH values remained relatively stable and did not fall below 6.4, than in the upper reaches of the Blaenpelenna and Gwenffrwd, where extreme acid episodes were recorded.

Aluminium and low pH may affect invertebrates as a result of direct toxicity, which causes physiological stress. In addition, episodes of acidity may cause downstream drift, as acid-sensitive taxa avoid the adverse conditions by being washed downstream to buffered areas. Such episodes are more common in winter and spring than in summer; this may explain why taxon richness upstream of the minewater discharges was generally greater in summer than in spring.

Conversely, macroinvertebrate communities downstream of the minewater discharges are more likely to be adversely affected following low flow conditions, due to the absence of scouring and subsequent increases in deposition of iron hydroxide. These deposits can affect benthic macroinvertebrates by interfering with feeding and respiration, altering their habitat and by direct metal toxicity. Species with external gills are particularly sensitive to fine particles which clog their gills and impair respiration (Scullion & Edwards, 1980). Of the thirteen taxa found at sites immediately below the discharges in 1994, only two species had external gills (Higham, 1994). Species which feed by grazing may also be highly susceptible to deposition of iron hydroxide, which reduces food availability by coating the substrate.

The overall improvement in biological quality observed between 1993 and 1994 may be due to differences in flow conditions between these years, rather than a reduction in acidification or minewater pollution. Further extensive investigations would be required to determine whether there are any significant long-term trends.

An overall recovery in taxon richness was observed downstream on the River Pelenna, as acid episodes became less pronounced and smothering of the substrates with iron hydroxide became less severe. No impact was observed on the River Afan, where observed macroinvertebrate assemblages were generally similar to those predicted by the RIVPACS model.

4.3. Fisheries Assessment

Water quality problems appear to have had a severe impact on fish populations both upstream and downstream of the minewater discharges. Juvenile trout populations were very poor on the Blaenpelenna, while the Gwenffrwd was virtually fishless. In contrast, the control site on the Fforch-dwm was classified as "Excellent" according to the RJSMP system. Trout densities on the main River Pelenna are greatest in the lower reaches, where the impact of the minewater discharges and surface water acidification is less severe.

Poor or absent fish populations in the headwaters of the catchment are attributable to the combined toxic effects of hydrogen ions (low pH) and high concentrations of aluminium. In waters of low pH, dissolved aluminium has been demonstrated to exert a chronic effect through reproductive failure, and an acute effect through mucous clogging of the gills (Gun, 1987). As a result, trout populations are likely to be poor or absent in streams where dissolved aluminium >0.1mg/l is coincident with pH <5.4 (Milner & Varallo, 1990). Such adverse conditions occur frequently in both the Gwenffrwd and the Blaenpelenna.

Downstream of the minewater discharges on the Blaenpelenna and Gwenffrwd, the effects of acidification on salmonid egg and fry survival are compounded by toxic and smothering effects of iron compounds. Deposits of iron hydroxide may cause egg mortalities by reducing levels of intragravel dissolved oxygen, while fine particulate solids may affect juvenile fish by clogging their gills and interfering with respiration. Dissolved iron, particularly in the presence of low pH and high concentrations of other metals, may also exert an impact on fish populations, through direct toxicity. Geertz-Hansen & Rasmussen (1994) reported that the survival of brown trout alevins is significantly reduced when soluble iron concentrations exceed 0.5mg/l. The synergistic toxic effects of dissolved metals, such as iron, aluminium, manganese and zinc, are however not yet adequately understood.

Water quality problems associated with acidification or minewater pollution may also affect fish populations indirectly, by affecting populations of benthic invertebrates, which form the principle food source at the fry stage.

Experiments with trout eggs in artificial redds indicated that egg survival, although poor upstream of the minewater discharges, was adversely affected to an even greater extent immediately downstream of the discharges. The egg boxes may however have acted as silt traps, and as such may have further reduced egg and alevin survival by creating artificially low concentrations of intragravel dissolved oxygen.

The acute toxic effects of acidity and dissolved metals were perhaps most effectively demonstrated by the parr survival experiments in February and March 1994. These experiments were carried out during severe weather conditions with high river flows, and the brown trout held in cages had little opportunity to acclimatise to these conditions. Nevertheless, the results showed clear differences between the ability of these fish to survive in the Blaenpelenna and Gwenffrwd, which are susceptible to episodes of extreme acidity under high flow conditions, compared with the relatively stable Fforch-dwm. The Gwenffrwd also appeared to cause a deterioration in water quality in the River Pelenna, as survival was reduced by 75% on the Pelenna below the confluence of these two watercourses.

One of the consequences of combined metal and pH toxicity on freshwater fish is the loss of plasma electrolytes, due to sublethal effects upon gill function (McDonald *et al*, 1989). Reductions in chloride and sodium concentrations were observed in the plasma of fish in all the cages where fish were still alive to be sampled, although these reductions were less pronounced in the fish held in the Fforch-dwm than in fish held in the Blaenpelenna or River Pelenna. The high levels of accumulated iron and aluminium in the gills of fish kept in the Gwenffrwd, Blaenpelenna and River Pelenna may have contributed to the toxic effects and the mortalities observed.

Another factor which may affect the recovery of the Pelenna catchment as a spawning ground for migratory salmonids, is the presence of physical barriers to migration. Upstream fish migration may be partially restricted by a culvert on the Nant Gwenffrwd, immediately upstream of the Gwenffrwd/Pelenna confluence, and by a culverted road bridge on the Blaenpelenna, immediately upstream of the Garth Tonmawr discharge. Another culvert on the Nant Gwenffrwd, immediately downstream of the Whitworth lagoon discharge, forms a total barrier to all upstream fish migration past this point (See Fig.18).

It was estimated that improvements to water quality in the Pelenna catchment, downstream of the minewater discharges, could increase the capital value of the migratory trout fishery in River Afan by nearly £80,000. This figure is based on the assumption that no other factors, such as accessibility of spawning grounds, are limiting fish populations. Although no juvenile salmon were captured in the Pelenna catchment during electrofishing surveys in 1994, the catchment might also offer potential as a salmon spawning area if water quality conditions improved.

5. CONCLUSIONS

5.1. Water quality assessment

5.1.1. Approximately 7 km of the River Pelenna catchment, including sections of the Blaenpelenna and Gwenffrwd and the entire length of the River Pelenna, were found to contain elevated concentrations of iron as a result of discharges from abandoned coal mines.

5.1.2. Iron concentrations were extremely variable in the minewater discharges. The diluting and scouring effects of rainfall episodes strongly influenced concentrations of metals and deposition of iron hydroxide downstream of these discharges.

5.1.3. The minewater discharges, with the possible exception of the Gwenffrwd discharge, did not appear to cause reductions in pH in their receiving rivers.

5.1.4. The effects of minewater pollution on water quality were less pronounced in the lower part of the River Pelenna than immediately downstream of the minewater discharges. No significant impact was identified by water quality monitoring in the River Afan.

5.1.5. A surface water acidification problem was identified upstream of the minewater discharges. This is attributable to the combined effects of atmospheric pollution, conifer afforestation and base-poor underlying geology.

5.1.6. Upstream of the minewater discharges on the Gwenffrwd and Blaenpelenna, rainfall episodes were found to cause severe decreases in pH and conductivity, and corresponding increases in aluminium concentrations.

5.1.7. The acidification problem was less pronounced further downstream, as a result of increased buffering. No acidification was identified by water quality monitoring in the Fforch-dwm or River Afan.

5.2. Biological assessment

5.2.1. Macroinvertebrate assemblages upstream of the minewater discharges were typical of those occurring in acidified streams. This is attributable to the combined toxic effects of low pH and high aluminium concentrations, which occur following episodes of high rainfall.

5.2.2. Macroinvertebrate taxon richness was further reduced immediately downstream of the minewater discharges. This may have been due to the blanketing of the substrate with precipitated iron hydroxide, and the combined toxic effects of metals such as aluminium and iron, in low pH conditions.

5.2.3. A gradual recovery in invertebrate taxon richness was observed downstream of the minewater discharges. No significant impact from acidification or minewater pollution was observed in the Fforch-dwm or in the River Afan.

5.3. Fisheries assessment

5.3.1. Juvenile trout populations were poor on the Blaenpelenna and virtually absent on the Gwenffrwd, both upstream and downstream on the minewater discharges. Trout densities were higher in the lower reaches of the River Pelenna, while trout densities in the Fforch-dwm were classified as "Excellent". No salmon were observed in the Pelenna catchment.

5.3.2. The paucity or absence of fish populations upstream of the minewater discharges is attributable to the toxicity of aluminium in low pH conditions, which is particularly harmful to the young life stages of salmonids.

5.3.3. Minewater discharges may have caused an additional impact on the spawning success and juvenile recruitment of salmonids, through metal toxicity and smothering effects of precipitated iron hydroxide.

6. RECOMMENDATIONS

6.1. It is recommended that the findings of this report, as well as the findings from the aesthetic and sediment studies carried out this year, are used as a basis for assessing improvements to the River Pelenna catchment following the installation of wetland treatment systems.

6.2. Discrete monitoring of the water quality of minewater discharges and river sites should be continued on a monthly basis. The suite of determinands to be included in these analyses should be modified to enable a greater understanding of the chemical processes occurring in the minewater discharges and in their receiving rivers. This information is necessary for the design of effective treatment systems as well as for monitoring improvements resulting from their installation.

6.3. The occurrence of acute acidic episodes in the upper reaches of the Pelenna catchment is likely to reduce the potential for recovery of fish and invertebrate populations and water quality, following the installation of wetland treatment systems. It is therefore recommended that the findings of the liming feasibility study carried out by ACER Environmental are considered, with a view to alleviating the acidification problem.

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Table 1. Sampling site locations

Site ref. (NRA sample point no.)	Description	Grid ref.
BP1	Blaenpelenna u/s Twynpumerw confluence	SS 827 990
BP2	Blaenpelenna u/s Nant-y-Cywian confluence	SS 823 985
BP3(71063)	Blaenpelenna u/s Middle mine discharge	SS 817 978
BP4(71020)	Blaenpelenna u/s Garth Tonmawr discharge	SS 816 974
BP5(71059)	Blaenpelenna d/s Garth Tonmawr discharge	SS 816 970
TP1	Twynpumerw u/s Blaenpelenna confluence	SS 799 943
NC1	Nant-y-Cywian u/s Blaenpelenna confluence	SS 823 984
FD1	Fforch-dwm u/s Sychnant confluence	SS 823 972
FD2	Fforch-dwm d/s Sychnant confluence	SS 822 971
FD3(71066)	Fforch-dwm u/s Blaenpelenna confluence	SS 817 969
S1	Sychnant u/s Fforch-dwm confluence	SS 822 973
CP1	Cwm-y-pant u/s Fforch-dwm confluence	SS 820 969
P1(71051)	Pelenna u/s Gwenffrwd confluence	SS 798 962
P2(71026)	Pelenna d/s Gwenffrwd confluence	SS 787 955
P3(11004)	Pelenna u/s Afan confluence	SS 793 942
G1	Gwenffrwd @ Blaen Cwm-bach Farm	SS 800 985
G2	Gwenffrwd near Roman Camp	SS 797 984
G3(71017)	Gwenffrwd u/s Whitworth lagoon	SS 795 977
G4(71064)	Gwenffrwd d/s Whitworth lagoon	SS 799 972
G5(71065)	Gwenffrwd d/s Gwenffrwd discharge	SS 798 968
G6(71019)	Gwenffrwd u/s Pelenna confluence	SS 798 963
BG1	Blaengwenffrwd 300m u/s Gwenffrwd confluence	SS 802 977
GT1	Gwenffrwd trib. u/s Gwenffrwd discharge	SS 803 970
A1(71011)	R.Afan @ Corlannau footbridge	SS 819 951
A2(11005)	R.Afan @ Pontrhydyfen, u/s road bridge	SS 797 941
A3(71027)	R.Afan @ Cwmafan	SS 781 919
	Minewater discharges:	
- (71021)	Middle mine discharge	SS 817 978
- (71016)	Garth Tonmawr discharge	SS 817 972
- (71057)	Whitworth A (North inlet to lagoon)	SS 800 974
- (71058)	Whitworth B (South inlet to lagoon)	SS 800 974
- (71014)	Whitworth lagoon discharge	SS 799 974
- (71015)	Gwenffrwd discharge	SS 801 970
- (71022)	Whitworth No.1.	SS 798 965

See Fig.4 for map showing locations of sampling sites.

Table 2. Environmental assessment work carried out in the Pelenna catchment, 1990-1994

Investigation	Dates	Sampling site																									
		BP1	BP2	BP3	BP4	BP5	TP1	NC1	FD1	FD2	FD3	S1	CP1	P1	P2	P3	G1	G2	G3	G4	G5	G6	BG1	GT1	A1	A2	A3
Water quality:																											
Spot sampling (monthly)	1990-91				*											*			*			*				*	
	1992			*	*	*								*	*	*			*			*				*	
	1993			*	*	*								*	*	*			*			*				*	*
	1994			*	*	*					*			*	*	*			*	*	*	*				*	*
Continuous monitoring	Feb-Mar'94				*														*								
Autosamplers	Jan-Mar'92				*	*													*		*						
Biological monitoring:																											
BMWP scores (spring & summer)	1990-92				*											*			*		*						
	1993				*	*								*	*	*			*	*	*	*			*		*
	1994				*	*					*			*	*	*			*	*	*	*			*		*
Acid indicator key	Feb'94	*	*	*			*	*	*	*	*	*	*				*	*	*				*	*			
Fisheries monitoring:																											
Electrofishing (summer)	1993			*	*									*	*	*			*	*	*	*			*		*
	1994			*	*						*			*	*	*			*	*	*	*			*		*
Egg/alevin survival	Feb-Mar'94				*	*									*	*			*			*					
Parr survival	Feb-Mar'94				*	*					*			*	*				*			*					

See table 1 for sampling site locations

Sampling of minewater discharges: Monthly spot sampling since 1991 (except Whitworth A & B, since 1993)
Autosamplers deployed from Jan-Mar 1992 at Whitworth no.1, Whitworth lagoon, Gwenffrwd discharge and Garth Tonmawr

Table 3. Iron loadings from minewater discharges in the Pelenna catchment

Discharge	Mean total iron (mg/l)	Mean flow (cumecs)	Iron loading (kg/day)
Garth Tonmawr	25.4	0.030	66.5
Whitworth A	42.6	0.012	44.2
Whitworth B	2.7	0.0007	0.2
Whitworth lagoon	40.3	0.013	45.3
Gwenffrwd	10.6	0.013	11.9
Whitworth no.1	26.4	0.003	6.8

Table 4. Results of macroinvertebrate surveys in the Pelenna catchment, 1993-1994

Site	Spring 1993				Summer 1993				Spring 1994				Summer 1994			
	BMWP		no.taxa		BMWP		no.taxa		BMWP		no.taxa		BMWP		no.taxa	
	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred
BP4	66	159	8	24	28	136	5	22	60	160	12	24	46	137	12	21
BP5	8	158	1	24	34	135	6	21	35	160	6	24	40	132	8	21
FD3	-	-	-	-	-	-	-	-	119	161	19	24	102	135	20	21
P1	35	158	5	24	41	136	7	22	69	160	11	24	32	136	8	22
P2	19	158	5	24	39	136	8	22	67	160	11	24	63	137	17	22
P3	45	158	8	24	39	137	8	22	84	158	15	24	71	136	19	22
G3	51	161	8	24	52	136	10	22	51	161	8	24	66	135	14	21
G4	12	160	3	24	19	136	3	22	30	161	6	24	15	135	4	21
G5	10	160	3	24	27	137	7	22	31	161	5	24	15	136	5	22
G6	38	160	7	24	22	136	4	22	60	160	10	24	37	136	7	21
A1	125	154	20	24	125	136	16	23	126	156	21	24	102	137	26	23
A3	88	148	16	24	62	132	14	22	106	149	18	24	69	132	22	22

Obs = Observed BMWP score or number of taxa (families) present in sample
Pred = Predicted BMWP score or number of taxa according to RIVPACS model

Table 5. Results of acidification survey, February 1994

Site	Acid group	BMWP score	pH	Ca(dis)	Al(dis)
BP1	4	14	6.0	2.2	0.07
BP2	4	42	6.1	3.5	0.08
BP3	4	42	6.5	3.8	0.07
TP1	4	42	5.5	3.5	0.18
NC1	2	76	6.4	4.0	0.06
S1	4	14	6.5	7.7	0.02
CP1	2	33	6.2	4.3	0.08
FD1	2	49	6.1	4.3	0.13
FD2	2	86	5.8	3.0	0.17
FD3	2	80	7.1	4.7	0.12
G1	4	30	4.3	1.7	0.89
G2	4	35	4.4	2.1	0.80
G3	4	34	5.7	4.7	0.08
BG1	4	67	5.7	3.0	0.07
GT1	3	73	6.0	3.8	0.05

Al and Ca concentrations expressed as mg/l

See Appendix 2 for descriptions of acid groups

Table 6. Results of quantitative electrofishing surveys in the Pelenna catchment

Site	Trout densities 1993			Trout densities 1994		
	0+	>0+	RJSMP class	0+	>0+	RJSMP class
BP4	0.0 ***	1.7 ***	D	0.0 ***	5.9 *	D
BP5	0.6 ***	0.7 ***	D	0.7 ***	0.7 ***	D
P1	0.0 ***	2.6 ***	D	5.4 ***	10.6 *	C
G3	0.0 ***	0.0 ***	E	0.0 ***	0.0 ***	E
G4	0.0 ***	0.0 ***	E	0.0 ***	0.0 ***	E
G5	0.0 ***	0.0 ***	E	0.0 ***	1.7 ***	D
G6	0.0 ***	0.0 ***	E	0.0 ***	0.0 ***	E
P2	1.8 ***	7.2 ns	C	16.0 ns	6.8 ns	C
P3	3.9 ***	6.5 ns	C	40.9 ns	13.8 ns	B
FD3	-	-	-	32.1 ns	28.0 ns	A

Densities expressed as number of fish per $100m^2$

Key

* Significantly lower than HABSCORE prediction at the P<0.05 level
** Significantly lower than HABSCORE prediction at the P<0.01 level
*** Significantly lower than HABSCORE prediction at the P<0.001 level
ns Not significantly low

RJSMP classes: A=Excellent, B=Good, C=Moderate, D=Poor, E=Absent

NB No salmon caught during these surveys

Table 7. Results of trout parr survival experiments. February-March 1994

(i) After 24 hours

Site	% survival	mean concentrations in gills*1				mean concentrations in blood plasma*2					
		Zn	Al	Mn	Fe	Cl	Na	K	Mg	Ca	Fe
FD3	100	231	22	5	96	46	31	0.55	max0.13	max1.01	max0.02
BP4	25	99	271	10	530	23	16	3.17	<0.1	1.19	0.08
BP5	0	213	123	12	219	-	-	-	-	-	-
G3	0	198	103	11	151	-	-	-	-	-	-
G6	0	186	85	12	147	-	-	-	-	-	-
P1	100	174	255	8	445	40	28	0.70	max0.13	1.07	max0.01
P2	25	307	371	12	913	31	23	1.72	max0.13	1.33	0.03

(ii) After 48 hours

Site	% survival	mean concentrations in gills*1				mean concentrations in blood plasma*2					
		Zn	Al	Mn	Fe	Cl	Na	K	Mg	Ca	Fe
FD3	100	232	79	7	152	35	25	1.03	max0.12	1.3	0.24
BP4	0	191	300	10	311	-	-	-	-	-	-
BP5	0	-	-	-	-	-	-	-	-	-	-
G3	0	-	-	-	-	-	-	-	-	-	-
G6	0	-	-	-	-	-	-	-	-	-	-
P1	0	301	375	19	909	29.5	20.6	2.13	<0.10	1.17	0.017
P2	0	230	224	15	374	-	-	-	-	-	-

Control samples	mean concentrations in gills*1				mean concentrations in blood plasma*2					
	Zn	Al	Mn	Fe	Cl	Na	K	Mg	Ca	Fe
At hatchery	226	14	4	117	47	32	0.96	0.16	1.11	max0.01
In tanks after 48hrs	245	34	4	142	46	31	1.23	0.14	1.16	max0.01

*1 Expressed as mg/kg dry wt.

*2 Expressed as mg/l

Fig.1. Rivers, towns and minewater discharges in the Pelenna catchment

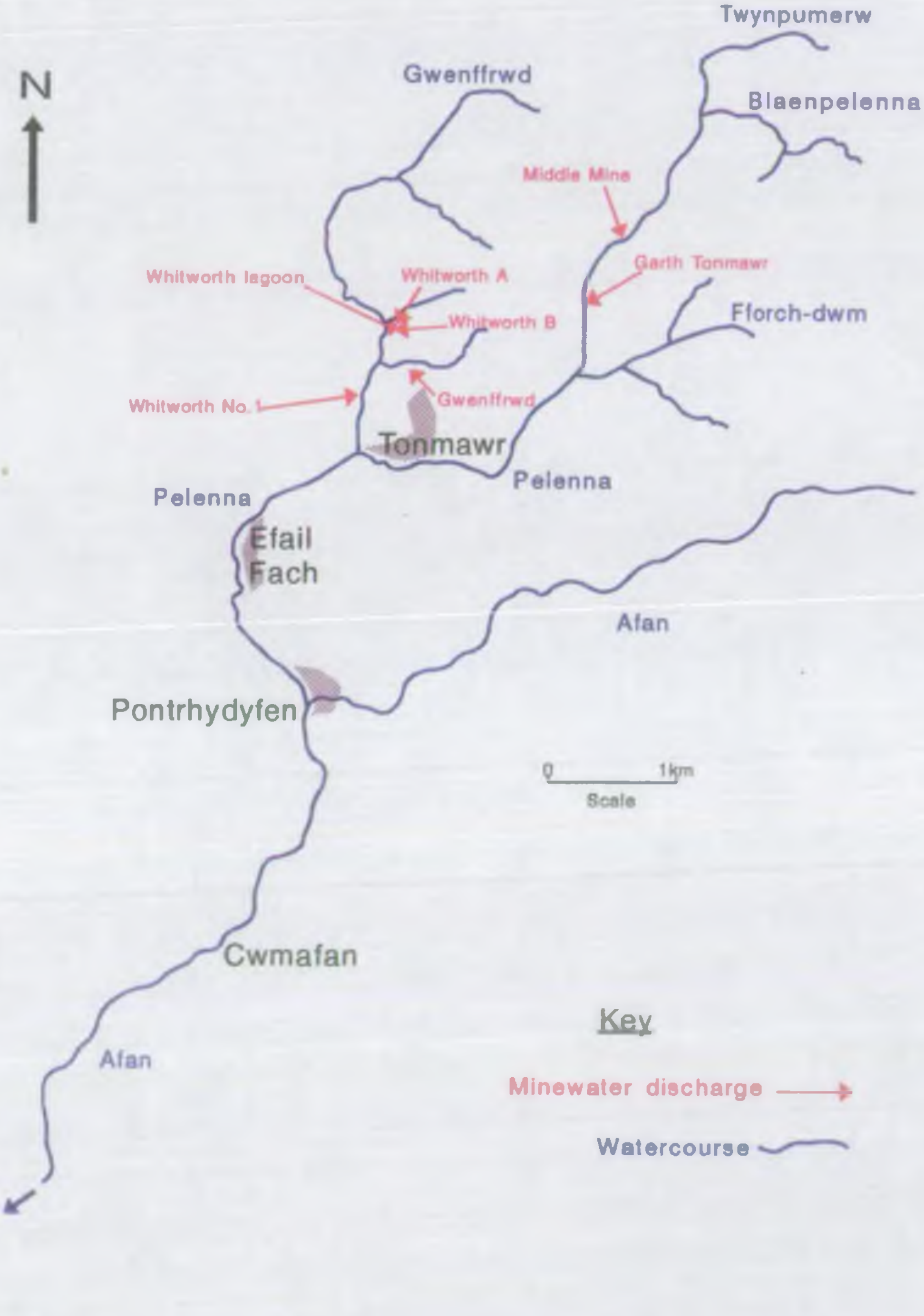


Fig.2. Principal land use within the Pelenna and Lower Afan catchments

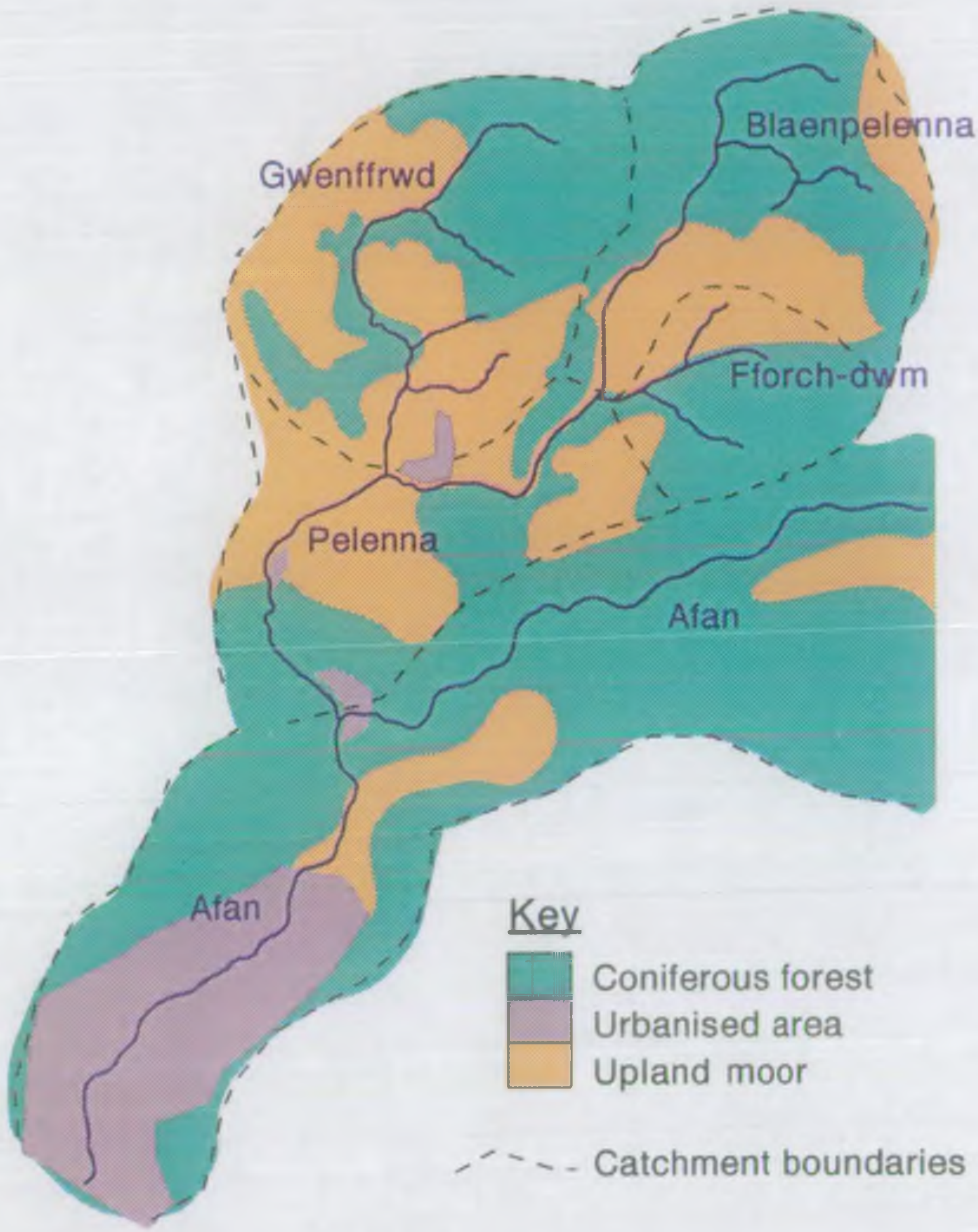


Fig.3. Geology of the Pelenna and Lower Afan catchments

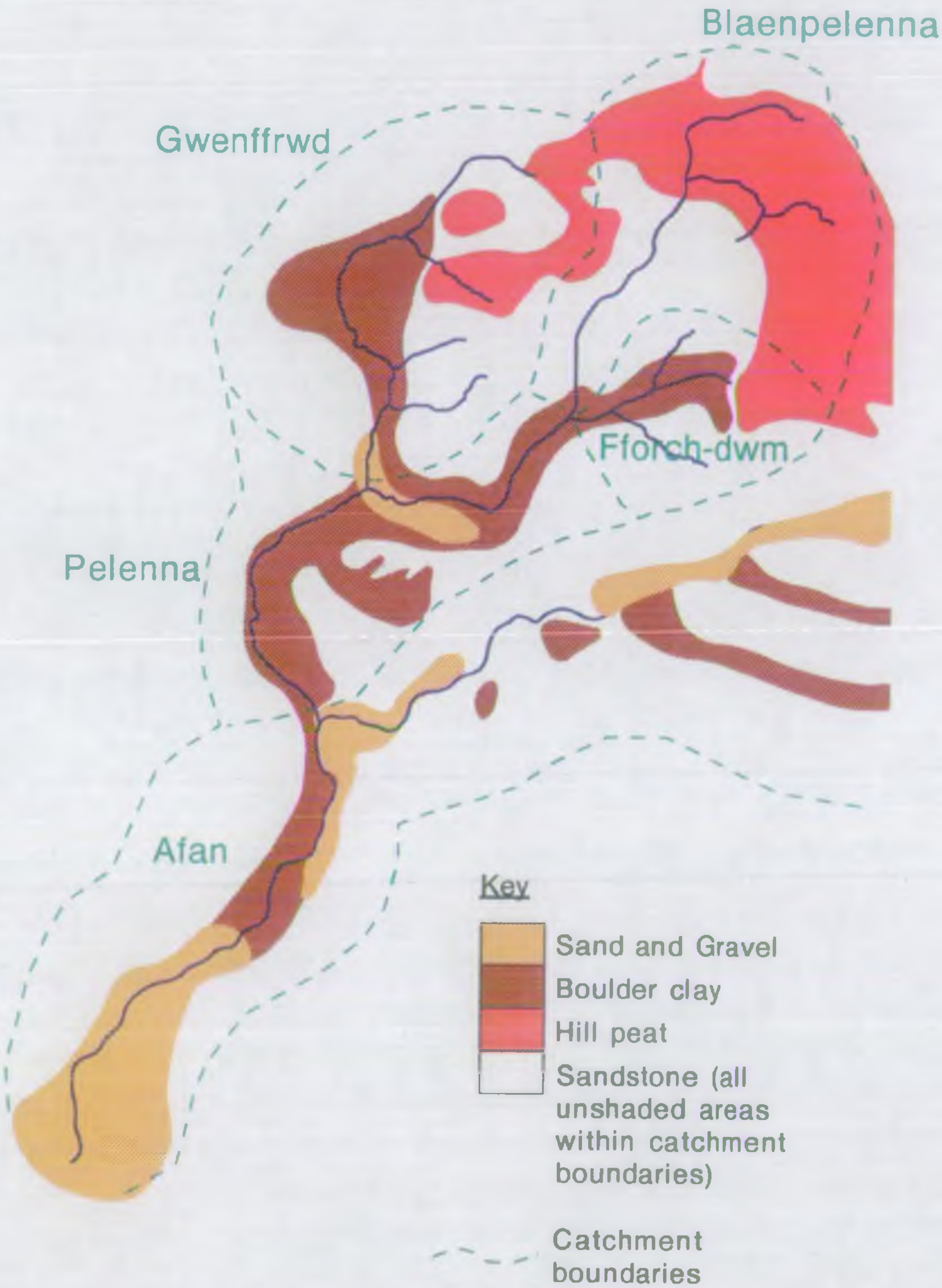


Fig.4. Locations of sampling sites in the Pelenna catchment

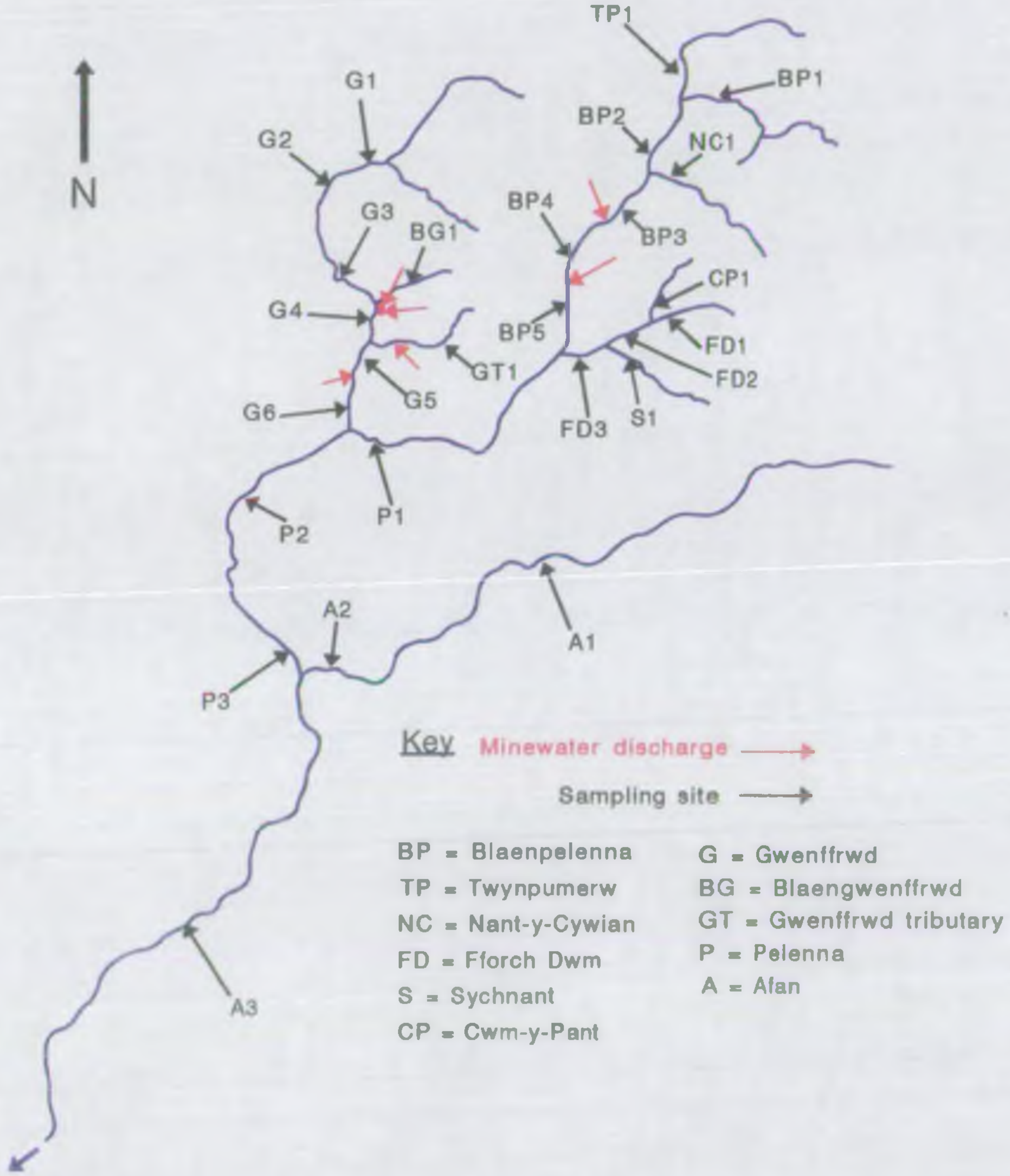
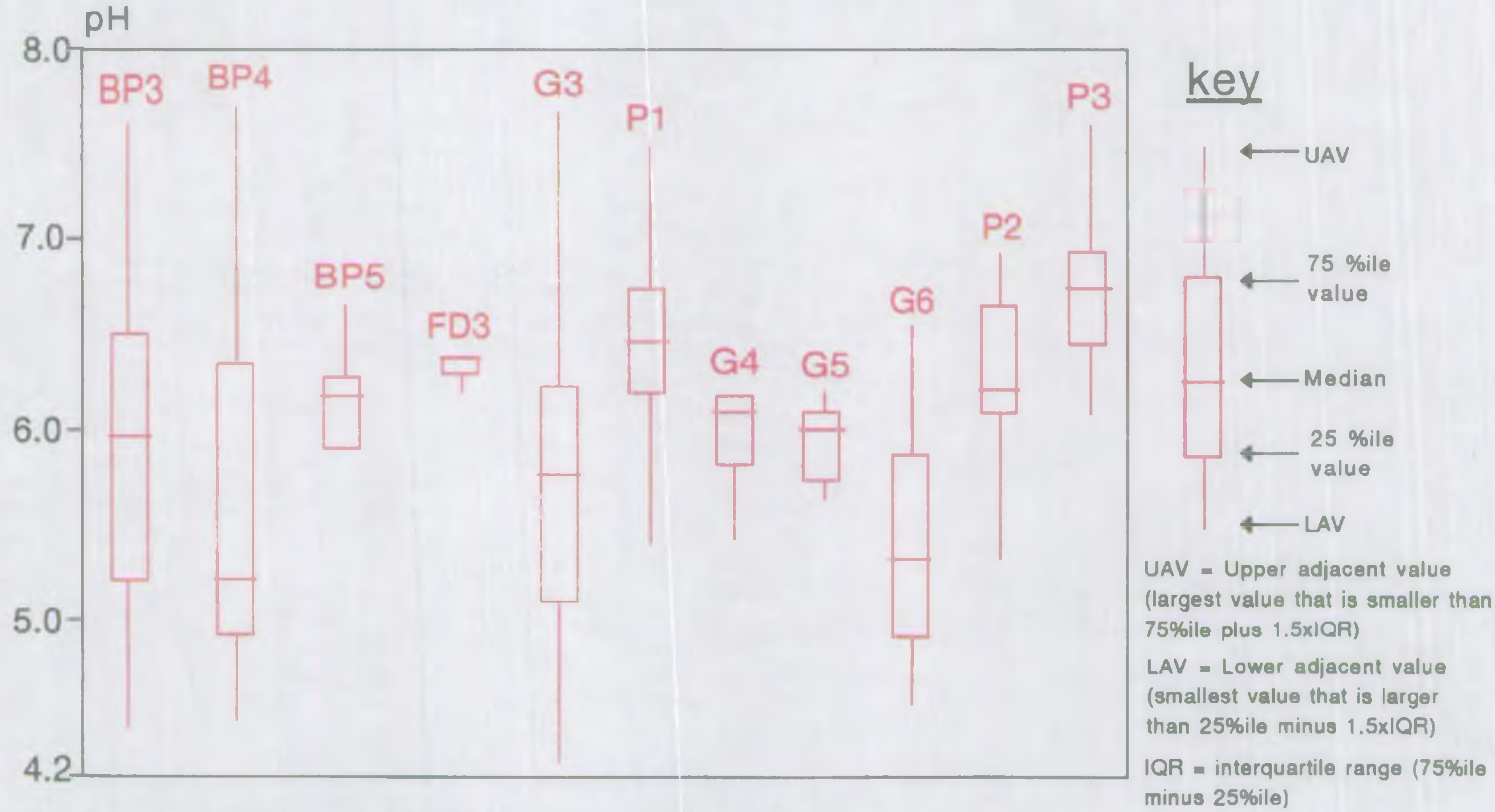


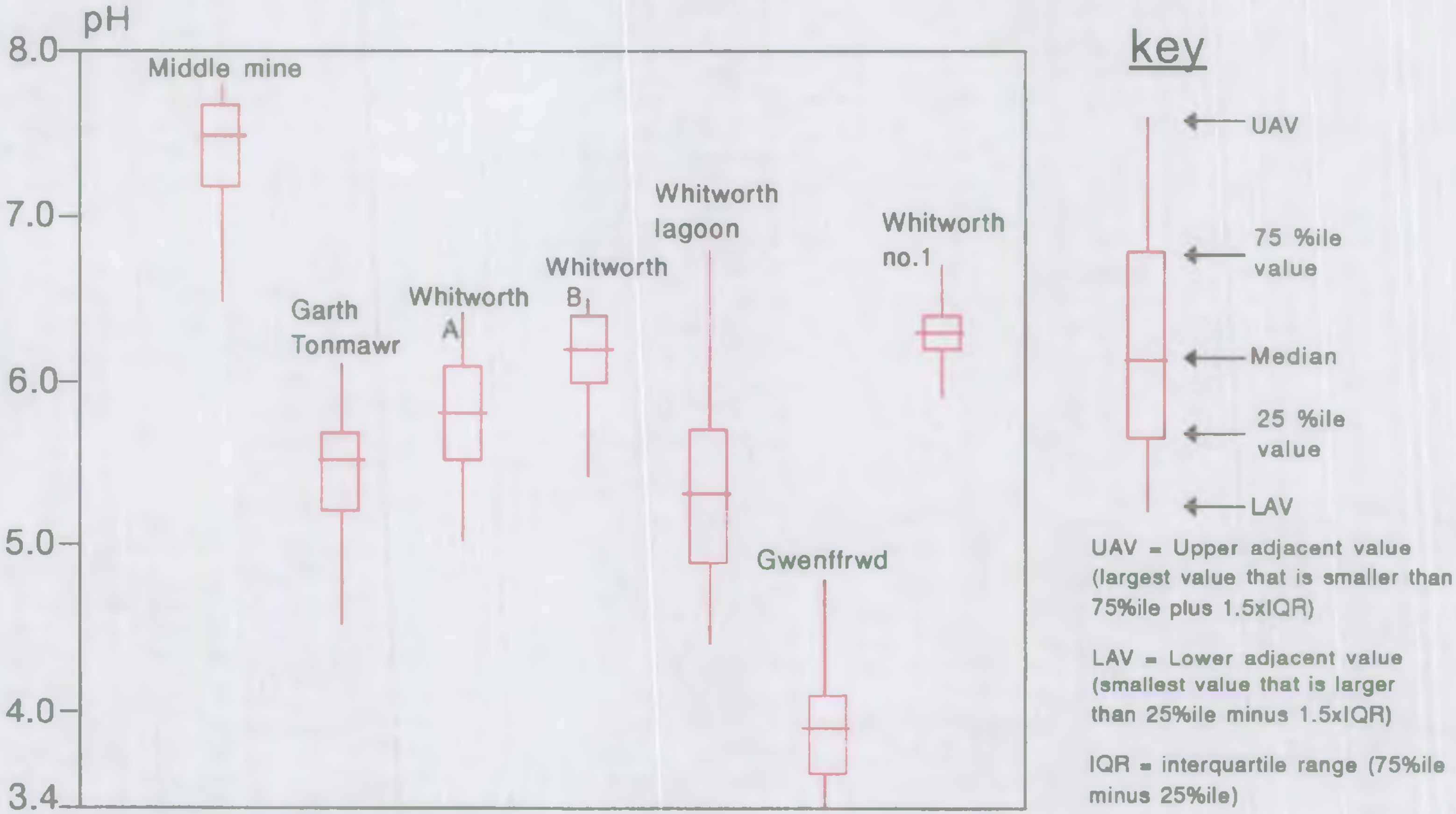
Fig.5. Ranges of pH values at river sampling sites in the Pelenna catchment



Data recorded from 1990-1994 (see Appendix 4 for full data summary)

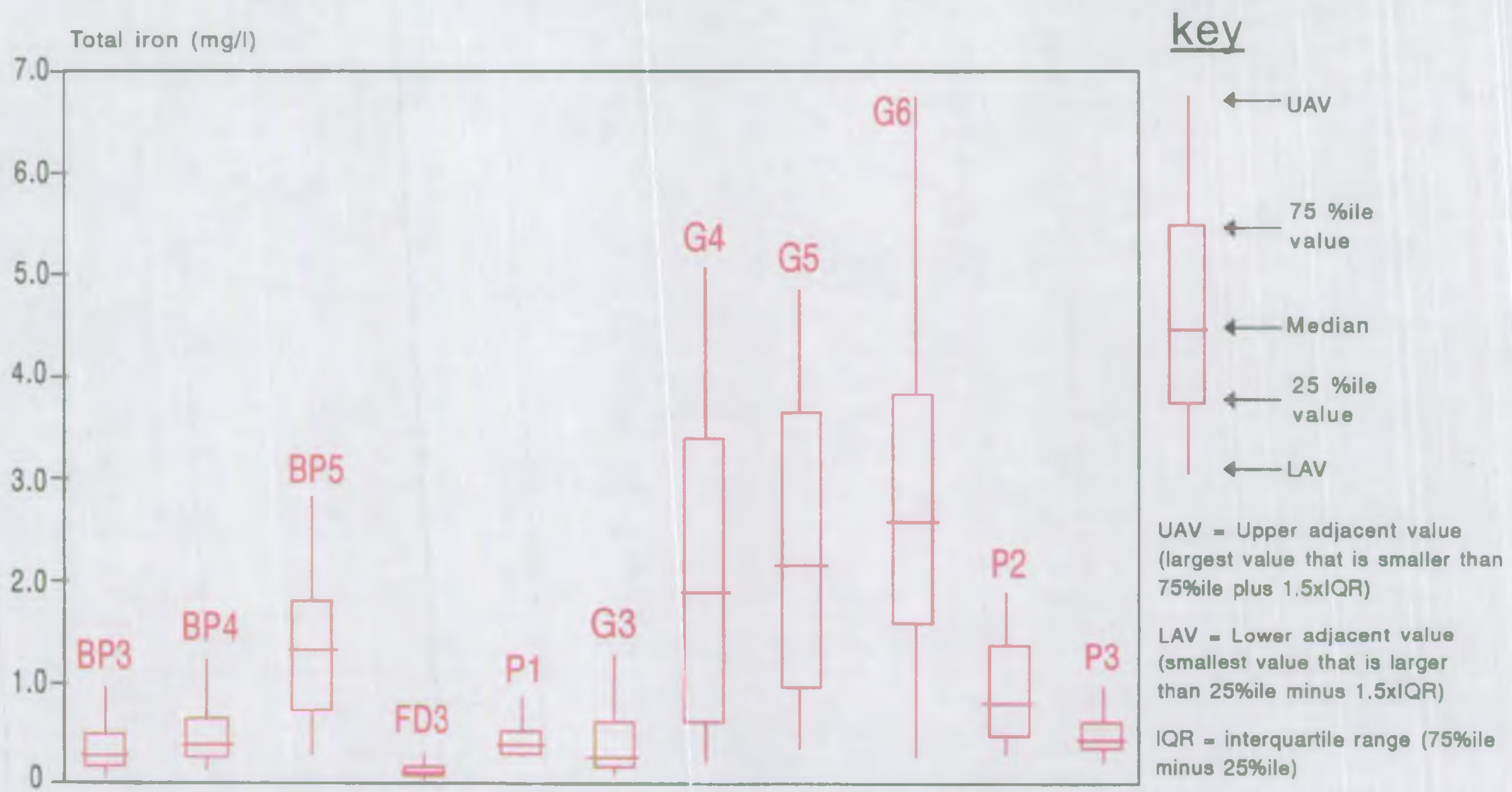
See Fig.4 for site locations

Fig.6. Ranges of pH values in minewater discharges in the Pelenna catchment



Data recorded from 1992-1994 (See Appendix 5 for full minewater chemistry summary)

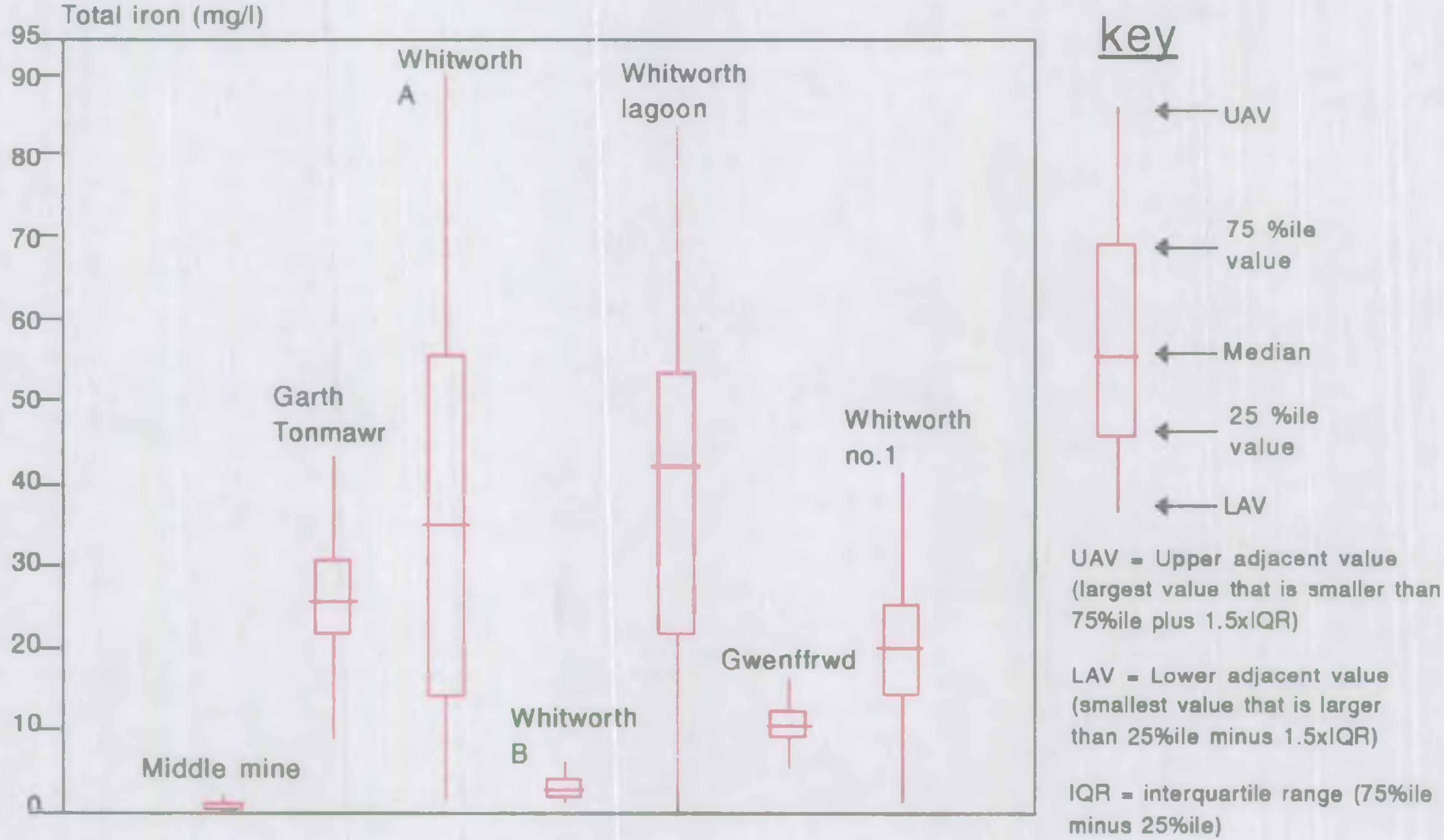
Fig.7. Ranges of iron concentrations at river sampling sites in the Pelenna catchment



Data recorded from 1990-1994 (see Appendix 4 for full water quality summary)

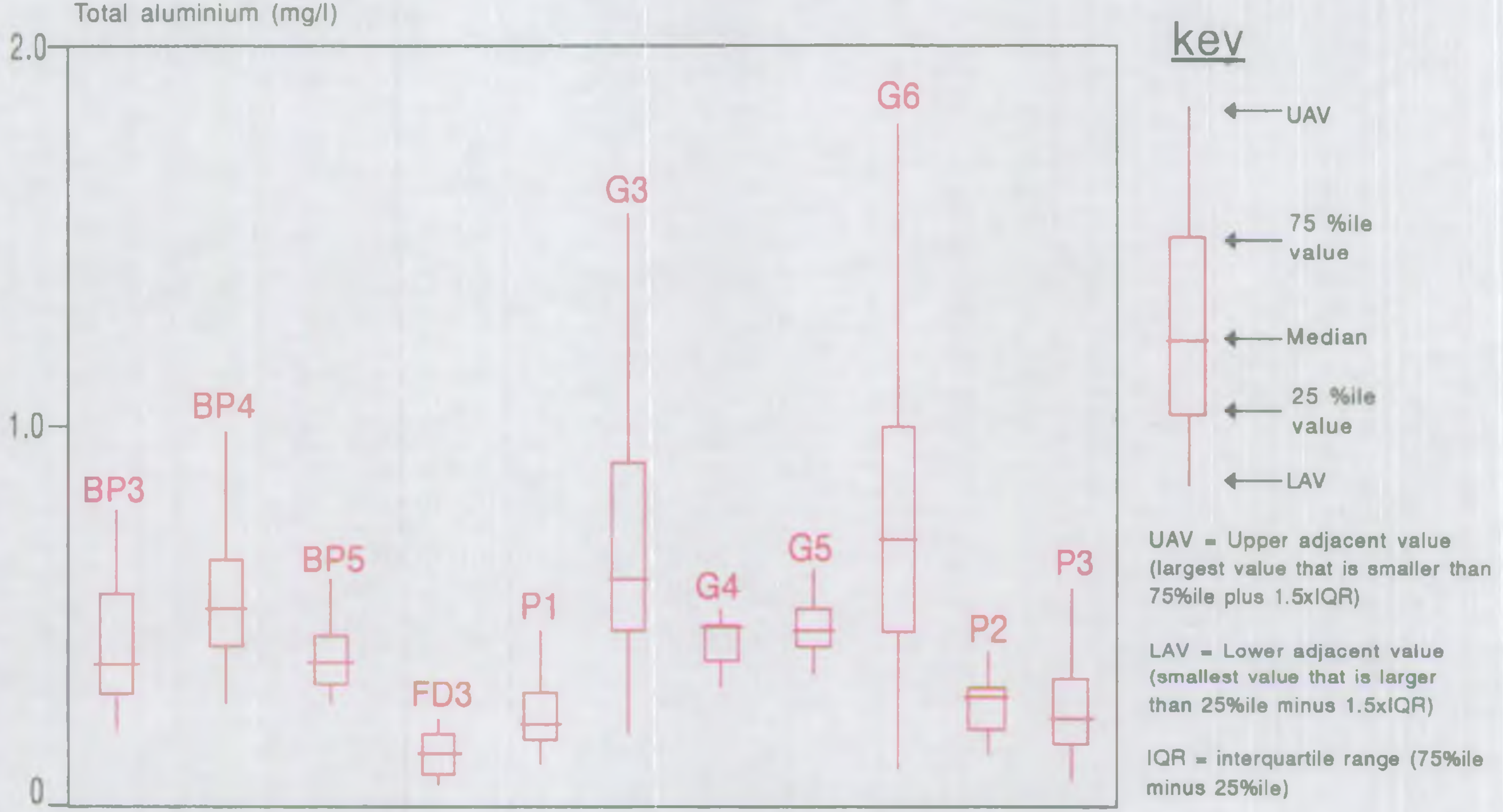
See Fig 4 for site locations

Fig.8. Ranges of iron concentrations in minewater discharges in the Pelenna catchment



Data recorded from 1992-1994 (see Appendix 5 for full summary of minewater chemistry)

Fig.9. Ranges of aluminium concentrations at river sampling sites in the Pelenna catchment



Data recorded from 1990-1994 (see Appendix 4 for full water quality summary)

See Fig.4 for site locations

Fig.10. Variations in pH and conductivity in the Pelenna catchment in February and March 1994

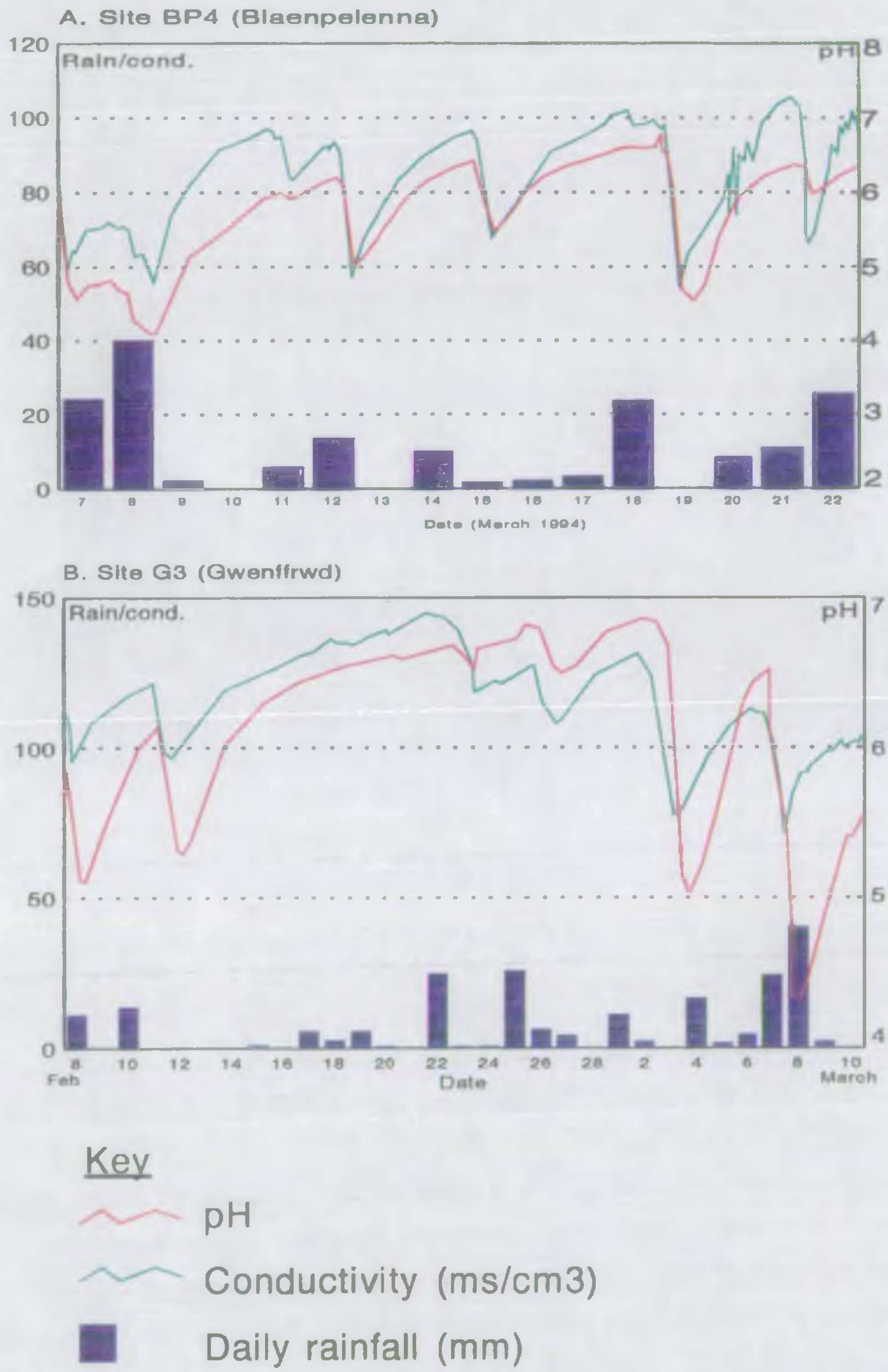


Fig.11. Variations in pH and aluminium in the Blaenpelenna and Gwenffrwd, following periods of high rainfall

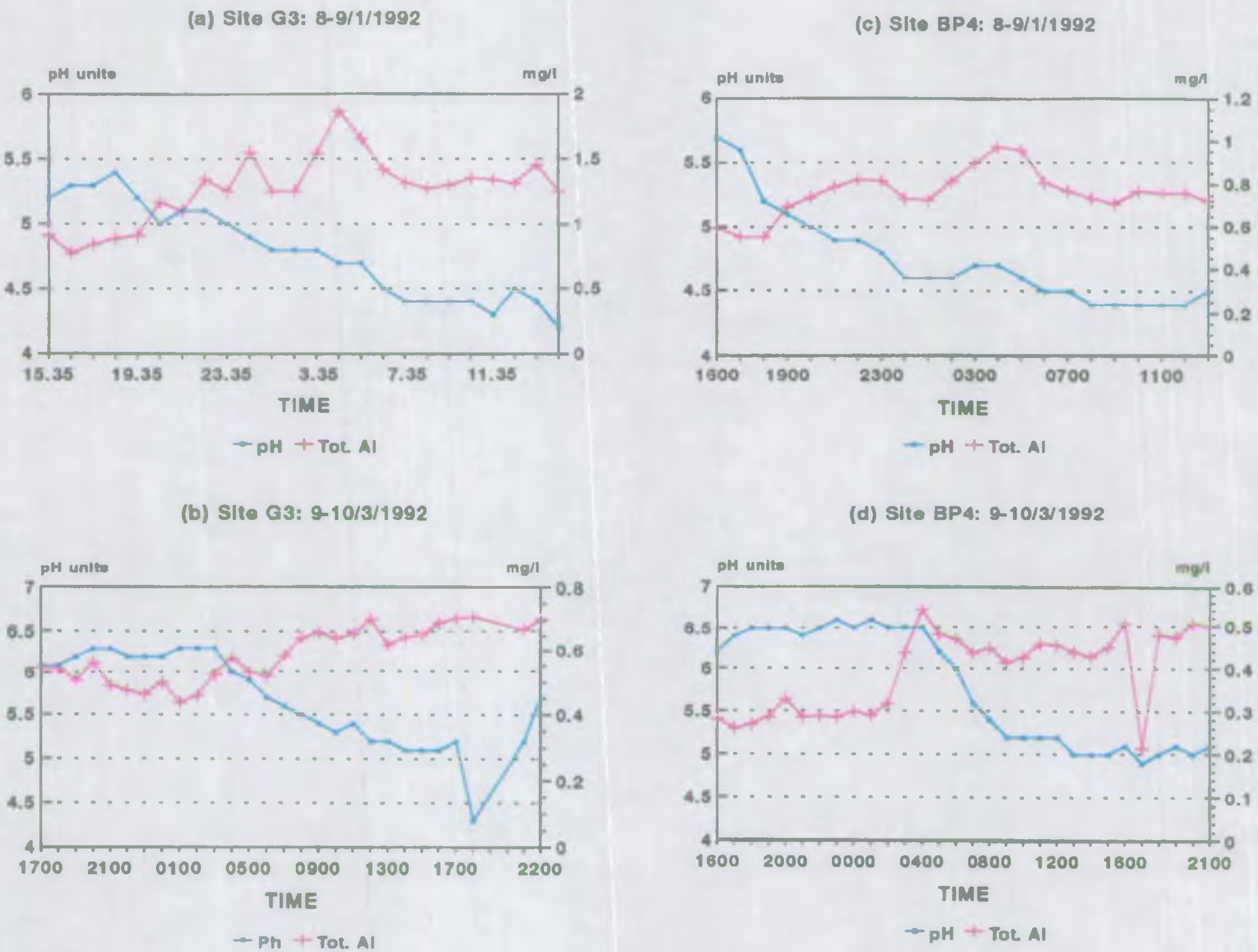
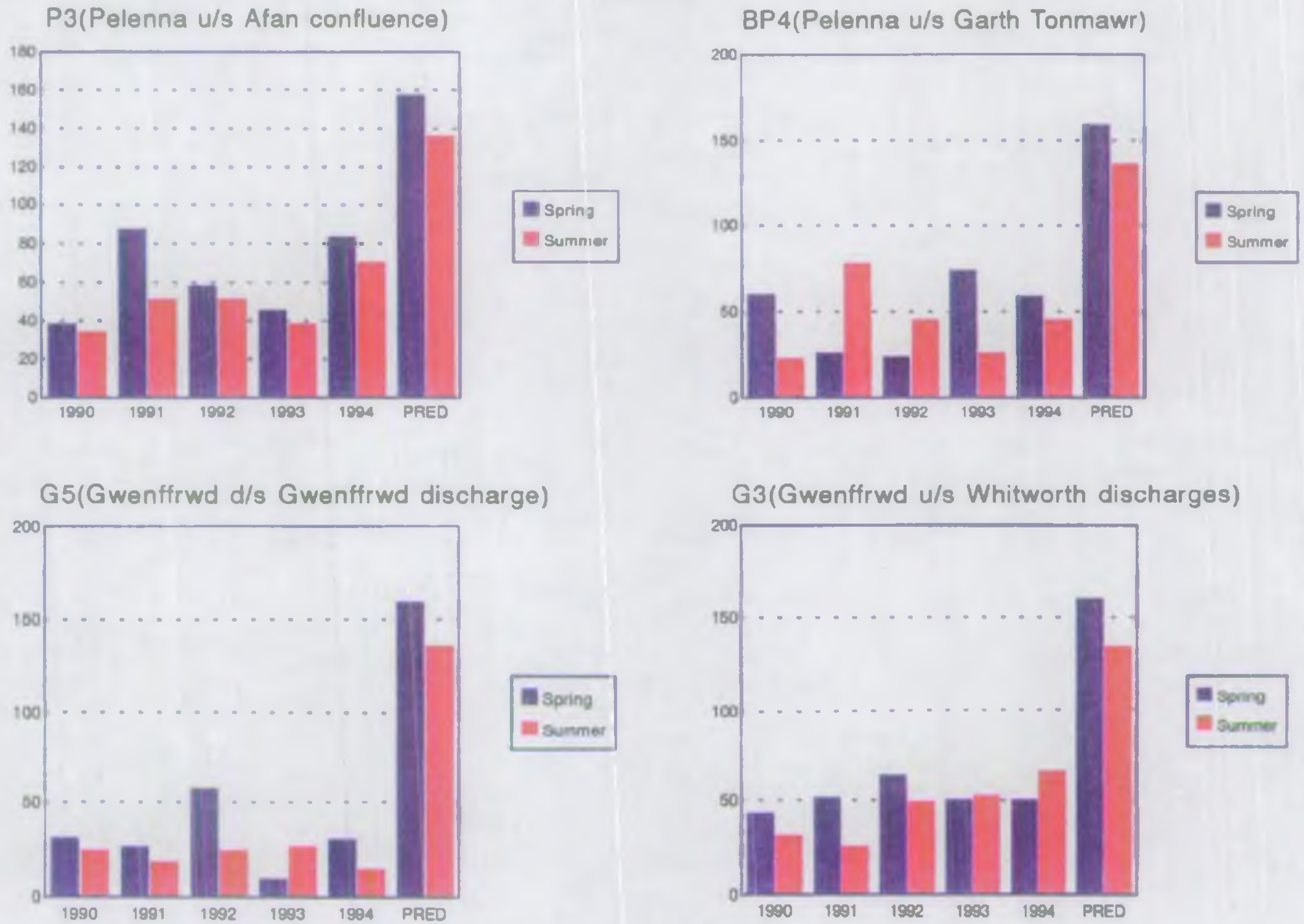
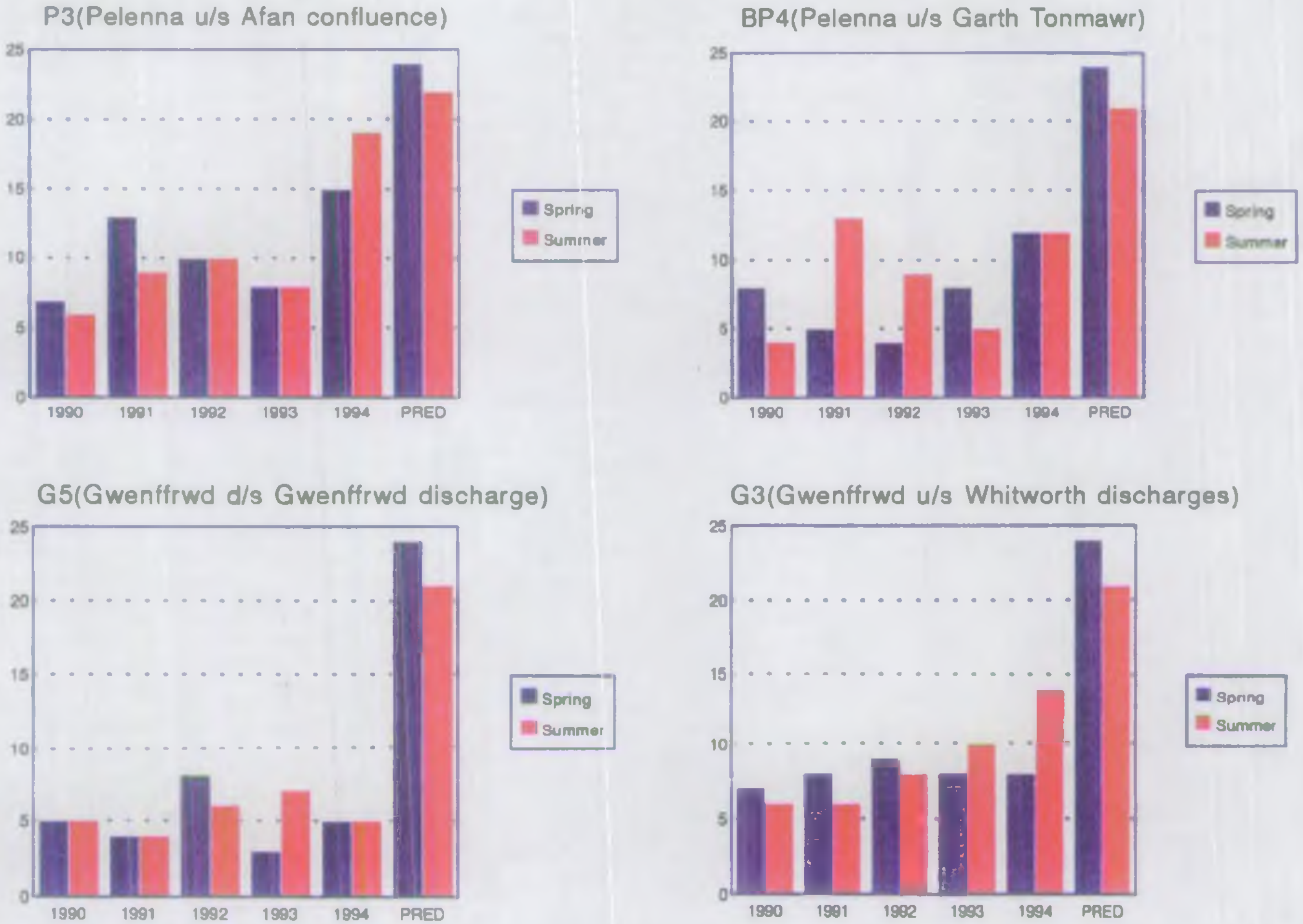


Fig.12a. Results of routine biological monitoring (BMWP scores) in the Pelenna catchment, 1990-1994



PRED = Predicted RIVPACS score in 1994

Fig.12b. Results of routine biological monitoring (no.taxa) in the Pelenna catchment, 1990-1994



PRED = Predicted no. taxa in 1994 according to RIVPACS

Fig.13. Observed BMWP scores in spring 1994 expressed as percentages of predicted BMWP scores (spring 1993 results in brackets)

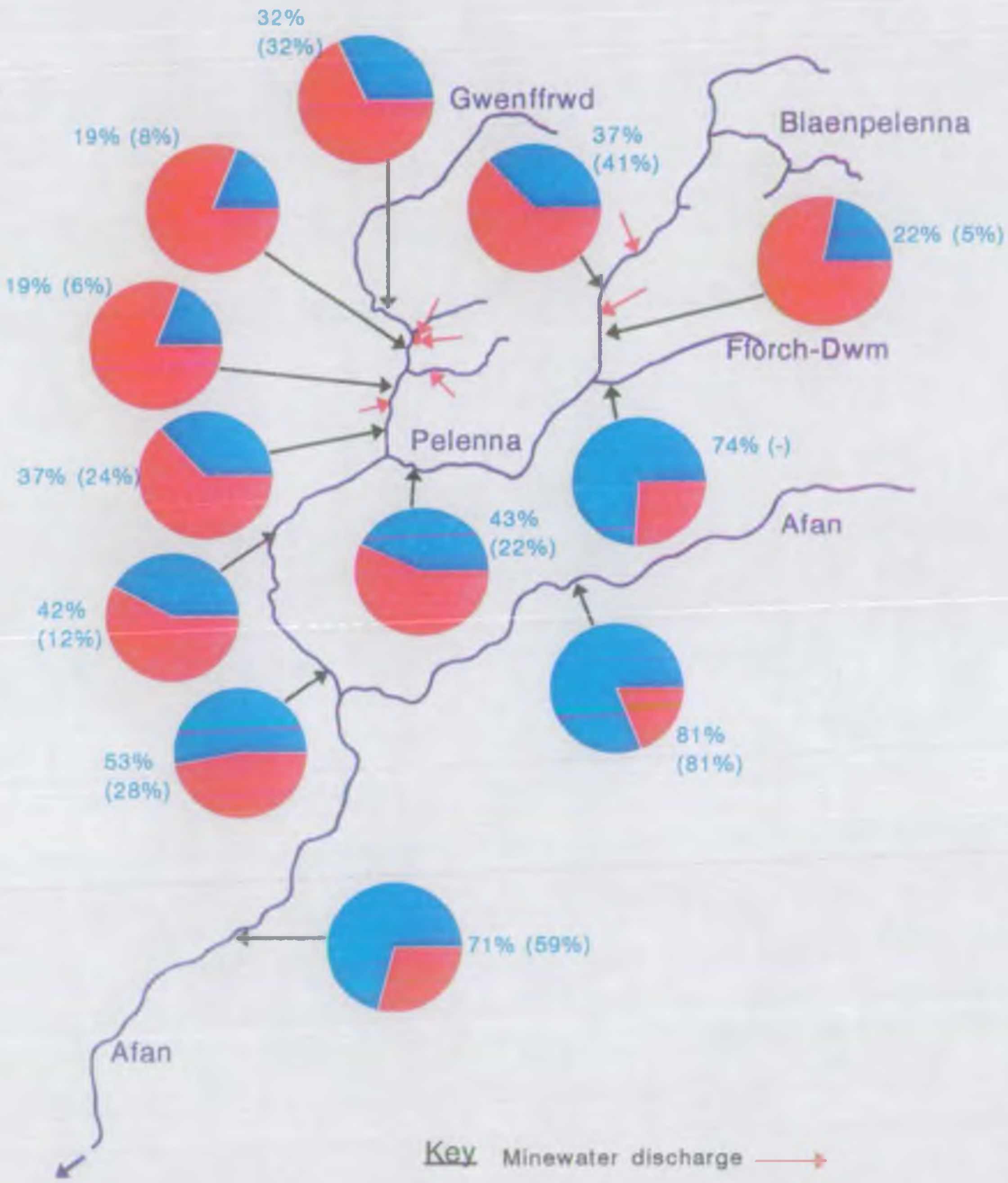


Fig.14. Observed BMWP scores in summer 1994 expressed as percentages of predicted BMWP scores (summer 1993 results in brackets)

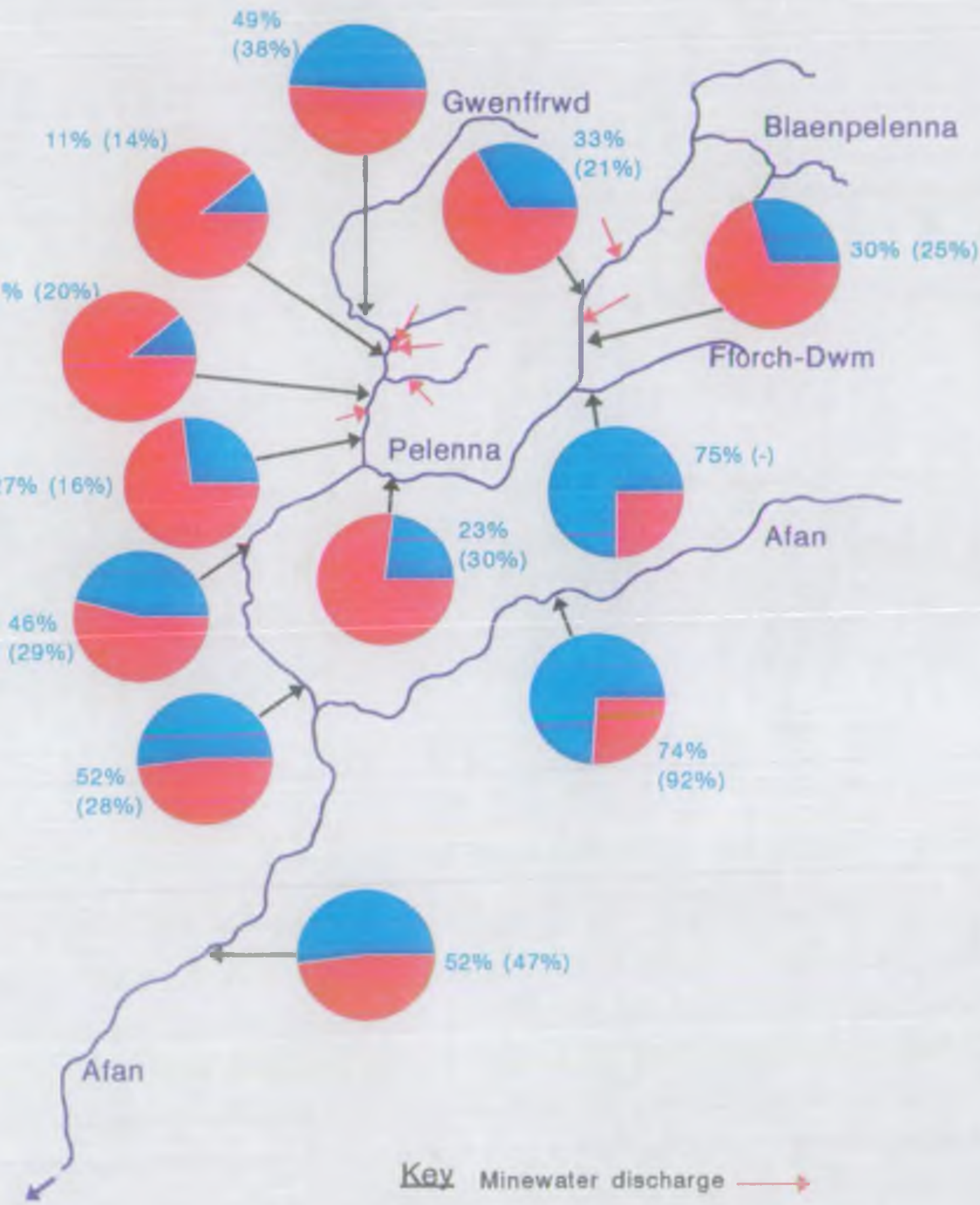


Fig.15. Observed numbers of invertebrate taxa in spring 1994 expressed as percentages of predicted no.taxa (spring 1993 results in brackets)

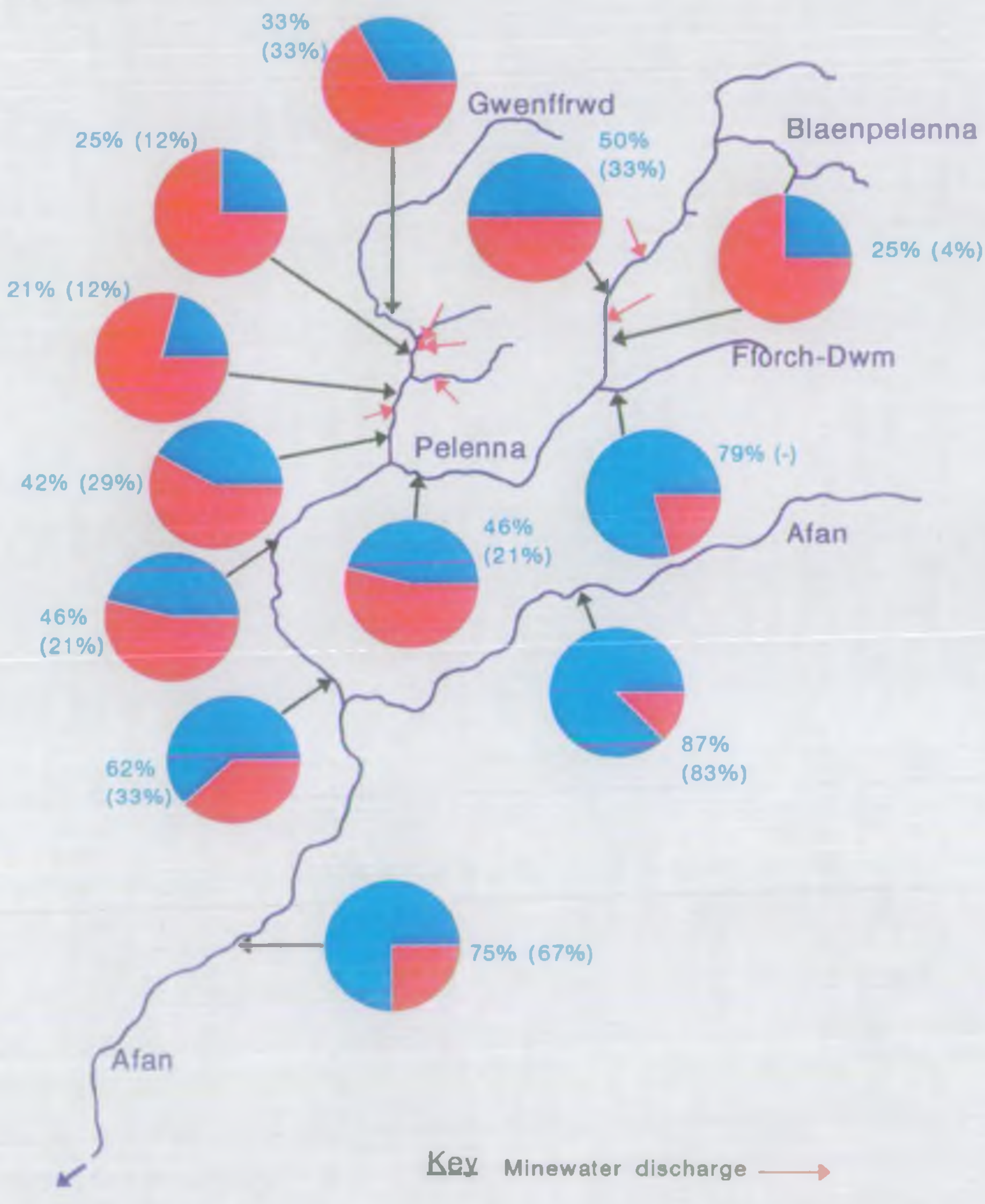


Fig.16. Observed numbers of invertebrate taxa in summer 1994 expressed as percentages of predicted no.taxa (summer 1993 results in brackets)

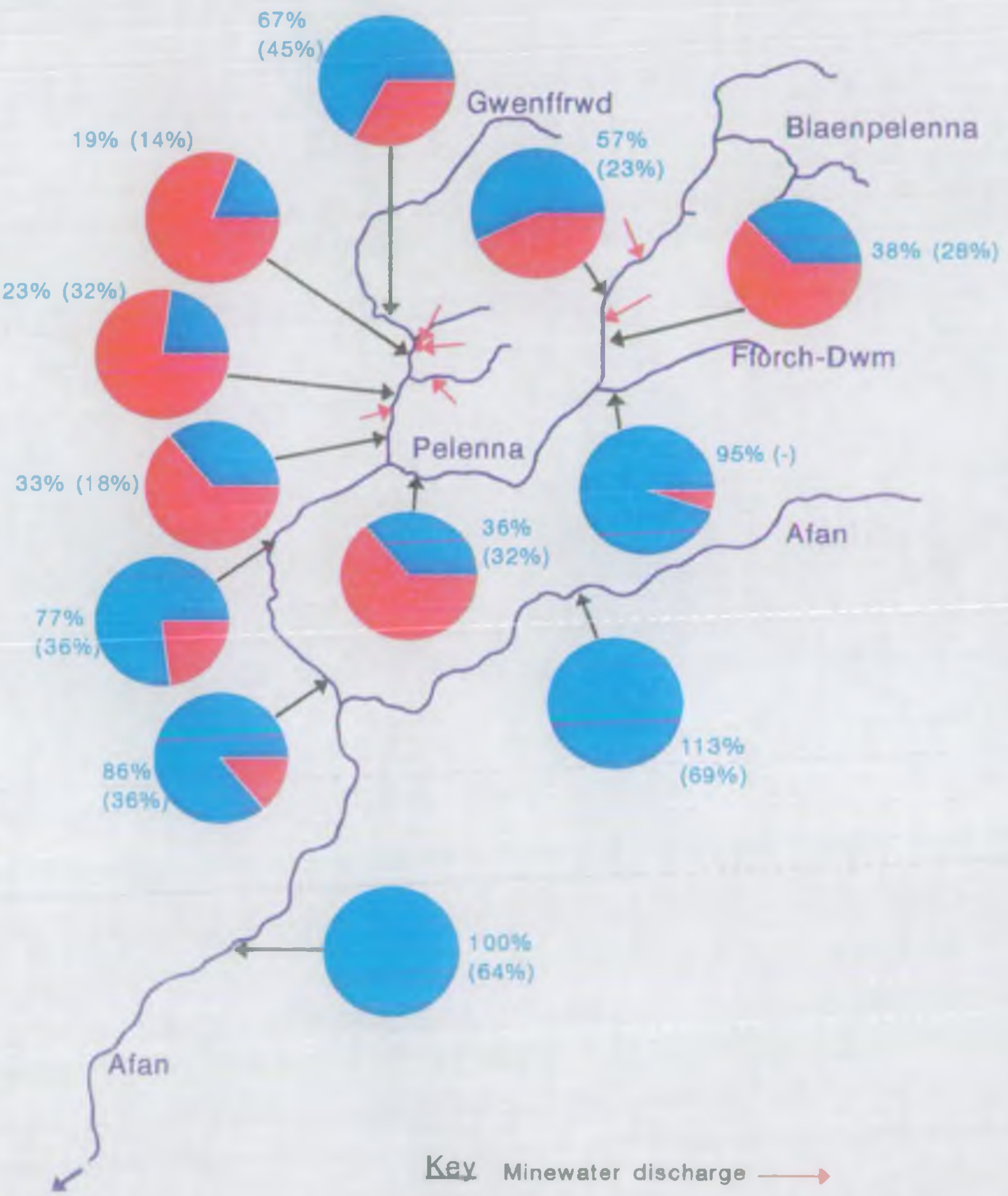


Fig.17. Results of biological monitoring using acid indicator key (February 1994)

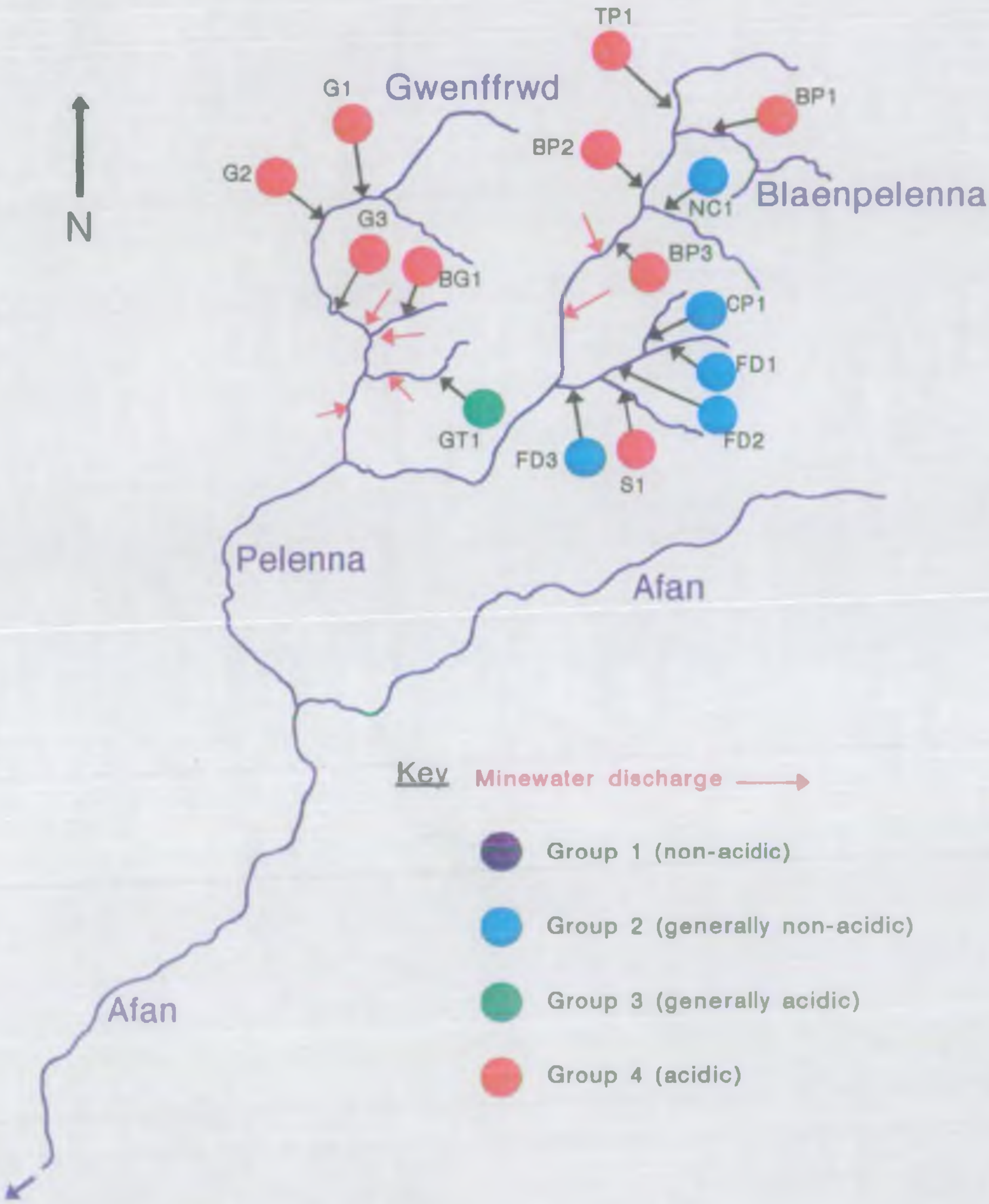


Fig.18. Observed trout fry densities in 1994 expressed as percentages of HABSCORE predicted fry densities (1993 results in brackets)

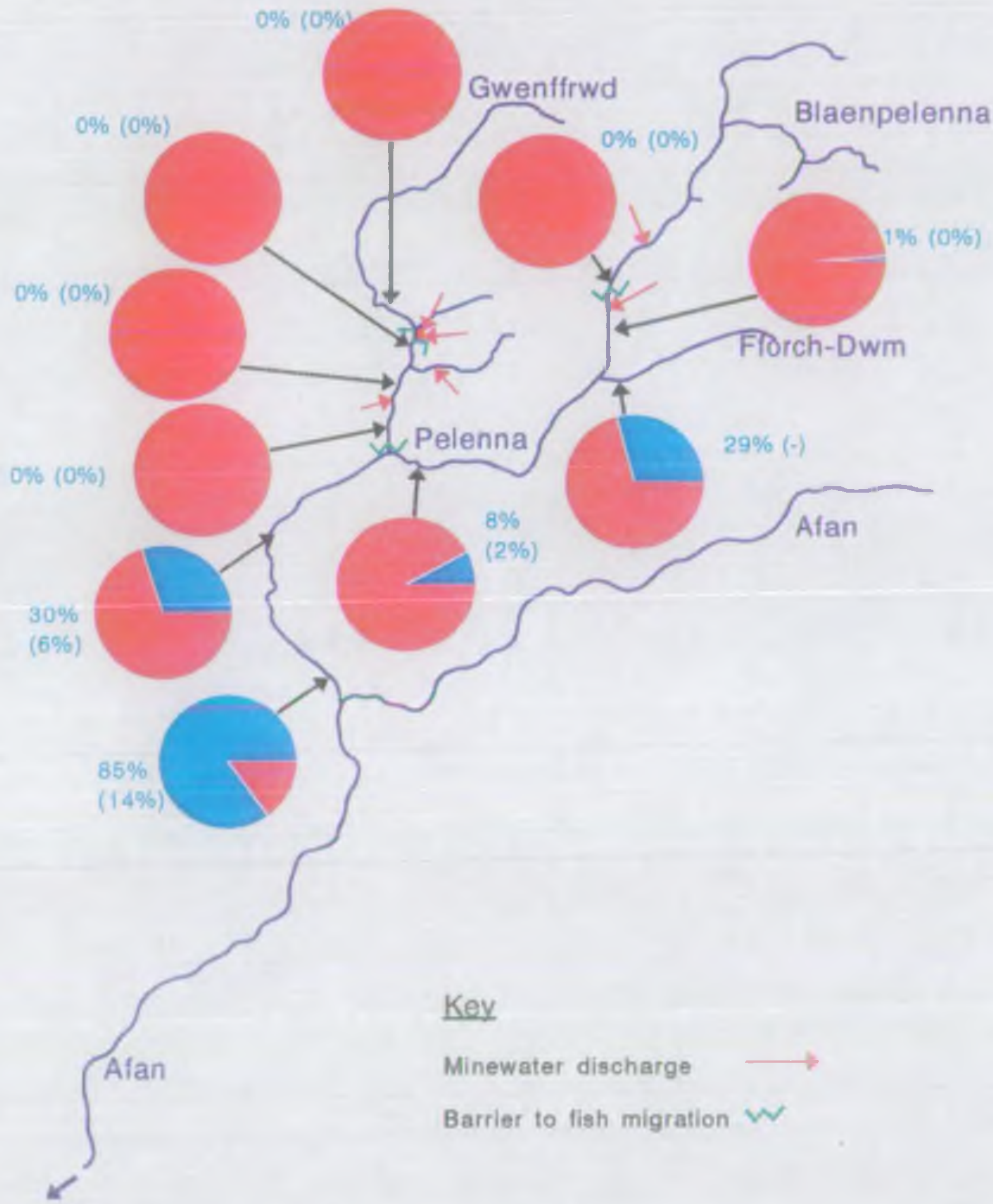


Fig.19. Observed trout parr densities in 1994 expressed as percentages of HABSCORE predicted parr densities (1993 results in brackets)

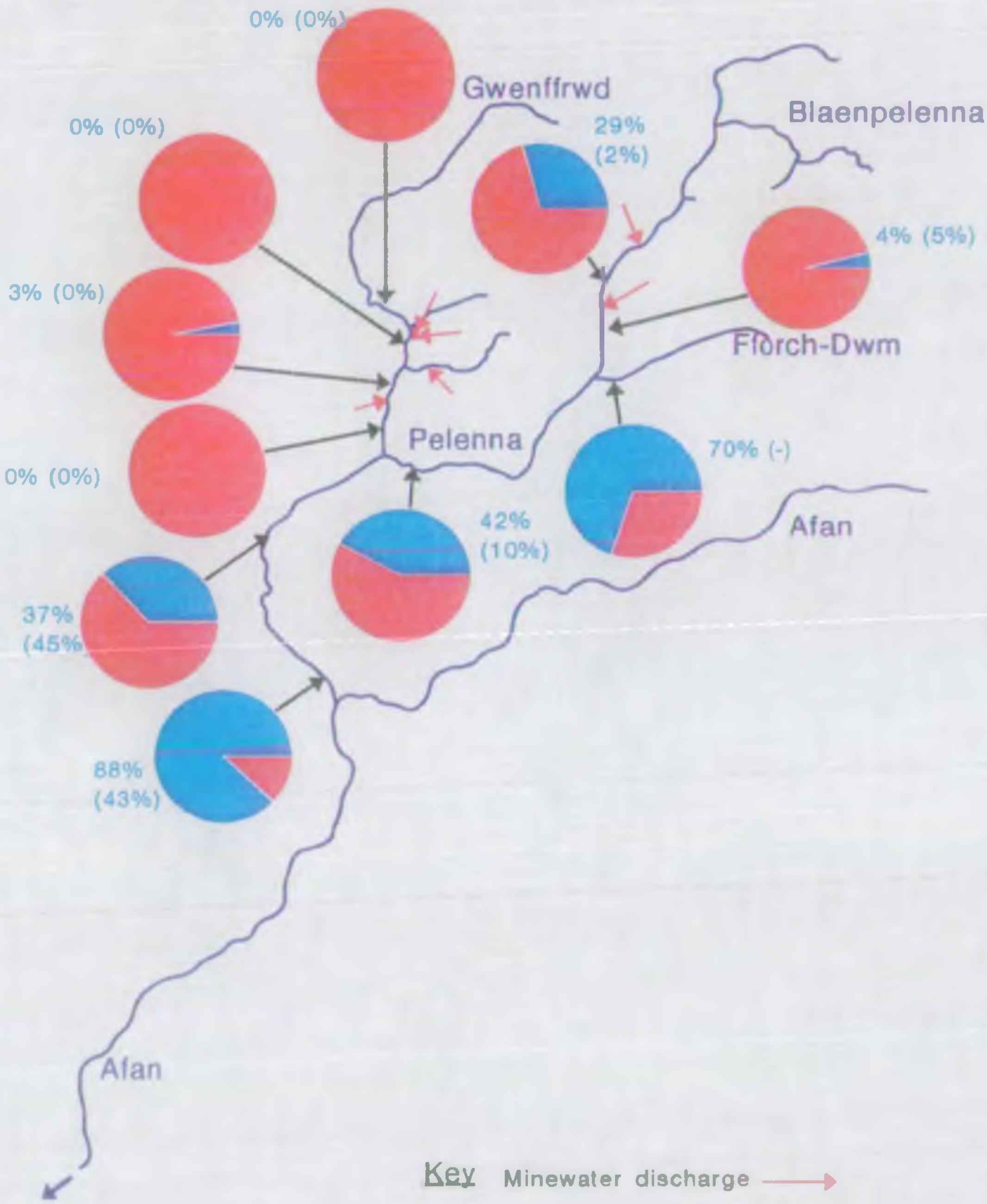


Fig.20. Percentage survival to hatching of brown trout eggs in artificial redds (Feb-March 1994)

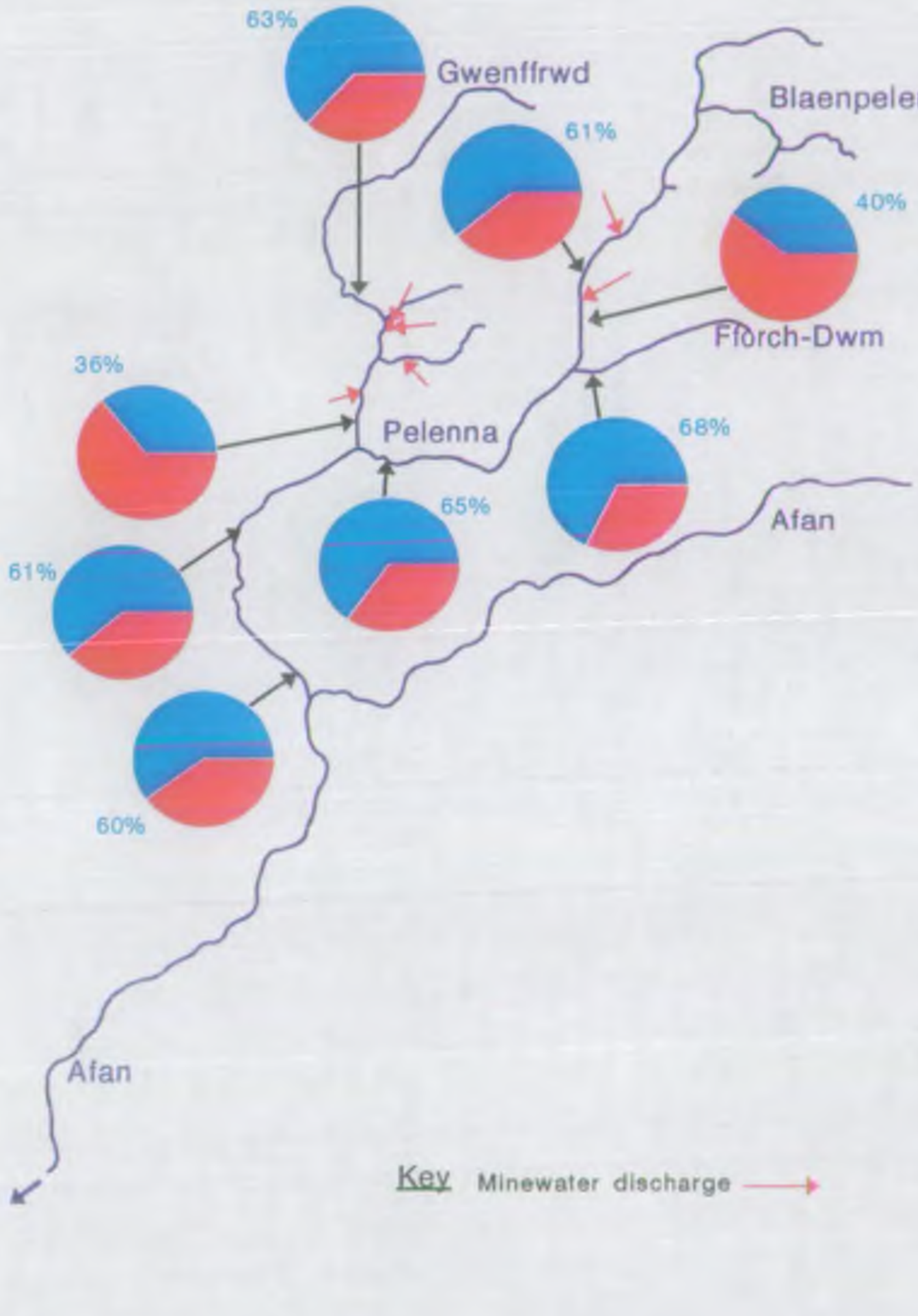


Fig.21. Survival of brown trout alevins expressed as a percentage of the total number of eggs kept in artificial redds (Feb-March 1994)

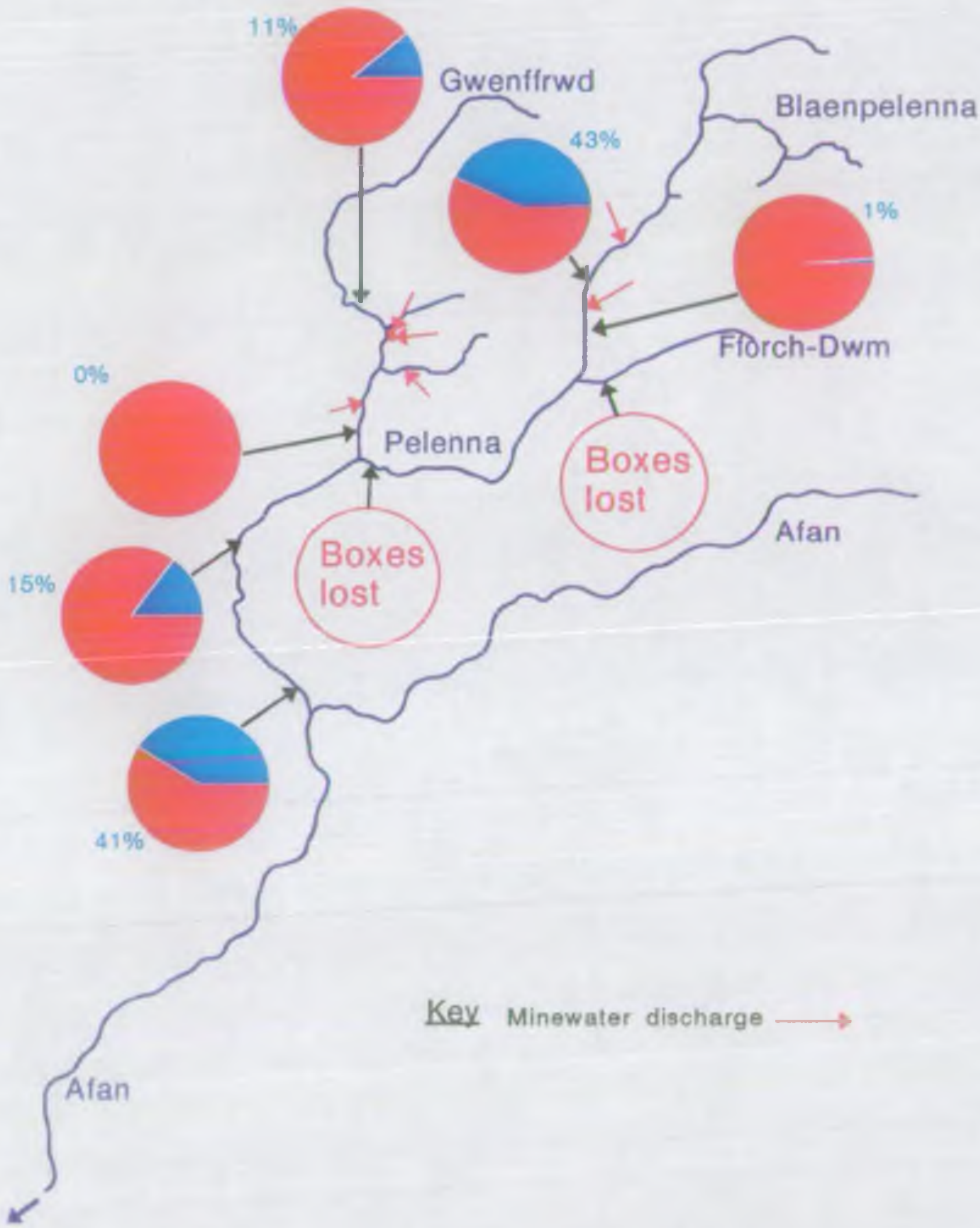


Fig.22. Percentage survival of brown trout parr after 24 hours in cages (Feb-March 1994)

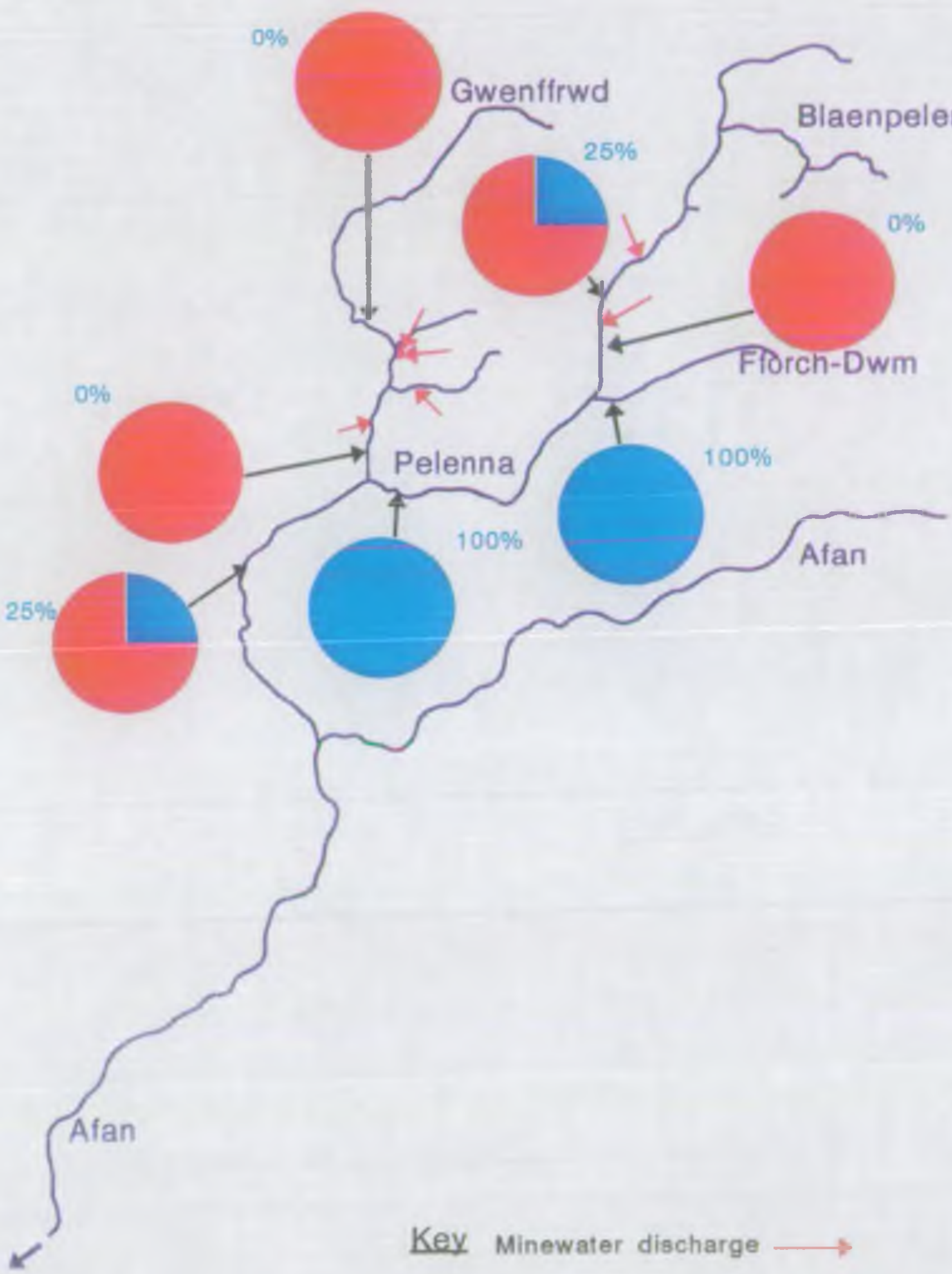
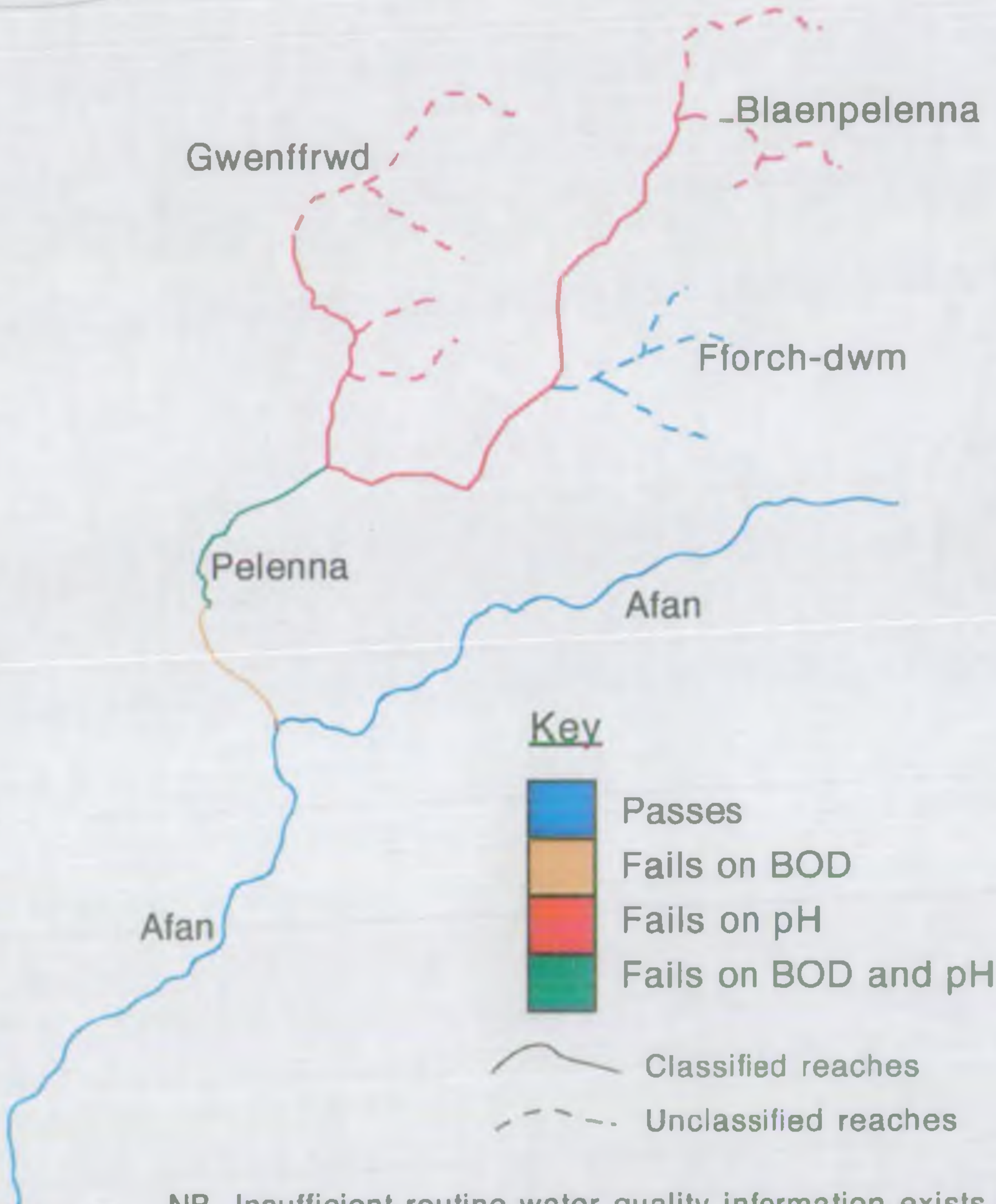


Fig.23. Compliance of the Pelenna catchment with NRA (Rivers Ecosystem) water quality objectives

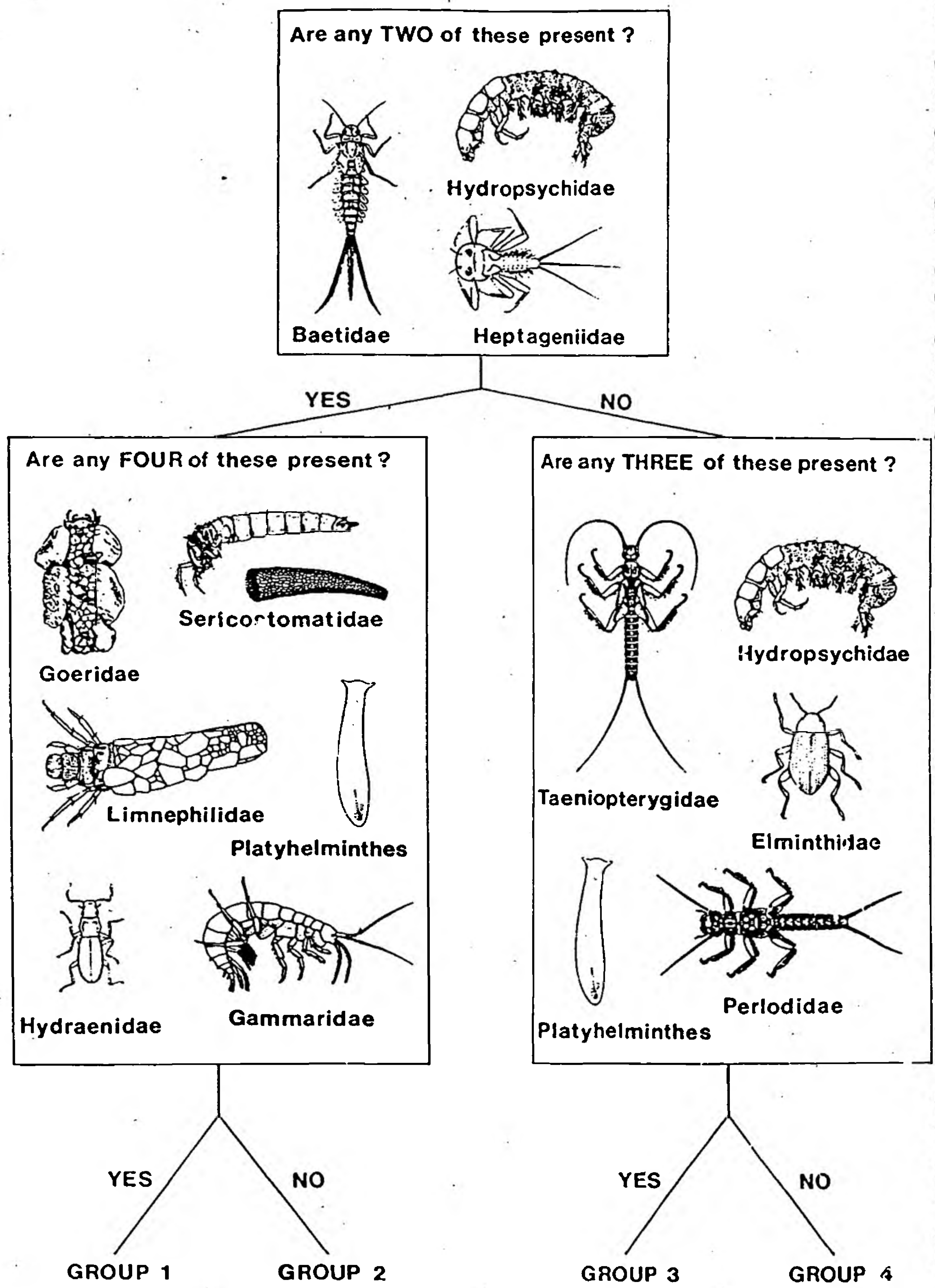


NB. Insufficient routine water quality information exists to test for compliance with List 2 metals (General Ecosystem) objectives

Appendix 1 - Biological Monitoring Working Party (BMWP) Scoring System

Family	Common Group Name	BMWP Score
Siphlonuride, Heptageniidae, Potamanthidae, Ephemerellidae, Ephemeridae, Leptophlebiidae	Mayflies	10
Taeniopterygidae, Leuctridae, Capniidae, Perlidae, Perlodidae, Chloroperlidae	Stoneflies	
Aphelocheiridae	Water bugs	
Beraeidea, Odontoceridae, Leptoceridae, Goeridae, Leptostomatidae, Brachycentridae, Sericostomatidae, Phryganeidae, Molannidae	Caddis Flies	
Agriidae, Cordulegasteridae, Lestidae, Gomphidae, Aeshnidae, Corduliidae, Libellulidae	Dragonflies	8
Astacidae	Crayfish	
Psychomyiidae, Philopotamidae	Caddis Flies	
Caenidae	Mayflies	7
Nemouridae	Stoneflies	
Rhyacophilidae, Polycentropodidae, Limnephilidae	Caddis Flies	
Ancylidae, Neritidae, Viviparidae, Unionidae	Molluscs	6
Hydroptilidae	Caddis Flies	
Platycnemididae, Coenagriidae	Dragonflies	
Gammaridae, Corophiidae	Crustacea	
Mesovelidae, Veliidae, Gerridae, Pleidae, Hydrometridae, Nepidae, Naucoridae, Notonectidae, Corixidae	Water Bugs	5
Haliplidae, Dytiscidae, Gyrinidae, Helodidae, Hygrobiidae, Chrysomelidae, Clambidae, Hydrophilidae, Elminthidae, Curculionidae, Dryopidae	Beetles	
Hydropsychidae	Caddis Flies	
Tipulidae, Simuliidae	Fly Larva	
Planariidae, Dendroceolidae	Flat Worms	
Baetidae	Mayflies	4
Piscicolidae	Leeches	
Sialidae		
Hydrobiidae, Lymnaeidae, Sphaeriidae, Valvatidae, Physidae, Planorbidae	Molluscs	3
Glossiphoniidae, Hirudidae, Erpodellidae	Leeches	
Asellidae	Crustacae	
Chironomidae	Midge Larva	2
Oligochaeta	Round Worms	1

Appendix 2. Acid indicator key (from Rutt *et al*, 1990)



Appendix 2 (continued). Characteristics of the stream groups

Stream Group	Characteristics (all values are annual means)
1	Non-acidic streams, generally of small catchment area (< 10 km^2). 83 % have pH > 6.0, 100 % have pH > 5.5. 75 % of streams have a filterable aluminium concentration < 50 µg l^{-1}, 93 % < 100 µg l^{-1}. In general moderately well-buffered: 80 % have total hardness > 10 mg l^{-1}. Diverse fauna.
2	Non-acidic streams, generally with catchment area > 10 km^2. 91 % with pH > 6.0, 97 % with pH > 5.5. 90 % of streams have filterable aluminium < 100 µg l^{-1}. Variable buffering capacity: 69 % with total hardness > 10 mg l^{-1}. Fairly diverse fauna.
3	Acidic streams : 71 % with pH < 6.0, 87 % with filterable aluminium > 50 ug l^{-1}, 53 % with Al > 100 µg l^{-1}. Poorly buffered : 76 % with total hardness < 10 mg l^{-1}, 95 % with hardness < 15 mg l^{-1}. Impoverished fauna. Likely to be vulnerable to enhanced acidification by conifer forestry.
4	Acidic streams : 75 % with pH < 6.0, 89 % with filterable aluminium > 50 µg l^{-1}, 78 % with Al > 100 µg l^{-1}. Poorly buffered : 83 % with total hardness < 15 mg l^{-1}. Very impoverished fauna. Likely to be vulnerable to enhanced acidification by conifer forestry.

Appendix 3. <u>Potential economic benefit to the River Afan fishery resulting from improvements to the area impacted by minewater pollution in the Pelenna catchment</u>

Increased capital value of Afan fishery resulting from increased rod catches:

No. trout parr per $100m^2$ in impacted area (weighted mean from 1994 survey, based on width of site and observed densities)	= 6.4
Potential No. trout parr per $100m^2$ (weighted mean HABSCORE prediction)	= 25.5
Additional No. parr/$100m^2$ resulting from improvements	= 19
Area of Pelenna to be improved (7km x 5m)	= $35,000m^2$
Total increase in parr production	= 6650
Total increase in smolt production (assuming 50% survival & 100% smoltification)	= 3325
No. smolts returning as adult sea trout (20%)	= 665
No. adults captured by anglers (20%)	= 133
Increase in capital value of fishery (@ £400 per capita)	= £53,200
Consumer surplus (@ 50% of increase in capital value)	= £26,600
Potential economic benefit to fishery	= <u>£79,800</u>

Calculations derived from Merrett (1992).

value of seatrout = ?

Appendix 4. Summary of the analyses of water samples collected from the Pelenna catchment (1/10/90-30/9/94)

Determinand	Statistic	BP3	BP4	BP5	FD3	P1	P2	P3	G3	G4	G5	G6	A2	A3
pH	mean	5.9*	5.6*	5.9*	6.5	6.4	6.4	6.7	5.7*	5.9*	5.8*	5.4*	7.3	7.1
	median	6.0	5.2	6.2	6.4	6.5	6.3	6.7	5.7	6.1	6.0	5.2	7.4	7.2
	maximum	7.6	7.5	7.2	7.0	8.1	8.0	7.6	7.8	6.2	6.3	6.6	7.9	7.6
	minimum	4.4	4.4	4.5	6.1	4.9	5.3	6.1	4.2	4.6	4.6	4.5	6.5	6.6
	no.samples	59	86	22	15	44	29	46	104	16	16	129	43	16
Alkalinity (from Feb'94)	mean	2.6	4.6	3.9	6.9	3.9	4.1	8.5	3.3	3.7	3.5	3.0	21.0	20.9
	median	2.6	3.8	3.4	7.2	3.9	4.0	8.2	3.6	3.9	3.7	2.7	22.0	22.8
	maximum	4.3	10.0	9.8	8.5	6.4	6.0	14.4	6.5	6.6	5.7	5.2	31.3	31.1
	minimum	1.1	0.5	0.2	5.0	1.4	2.4	4.7	0.4	0.7	1.0	0.8	12.7	12.1
	no.samples	6	9	10	10	11	7	8	7	7	7	10	7	7
Hardness (from Feb'94)	mean	38.9	23.4	35.9	26.4	40.4	38.0	45.8	34.0	37.3	39.6	71.2	47.5	43.2
	median	19.1	23.3	30.8	26.9	38.8	41.5	44.4	34.1	34.6	37.1	62.1	46.1	42.0
	maximum	505.0	42.2	73.9	31.1	67.6	51.3	75.0	51.6	59.2	62.0	572.0	82.1	78.5
	minimum	8.5	8.2	11.0	21.3	16.4	22.6	21.1	12.7	16.9	18.3	16.1	22.2	27.1
	no.samples	29	21	14	10	38	9	38	38	8	8	42	35	9
Iron (total/ dissolved)	mean	0.55/0.14	0.49/0.13	1.69/1.45*	0.05/0.03	0.66/0.27	0.99/0.68	0.58/0.23	0.49/0.12	2.54/1.65*	2.56/1.82*	2.87/1.43*	0.10/0.05	0.17/0.08
	median	0.23/0.12	0.41/0.08	1.40/0.99	0.03/0.03	0.39/0.28	0.80/0.46	0.43/0.17	0.21/0.08	1.96/0.49	1.98/0.84	2.63/0.87	0.11/0.05	0.16/0.08
	maximum	4.30/0.41	1.96/0.28	4.91/2.40	0.17/0.10	6.16/0.42	3.41/1.40	4.02/0.50	4.53/0.27	9.02/4.40	9.14/4.50	7.79/3.3	0.12/0.06	0.30/0.11
	minimum	0.07/0.01	0.08/0.01	0.26/0.33	0.01/0.01	0.19/0.10	0.23/0.19	0.16/0.09	0.06/0.04	0.17/0.11	0.30/0.20	0.32/0.29	0.09/0.03	0.05/0.06
	no.samples	57/11	84/11	21/10	13/10	44/11	28/7	45/8	102/9	15/7	15/7	127/3	8/7	15/5
Aluminium (total/ dissolved)	mean	0.51/0.26	0.55/0.19	0.38/0.20	0.12/0.09	0.27/0.12	0.25/0.08	0.27/0.07	0.74/0.30	0.44/0.14	0.46/0.12	0.78/0.20	0.15/0.06	0.13/0.07
	median	0.37/0.21	0.50/0.09	0.36/0.17	0.08/0.07	0.20/0.09	0.26/0.04	0.20/0.05	0.57/0.08	0.47/0.04	0.46/0.04	0.68/0.09	0.15/0.05	0.12/0.05
	maximum	3.39/0.58	1.36/0.39	0.57/0.40	0.41/0.23	2.31/0.27	0.47/0.28	1.39/0.23	2.81/1.06	0.75/0.60	0.74/0.54	2.83/0.54	0.23/0.13	0.26/0.15
	minimum	0.21/0.02	0.26/0.04	0.26/0.02	0.03/0.02	0.07/0.03	0.11/0.03	0.04/0.03	0.16/0.04	0.17/0.02	0.25/0.02	0.07/0.03	0.07/0.03	0.00/0.05
	no.samples	57/11	84/11	21/10	14/10	44/11	28/7	45/8	102/11	15/7	15/7	127/13	8/7	15/5
Zinc (total/ dissolved)	mean	0.03/0.03	0.04/0.04	0.04/0.04	0.04/0.03	0.04/0.03	0.03/0.03	0.03/0.03	0.05/0.05	0.05/0.05	0.06/0.04	0.05/0.05	0.01/0.01	0.02/0.02
	median	0.03/0.03	0.04/0.03	0.04/0.03	0.03/0.03	0.03/0.03	0.03/0.03	0.03/0.03	0.05/0.05	0.05/0.05	0.05/0.04	0.05/0.05	0.01/0.01	0.02/0.02
	maximum	0.04/0.04	0.05/0.05	0.05/0.05	0.15/0.08	0.06/0.05	0.05/0.04	0.04/0.04	0.06/0.05	0.05/0.05	0.13/0.05	0.08/0.06	0.02/0.01	0.03/0.02
	minimum	0.03/0.03	0.03/0.03	0.03/0.03	0.02/0.02	0.02/0.02	0.03/0.03	0.02/0.02	0.04/0.04	0.04/0.04	0.04/0.04	0.04/0.04	0.01/0.01	0.01/0.01
	no.samples	7/7	11/10	11/9	10/10	11/10	7/7	9/8	8/6	7/7	7/7	12/10	7/7	7/6
Conductivity	mean	59.1	77.1	104.2	88.8	96.4	117.1	125.6	102.1	121.1	126.0	121.5	116.8	124.7
	median	67.0	79.0	104.5	89.5	104.5	124.0	129.0	103.0	112.0	119.0	118.0	115.0	128.0
	maximum	73.0	96.0	152.0	97.0	125.0	147.0	162.0	123.0	170.0	177.0	208.0	149.0	151.0
	minimum	6.0	54.0	61.0	78.0	35.0	82.0	88.0	80.0	79.0	80.0	36.0	83.0	88.0
	no.samples	7	11	10	10	10	7	8	8	7	7	11	7	7
BOD	mean	0.98	0.73	0.59	0.56	0.89	0.87	1.34	0.94	0.62	0.61	1.01	1.12	0.72
	median	0.70	0.50	0.50	0.50	0.70	0.50	1.10	0.80	0.60	0.50	0.85	0.90	0.70
	maximum	4.50	1.90	1.20	1.00	3.40	2.00	7.80	2.60	1.0	1.00	2.40	3.70	1.30
	minimum	0.50	0.20	0.50	0.50	0.50	0.50	0.20	0.50	0.5	0.50	0.50	0.20	0.50
	no.samples	38	22	21	14	42	28	44	45	15	15	48	42	15

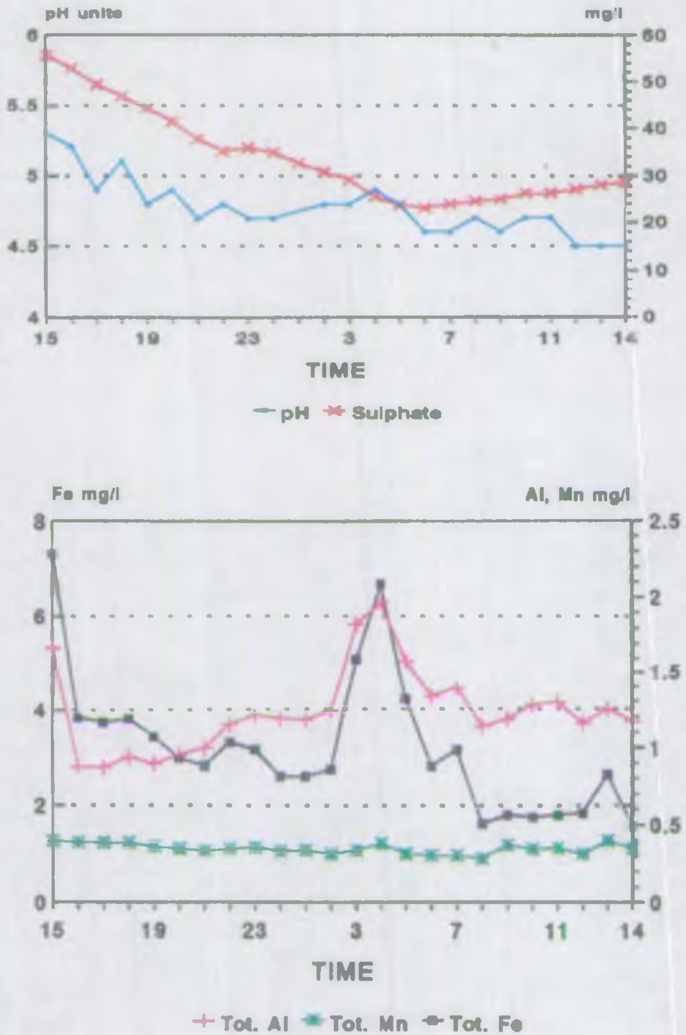
* Recorded values fail to comply with EIFAC standards for water quality to support salmonid fisheries

Appendix 5. Summary of the analyses of water samples collected from minewater discharges in the Pelenna catchment (1992-1994)

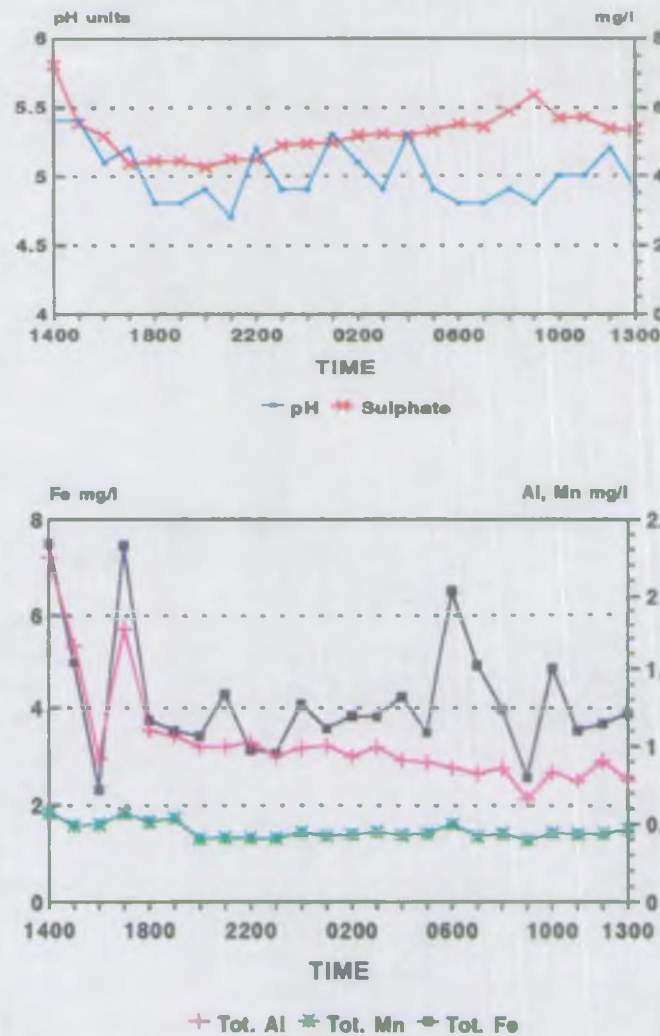
Determinand	Statistic	Middle Mine	G. Tonmawr	Whitworth A	Whitworth B	Whit. Lagoon	Gwenffrwd	Whit. no.1
pH	mean	7.2	5.5	5.8	6.1	5.3	4.0	6.3
	median	7.5	5.5	5.8	6.2	5.3	3.9	6.3
	maximum	7.8	7.6	6.4	6.5	6.8	6.8	7.0
	minimum	4.7	4.1	5.0	5.4	4.4	3.4	5.4
	no.samples	113	102	19	19	119	119	119
Alkalinity (from Feb'94)	mean	34.6	10.4	15.3	12.8	7.9	4.5	32.9
	median	33.0	9.8	15.8	13.5	6.8	4.1	21.0
	maximum	58.2	21.3	31.1	17.7	17.6	11.5	82.9
	minimum	16.2	2.4	5.1	7.7	0.7	0.6	7.4
	no.samples	29	31	17	17	27	18	28
Iron (total/ dissolved)	mean	1.29/1.23	25.4/18.5	42.6/41.1	2.66/2.62	40.3/32.6	10.6/9.73	26.4/22.3
	median	0.93/0.67	26.4/18.2	38.1/35.1	2.09/2.07	42.5/32.2	10.8/9.64	25.6/20.8
	maximum	28.7/28.0	46.7/35.8	98.9/94.0	9.12/9.03	84.0/79.6	16.7/16.4	55.5/53.2
	minimum	0.10/0.03	0.06/0.004	0.88/0.71	0.37/0.16	0.13/0.004	0.82/0.09	1.05/0.12
	no.samples	112/41	102/43	19/17	19/18	119/27	120/40	119/37
Aluminium (total/ dissolved)	mean	0.88/0.16	0.42/0.23	0.02/0.01	0.04/0.02	0.16/0.04	1.75/1.17	0.39/0.11
	median	0.76/0.10	0.39/0.16	0.01/0.01	0.03/0.02	0.16/0.02	1.65/1.01	0.13/0.10
	maximum	2.76/0.76	2.20/2.10	0.12/0.06	0.14/0.05	0.40/0.25	4.57/4.26	2.17/0.36
	minimum	0.11/0.02	0.10/0.004	0.004/0.004	0.01/0.005	0.004/0.004	0.57/0.06	0.004/0.004
	no.samples	112/41	102/45	19/18	19/18	119/39	120/39	119/40

Appendix 6. Storm event chemistry downstream of minewater discharges

(a) Site G5: 8-9/1/1992

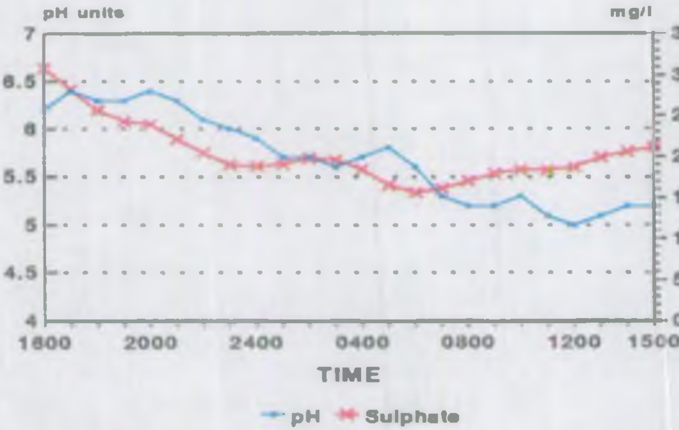


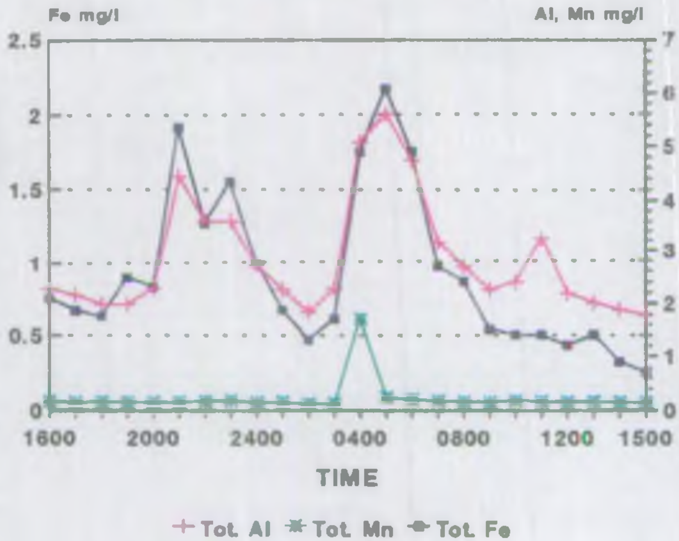
(b) Site G5: 12-13/2/1992



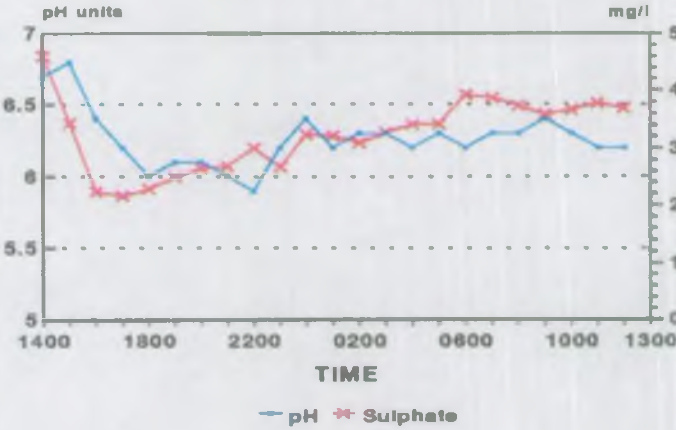
Appendix 6. Continued

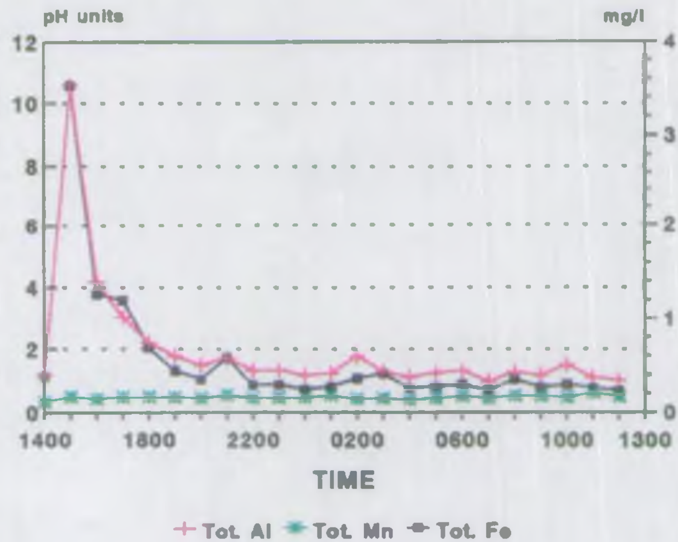
(c) Site BP5: 8-9/1/1992





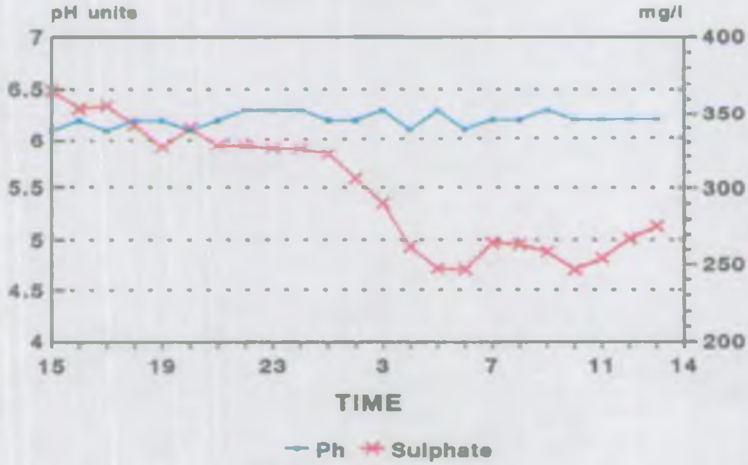
(d) Site BP5: 12-13/2/1992

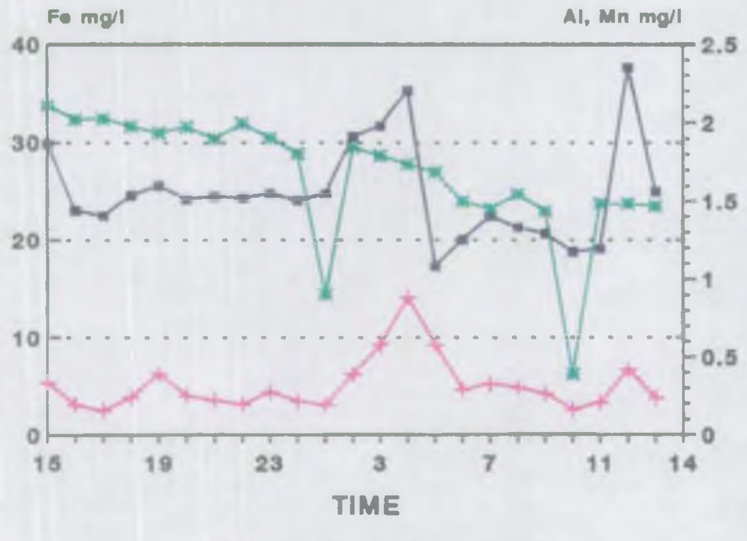




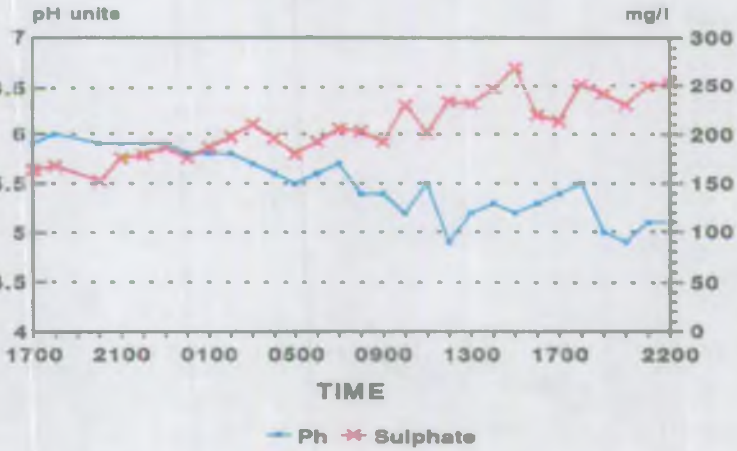
Appendix 7. continued

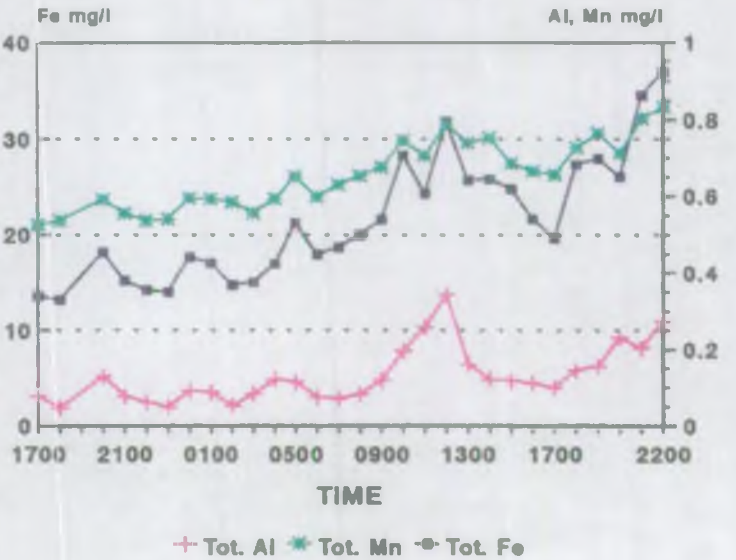
(c) Whitworth no.1 8-9/1/92





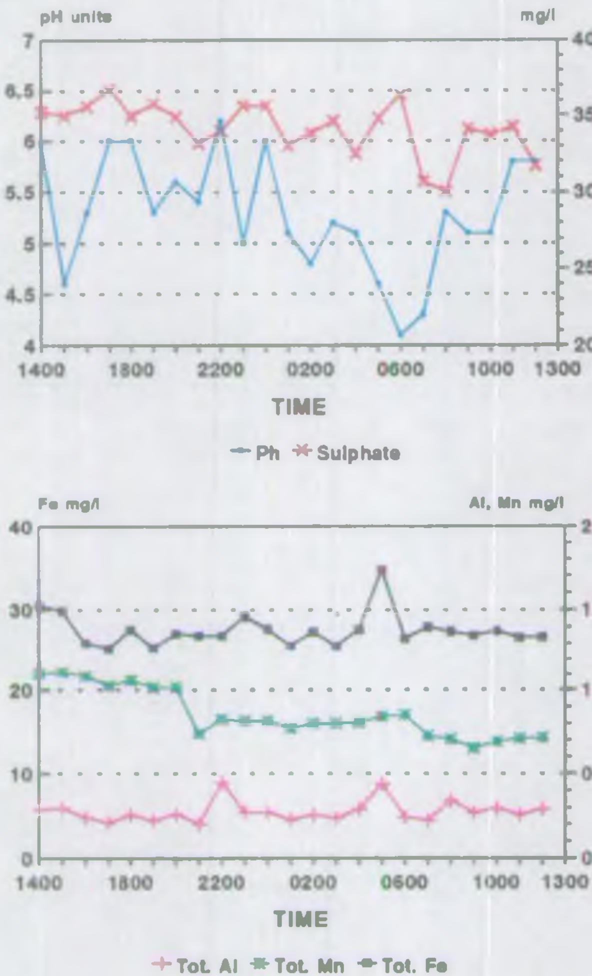
(d) Whitworth lagoon 9-10/3/1992



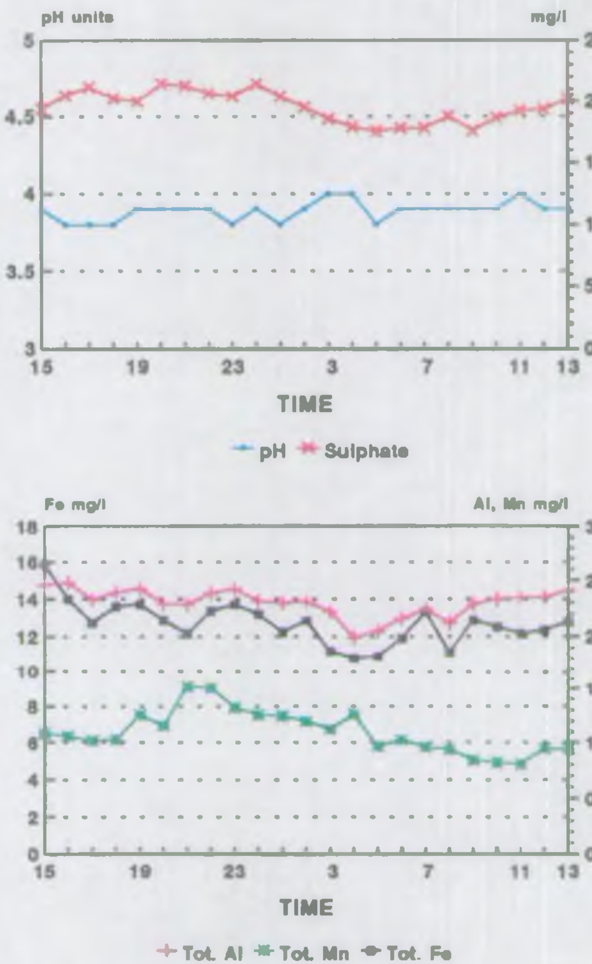


Appendix 7. Changes in minewater chemistry following episodes of high rainfall

(a) Garth Tonmawr minewater 12-13/1/1992



(b) Gwenffrwd minewater 8-9/1/92



TAXA	SPECIES	SITE BP4 I	BP4 II	BP5 I	BP5 II	P1 I	P1 II	G3 I	G3 II	G4 I	G4 II	G5 I	G5 II	G6 I	G6 II	P2 I	P2 II	P3 I	P3 II	A1 I	A1 II	A3 I	A3 II	FD3 I	FD3 II
<u>EPHEMEROPTERA</u>																									
Baetidae	Baetis rhodani (<u>Pictet</u>)		31	1	4	1	3		51							1	335	2	505	158	433	194	594	156	80
	Baetis scambus <u>Eaton</u>								3								2		2	4	6	8			
	Baetis muticus (<u>Linnaeus</u>)																				1				
	Cloeon dipterum (<u>Linnaeus</u>)				1				2																
Heptageniidae	Ecdyonurus torrentis <u>Kimmins</u>																			4	49	2	24		
	Heptagenia lateralis (<u>Curtis</u>)																							5	9
	Rithrogena semicolorata (<u>Curtis</u>)																			314	26	143	5	1	
Ephemerellidae	Ephemerella ignita (<u>Poda</u>)																1		9		57		41		55
Caenidae	Caenis rivulorum <u>Eaton</u>																			3	1	1			
<u>PLECOPTERA</u>																									
Taeniopterygidae	Brachyptera risi (<u>Morton</u>)					2																2		16	
Leuctridae	Leuctra inermis <u>Kempny</u>	1				11										6		6		65		18		158	
	Leuctra hippopus (<u>Kempny</u>)					2	2					2				2	12	3	118	2	24	3	17	31	26
	Leuctra moselyi <u>Morton</u>		32	1	2	1	10		6					1		2	4	2	5	2	2	2		20	16
	Leuctra nigra (<u>Olivier</u>)	3	1			8		6		3				12	1	7			2					5	
Perlodidae	Isoperla grammatica (<u>Poda</u>)	1				2		1								1		2		2	2			31	3
Chloroperlidae	Chloroperla tripunctata (<u>Scopoli</u>)																	2		4		2		21	1
	Chloroperla torrentium (<u>Pictet</u>)	2				2								1						1				13	2
Nemouridae	Amphinemura sulcicollis (<u>Stephens</u>)	10		4		6		10		3		4		4		14	1	3	2	22		15		7	
	Protonemura praecox (<u>Morton</u>)							1								1		1	1					1	
	Nemoura cambrica (<u>Stephens</u>)	1				2		1		1						1		1						4	
	Nemurella picteti <u>Klapalek</u>								2																
<u>TRICHOPTERA</u>																									
Goeridae	Silo pallipes (<u>Fabricius</u>)															1		2		2				4	6
Philopotamide	Philopotamus montanus (<u>Donavan</u>)								1										1					3	
	Genus Wormaldia (<u>Kimmins</u>)																							5	
Rhyacophilidae	Rhyacophila doralis (<u>Curtis</u>)								3								3	2	8	20	27	8	10	6	6
	Rhyacophila obliterata <u>McLachlan</u>													1							1				
	Rhyacophila septentrionis <u>McLachlan</u>		1		1												4		2	1	3	1			
Polycentropodidae	Plectrocnemia conspersa (<u>Curtis</u>)	1	2	1		1			1	1		2			4		1	1	1	2	4				
	Plectrocnemia geniculata <u>McLachlan</u>	2	3					4																3	2
	Polycentropus irroratus (<u>Curtis</u>)				1																				
Limnephilidae	Halesus digitatus (<u>Schrank</u>)							4			1		1							1					
	Drusus annulatus <u>Stephens</u>														1										
Glossosomatidae	Agapetus fuscipes <u>Curtis</u>																			1					
	Glossosoma boltani <u>Curtis</u>																				3		24		1
Hydropsychidae	Hydropsyche angustipennis (<u>Curtis</u>)																			76		66	3	2	
	Hydropsyche instabilis (<u>Curtis</u>)																					3		5	
	Hydropsyche siltalai <u>Dohler</u>																			9		9	3		
	Hydropsyche contubernalis <u>McLachlan</u>																			3			2		
	Diplectrona felix <u>McLachlan</u>							1						1		1		1							

Appendix 8a: Macroinvertebrate species observed in the Pelenna catchment in 1994 (I= Spring, II= Summer populations).

		SITE																							
		BP4		BP5		P1		G3		G4		G5		G6		P2		P3		A1		A3		FD3	
TAXA	SPECIES	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
<u>DIPTERA</u>																									
Chironomidae		3	20	1	3	2	12		3		5	1	4	2	10	3	487	33	285	3	75	80	608	31	100
Simuliidae		3	20		1		1		13		9				1		50		77		18		1067		4
Tipulidae	Genus Dicranota		1				5								1		13	3	15	1	10		1	9	17
	Genus Elaeophila	3								1						1		1			1	4		1	4
	Genus Pedicia					1						1													
	Genus Clinocera							1									13		2				3		
	Tipula maxima													1											
	Genus Helius																1								
	Genus Hemerdroma																2						1		
Tabanidae		4																1							
Psychodidae	Pericoma																							1	
Rhagioniidae	Genus Atherix																						1		
<u>HEMIPTERA</u>																									
Gyrinidae																				2		3			
Veliidae	Velia caprai <u>Tamanini</u>																								1
Mesoveliidae	Mesovelia furcata <u>Mulsant and Rey</u>						1		3				2												
Hebridae	Hebrus ruficeps (<u>Thoms.</u>)																				2	1			
<u>COLEOPTERA</u>																									
Dytiscidae	Subfamily Dytiscinae																								
	Species A (larvae)													1											
	Species B (larvae)													1											
	Oredytes sanmarkii (adult)																				1	1	1		
	Hydroporus species																				1		1		
Elmidae	Limnius volckmari		1																	5		10	3		
	Esolus parallelepipedus								1													2		1	
Hydrophilidae	Subfamily Spercheinae			1																					
	Helophorus arvernicus				1												2		1						
	Helophorus brevipalpis								1																
Scirtidae	Limnius species															1				11	14	17	18	2	1
<u>CRUSTACEA</u>																									
Gammaridae	Gammarus pulex (<u>Linn.</u>)																	1							
<u>HIRUDINEA</u>																									
Glossiphonidae	Helobdella stagnalis	1				1															1				
<u>MOLLUSCA</u>																									
Gastropoda																									
Lymnaeidae	Lymnaea (Radix) peregra (<u>Mull</u>)																					1			
Lamellibranchiata																									
Sphaeriidae	Pisidium species																							1	
Ancylidae	Ancylus fluviatilis <u>Mull</u>																				1				2

Appendix 8b. Macroinvertebrate species observed in the Pelenna catchment in 1994 (I= Spring, II= Summer populations).

		SITE																							
		BP4		BP5		P1		G3		G4		G5		G6		P2		P3		A1		A3		FD3	
TAXA	SPECIES	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
TRICLADIA Planariidae	Polycelis tenius/nigra																			2		7			
ODONATA Cordulegasteridae	Cordulegastser boltoni (Donovan)													1		1									
ARACHNIDA Hydracarina	Hydrachnellae		1																	2			1		
COLLEMBOLA	Proistoma species							1		1			1												
OLIGOCHAETA		4	1			10	2		2	4	1		2	1	3	5	9	6	22		6	98	11	5	15
HETEROPTERA Gerridae	Gerris (Aquarius) najas (Deg.)																			1					

Appendix 8c. Macrounvertebrate species observed in the Pelenna catchment in 1994. (I= Spring, II= Summer populations).

Appendix 9. Glossary of terms

Acidity: The base-neutralising capacity of a solution (see pH)

Aerobic: A process that requires the presence of oxygen

Alevin: A newly hatched fish which is sustained by its yolk sac

Alkalinity: The acid neutralising capacity of a solution (see pH)

Anaerobic: A process that does not require the presence of oxygen

Base: A chemical compound that combines with an acid to form a salt and water

Buffering capacity: The ability of a solution to maintain its hydrogen ion concentration when an acid or alkali is added

Ferric: An insoluble substance containing iron in a trivalent form (i.e. Fe^{3+})

Ferrous: A soluble substance containing iron in a divalent form (i.e. Fe^{2+})

Ferruginous: Containing iron

Fry: In this report refers to a trout or salmon in its first year of growth

Hydrolysis: A chemical reaction in which a compound reacts with water to produce other compounds

Ochre: An orange-coloured precipitate containing iron hydroxide

Oxidation: A chemical reaction involving the addition of oxygen to a substance, usually resulting in the formation of an oxide

pH: A measure of the acidity or alkalinity of a solution. pH values may range from 0 to 14 (ie. very acidic to very alkaline). Most natural waters have a pH of between 6.0 and 8.5

Parr: In this report refers to a juvenile trout or salmon in its second or third year of growth

Precipitate: A substance which has become deposited in solid form from a solution

Salmonid: A fish of the family *Salmonidae* (ie. trout or salmon)

Wetland treatment system: A passive treatment system which utilises biological and chemical processes occurring in reedbeds to precipitate iron compounds and promote sulphate reduction.

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