FAUNAL AND ENVIRONMENTAL CHARACTERISTICS OF SITES RECEIVING RESIDUAL FLOWS FROM RESERVOIRS

A report to the Institute of Hydrology

by

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SUMMARY

1. The macroinvertebrate faunas of 31 sites below reservoirs releasing water as compensation flow and 2 unregulated control sites were examined in April, June/July and September 1983.
2. A total of 70 families of macroinvertebrates were recorded from combined seasons' data from the 33 sites. The numbers of families recorded in single seasons were 63, 61 and 61 in spring, summer and autumn respectively.
3. At family level the fauna of most of the residual flow sites did not appear to be impoverished by the regulated flow regime.
4. There was no statistically significant relationship between environmental site characteristics and family richness but sites below the oldest reservoirs tended to have more families. Temperature ranges within the 33 sites were greatest in summer. Sites with the coldest summer temperatures also had the lowest number of families.
5. Unregulated control sites supported the same number or fewer families than did adjacent regulated streams. Summer temperatures were lower in regulated sites than in the adjacent unregulated sites.
6. Ordination (DECORANA) and classification (TWINSPAN) analyses of data from 301 sites (268 FBA project 103 sites and 33 residual flow sites) identified regulated sites as having distinct faunal characteristics which resulted in 24 of the 33 sites occurring in two adjacent groups. The remaining 9 sites occurred in outlying groups. Application of prediction techniques and examination of TWINSPAN group membership indicated that some of these outliers contained sites most affected by regulation. The faunal composition of outlying regulated sites was markedly different from that of unregulated sites with similar physical and chemical characteristics.

7. Use of the BMWP score system enabled faunistically unusual sites to be identified. The results agreed with the findings from the TWINSPAN analysis. Lowest scores and ASPT were recorded most frequently in autumn.

8. The sampling of sites subject to extremes of discharge and experimental work involving test releases from reservoirs are suggested as a means of quantifying the effects of regulating flows.

INTRODUCTION

In the past the quantities of water released from reservoirs have been subject to arbitrary rulings. Throughout Great Britain there are a large number of reservoirs where decisions as to the amount of compensation flow to be released were made many years before the present archive of river flow data was available. These data are now being used by the Institute of Hydrology as the basis for preparing guidelines for resetting reservoir operating policy and compensation releases in order to minimise disturbance to the flow regime downstream and wherever possible to conserve water for supply purposes.

Before such guidelines can be prepared it is important that information should be obtained on the biological consequences of particular compensation flows and in 1983 the Institute of Hydrology offered the Freshwater Biological Association a sub-contract to examine the macroinvertebrate fauna below 29 reservoirs. The chief aims of the biological study were:-

1. to relate below-reservoir faunas to conditions of flow and other physical and chemical characteristics of the sites
2. to answer the question "Are the regulated-stream faunas distinct from unregulated-stream faunas in similar areas?"

The time and funds available for biological work were limited so all analyses of faunal data were carried out at family level.

STUDY AREA AND METHODS

Site selection

Hydro-electric and regulating reservoirs were excluded from the pool of sites available because the Institute of Hydrology's main interest was in reservoirs whose discharge was released as compensation flow. Emphasis was therefore placed on sampling a wide range of compensation flows from reservoirs throughout the country. Using a comprehensive list of reservoirs prepared by the Institute of Hydrology a total of 31 sites below reservoirs in south-west England, south Wales, the Pennines and the catchment area of the Tweed in Scotland were selected for study (Fig. 1). Ease of access, absence of pollution and well-monitored discharge were factors important for the final selection. Two unregulated streams which were adjacent to regulated sites were sampled as controls. The full site list is presented in Table 1a b, together with discharge data.

Sampling frequency and methods

Samples were taken in spring (April 10-16), summer (June 28-July 4) and autumn (September 19-25) downstream of the reservoir outflows. Fauna was sampled by disturbing the substratum upstream of an FBA pond net (mesh size 900 μm) for 3 minutes across all major biotopes.

Environmental data for each site were recorded on forms developed for FBA Project 103 'The analysis of natural river communities in Great Britain' (Wright et al. 1981). Henceforth in this report this project will be referred to as FBA 103. Chemical data were obtained from the relevant Water Authority or River Purification Board. The environmental and chemical variables recorded for the survey are listed in Table 2 and a summary of the data for each site is given in Table 3.

The procedure adopted for sorting each biological sample is given in Furse et al. (1981) together with a demonstration of the field sampling technique. Each sample was sorted for about 2 h in order to obtain as wide a range of taxa as possible. In addition a $\log_{10}$ scale was used to categorise the abundance of animals in each family (<10 animals = 1, <100 = 2, <1000 = 3, <10,000 = 4, >10,000 = 5).

Data analyses

Emphasis was placed on ordination and classification techniques so that the relationship between unregulated sites sampled for FBA 103 and regulated sites sampled for this study could be demonstrated.

Ordination was carried out using detrended correspondence analysis (Hill & Gauch 1980) an improved version of reciprocal averaging (Hill 1973) in which the 'arch' effect and compression of axis ends is avoided.

Sites were classified using two-way indicator species analysis, TWINSPAN, (Hill 1979). This is an improved version of indicator species analysis which classifies both samples and species and constructs ordered two-way tables to show the relationship between them as clearly as possible. Since two-way indicator species analysis is a divisive technique the division of samples into progressively smaller groupings may be continued for as long as seems profitable. The program also constructs a key to the sample classification by identifying one or more differential taxa which are particularly diagnostic of each division in the classification. The key can therefore be used to classify new sites without the need to reclassify all sites.

Detailed descriptions and discussion of the application and merits of these methods for the analysis of freshwater benthic survey data are found in Wright et al. (1981).

RESULTS

The fauna

A total of 70 families were recorded from the 33 sites when the samples taken in the three seasons were combined. The number of families recorded in single seasons were 63, 61, 61 in spring, summer and autumn respectively. Table 4 lists the seasonal variations in numbers of families taken at each site. Ten sites had the highest number of families in spring, 10 in summer and 8 in autumn. The remaining sites had high numbers of families in more than one season.

Examination of the environmental characteristics of both family-rich and family-poor sites showed no obvious relationships with the numbers of families recorded. However there did appearto be a relationship between age of reservoir and family richness, though this could not be proved statistically for the whole data set. Five out of the 6 richest sites are below reservoirs which are more than 70 years old. In contrast 3 out of the 4 poorest sites are below reservoirs which are less than 12 years old. At 2 of these, Meldon and Boothwood, only 16 and 18 families were recorded respectively.

The number of families taken in the unregulated control site, Sett (36), was the same as that taken in the adjacent regulated site Kinder 1. Further downstream, Kinder 2, which receives Sett water in addition to reservoir discharge, supported 40 families. The site Wearhead on the unregulated R. Wear had 24 families represented whereas 35 were found in the adjacent regulated site Burnhope.

Thirty-six of the 70 families recorded occurred in more than 50% of the sites. Of these, 12 were abundant and included stoneflies (Nemouridae and Leuctridae), mayflies (Baetidae), crustaceans (Gammaridae), caseless caddis (Polycentropodidae, Hydropsychidae and Rhyacophilidae), oligochaetes (Naididae, Lumbriculidae) and 3 subfamilies/tribes of chironomids (Orthocladiinae, Tanypodinae and Tanytarsini). In contrast 28 families occurred at 9 or less sites and were never abundant.

The full family list for all sites based on 3 combined seasons' data is presented in Table 5 together with information on the abundance and number of occurrences.

Temperature effects

Temperature data were collected at the same time as sampling in spring, summer and autumn and the results are presented in Table 3a. Diel fluctuations in temperature are known to be slight below reservoirs (Ward & Stanford 1979) but the value of spot readings taken at different times of the day is questionable and it should be stressed that the remarks below are based on very inadequate data. Features to emerge were:-

1. Temperature ranges within seasons were greatest in the summer.

spring	4.6- 8.0	3.4°C (limited data set)
summer	7.7-21.0	13.3°C
autumn	8.8-14.1	5.3°C

2. In the data set as a whole there was no statistically significant relationship between summer temperature and the number of families recorded at a site.
3. Sites with the coldest summer temperatures, that is Meldon, Boothwood, Winscar and Fernilee, also had the lowest number of families.
4. The three sites with the warmest summer temperatures, Belmont, Gouthwaite and Widdop also had the largest ranges between summer and autumn. All 3 sites were amongst sites situated >0.5 km below the dam. Gouthwaite supported the highest number of families (49) in the whole data set but at Belmont and Widdop only 33 and 29 families were recorded respectively.
5. At the unregulated control sites Sett and Wearhead, summer temperatures were higher and the observed temperature range between spring and summer greater than at the adjacent regulated sites, Kinder 1 and Burnhope.

	Summer T°C	Summer-Spring
Sett	12.2	5.9
Kinder 1	10.9	4.9
Wearhead	13.6	7.0
Burnhope	12.0	6.8

Seasonal ranges at Wearhead and Burnhope were very similar and the range between all 3 seasons was slightly greater at Burnhope (7.3) than at Wearhead (7.0).

It is not possible to draw any firm conclusions from these observations. However there are indications at some sites that regulation of the flow is depressing summer temperature values. The degree to which this takes place will depend on several factors including distance from the dam, the level at which water is released from the reservoir and the amount of the discharge (high discharges will be affected less by ambient air temperatures than will low discharges).

More data are required on temperatures, release point and pattern before their relationship to the benthic macroinvertebrate communities found below dams can be assessed.

Ordination

Fig. 2 presents an axis 1 by axis 2 ordination plot of the 33 residual flow sites. Correlation coefficients between the ordination scores for axes 1-4 and the environmental variables listed in Table 2 are presented in Table 6.

Most variation (75.6%) is accounted for by the first two axes of the ordination and by using the data in Table 6 with Fig. 2 it is possible to examine the distribution of sites in relation to environmental variables. Along axis 1 there is a gradation of sites from those situated at high altitudes, with high water velocities and coarse substrata on the right to low altitude, low velocity, fine substrata sites on the left. Along axis 2 there is a gradation from small streams with low pH at the bottom of the figure to larger streams with higher pH at the top. There is also a tendency for sites with low axis 2 scores to have low numbers of families ($r = 0.756$, $n = 33$, $P = <0.001$).

Classification

The relationship between the 268 mainly unregulated sites sampled during the FBA 103 project (Wright et al. 1981) and the 33 sites sampled during this study was investigated by amalgamating the two data sets and classifying the 301 sites at family level using TWINSPAN. Fig. 3 presents a dendrogram showing how TWINSPAN groups are developed through successive divisions 1-5. It is provided so that when various groups are referred to in the report their nomenclature and relationship one to another can be readily comprehended.

A dendrogram based on the combined data set showing group membership of sites is presented in Fig. 4. Residual flow sites are indicated in parentheses for the 4th level of division when 16 groups of sites have been generated.

The faunal similarity of most of the residual flow sites which was indicated by the initial ordination (Fig. 2) is emphasised here where 24 of the 33 sites occupy two adjacent groups (M & N). Table 7 lists all sites present in division 5 TWINSPAN groups which contain residual flow sites and provides data on the number of families recorded at each site. Table 7a gives data on the mean and variance of 9 environmental variables for unregulated and regulated sites within these TWINSPAN groups.

Of the 33 sites two, Scout Dike and Bottoms/Teggsnose were separated from the remainder at the first division. Scout Dike in group D differed from the unregulated sites in its group in having a steeper slope, being nearer to the true source of the river and having a lower channel depth and discharge.

The second outlying site Bottoms/Teggsnose in group G was again nearer to the source and had a steeper slope than the other sites in its group. Alkalinity was lower at Bottoms/Teggsnose but discharge was similar in all sites.

Regulated sites group with unregulated sites because their faunal composition is similar despite physical differences. Since physical and chemical site characteristics are usually major factors in the control of faunal composition it follows that regulated and unregulated sites within a TWINSPAN group must have some physical characteristic in common which has not been recorded in this study, e.g. spateyness factor, fine sediment deposition on the surface of the substratum or temperature regime.

The 2 sites with which Scout Dike is grouped are both in pool areas of otherwise riffly streams and these would dampen the effects of spates. Bottoms/Teggsnose is grouped with sites having a fairly stable flow regime as indicated by their Base Flow Indices (0.63-0.86). The remaining 31 sites all classify into groups on the right hand side of the dendrogram.

Lindley Wood 2 in group J is further from the source, has a higher macrophyte cover and lower alkalinity than unregulated sites in its group. Here regulation appears to be creating conditions suitable for a fauna characteristically found in smaller streams nearer their source.

Lindley Wood 1, Thirlmere and Gouthwaite group with sites situated low down on spatey streams or near the source of small streams with stable flow regimes and which include the Cumbrian Derwent at Ouse Bridge 0.1 km below Bassenthwaite Lake. The 3 residual flow sites do not possess physical or chemical features which differentiate them from the unregulated sites in the group K.

Group M contains 14 residual flow sites which are distinguished from unregulated sites in being generally closer to the source, having a steeper slope, lower discharge and higher macrophyte cover. Group M is made up of groups 56 and 57 (from division 5 of the classification, Fig. 3) and 13 of the residual flow sites are found in group 56. This group includes the site Cauldron Snout on the Tees which is about 0.3 km below Cow Green reservoir and also Boat of Garden on the Spey which may be affected by the lake-like section upstream at Kincraig. In group 57 Westwater, a regulated site, groups with sites which are generally low down on spatey systems or in the case of the R. Wansbeck have a lake at the source of the stream.

Group N contains 10 residual flow sites including the unregulated control site on the R. Sett. The discharge is generally lower in the regulated sites but most other physical and chemical variables are similar to those of the unregulated sites. Included in this group are Kinlochard and Aberfoyle Bridge, sites on the R. Forth system situated 3 and 2 km below Loch Chon and Loch Ard respectively. Also included in group N is Wooton

Bridge on the Avonwater, again with a small lake at its source and with a base-flow index (BFI) of 0.71. It is not possible to explain the inclusion of the Hodder at Great Bridge in this group with the present data as there are no lakes or reservoirs upstream and the BFI is only 0.21.

Group O contains one regulated site, Kinder 2, which does not differ markedly in most physical characteristics from the other sites. However discharge in 10 of the 11 unregulated sites is much higher than at Kinder 2. The group contains two sites, High Stock Bridge on the Derwent and Ennerdale Bridge on the Ehen which are situated 3 and 2 km downstream of Derwent Water and Ennerdale Water respectively.

Group P includes the unregulated control site on the R. Wear at Wearhead and the regulated site Boothwood. The latter site has the lowest discharge and the highest macrophyte cover (Table 7a) in the group but cannot be distinguished from the remaining sites in the group on other physical characteristics.

Table 8 summarises the faunal characteristics of residual flow sites within their TWINSPAN groups. Diptera are common and abundant at all sites but it is the subdominant orders which reveal the differences between groups. Ephemeroptera and Plecoptera do not feature prominently in groups 39, 44 and 50 but do so in higher numbered groups. Similarly there is a decline in both abundance and occurrence of families of Oligochaeta from group 39 to 63. Trichoptera occur widely but groups 50, 52, 56, 57 and 58 contain the highest numbers of families. Mollusca were abundant only in group 44.

Prediction

In the FBA 103 project (Wright et al. 1981) attempts were made to predict the TWINSPAN group membership of sites. This was achieved firstly by using the TWINSPAN key which allows new sites to be classified on the basis of their macroinvertebrate fauna and secondly with multiple discriminant analysis (MDA) which uses environmental data to produce equations to predict group membership of a new site. Both methods were applied to the 33 sites investigated in this project.

The TWINSPAN key was based on the classification of 268 FBA 103 sites using the combined seasons' quantitative family level data. Similarly the MDA equations were basedon environmental data collected for the 268 FBA 103 sites.

A comparison of the two methods is presented in Table 9. It is clear that there is very little agreement between the two sets of predictions and in 3 cases, Bottoms/Teggsnose, Scout Dike and Lindley Wood 1, the sites are placed in opposite halves of the classification.

Both key and MDA equations will only produce accurate predictions if the new sites have characteristics similar to those used to construct the key and develop the equations. The poor agreement in this area is probably due to the fact that residual flow sites do not come within the scope of the 268 site classification.

In general, predictions using the TWINSPAN key are more informative than those using MDA. For example the 3 sites Bottoms/Teggsnose, Scout Dike and Lindley Wood 1 which have been shown to be widely separated from most of the other residual flow sites both by ordination, classification and the key, are not indicated as being in any way unusual by the MDA equations. It is likely therefore that some environmental variable or combination of variables, such as discharge pattern, sediment deposition or temperature regime, which would characterise sites with regulated flows are not being recorded or used in the derivation of the predictive equations.

Application of BMWP score system

The biotic score system developed by the Biological Monitoring Working Party and described and tested by Armitage et al. (1983) was applied to the 33 residual flow sites.

Scores and ASPT values for separate and combined seasons' samples are presented in Table 10. Scores below 100 were recorded at 13, 17 and 20 sites in spring, summer and autumn samples respectively. The equivalent data for ASPT's below 6.00 were 10, 13 and 21. In the combined seasons' data set 4 sites, Meldon, Bottoms (Longdendale), Winscar and Boothwood had scores below 100 and 6 sites, Bottoms/Teggsnose, Bottoms (Longdendale), Scout Dike, Castleshaw, Widdop and Lindley Wood 1 had ASPT values below 6.00.

Armitage et al. (1983) have shown that there is considerable variation in achievable score and ASPT in different categories of unpolluted sites. In order to assess the meaning of these low scores and ASPT's at particular sites it is necessary to see if the values fall within the normal range observed in groups which include those sites. The TWINSPAN key derived from the BMWP family level combined seasons' classification of 268 FBA 103 sites was used to predict the group membership of residual flow sites. Table 11 compares actual score and ASPT for the 9 sites with expected values and ranges for each TWINSPAN group to which the residual flow sites key out.

At all these sites, except Lindley Wood 1, score and/or ASPT's are lower than expected for the group to which they key out. This suggests that regulation is altering the fauna by increasing the number of low scoring taxa and reducing the number of high scoring taxa as in sites with relatively high scores and low ASPT's, or in the case of Meldon, Boothwood and Winscar reducing the total number of families without reducing high scoring taxa which results in low scores and high ASPT's.

Armitage et al. (1983) developed multiple regression equations to predict score and ASPT from environmental data. The results of using physical and chemical data in the published equations to predict scores and ASPT of the residual flow sites are presented in Table 12. Predicted values for both parameters were for the most part greater than the observed values which suggests that regulation is depressing the faunal potential of the sites. Calculation of the ratio of observed/predicted scores and ASPT provides an indication of sites which may be unusual faunistically. The greatest deviations from unity are seen at Bottoms/Teggsnose, Bottoms (Longdendale), Castleshaw and Boothwood for ASPT and at Meldon, Bottoms (Longdendale) and Castleshaw for score. All these sites were identified as unusual in the initial examination of score and ASPT values.

Therefore, although the predictive methods have some use in identifying problem sites it is simpler and more informative at this stage to consider the observed scores and ASPT's and to look at these in relation to the family composition of a site. In large data sets the score system, as a summary of faunal conditions, would be useful for focussing attention on unusual sites.

DISCUSSION

Scope of study

The regulated sites selected for this study include areas subject to compensation discharges where only a proportion of the natural flow (before regulation) is released to the river downstream of the dam.

Within the data set of 31 regulated sites this proportion ranged from about 80% at Belmont to 3.5% at Castleshaw and covered areas in England, Scotland and Wales.

In view of the decision to include a wide geographic range of sites with varied compensation flows and the limited time available, samples at increasing distance from outflows were lacking from the data set and only two controls (unregulated streams adjacent to regulated discharges) were sampled.

Site grouping and environmental variables

This survey has demonstrated that a range of communities occurs below reservoirs releasing water as compensation flow. However in the combined seasons' data set most of the sites fall into 2 closely related groups.

It has not been possible to associate group membership with any one particular environmental variable or group of variables. There was no obvious relationship between discharge type or quantity and group number, for example, Gouthwaite which is subject to control rules which can allow flows from the reservoir to range from 23-709 MLD occurred in the same group as Lindley Wood 1 which receives a constant discharge of <18 MLD.

There did appear to be a positive relationship between age of reservoir and number of families recorded. This might be expected since the fauna would have had longer to colonise and adapt below older reservoirs. However there were several exceptions and more data would be required to test this hypothesis. In some of the groups of residual flow sites the regulation of the discharge appeared to alter the complement of families to a community type normally associated with conditions further downstream. The faunal communities present were not consistent with the physical characteristics of the site, that is, what in physical terms was a headwater stream had communities more normally found further downstream. This may be a consequence of the reduction in fluctuations in flow which are normally associated with hill streams.

A corollary of this is the fine sediment which covers the substratum in the majority of regulated sites. The flow fluctuations were insufficient to mobilise this material and as a result oligochaetes and chironomid larvae, which are often associated with fine sediments, were abundant. The quantities of this material did not appear to have an adverse effect on the macroinvertebrate fauna as a whole but it is possible that by altering flow and water chemistry through interstitial spaces in the substratum conditions would be unsuitable for spawning salmonids.

Regulated/unregulated sites

Only 2 unregulated control sites were sampled in the survey. In both the numbers of families recorded were the same or lower than in the adjacent regulated streams. This agrees with Ward & Stanford (1979) who found that most major taxa (with the exception of Plecoptera, Ephemeroptera and Coleoptera) are relatively more abundant downstream of reservoirs than at nearby control sites.

At the unregulated site Wearhead a severe flood which occurred just before the autumn samples were taken resulted in a reduction in the total number of families as a result of scouring. A secondary effect of the flood was the deposition of large quantities of silty sand at the mouth of the adjacent regulated site (Burnhope) thereby changing the substratum from a cobble/boulder bottom to one where sand dominates. The constant discharge from Burnhope reservoir failed to shift this deposit by the time the autumn samples were taken.

Burnhope and Wearhead occupied different TWINSPAN groups but Sett (unregulated) and Kinder 1 (regulated) were found in the same group. This indicates that Burnhope is more affected by regulation processes than is Kinder 1.

Ordination, classification and prediction

In general these procedures were useful in identifying major groupings of regulated sites. However the classification is not a rigid framework and if individual seasonal data were used in place of those from combining the seasons the group membership of sites would probably change. The advantage of using data from all seasons together is that it provides a summary of conditions for the whole year and gives a more comprehensive listing of families and hence a more valid classification.

The methods identified certain sites as being particularly unusual in that they occurred in groups well separated from other sites. The available environmental data do not explain why they were outliers. The MDA equations which use environmental data failed to predict correct group membership suggesting that regulated sites possess unique characteristics which are not used in the predictive equations. In order to explain these anomalies a larger number of sites should be investigated with more attention to the physical environment. For example no data on fine sediment deposition were used in the equations, which were formulated for unregulated sites, yet this is an important feature of streams with regulated flow. The discharge data do not adequately describe the flow conditions since the winter spillage is not taken into account. In addition no data, other than spot readings, are available on water temperature which is known to be a feature affected by regulation and one which may have a considerable effect on the fauna (Armitage in press) depending on whether top or bottom water is released downstream.

Despite these deficiencies the classification and prediction procedures used in this study have revealed relationships between sites in an objective way. Explanations of why sites with apparently similar physical and chemical characteristics are not grouped together in all cases awaits more detailed study.

Discharge regime

The detrimental effects of flow regulation often reported in the literature were not noticeable within the range of sites examined during this survey. The effect of regulated flow would be most marked at sites with constant discharge. Only 15 of the 29 regulated sites in this survey were subject to a constant discharge and at least half of these received winter spillage which would help counteract the effects of regulation. The remaining 14 sites received constant discharges with occasional freshets or were subject to control rules which varied flows throughout the year. Discharge patterns were therefore not so extreme as to have an adverse effect on the fauna. Twenty-one of the 31 sites have been subject to regulated flows for greater than 50 years. This would certainly have given the benthic fauna a chance to adapt to the unnatural flow regime and its concomitant effects.

At one site large fluctuations in discharge took place but not as a regular event throughout the year. Below Thruscross reservoir on 2nd and 3rd July the flow was increased from about 45 to 363 MLD to accommodate a canoeing event. To compensate for water lost downstream no water was released from the reservoir on the 4th, 5th and 6th July until 1015 h when 45 MLD was released. Samples of macroinvertebrates collected at about 1030 h showed no signs of faunal impoverishment and contained 8 more families than did spring and autumn samples. At this site sufficient water was retained at the base of the boulders and around the dense moss growth to provide refuge areas for the fauna when no water was released from the reservoir. Repeated events of this nature would have an adverse effect on the benthos.

It should be stressed that samples for this project were taken as close as possible to the reservoir outflows in order to have data on areas likely to be most affected. It is possible, but not yet demonstrated, that sites further downstream would have shown reduced effects of the regulated flow regime.

While no major detrimental effects were observed using family level identifications it should not be assumed that such effects might not be demonstrated if the data had been analysed at species level. Low species diversity is a feature of regulated sites (Armitage 1978).

CONCLUSION

The resilience of benthic macroinvertebrates to environmental change has implications for the recommendation of optimal management procedures. In order to answer the question, "How high or how low can discharge be before the fauna is adversely affected?" it would be necessary to examine sites subject to extremes of discharge range. Such extremes are absent from the present data set. Nevertheless the survey has revealed sites which appear to be most affected by regulation. If these sites were subject to further severe reductions in flow it is probable that family richness would be lowered. However the effects of change to greater flow constancy are less easy to predict and would depend on the actual quantity of water released but it is likely that a uniform current and bank stability would result in increases in aquatic and riparian vegetation which, in the short term, would be favourable to macroinvertebrates (Armitage in press). However without periodic floods interstitial spaces in the substratum would soon be clogged which would reduce the number of niches available to the benthic fauna.

Survey data, while useful for catalogueing the fauna to be found below reservoirs cannot provide information on the rate of reduction in diversity and abundance in response to extreme discharge patterns. To obtain this it would be necessary to carry out experimental work involving test releases from reservoirs or to survey sites already subject to very low or very high constant discharges. In addition further work should include more controls and also the examination of sites at increasing distance from the reservoir outflow.

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Site Name	River	Grid Ref.	Code
SWWA			
Meldon	West Okement	SX 564 917	620101
Wimbleball	Haddeo	SS 960 295	630101
WW			
Llwyn-on	Taff	SO 013 109	640101
Taf Fechan	Taf Fechan	SO 059 114	650101
Talybont	Caerfanell	SO 107 207	660101
NWWA			
Bottoms/Teggsnose	Bollin	SJ 943 716	670101
Fernilee	Goyt	SK 013 780	680101
Kinder (1)(a)	Kinder	SK 051 876	690101
Kinder (2)(b)	Kinder	SK 047 868	690301
Sett (unregulated)	Sett	SK 051 869	700101
Bottoms (Longdendale)	Etherow	SK 020 969	710101
Castleshaw Lower	Tame	SD 991 090	740101
Thirlmere	St Johns Beck	NY 310 195	880101
Haweswater	Haweswater Beck	NY 510 159	890101
Belmont	Belmont Brook	SD 691 155	900101
YWA			
Winscar	Don	SE 158 024	720101
Scout Dike	Don	SE 238 045	720301
More Hall (1)(c)	Ewden Beck	SK 291 956	730101
More Hall (2)(d)#	Ewden Beck	SK 291 956	730102
Booth Wood	Booth Dean Stream	SE 032 165	750101
Widdop	Hebden Water	SD 962 313	760101
Lindley Wood (1)(e)	Washburn	SE 226 482	770101
Lindley Wood (2)(f)	Washburn	SE 226 482	770102
Thruscross	Washburn	SE 156 571	770301
Gouthwaite	Nidd	SE 144 679	780101
NWA			
Hury	Balder	NY 968 195	790101
Grassholme	Lune	NY 960 240	800101
Burnhope	Burnhope Burn	NY 857 394	810101
Wearhead (unregulated)(g)	Wear	NY 857 395	820101
Derwent	Derwent	NZ 033 511	830101
TRPB			
Fruid	Fruid Water	NT 088 206	840101
Talla	Talla Water	NT 105 234	850101
Baddinsgill	Baddinsgill	NT 130 550	860101
West Water	West Water	NT 124 518	870101

(a) u/s of Sett confluence; (b) d/s of Sett confluence;

(c) & (d) u/s & d/s of settling tank output;

(e) & (f) u/s & d/s of fish hatchery: (g) unregulated site on Wear u/s of confluence

sampled only in spring

Table 1a. Site list with National Grid References and computer codings.

Site Name	Age	Distance from dam (km)	Discharge characteristics: Compensation flow as MLD	COMP/ADF %	Release pattern	
SWWA						
Meldon	1972	0.11	7.7	8.5	CD	Sp
Wimbleball	1977	0.60	9.1	13.6	CD + F	Sp
WW						
Llwyn-on	1927	0.37	23.2	13.6	CD	Sp
Taf Fechan	1927	0.41	21.8	15.8	CD	X
Talybont	1938	0.23	13.6-25.0	13.8-25.3	CR	X
NWWA						
Bottoms/Teggsnose	1850/71	0.22	2.4	27.3	CD	Sp
Fernilee	1927	0.25	13.6	20.4	M	Sp
Kinder (1)[(a)]	1912	0.60	1.1	4.2	CD	Sp
Kinder (2)[(b)]	1912	1.62	-		CD + U	Sp
Sett (unregulated)	-	-	-		U	-
Bottoms (Longdendale)	1877	0.25	22.7-68.2	10.2-30.5	M	SpSuAu
Castleshaw Lower	1891	0.35	0.34- 2.3	3.1-23.9	CD	X
Thirlmere	1894	0.41	13.6	5.5	CD	X
Haweswater	1941	0.75	21.8	12.8	CD	X
Belmont	1826	2.25	15.6	79.6	CD	X
YWA						
Winscar	1975	0.50	9.1-11.8	26.1-33.9	M	Sp
Scout Dike	1924	0.30	2.7- 3.9	12.4-17.9	CR	?
More Hall (1)[(c)]	1930	0.30	9.1-12.0	20.4-26.9	CR	Sp
More Hall (2)[(d)] ≠	1930	0.32	9.1-12.0	20.4-26.9	CR	Sp
Boothwood	1971	0.25	9.7	28.5	CD	X
Widdop	1878/1974	1.75	20.0	22.9	M	?
Lindley Wood (1)[(e)]	1875	0.60	<18.2	<15.3	CD	Sp
Lindley Wood (2)[(f)]	1875	0.61	18.2	15.3	CD	Sp
Thruscross	1967	0.30	spill only	-	V	Sp
Gouthwaite	1901	0.55	22.7-70.9	8.8-27.5	CR	?
NWA						
Hury	1894	0.20	15.2	16.9	CD	SpSuAu
Grassholme	1915	1.90	28.4	12.6	CD	SpAu
Burnhope	1936	1.10	9.1	15.1	CD	?
Wearhead (unregulated)[(g)]	-	-	-	-	U	-
Derwent	1916	0.40	22.7-25.0	17.1-18.8	CR + F	Su
TRPB						
Fruid	1968	0.25	9.0-18.0	12.4-24.7	CR + F	X
Talla	1905	0.25	0 -16.6	0 -18.5	CR + F	X
Baddinsgill	1930	0.25	2.3- 4.0	10.9-18.9	CR + F	X
Westwater	1967	0.50	1.6- 2.9	11.8-21.3	CR + F	Sp

Table 1b. Year of completion of each reservoir, distance of sample site below dam; compensation flow; proportion of unregulated ADF released as compensation flow, (%); and release pattern. [(a) u/s of Sett confluence; (b) d/s of Sett confluence; (c) and (d) u/s and d/s of settling tank output; (e) and (f) u/s and d/s of fish hatchery; (g) unregulated site on Wear u/s of confluence; ≠ sampled only in spring; CD Constant discharge; CR Control rules; M Maintained flow; F Freshets; V Variable; U Unregulated. Occurrence of spillage on sampling occasions Sp = Spring; Su = Summer; Au = Autumn; X = no spillage; ? = no observation].

Table 2. The 27 environmental variables used in the analyses together with their abbreviations and brief notes on data collection procedures. Variables whose abbreviations are prefixed L were $\log_{10}$ transformed.

Environmental variable	Abbreviation	Units of measurement or no. categories
Information from maps		
Distance of site from source	LKM	km
Slope of site	LSLOPE	m km^{-1}
Altitude of site	LALT	m
Discharge category for site	DISCH	9 categories
Information from survey area sheet (completed once)		
Mean channel width of survey area	LMEANW	m
Depth category of survey area	DEPTHC	5 categories
Information from sample data sheet (completed in 3 seasons)		
Date of sampling - spring	DAY 1	1-365
Date of sampling - summer	DAY 2	1-365
Date of sampling - autumn	DAY 3	1-365
Mean width of water in sample area	LMWIDTH	m
Mean depth of water in sample area	LMDEPTH	cm
Maximum surface velocity of water in sample area	MAXVEL	5 categories
Minimum surface velocity of water in sample area	MINVEL	5 categories
Modal/Median surface velocity of water in sample area	MEDVEL	5 categories
Mean substratum in sample area	MSUBST	phi
Minimum dominant particle size in sample area	MINDOM	7 categories
Maximum dominant particle size in sample area	MAXDOM	7 categories
Modal/Median dominant particle size in sample area	MEDDOM	7 categories
Maximum percentage macrophyte cover in sample area	MAXMAC	%
Minimum percentage macrophyte cover in sample area	MINMAC	%
Mean percentage macrophyte cover in sample area	MEANMAC	%
Chemical data provided by the water industry		
pH	pH	
Dissolved oxygen	O2B	mg l^{-1} O
Total oxidised nitrogen (Nitrate + Nitrite)	LTON	mg l^{-1} N
Chloride	LCL	mg l^{-1} Cl
Dissolved orthophosphate	LORPH	mg l^{-1} P
Total alkalinity	ALK	mg l^{-1} $CaCo_3$

1. Obtained from 1:250,000 O.S. maps
2. Obtained from maps by WA/RPB biologists
3. Provided by Water Data Unit as average daily flow. 1 ≤0.31 cumecs; 2 ≤0.62; 3 ≤1.25; 4 ≤2.5; 5 ≤5.0; 6 ≤10.0; 7 ≤20.0; 8 ≤40.0; 9 ≤80.0.
4. Normally assessed using occurrence of bankside vegetation etc.
5. Depth in over 50% of survey area. 1 <25 cm; 2 <50; 3 <100; 4 <200; 5 ≥200.

7. Mean width from three sampling dates.
8. Mean of nine depth readings: ¼, ½ and ¾ width x three sampling dates.
9,10,11. Maximum, minimum and modal/median categories respectively from three sampling dates. Categories: 1 ≤10 cm sec^{-1}; 2 ≤25; 3 ≤50; 4 ≤100; 5 >100.
12. Mean phi values from three sampling dates weighted by % composition of the substratum in each season and based on four phi values estimated by eye: boulders/cobbles (phi -7.75); pebbles/gravel (-3.25); sand (2.0); silt/clay (8.0
13,14,15. Minimum, maximum and modal/median categories respectively from three sampling dates.

7 phi categories:	-9	-6.5	-4.5	-2	2	6.5	9.5
range of phi values:	-10,-9,-8	-7,-6	-5,-4	-3,-2,-1	0,1,2,3,4	5,6,7,8	9,10
name of particle:	boulders	cobbles	pebbles	gravel	sand	silt	clay

16,17,18. Maximum, minimum and mean % cover respectively from three sampling dates.
19. Mean of all determinations available for one year.

SITE CODE	LKM	LSLOPE	LALT	DISCH	LMEANW	DEPTHC	DAY1	DAY2	DAY3	LMWIDTH	LMDEPTH	VEL			MSUBST	MINDOM	MAXDOM	MEDDOM	MAC			PH	O2B	LTON	LCL	LORPH	ALK
												MAX	MIN	MED					MAX	MIN	MEAN						
6201	0.88	1.29	2.37	3	0.85	1	100	179	262	0.82	1.38	5	3	3	-6.73	-9.00	-9.00	-9.00	5	0	1.7	6.32	11.00	-0.12	1.01	-1.82	9.67
6301	0.83	1.23	2.26	3	0.73	1	100	179	262	0.78	1.49	4	3	3	-5.65	-6.50	-6.50	-6.50	30	0	11.7	6.33	10.70	0.20	1.10	-1.70	27.33
6401	1.01	1.06	2.37	4	1.02	2	101	180	263	1.02	1.50	5	3	4	-7.36	-9.00	-6.50	-6.50	15	0	8.3	7.63	9.70	-0.51	0.99	-1.35	45.73
6501	1.01	1.18	2.47	3	1.00	2	101	180	263	1.17	1.25	4	3	4	-6.47	-6.50	-6.50	-6.50	40	10	23.3	7.85	10.60	-0.19	0.93	-1.70	76.86
6601	0.95	1.49	2.20	3	0.90	2	101	180	263	0.97	1.47	3	2	3	-6.14	-6.50	-6.50	-6.50	70	0	36.7	7.45	10.80	-0.27	0.87	-1.52	43.50
6701	0.43	1.56	2.26	1	0.54	1	101	180	263	0.60	1.11	3	2	2	-1.74	-6.50	6.50	-6.50	25	0	15.0	7.58	11.00	0.15	1.70	-1.00	25.00
6801	0.89	1.26	2.32	1	0.55	2	102	181	264	0.81	1.51	3	3	3	-5.17	-7.75	-6.50	-6.50	65	1	38.7	7.03	11.53	-0.20	1.23	-1.48	17.43
6901	0.74	1.31	2.36	1	0.65	1	102	181	264	0.62	1.09	3	3	3	-4.73	-6.50	-4.50	-6.50	5	0	2.0	6.82	11.00	-0.19	1.20	-1.30	11.00
6903	0.82	1.34	2.32	1	0.74	1	102	181	264	0.74	1.41	3	3	3	-4.23	-6.50	-4.50	-6.50	10	1	4.3	6.82	11.00	-0.19	1.20	-1.30	11.00
7001	0.65	1.34	2.33	1	0.65	1	102	181	264	0.62	1.32	3	1	3	-4.60	-6.50	-6.50	-6.50	0	0	0.0	6.82	11.00	-0.19	1.20	-1.30	11.00
7101	1.11	1.26	2.11	4	1.15	2	102	181	264	1.21	1.55	3	2	3	-4.47	-9.00	-6.50	-6.50	30	1	17.0	7.07	10.36	-0.14	1.29	-1.45	15.71
7201	0.48	1.09	2.47	4	0.60	1	102	181	264	0.34	1.35	5	3	4	-5.20	-6.50	-4.50	-6.50	70	5	35.0	7.48	11.46	0.03	1.62	-1.30	62.98
7203	0.89	1.13	2.31	1	0.65	1	102	181	264	0.71	1.11	4	3	3	-4.19	-6.50	-5.50	-6.50	5	0	2.0	7.35	9.88	0.51	1.73	-1.00	85.09
7301	1.01	1.12	2.07	1	0.51	1	102	181	264	0.87	1.45	4	3	3	-5.83	-6.50	-6.50	-6.50	20	5	11.7	7.23	10.68	0.22	1.62	-1.30	57.51
7401	0.40	1.35	2.31	1	0.40	1	103	182	264	0.39	0.89	4	4	4	-4.85	-6.50	-4.50	-6.50	35	1	13.7	7.32	11.68	-0.21	1.45	-1.40	36.11
7501	0.44	1.54	2.33	1	0.65	1	103	182	265	0.64	1.21	5	5	5	-6.33	-6.50	-6.50	-6.50	20	1	13.7	5.56	11.00	-0.46	1.65	-1.77	3.19
7601	0.93	1.33	2.36	3	0.90	1	103	182	265	0.97	1.27	4	3	4	-5.17	-7.75	-6.50	-6.50	70	30	52.3	4.53	11.00	-0.46	0.90	-1.96	0.50
7701	1.32	0.94	1.83	2	1.02	1	103	182	265	0.99	1.24	3	2	2	-4.19	-9.00	-6.50	-6.50	90	10	46.7	7.80	10.34	0.11	1.33	-1.10	66.67
7701	1.32	0.94	1.63	2	0.72	1	103	182	265	0.89	1.36	3	3	3	-3.94	-6.50	2.00	-6.50	75	20	38.3	7.80	10.34	0.11	1.33	-1.10	66.67
7703	0.89	1.04	2.25	1	0.93	1	103	186	265	0.86	1.38	4	4	4	-6.32	-6.50	-6.50	-6.50	95	80	88.3	x-1	-1.00	-1.00	x-1	-1.00	-1.00
7801	1.19	0.74	2.10	5	1.11	2	103	182	265	1.10	1.45	4	2	3	-5.20	-6.50	-6.50	-6.50	1	0	0.3	7.36	10.84	-0.24	1.11	-1.89	29.86
7901	1.10	1.48	2.39	2	1.00	3	104	183	266	0.90	1.49	5	3	4	-5.39	-7.75	-6.50	-7.75	70	25	43.3	7.40	11.00	-0.55	0.85	-1.30	27.00
8001	1.28	1.21	2.34	3	1.20	1	104	183	266	1.23	1.52	4	2	4	-6.43	-9.00	-5.50	-9.00	85	5	50.0	7.40	11.00	-0.51	0.84	-1.52	33.00
8101	0.80	1.31	2.53	3	0.51	2	104	183	266	0.81	1.61	4	2	2	-3.23	-6.50	2.00	-6.50	95	0	35.0	7.39	11.00	-0.36	0.30	-1.55	23.02
8201	0.90	1.14	2.53	2	0.88	1	104	183	266	0.82	1.37	4	2	4	-4.11	-6.50	-4.50	-6.50	5	0	1.7	x-1	-1.00	-1.00	x-1	-1.00	-1.00
8301	1.22	0.88	2.28	3	0.98	2	104	183	266	0.91	1.24	4	4	4	-5.76	-6.50	-6.50	-6.50	65	22	37.3	7.33	11.00	-0.06	1.03	-1.70	17.83
8401	0.89	0.86	2.45	1	0.70	1	105	184	267	0.67	1.22	4	4	4	-6.09	-6.50	-5.50	-6.50	30	0	11.7	7.23	10.55	-0.37	0.86	-1.52	33.75
8501	1.01	1.26	2.43	1	0.70	1	105	183	267	0.92	1.18	3	2	3	-6.48	-6.50	-6.50	-6.50	75	10	48.3	7.23	10.55	-0.37	0.86	-1.52	33.75
8601	0.44	1.45	2.47	1	0.48	2	105	184	267	0.49	1.34	4	2	3	-5.85	-6.50	-6.50	-6.50	95	15	60.0	7.59	10.93	-0.12	1.00	-1.30	62.23
8701	0.63	1.22	2.45	1	0.44	1	105	184	267	0.48	1.26	4	3	3	-5.36	-6.50	-2.00	-6.50	70	40	53.3	7.54	10.69	0.08	1.03	-1.30	70.49
8801	1.12	1.20	2.23	3	0.90	1	105	185	266	0.94	1.30	3	3	3	-6.15	-6.50	-6.50	-6.50	100	5	55.0	6.25	11.00	-0.68	0.48	-2.05	6.50
8901	0.96	1.09	2.31	3	0.90	2	106	185	267	0.90	1.43	3	3	3	-6.51	-6.50	-6.50	-6.50	55	20	35.0	6.83	11.00	-0.64	0.60	-1.82	14.75
9001	0.68	1.44	2.25	2	0.65	2	106	185	268	0.64	1.14	5	4	4	-5.84	-7.75	-6.50	-6.50	95	30	68.3	7.22	10.46	-0.05	1.40	-0.72	30.00

Table 3. Summary of mean values of physical and chemical variables recorded at each site.

Site	Temperature °C		
	Sp	Su	Au
SWWA			
Meldon	-	9.1	12.6
Wimbleball	-	11.7	14.0
WW			
Llwyn-on	-	10.7	12.8
Taf-Fechan	-	11.6	12.6
Talybont	6.5	13.1	13.4
NWWA			
Bottoms/Teggsnose	6.4	13.3	12.7
Fernilee	5.2	9.0	9.1
Kinder 1	6.0	10.9	10.5
Kinder 2	6.5	12.6	10.0
Sett	6.3	12.2	9.6
Bottoms (Longdendale)	5.7	14.3	11.7
Castleshaw	5.4	13.4	11.2
Thirlmere	-	13.5	12.4
Haweswater	-	14.5	12.4
Belmont	-	21.0	11.7
YWA			
Winscar	4.6	10.4	8.9
Scout Dike	6.2	14.4	11.5
More Hall 1	6.1	10.2	12.5
Boothwood	4.9	7.7	11.6
Widdop	6.1	15.1	8.8
Lindley Wood 1	8.0	13.4	12.3
Lindley Wood 2	8.0	14.5	13.6
Thruscross	5.5	12.0	12.1
Gouthwaite	6.2	16.0	10.6
NWA			
Hury	4.9	13.4	11.4
Grassholme	5.1	10.6	11.8
Burnhope	5.2	12.0	12.5
Wearhead	6.6	13.6	13.4
Derwent		14.3	14.1
TRPB			
Fruid	-	13.5	11.0
Talla	-	12.8	10.1
Baddinsgill	-	10.5	10.6
Westwater	-	13.5	11.3

Table 3a. Temperature readings at the 33 residual flow sites obtained at the time of sampling in spring, summer and autumn. (Missing values are indicated by -)

Sites	Sp	Su	Au	Co
Meldon	7	14	9	16
Wimbleball	31	21	31	39
Llwyn-on	18	18	23	29
Taf Fechan	17	23	18	31
Talybont	26	24	26	35
Bottoms/Teggsnose	31	30	25	41
Fernilee	17	17	18	28
Kinder 1	24	24	28	36
Kinder 2	29	28	28	40
Sett	25	21	21	36
Bottoms (Longdendale)	13	22	20	30
Winscar	19	22	19	28
Scout Dike	22	21	22	33
More Hall 1	26	26	24	34
Castleshaw	19	24	24	32
Boothwood	13	12	16	18
Widdop	14	18	22	29
Lindley Wood 1	39	34	31	47
Lindley Wood 2	33	38	33	47
Thruscross	19	27	17	29
Gouthwaite	36	35	28	49
Hury	34	35	33	44
Grassholme	28	33	27	39
Burnhope	17	18	19	35
Wearhead	17	14	11	24
Derwent	28	27	26	36
Fruid	23	20	21	37
Talla	26	26	29	38
Baddinsgill	25	27	23	35
Westwater	31	36	26	43
Thirlmere	22	27	29	36
Haweswater	29	27	26	39
Belmont	24	23	19	33
Total families	63	61	61	70

Table 4. Seasonal variations in the number of families recorded at 33 sites. (Sp = spring; Su = summer; Au = autumn; Co = combined seasons).

Table 5. The occurrence and relative abundance of families of macroinvertebrates recorded at 33 sites in Spring, Summer and Autumn samples. The abundance figures are the sum of the values recorded in each season.

Table 5.

	Meldon	Wimbleball	Llwyn-on	Taf Fechan	Talybont	Bottoms/Teggsnose	Fernilee	Kinder 1	Kinder 2	Sett	Bottoms (Longdendale)	Winscar	Scout Dike	More Hall 1	Castleshaw	Boothwood	Widdop	Lindley Wood 1	Lindley Wood 2	Thruscross	Gouthwaite	Hury	Grassholme	Burnhope	Wearhead	Derwent	Fruid	Talla	Boddinsgill	Westwater	Thirlmere	Haweswater	Belmont	Occurrences
Spongillidae						2																												1
Hydridae														1					3								3	2			2			5
Planariidae		2			5	4	2	2						6	6		1	5	4		3		1			1		2	4	5	2	6		18
Dendrocoelidae		1																	1															2
Hydrobiidae		4				8		1			1		2	3	1			2	7															9
Lymnaeidae		4	2	2	3	6			1					1	4			2	3		1	2	2	4		3	2	3	5	1	2	3	2	22
Planorbidae			1			2																									6			3
Ancylidae		5	2	1		2	2		3	1			1	4				2	2		3	4	4	1		4	1	3	4	5		3	7	22
Sphaeriidae	1		1		1	9	2	3	2	2	5	2	5	3	2		1	2	4	3	5	4	3	3		5	1	4	3	4	9	1	8	29
Naididae	6	1	4	6	7	9	1	7	3		4	1	6	1	5	5	1	1	9	2	5	4	1	1		5	7	2	5	5	5	3	7	31
Tubificidae						3	2	3	4	6	2	2	5	4	3	1	2	5	8	4	6	2	2	4		1	2		2	5	1	4	5	26
Enchytraeidae	5	2		1		2		2		1	1	1	2	1	2	3	2	3	2	3	2	4					2	2	1	2	2	1		24
Haplotaxidae		2																																1
Lumbriculidae	3	2	1	2	3	7	1	4	2	1	2	5	6	5	4	3	3	4	8	3	6	3	5	4		2	3	2	4	2	3	3	9	32
Lumbricidae		3		1	1	3		2	1		1	3	1	2	3			1	3	3	3	4	2	1	1	1	1	3	3	3	2	2	6	27
Glossiphoniidae						4							1					4	4		1		1	2		1	1			1	2	1		12
Erpobdellidae						2							3		1			4	6		1										2			7
Hydracarina			1	1	1		1		2	2	2	2	2		1		1	3	5		1	3		1	1	4	1		4	1	4	2	2	24
Asellidae					3	1							4								2													4
Gammaridae			6	1	6	9	6	3	1	2		5	8	7	4			6	7	9	5	6	5	2			6	9	9	8	4	5		25
Siphlonuridae										1																								1
Baetidae		7	6	5	6	5	4	9	7	5	4	8	6	7	8	4	3	4	8	3	4	7	9	2	6	5	6	8	6	9	5	5	9	32
Heptageniidae		4	3	1	2		1	2	6	7		1						1		1	3	3	7	1	5		1	4	2	6		3		21
Leptophlebiidae		1						2	1	1			1	1			1	2	1		3	4	3	1		2	3	2	1	5	1	1	1	21
Ephemerellidae		5	2	3	2	2	4	3	4	3			2	4	3			2	4	3	3	2	3		1	2	2	4	3	4	1	4	4	27
Ephemeridae		3				1															6	4	1	1		3								7
Caenidae		5	2	1		1												3	4		5	5	4	1	1	5	4	4		2		3		16
Taeniopterygidae			1		1		1	1	2																2									6
Nemouridae	2	3	4	1	2	1	5	7	4	2	4	6	1	5	3	5	7	4	4	6	2	4	2	2	3	3	1	3	7	4	3	3	4	33
Leuctridae	5	5	4	3	4	3	4	9	5	5	5	3		7	3	4	7	5	6	6	7	4	6	1	4	7	4	4	5	6	6	6	2	32
Capniidae																											1	1	1					3
Perlodidae	2	2	2		1	1	2	1	3	1		1				2	3			3		3	1	1	3	2	2	3	3	4	3	3	1	25
Perlidae									2	1													3					2						4
Chloroperlidae	1	7	2					3	3	4	1	2		2		2	2	1			2	1	2		1		3	2	4	1	4	2	1	23
Corixidae																												1						1
Haliplidae						1												1											1					3
Dytiscidae				1			1	2	1	2	3	2	1		1		1	1	1	1	1	3		1		1	1		1	2		2		21
Gyrinidae																		1			2													2
Hydrophilidae	1								1					1	1		1	1		1	1						1			3		1		11
Helodidae																														1				1
Elminthidae		2		3			2	2	5	3	3			1			5	3	1	2	5	6	6	2	5	4	1	6	2	9		2	1	24
Sialidae						2	2	3	1	1	1	1	2	3	1		2	3	2			2	1			2						2	1	18
Rhyacophilinae	1	3	5	4	3	2		5	4	1	3	4		2	3	4	2	2	6	3	2	3	3	1	2	3	2	4	4	4		3	6	30
Glossosomatinae							1	1	2	2									1			1										1		7
Polycentropodidae	2	4	5	5	6		4	6	3	3	7	6	1	6	2	2	5	6	6	6	7	5	5	1	3	6	7	6	5	4	7	6	3	32
Psychomyiidae										1				1				3	1		1	1	1					1		1				9
Hydropsychidae		6	6	7	8	6		4	6	3	1		6	5	2		1	5	7	1	8	7	5		1	3	6	8		6	5	4	3	27
Hydroptilidae		2		1	2						1		1				1	2	1			2	4	2	1	5	3	1	4	2	6	1		19
Limnephilidae		2		3		3	4	4	4	3		1	2	4	2	1	4	2	3	2	2	2	1		1	3	1	1	1	6	1	3	1	28
Molannidae																			1															1
Beraeidae																			1					1						1				3
Odontoceridae					1			1	3														2					3		1				6
Leptoceridae		3		3	2						3		4		1			4	3		6	4				5				1	4		2	14
Goeridae		1							1	1																				6				4
Lepidostomatidae		1			1														1	2	5	4	2								2	3		9
Brachycentridae																					1													1
Sericostomatidae		4		1	2	1		1	3				2	3				3	3	2	4	4	2	2	1	4		1			2	2		20
Tipulidae		1	1	2	2	6	1	4	3	3	3	4			6	2	1	2	4	3	2	4	3	1	2	1	2		1	4		1	3	28
Psychodidae						1										1		1			1	2		1										6
Ceratopogonidae			3	4	1	3					1				1			3	2		2	1		2						1	1		2	14
Tanypodinae	3	1	3	3	6	6	2	4	2	3	4	5	6	3	3		4	5	6	2	3	3	3	5		2	3	5	3		6	3	6	30
Diamesinae	1	5	5	6	6	5	3	2	2	1	3	3	5	1		4	1	2	4	2	3	3	4	2	4	3	5	3	7	7	2	3	4	32
Orthocladiinae	5	7	7	6	8	9	3	6	5	4	7	6	9	7	7	6	7	7	8	4	5	7	7	4	5	7	7	7	9	7	7	7	8	33
Prodiamesinae		1			5	3		2	1	3	1	1	1		2				3		1			2					1				1	15
Chironomini	1	1	3	1	4	4	1		2	3	1	2	3	4				4	5		5	6	4	2		2	5	3	3	2	7	4	2	27
Tanytarsini	4	4	6	2	7	5		3	1	5	5	6		3	6	2	2	6	9	3	5	7	5	3	1	4	2	3	7	6	7	5	5	31
Simuliidae			4		1	4	1	1	5	2	2	3	1	3	6		2	4	1		1	1	4		1		1	1		4	1		2	24
Empididae		1		2	3	6	1	2	3	1	2		1	2	5	5	3	4	4	3	3	3			3	3		2	4	3	1		2	26
Rhagionidae		1																			1	3		1		1								5
Muscidae			1		1	3						2	1					2		2	2												1	9
Total taxa	16	39	29	31	35	41	28	36	40	36	30	28	33	34	32	18	29	47	47	29	49	44	39	35	24	36	37	38	35	43	36	39	33	

Table 6. COMBINED SEASONS RESIDUAL FLOW SITES

CORRELATIONS BETWEEN DECORANA SCORES AND ENVIRONMENTAL VARIABLES

	AXIS 1	AXIS 2	AXIS 3	AXIS 4
LOG KM	0.078	0.530	0.002	-0.203
LOG SLOPE	-0.070	-0.382	0.127	0.207
LOG ALT	-0.464	-0.119	0.338	0.147
DISCH	0.132	0.202	0.350	0.070
LOG MEANW	-0.054	0.321	0.114	-0.036
DEPTHC	0.104	0.292	0.134	0.223
DAY1	-0.110	0.292	-0.099	-0.091
DAY2	-0.080	0.199	-0.164	-0.188
DAY3	-0.146	0.303	-0.098	-0.040
LOG MWIDTH	-0.011	0.373	0.170	-0.044
LOG MDEPTH	-0.220	0.281	0.015	0.004
MAX VEL	-0.044	-0.243	0.194	0.149
MIN VEL	0.041	-0.353	0.007	-0.154
MED VEL	-0.388	-0.298	0.233	-0.025
MSUBST	0.290	0.029	-0.282	0.386
MIN DOM	0.021	0.152	-0.070	0.050
MAX DOM	0.386	0.076	0.138	0.481
MED DOM	0.173	0.020	-0.101	0.187
MAX MAC	0.186	0.197	-0.076	-0.044
MIN MAC	-0.077	-0.031	-0.356	-0.091
MEAN MAC	0.061	0.101	-0.159	-0.112
pH	0.359	0.428	0.015	0.394
O2B	-0.262	-0.264	-0.330	-0.095
LOG TON	0.361	-0.011	-0.226	0.144
LOG CL	0.273	-0.427	-0.284	0.213
LOG ORPH	0.258	-0.017	-0.184	0.388
ALK	0.353	0.216	0.001	0.219

N

Group 39 Contains 3 members

R. Wansbeck	Bothal	40
R. Spey	Kincraig	34
R. Don	*Scout Dike**	33

Group 44 Contains 4 members

R. Rother (Sussex)	Durford Bridge	50
Great Eau	Swaby	40
Great Eau	Bellau	42
R. Bollin	*Bottoms/Teggsnose**	41

Group 50 Contains 3 members

Gwendraeth Fach	Garn-Lwyd	54
Great Eau	Ruckland	42
R. Washburn	*Lindley Wood 2**	47

Group 52 Contains 12 members

R. Dudwell	Burwash Weald	48
R. Rother (Kent)	Etchingham	47
R. Tillingbourne	Wotton	45
R. Wey	Eashing	39
R. Derwent (NWWA)	Ouse Bridge ≠≠	40
R. Derwent (YWA)	Langdale End	44
R. Swale	Topcliffe	51
R. Wansbeck	Mitford Gauging Station	48
R. Forth	Parks of Garden	51
R. Washburn	*Lindley Wood 1*	47
R. Nidd	*Gouthwaite*	49
St Johns Beck	*Thirlmere*	36

Group 56 Contains 15 members

R. Tees	Cauldron Snout*	34
R. Spey	Boat of Garten	45
R. Haddeo	*Wimbleball**	39
R. Taff	*Llwyn-On**	29
R. Taf Fechan	*Taf Fechan**	31
R. Caerfanell	*Talybont**	35
R. Balder	*Hury**	44
R. Lune	*Grassholme**	39
Burnhope Burn	*Burnhope**	35
R. Derwent	*Derwent**	36
Fruid Water	*Fruid**	37
Talla Water	*Talla**	38
R. Baddinsgill	*Baddinsgill**	35
Haweswater Beck	*Haweswater**	39
Belmont Brook	*Belmont**	33

Group 57 Contains 8 members

R. Ribble	Horton	37
R. Tees	Over Dinsdale	37
R. Tyne (NWA)	Wylam	39
R. Wansbeck	Kirk Whelpington≠≠	44
R. Wansbeck	Meldon	42
R. Teith	Bridge of Teith, Doune	39
R. Stinchar	Ballantrae	37
Westwater	*Westwater**	43

Group 58 Contains 16 members

Avonwater	Wooton Bridge (1)	43
R. Hodder	Cross of Greet Bridge	23
R. Esk	Westerdale	31
R. Esk	Castleton	30
Water of Chon	Kinlochard #	26
R. Forth	Aberfoyle Bridge #	46
R. West Okement	*Meldon**	16
R. Goyt	*Fernilee**	28
R. Kinder	*Kinder 1**	36
R. Sett	*Sett*	36
R. Etheroe	*Bottoms (Longdendale)**	30
R. Don	*Winscar**	28
Ewden Beck	*More Hall 1**	34
R. Tame	*Castleshaw*	32
Hebden Water	*Widdop**	29
R. Washburn	*Thruscross**	29

Group 60 Contains 12 members

R. Camel	Tuckingmill	38
R. Exe	Edbrooke	42
R. Avill	Wheddon Cross	40
R. Teifi (Tyfi)	Strata Florida	41
R. Hodder	D/S Langden Beck	44
R. Dane	Hug Bridge	47
R. Derwent (NWWA)	High Stock Bridge #	44
R. Ehen	Ennerdale Bridge #	36
R. Teith	Laighlands	37
R. Dee	D/S Aboyne	49
R. Dee	D/S Banchory	38
R. Kinder	*Kinder 2**	40

Group 63 Contains 13 members

Gayle Beck	Cam End	36
R. Swale	Keld	29
R. Tees	Moorhouse	32
R. Tees	Dent Bank	30
South Tyne	Dipper Bridge	29
South Tyne	Alston	28
South Tyne	D/S Knaresdale	27
South Tyne	Featherstone	28
R. Dee	Linn of Dee	23
R. Dee	Braemar	33
R. Spey	Garva Bridge	29
Boothdean Stream	*Boothwood**	18
R. Wear	*Wearhead*	24

Table 7. TWINSPAN analysis of combined seasons family quantitative data from 301 sites (268 River Communities Project sites + 33 residual flow sites). Only groups containing residual flow sites (in italics) are listed. Also shown are the numbers of families recorded from each site. (* = sites below reservoirs; # = sites below lakes)

	n	L.Km Mean	L.Km Var.	L.Slope Mean	L.Slope Var.	L.Alt. Mean	L.Alt. Var.	Discharge Mean	Discharge Var.	LM Width Mean	LM Width Var.	LM Depth Mean	LM Depth Var.	Med. Vel. Mean	Med. Vel. Var.	MSubst. Mean	MSubst. Var.	Mean Mac. Mean	Mean Mac. Var.
Group 39																			
U	2	1.66	0.001	0.24	0.06	1.67	0.45	6.0	1.0	1.60	0.16	2.03	0.07	2.0	0	1.20	9.55	10.0	100.0
R	1	0.88	-	1.15	-	2.31	-	1.0	-	0.70	-	1.11	-	3.0	-	-4.19	-	2.0	-
Group 44																			
U	3	0.95	0.02	0.31	0.15	1.44	0.03	2.0	0.67	0.69	0.09	1.44	0.05	4.0	0.67	-2.25	9.83	36.0	672.0
R	1	0.36	-	1.56	-	2.26	-	1.0	-	0.60	-	1.11	-	2.0	-	-1.74	-	15.0	-
Group 50																			
U	2	0.5	0.04	1.00	0.09	1.87	0.02	1.0	0	0.57	0.07	1.06	0.05	2.5	0.25	-4.47	2.10	2.0	4.0
R	1	1.32	-	0.95	-	1.83	-	2.0	-	0.90	-	1.36	-	3	-	-3.94	-	38	-
Group 52																			
U	9	1.25	0.17	0.19	0.34	1.59	0.11	4.22	5.06	0.99	0.15	1.40	0.05	3.44	0.47	-1.93	13.29	38.11	420.99
R	3	1.20	0.01	0.98	0.03	2.05	0.03	3.33	1.56	0.99	0.01	1.37	0.004	3.0	0	-5.10	0.82	31.1	522.49
Group 56																			
U	1	1.82	-	-0.04	-	2.30	-	8.0	-	1.65	-	1.80	-	4.0	-	-6.40	-	1.3	-
R	13	0.94	0.04	1.22	0.04	2.37	0.009	2.85	3.05	0.87	0.04	1.46	0.10	4.0	3.38	-5.94	0.85	36.77	313.87
Group 57																			
U	7	1.48	0.20	0.54	0.12	1.50	0.38	6.14	4.98	1.29	0.13	1.48	0.05	3.71	1.63	-5.18	2.30	11.76	146.07
R	1	0.60	-	1.23	-	2.45	-	1.0	-	0.48	-	1.26	-	3.0	-	-5.36	-	53.0	-
Group 58																			
U	6	0.81	0.07	0.78	0.18	1.89	0.15	2.67	1.56	0.80	0.07	1.28	0.02	3.33	1.22	-5.19	2.98	8.55	52.75
R	9	0.93	0.08	1.34	0.09	2.18	0.09	2.1	1.65	0.76	0.07	1.32	0.04	3.44	0.25	-5.39	0.52	28.93	704.57
Group 60																			
U	11	1.21	0.28	0.64	0.18	2.02	0.05	5.18	6.51	1.06	0.19	1.43	0.10	4.18	0.33	-5.98	0.85	3.88	22.61
R	1	0.85	-	1.34	-	2.32	-	1.0	-	0.78	-	1.41	-	3.0	-	-4.23	-	4.3	-
Group 63																			
U	11	1.04	0.14	0.99	0.13	2.47	0.03	5.0	1.64	1.14	0.17	1.39	0.02	3.73	0.20	-6.71	0.54	0.94	1.09
R	1	0.44	-	1.54	-	2.33	-	1.0	-	0.64	-	1.21	-	5.0	-	-6.33	-	13.7	-

Table 7a. The mean and variance of 9 environmental variables for unregulated (U) and regulated (R) sites within TWINSPAN groups generated from a combined data set including 268 FBA Project 103 sites and the 33 residual flow sites.

Major taxonomic groups	Rank relative abundance									Families per group								
	39	44	50	52	56	57	58	60	63	39	44	50	52	56	57	58	60	63
Mollusca	6	2	5	6	6	6	6	7	7	3	5	4	5	5	3	4	3	-
Oligochaeta	2	3	3	3	4	4	4	5	5	5	5	5	5	6	5	5	4	5
Hirudinea	7	7	6	9	9	8	9	9	7	2	2	2	2	1	1	1	-	-
Crustacea	4	5	7	7	7	7	8	8	7	2	2	1	2	2	1	1	1	-
Ephemeroptera	5	6	4	4	3	3	5	4	3	3	4	4	6	6	5	4	4	4
Plecoptera	8	8	6	5	5	5	3	3	2	1	3	2	4	6	4	6	6	5
Coleoptera	8	9	8	8	8	5	7	6	6	1	1	2	5	4	4	3	3	1
Trichoptera	3	4	2	2	2	2	2	1	4	6	4	12	10	13	10	12	8	6
Diptera	1	1	1	1	1	1	1	2	1	8	12	10	13	13	8	11	9	7

Table 8. Faunal composition of residual flow sites within TWINSPAN groups. Major taxonomic groups are ranked in order of abundance based on the original log categories. The number of families within each major taxonomic group is also presented.

Site	MDA	KEY
Meldon	59	62
Wimbleball	63	59
Llwyn-on	61	56
Taf-Fechan	58	62
Talybont	62	63
Bottoms/Teggsnose	56	40
Fernilee	58	63
Kinder (1)	59	58
Kinder (2)	57	58
Sett	58	63
Bottoms (Longdendale)	60	62
Winscar	50	62
Scout Dike	63	38
More Hall (1)	57	54
Castleshaw	62	56
Boothwood	62	62
Widdop	62	62
Lindley Wood (1)	50	42
Lindley Wood (2)	50	52
Thruscross	54	63
Gouthwaite	60	50
Hury	58	50
Grassholme	61	49
Burnhope	58	60
Wearhead	57	62
Derwent	59	60
Fruid	58	63
Talla	58	56
Baddinsgill	62	48
Westwater	54	58
Thirlmere	62	48
Haweswater	62	58
Belmont	62	60

Table 9. Predicted group membership (Division 5) of residual flow sites based on MDA equations and TWINSPAN key.

	Spring		Summer		Autumn		Combined	
	S	A	S	A	S	A	S	A
Meldon	30	6.00	62	6.20	20	5.00	62	6.20
Wimbleball	170	6.80	131	6.89	137	6.52	195	6.96
Llwyn-on	89	6.85	85	6.54	79	5.27	126	6.30
Taf Fechan	63	5.25	91	6.07	93	6.20	133	6.33
Talybont	105	6.18	99	6.19	104	5.78	154	6.70
Bottoms/Teggsnose	83	4.88	100	5.26	68	4.25	142	5.46
Fernilee	100	6.25	68	5.67	77	5.50	124	6.20
Kinder 1	113	5.95	98	6.13	126	6.00	166	6.64
Kinder 2	146	6.95	129	6.79	152	6.61	192	6.86
Sett	148	6.73	86	6.14	83	5.93	172	6.88
Bottoms (Longdendale)	57	5.70	68	5.23	77	5.50	94	5.53
Winscar	77	5.92	64	5.82	66	5.50	98	6.13
Scout Dike	70	4.67	74	4.93	69	5.31	115	5.48
More Hall 1	110	5.79	115	5.75	90	5.63	138	6.00
Castleshaw	54	4.50	89	5.93	79	4.94	112	5.33
Boothwood	56	6.22	48	6.00	60	6.00	70	6.36
Widdop	66	6.00	70	5.83	95	5.94	118	5.90
Lindley Wood 1	168	6.00	133	5.54	124	5.90	197	5.97
Lindley Wood 2	133	5.54	145	5.80	131	5.70	197	6.16
Thruscross	100	6.67	114	6.33	67	5.58	129	6.45
Gouthwaite	155	6.46	177	6.56	120	6.32	212	6.42
Hury	168	7.00	165	6.60	153	6.38	198	6.83
Grassholme	149	6.48	175	7.00	138	6.27	211	6.81
Burnhope	69	5.75	69	5.75	58	4.83	147	6.39
Wearhead	93	6.64	85	7.08	50	6.25	133	7.00
Derwent	133	6.33	127	6.05	129	6.14	162	6.23
Fruid	111	6.94	75	5.77	75	5.00	164	6.31
Talla	148	6.73	120	6.32	138	6.57	194	6.93
Baddinsgill	118	6.21	112	6.22	82	5.47	154	6.42
Westwater	160	6.67	172	6.37	130	6.50	212	6.63
Thirlmere	116	6.44	110	6.11	98	5.44	145	6.30
Haweswater	141	6.41	127	6.68	119	5.67	183	6.31
Belmont	95	5.94	58	5.27	71	5.46	126	6.30
Means	109	6.15	104	6.08	96	5.74	151	6.32

Table 10. BMWP scores (S) and average score per taxon (A) at residual flow sites for Spring, Summer, Autumn and Combined Seasons samples. Mean values for S and A are also shown.

	Observed			Expected	
	S	A	T	S	A
Scout Dike	115	5.48	13	190 (140-231)	6.07 (5.6-6.5)
Bottoms/Teggsnose	142	5.46	13	190 (140-231)	6.07 (5.6-6.5)
Lindley Wood (1)	197	5.97	13	190 (140-231)	6.07 (5.6-6.5)
Castleshaw	112	5.33	14	183 (148-219)	6.43 (6.1-6.7)
Meldon	62	6.20	15	149 (106-184)	6.65 (6.2-7.1)
Bottoms (Longdendale)	94	5.53	15	149 (106-184)	6.65 (6.2-7.1)
Winscar	98	6.13	15	149 (106-184)	6.65 (6.2-7.1)
Widdop	118	5.90	15	149 (106-184)	6.65 (6.2-7.1)
Boothwood	70	6.36	15	149 (106-184)	6.65 (6.2-7.1)

Table 11. A comparison of observed score (S) and ASPT (A) for 9 sites, with expected values and 10th and 90th percentiles for each TWINSPAN group (T) to which the sites key out.

	SCORE			ASPT		
	O	P	O/P	O	P	O/P
Meldon	62	180	0.34	620	672	0.92
Wimbleball	195	175	1.11	696	633	1.10
Llwyn-on	126	185	0.68	630	701	0.90
Taf Fechan	133	201	0.66	633	693	0.91
Talybont	154	195	0.79	670	697	0.96
Bottoms/Teggsnose	142	168	0.84	546	626	0.87
Fernilee	124	178	0.70	620	647	0.96
Kinder (1)	166	175	0.95	664	638	1.04
Kinder (2)	192	178	1.08	686	640	1.07
Sett	172	160	1.08	688	638	1.08
Bottoms (Longdendale)	94	173	0.54	553	648	0.85
Winscar	98	155	0.63	613	613	1.00
Scout Dike	115	157	0.73	548	585	0.94
More Hall (1)	138	158	0.87	600	606	0.99
Castleshaw	112	174	0.64	533	624	0.85
Boothwood	70	114	0.61	636	549	1.16
Widdop	118	135	0.87	590	575	1.03
Lindley Wood (1)	197	193	1.02	597	654	0.91
Lindley Wood (2)	197	205	0.96	616	640	0.96
Thruscross	129	*	*	645	*	*
Gouthwaite	212	184	1.15	642	673	0.95
Hury	198	211	0.94	683	726	0.94
Grassholme	211	199	1.06	681	712	0.96
Burnhope	147	207	0.71	639	726	0.88
Wearhead	133	*	*	700	*	*
Derwent	162	214	0.76	623	676	0.92
Fruid	164	201	0.82	631	675	0.93
Talla	194	186	1.04	693	681	1.02
Baddinsgill	154	189	0.81	642	684	0.94
Westwater	212	206	1.03	663	669	0.99
Thirlmere	145	196	0.74	630	689	0.91
Haweswater	183	203	0.90	631	697	0.91
Belmont	126	183	0.69	630	647	0.97

Table 12. The observed and predicted scores and ASPT x100 for combined seasons data. The ratio of observed/predicted values is also shown. Predicted values are calculated using published equations based on physical and chemical data (*no chemical data available).

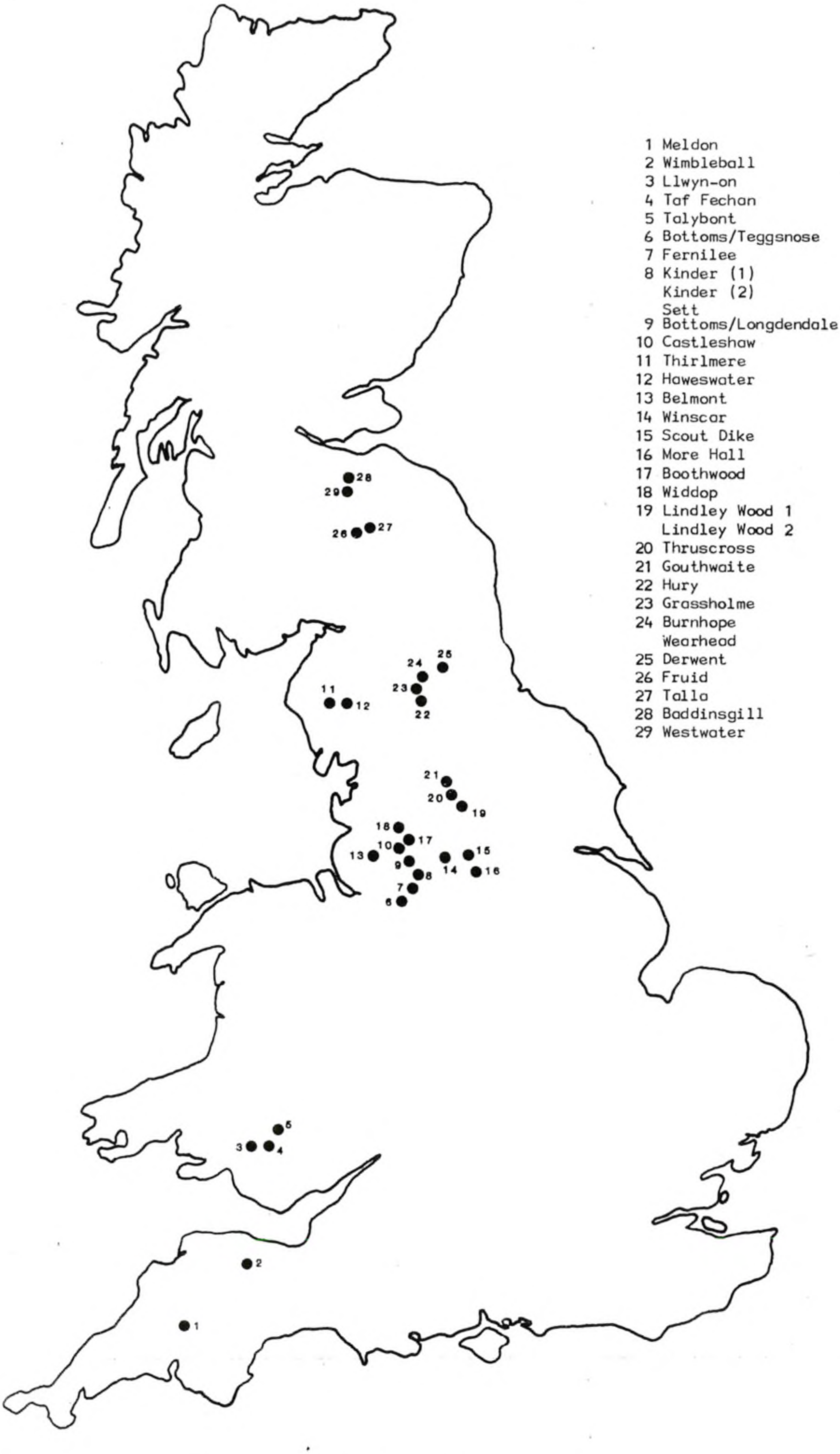
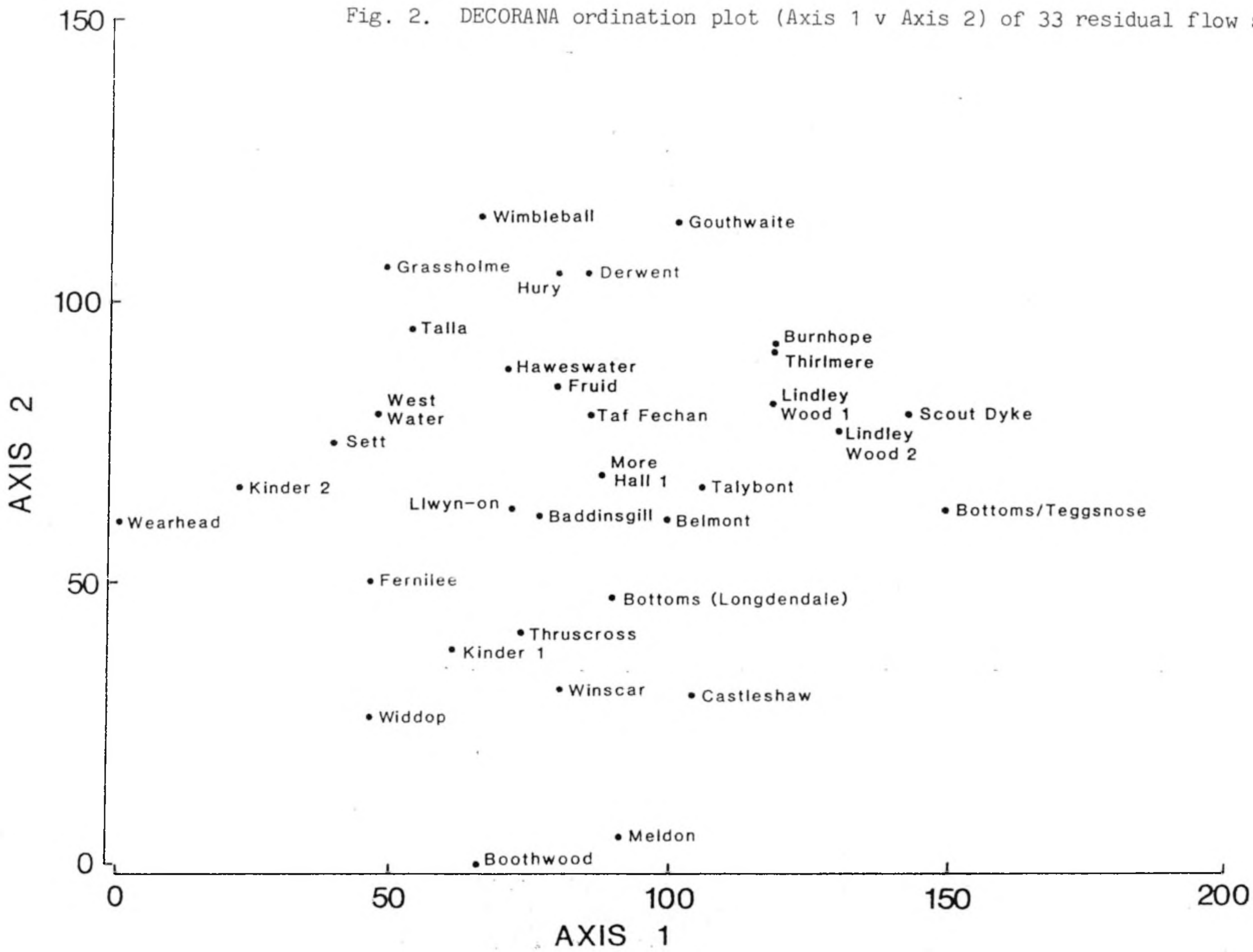


Fig. 1. The location of the sites.

Fig. 2. DECORANA ordination plot (Axis 1 v Axis 2) of 33 residual flow sites.



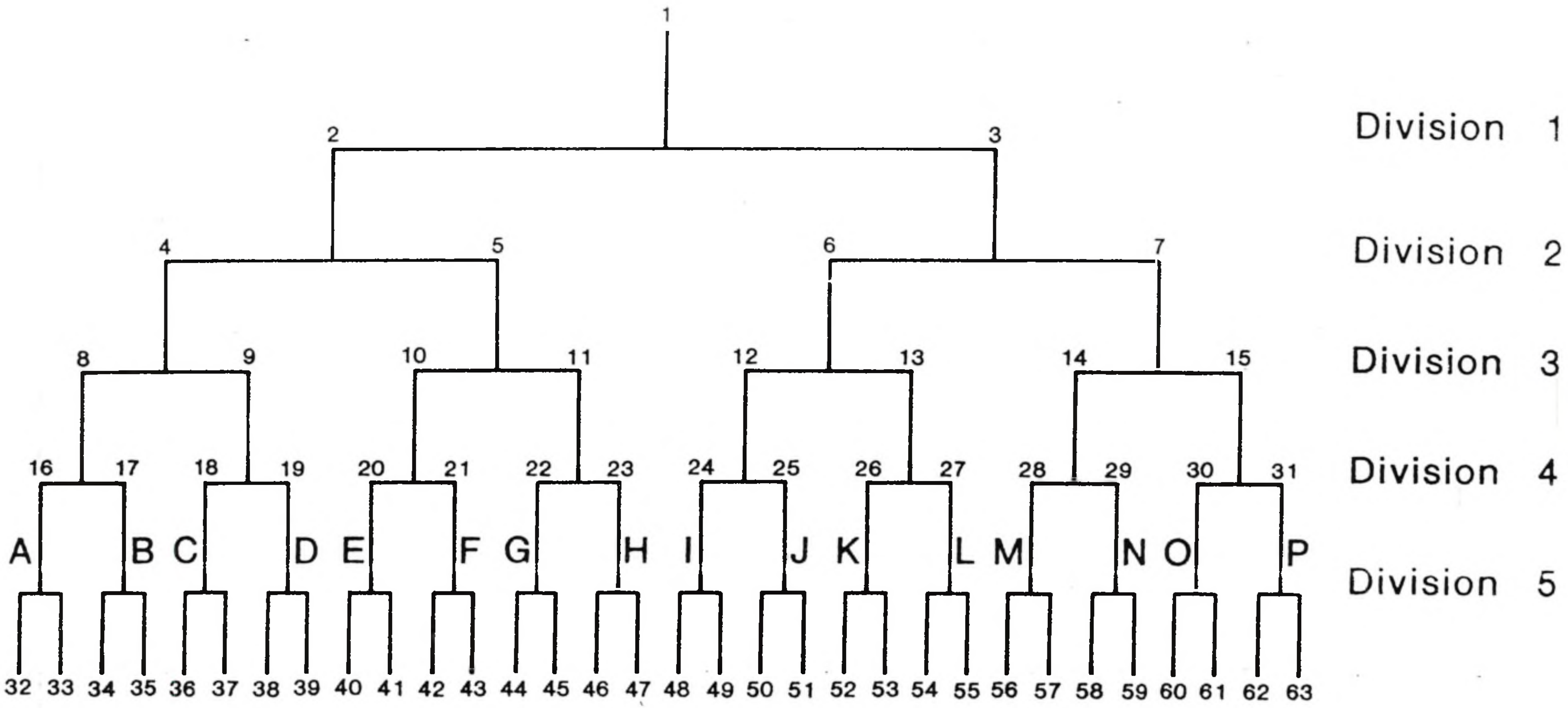


Fig. 3. A dendrogram showing how TWINSPAN groups are developed through successive divisions 1-5. The nomenclature of the groups is indicated in the Figure.

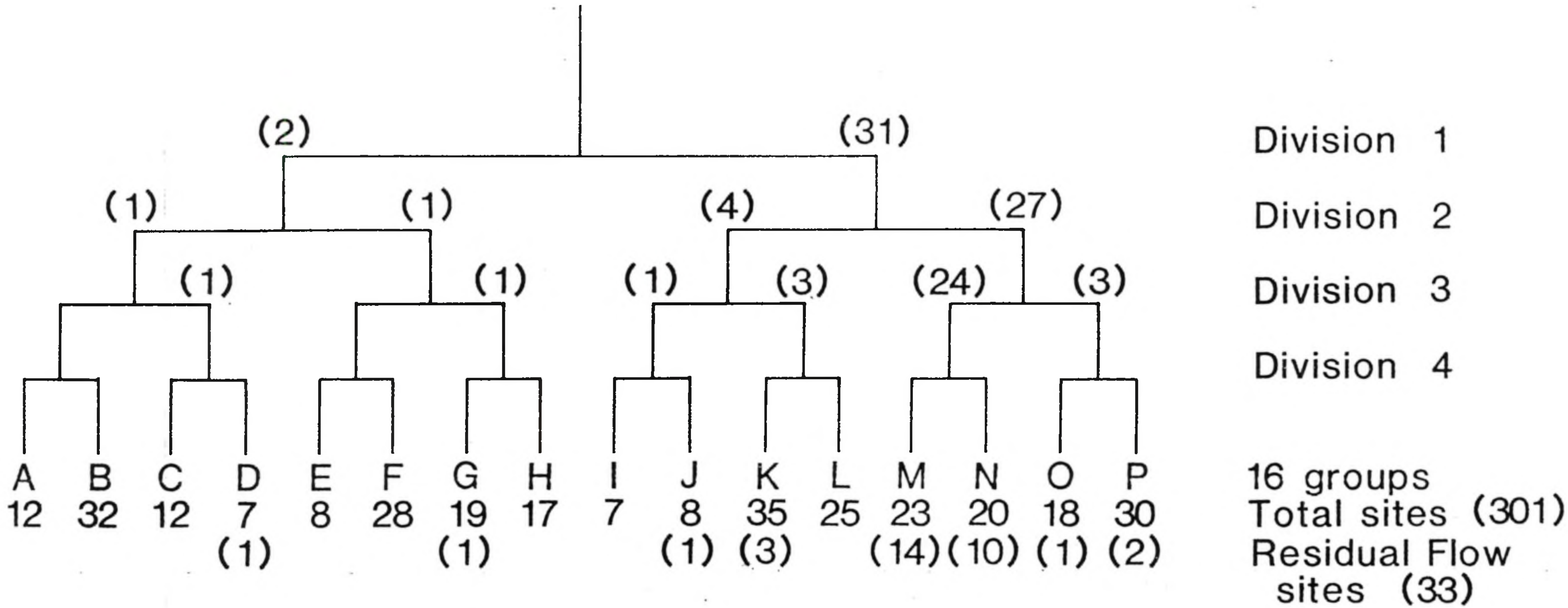


Fig. 4. TWINSPAN classification of combined River Communities Project sites (268) and Residual Flow sites (33) based on family quantitative data from combined seasons samples. Residual Flow sites are shown in parentheses.