LAND USE AND FISHERIES

Results of Sediment Trapping in Artificial Salmon Redds, Winter 1999/2000

R&D Technical Report W2-046/TR2

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Statement of Use

This report describes an over-winter study carried out to assess the quantity and source of fine sediments accumulating in salmonid spawning gravels across a wide range of rivers in England and Wales. A GIS system was used to provide environmental data for all gravel sampling sites. The data was used to investigate the effects of environmental and land-use factors on siltation rates and develop a Bayesian model of silt accumulation. The model was then applied within the GIS to all points on the river network, extrapolating the model to unsampled areas. Fisheries survey data was analysed in relation to the modelled silt accumulation data. The report will be of interest to Agency staff and others involved in the management of riverine salmonid fisheries.

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EXECUTIVE SUMMARY

This report is the second phase of a project initiated to increase our understanding of the extent and incidence of siltation of salmonid spawning gravels in England and Wales. Phase 1 of this project covered methodology development and summer trials of sampling equipment. This Phase 2 report is concerned with a more extensive over winter survey of salmonid spawning gravels in catchments across England and Wales.

A retrievable sampling basket method was to assess the quantity of fines accumulating within artificial salmon redds. One hundred and fifty baskets were successfully recovered from nineteen catchments in England and Wales. Baskets were left in position over the natural salmon incubation period of approximately 100 days.

The results showed that the greatest variability in total quantity of fines <0.85mm recovered was between individual samples at the same site, rather than between different sites on the same river, or different rivers. The percentage of fines accumulating at the sites sampled was above levels thought to cause problems in salmonid reproduction at 2 of the 43 sites sampled (5%). These sites occurred in the Yorkshire Esk and Ribble catchments. These results should be treated with caution, however, as different methodologies have been employed to calculate percentage fines in the studies used for comparison.

Chalk streams, despite their perceived siltation problems, did not have high levels of fines recorded. This is in line with other studies, and suggests that local hydrological conditions must be considered in chalk streams.

The source of the finest fraction (<0.125mm) was investigated using a simple fingerprinting approach based on a range of physical and chemical properties. These results are presented in a separate report (Walling *et al.,* 2002).

A Geographical Information System (GIS), ArcGIS, was used to provide environmental data for every gravel sampling site. This data was then used to investigate the effects of environmental and land use factors on siltation rates, and develop a model of silt accumulation.

The model used the proportion of arable land upstream, and the average altitude of the catchment upstream to estimate the accumulation of silt <0.85mm. This model accounted for 48.9% of the variation in silt accumulation between sites.

Within the GIS, the model was applied to catchments from which silt data had been collected. Due to constraints of the input data, the model could only be applied to 74% of the entire river network in the experimental catchments. This however covers the majority of spawning areas.

Fisheries survey data was analysed in relation to modelled silt accumulation data. This showed a significant, but very slight, relationship between salmon fry densities and modelled silt accumulation, with salmon density decreasing where higher silt levels were expected. No relationship was found for trout fry.

KEY WORDS

Salmon, trout, spawning, gravels, redds, sediment, siltation, land use.

1 INTRODUCTION

1.1 Background

Small quantities of silt are constantly introduced into watercourses through the natural processes of erosion and runoff. Aquatic communities are adapted to cope with these natural levels of input. Anthropogenic influences can, however, lead to a large increase in the amount of silt entering a stream, which can have detrimental effects on the aquatic community. High levels of silt can affect all levels of the food chain, from suppressing the growth of plants (Edwards, 1969), to the reduction of numbers and diversity of invertebrates (Cummins and Lauff, 1969). A full review of the impacts of siltation on rivers can be found in Wood and Armitage (1997). This project is concerned primarily with the effect of siltation on salmonid fish.

Silt can cause many problems for salmonid fish stocks. Silt from agricultural land is often associated with pesticides and fertiliser runoff, which can have toxic impacts on fish, or cause a long-term ecological change in their environment. The Environment Agency (2001) have found evidence of significant declines in the insect life of chalk streams, which is thought to be due mainly to the inputs of fertilisers and pesticides associated with agricultural runoff. This may reduce the levels of food available to salmonids. Even without these associated pollutants, inert silt can still cause serious problems for fish. High-suspended sediment can clog gills causing behavioural changes, or even death (Bruton, 1985). Exposure may also cause gill abrasion, increasing susceptibility to disease (Marks and Rutt, 1997). An increase in the turbidity of the water will also decrease the foraging efficiency of salmonid fish, as they are visual predators. It may also reduce prey availability as the silt smothers the riverbed, reducing the available habitat for prey species. The result is that increased siltation leads to decreased production of salmonid biomass (Crouse *et al.*, 1981).

The most important effect of siltation is, however, on reproduction (Theurer *et al.*, 1998; Turnpenny and Williams, 1980; Rubin ,1998; Chapman, 1998). Salmon and trout lay their eggs in redds which they create in clean river gravels. Silt in the water column can clog the gravel matrix, which results in a reduced flow through of water. This means that the eggs have a reduced oxygen supply, and waste products are not removed from them. This can dramatically decrease egg survival (Turnpenny and Williams, 1980; Crouse *et al.,* 1981; Rubin, 1998).

There has been concern for some time within the Agency and other organisations that siltation problems may be an extensive and serious threat to salmonid populations in England and Wales. Liaison with fisheries staff has shown that there are perceived problems across the majority of Environment Agency Areas (Theurer *et al.,* 1998 and pers. comm.). This concern has been increasing recently and the focus has been shifting away from the effects of eroding riverbanks to the role of catchment landuse on the siltation of gravels. This is because the most important fraction associated with decreasing egg survival within a redd is silt (<85μm, McNeil and Ahnell, 1964). Silt remains in suspension for long periods of time and runoff from fields can therefore contain a high proportion of such fines, because larger particles are deposited. Eroding riverbanks, although a much more visible source of suspended material, usually contain only a small proportion of the very fine sediment fractions which are thought to be causing the problems.

It is thought that changes in land use and land management practices may be increasing the rate of siltation, and contributing to the decline in salmonid stocks. Land use can contribute to increasing siltation in many ways. Specific events can be caused by the construction or forestry industries, which can cause problems on particular sites. Agricultural land tends to have a more diffuse, cumulative effect. Farm mechanisation has increased considerably since 1945, and this is thought to have increased the quantity of runoff from fields. This is because soil can loose its open structure and become compressed if it is overworked when wet (The Soil Code, 1998), making it less able to absorb rainfall. Fine seedbeds can also cause problems, as they can lead to a phenomenon called capping where water runs off the surface of fields taking silt with it, rather than being absorbed by the soil. It is thought that this has lead to an increase in the quantity of silt being delivered to rivers. As this increase in silt delivery has coincided with a general decline in salmonid abundance, research has been carried out looking at possible causal links.

The land use issue has also emerged through routes such as an OECD Fellowship, which reported in 1998 on the impacts of siltation on fisheries in England and Wales (Theurer *et al.,* 1998). This report recommended that, as a matter of urgency, procedures be set up to improve basic data on the incidence of siltation and that further work was required on the assessment of this risk to fisheries resources. The phase 1 report was therefore initiated to develop and test a sampling methodology. This report presents the results of a larger over winter survey of salmonid spawning gravels.

1.2 Methods of Assessing Siltation

There are several different approaches to the collection of data on the siltation of spawning gravels, most of which rely on an assessment of the size distribution of the sediments within the gravels. Methods using visual assessment techniques e.g. Iriondo (1972), may give a good indication of the overall suitability of a gravel for spawning, but cannot give quantitative results for fine sediment content. Other techniques, such as McNeil samples, use a coring cylinder which is pushed into the stream bed allowing a sample of the gravel to be extracted (McNeil and Ahnell, 1964). Shovel samples may be used instead of a core sampler and similar results are obtained if collection methods are appropriate (Hames *et al.*, 1996). The samples retrieved from these methods can be washed through a series of sieves to give a quantitative analysis of sediment composition. Freeze coring is one of the most common methods of assessment which has been applied to investigate gravel quality e.g. Stocker and Williams (1972), Milan *et al.* (2000). Freeze coring is very labour intensive, and difficult to undertake due to the necessity of using either liquid nitrogen or carbon dioxide to freeze the gravel core, but it does have the potential to provide the most accurate information on gravel composition by depth.

The application of these methods gives an assessment of the current state of gravels. This does not necessarily tell us about the environment experienced by salmonid eggs within a redd. When a salmonid creates a redd, the gravels are cleaned and fine sediments are washed downstream (Kondolf *et al.,* 1993; McNeil and Ahnell, 1964; Crisp and Carling 1989). In heavily spawned areas, a reduction in the level of fines can be detected by core sampling (McNeil and Ahnell, 1964). Although this method can detect large-scale changes in heavily spawned areas, it cannot give us information about the rate of accumulation of silt within a redd after its creation. To gain information on this aspect of siltation, it is necessary to adopt an alternative methodology. Retrievable sampling baskets have the greatest potential for measuring this. Retrievable sampling baskets are placed within gravels and filled with sediment from the surrounding area. They can be retrieved at a later date, allowing the levels of fines that have accumulated to be measured (Davey *et al.,* 1987; Sear 1993). By placing these baskets in a simulated salmon redd, and having the sampling interval matching the interval between deposition and hatching of salmon eggs, we have an opportunity to assess the conditions likely to be experienced by a salmon egg.

This study used the retrievable sampling basket methodology developed and refined in Phase 1 of the project. The full methodology can be found in the standard methodology manual, which was produced as an appendix to the phase 1 report.

1.3 Geographical Information Systems (GIS) and Fisheries Science

The use of GIS in freshwater fisheries research is a relatively new one. GIS provides a valuable tool for fisheries scientists and managers, but presently the use of GIS within fisheries lags behind that of other natural resource disciplines (Isaak and Hubert, 1997). Traditionally freshwater fisheries science has been applied to restricted spatial scales, usually in the intensive study of small areas and often over long timescales (e.g. Elliot, 1994). This is changing with a move to catchment-scale management and a consequent shift to larger scales, with the requirement to integrate disparate data sources. GIS has immediate benefits in handling the broad scale spatial data sets, and bringing together data from many sources. GIS also has benefits when creating spatially distributed process based models, which are likely to be more transportable than empirical models.

Fisher and Toepfer (1998) found that, in fisheries science, GIS is currently used mainly for mapping fish distributions and habitats. This is the most basic use of GIS and is widely employed by academic institutions and government services. In this form GIS can act as a data management and spatial query system. GIS has also been used to help target field surveys. GIS can help to highlight under-sampled areas in prime habitats, helping to make future sampling more efficient (Webb and Bacon, 1999). It can also identify areas of pristine or degraded habitat making GIS a rapid, objective and cost-effective tool to assist in the prioritisation of habitat conservation and restoration projects (Lunetta *et al.,* 1997). The more advanced analytical and predictive modelling capabilities of GIS are currently under-utilised in fisheries science (Fisher and Toepfer, 1998).

GIS are particularly well suited for large-scale integration of environmental data, which offers great potential for investigation of land use issues. Although data may have been available as hard copies in the past, the computing power now available means that a wide range of environmental data can be quickly summarised and analysed within a GIS. It was therefore decided to make extensive use of GIS within this project.

2 OBJECTIVES

This report addresses the overall objectives of the project which are:

- **To evaluate the quantity of fines accumulating within artificial salmon redds in representative locations in England and Wales.**

- **To use GIS to evaluate the impact of environmental factors of the siltation of artificial salmon redds.**

- **To create an empirical model of siltation using environmental and land use data.**

- **To apply the model across unsampled areas using GIS.**

- **To investigate relationships between the modelled silt accumulation and fish densities.**

- **To put this project into context with other modelling approaches undertaken in the UK.**

3 TO EVALUATE THE QUANTITY OF FINES ACCUMULATING WITHIN ARTIFICIAL SALMON REDDS IN REPRESENTATIVE LOCATIONS IN ENGLAND AND WALES

3.1 Method

For this project it was necessary to collect samples of fine material which had accumulated in salmonid spawning gravels. The method chosen to do this allows measurement of silt intrusion into an artificial redd by using a retrievable sampling baskets. This method has been used and developed by several authors (Davey *et al.*, 1987; Sear 1993; Nicholls, 2000). The sampling basket has a waterproof skirt, which is compressed around the base when the basket is buried in, and filled with, gravel. The skirt is raised around the basket when it is removed, preventing fine sediments being washed away by the current.

Full design specifications and placement methodologies are outlined in the manual entitled 'Assessing the quality of Salmonid Spawning gravels using a retrievable sampling basket methodology' which was an output from phase 1 of this project.

The protocol involved placing sampling baskets in each of the reaches in areas *where salmonids were known to spawn*. Eighteen catchments were sampled for this project but due to a data recording omission, it was not possible to include the samples from the Coquet catchment in the analysis. A total of seventeen catchments and 131 samples were therefore used in the subsequent analysis. Most sampling sites had several replicates installed, but due to some losses, not all sites had replicates recovered. Sites had, on average, three replicates successfully recovered (range 1 to 6) as shown in table 1, below. The catchments and sampling sites were not stratified in any way, but were well spread across the country (Figure 3.1). The suggested sites were checked to ensure there was no obvious bias in terms of topography, land use or location. Notes on the design can be found in appendix 1, which assessed the candidate catchments. It was concluded that the proposed sampling covered a diverse range of rivers and would be provide useful baseline data on the siltation of salmonid spawning gravels.

The sampling baskets were placed by the Area staff according to the sampling methodology manual and left for approximately 100 days (range 94 to 112) to simulate the incubation period of a salmon egg. This was a guide figure as incubation time is heavily dependent on temperature, and therefore latitude and altitude will have an effect on local incubation times. Different stocks may also have different laying and hatching times, and sea trout will differ when compared to salmon. For this project it was deemed necessary to try to replicate the conditions experienced by a salmon egg, so local knowledge of incubation time was used as the sampling interval, rather than standardising the sampling interval across the country. The sampling interval was also inevitably affected by work scheduled and spate events which restricted the times when baskets could safely be installed and removed.

When samples were removed they were forwarded to the Agency’s National Laboratory Service at Llanelli, for initial sample processing.

3.1.2 Sample processing

Particle size analysis

The particle size analysis was carried out by the Llanelli laboratory. Samples were oven dried and then passed though a sieve stack with each size fraction being retained and weighed. The collected samples were sieved into six fractions, <0.125mm, 0.125-0.85mm, 0.85-2mm, 2-4mm, 4-6.4mm and >6.4 mm. When the gravels were originally installed in the artificial redds, adjacent river gravels were used to fill the basket. These gravels were first passed through a 6.4mm sieve to simulate the cleaning which occurs during natural redd creation. Since the gravel placed in the baskets was all >6.4 mm, the presence of sediment in the first five categories would be indicative of sediment having moved into the basket from the surrounding gravel or from the surface of the channel bed. Analysis of the amounts of sediment collected was undertaken to assess rates of gravel siltation, the calibre of the material involved and more particularly on contrasts between different rivers in response to differences in land use.

3.2 Results

The distribution of the 131 samples used in the analysis are shown in Figure 3.1, below, with a summary of sample numbers shown in Table 3.1. The samples came were taken from 43 sites across 17 catchments.

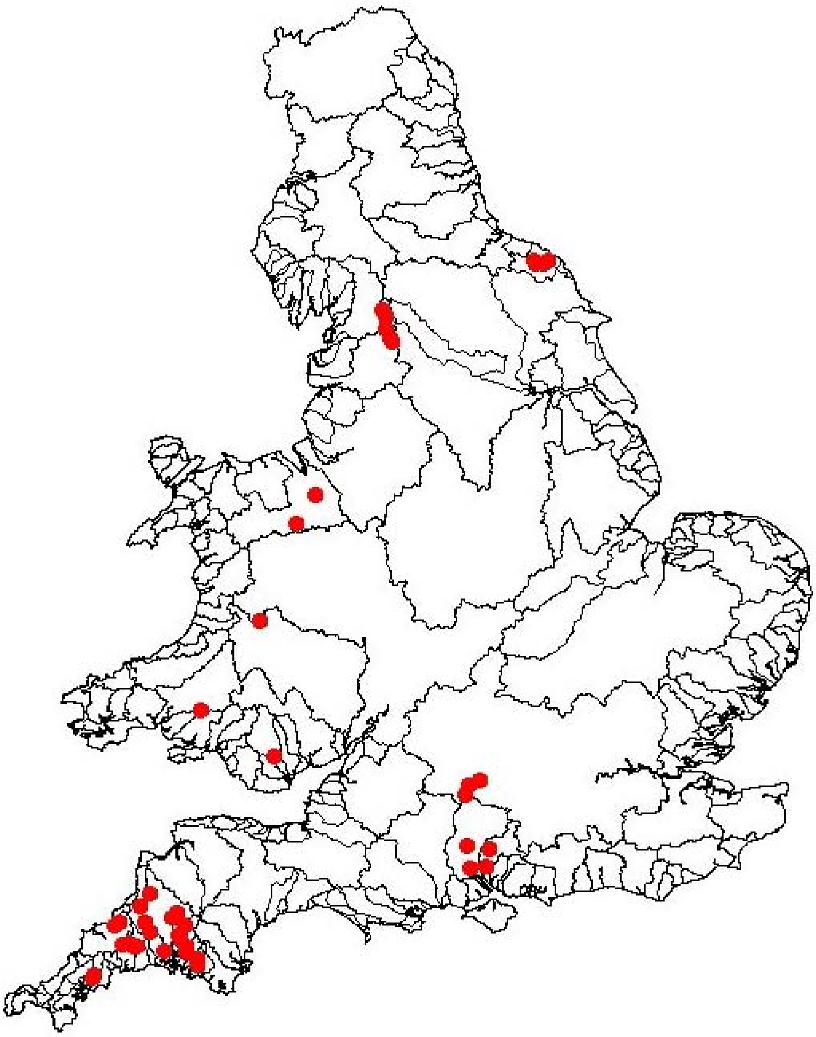


Figure 3.1: Distribution of sampling sites.

Table 3.1: Sites and numbers of sampling baskets installed.

Catchment	Tributary	NGR	No Samples
Camel	Allen	SX066791	3
Camel	Camel	SX096807	3
Dee	Alyn	SJ358568	4
Dee	Ceiriog	SJ233378	4
Esk (Yorkshire)	Esk	NZ76400760	3
Esk (Yorkshire)	Esk	NZ78100550	3
Esk (Yorkshire)	Esk	NZ82600550	3
Esk (Yorkshire)	Esk	NZ86300780	3
Fal	Fal	SW922450	3
Fal	Fal	SW929468	3
Fowey	Fowey	SX111664	2
Fowey	Fowey	SX158676	3
Fowey	Fowey	SX202661	3
Fowey	St. Neot	SX185654	1
Itchen	Itchen	SU48032808	6
Itchen	Itchen	SU46061705	6
Lynher	Deans Brook	SX382623	3
Lynher	Lynher	SX286749	3
Plym	Meavy	SX526655	3
Plym	Plym	SX526618	3
Ribble		SD793759	1
Ribble		SD807720	1
Ribble		SD811632	1
Ribble		SD841580	1
Ribble		SD852552	1
Taff	Taff	ST0881488111	4
Tamar	Inny	SX260815	3
Tamar	Lew	SX458874	3
Tamar	Lyd	SX429838	3
Tamar	Ottery	SX229917	3
Tamar	Tamar	SX289994	3
Tavy	Tavy	SX477733	3
Tavy	Tavy	SX511786	2
Tavy	Walkham	SX488709	3
Test	Test	SU33073006	5
Test	Test	SU35061605	3
Thames	Kennet	SU323635	3
Thames	Kennet	SU341693	3
Thames	Lambourne	SU414726	4
Tywi	Cennen	SN61901810	6
Wye	Marteg	SO0020475333	4
Yealm	Piall	SX599576	3
Yealm	Yealm	SX595538	3
Total			**131**

3.2.1 Particle size analysis

The results of individual samples can be seen in Appendix 2. A summary of the results is shown in Figures 3.2 and 3.3, below.

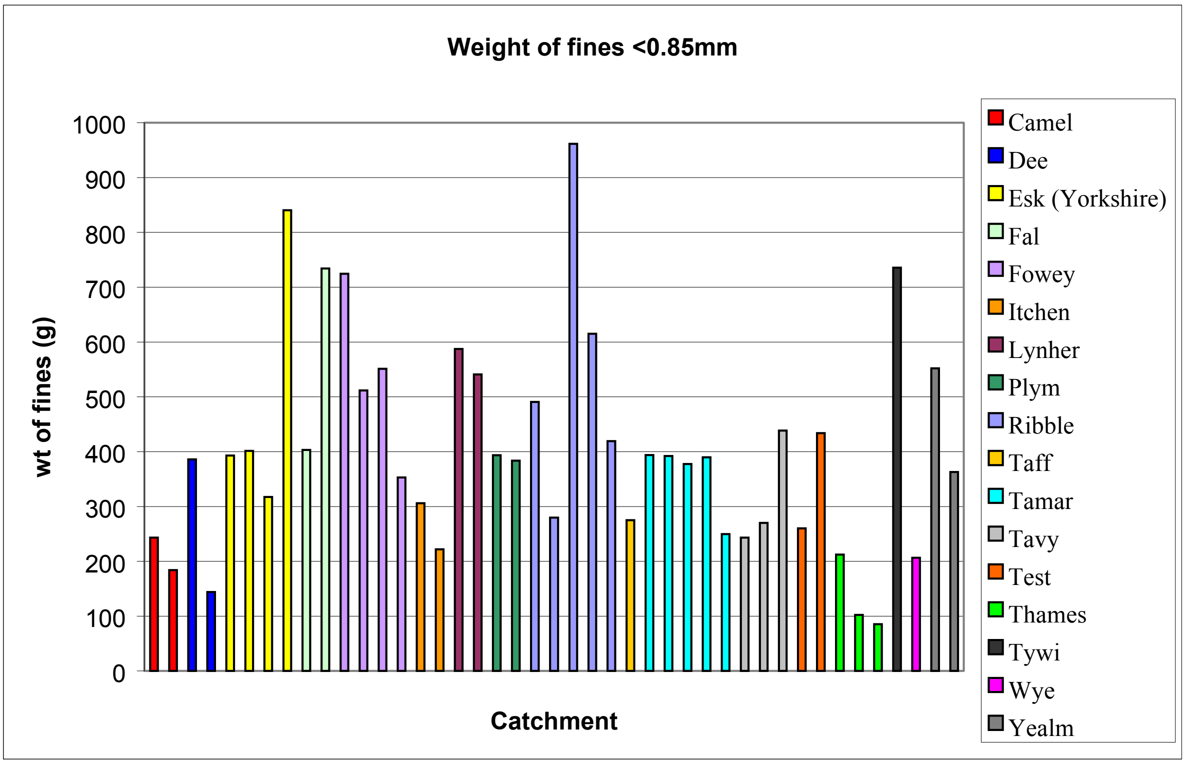


Figure 3.2: Weight of fines (<0.85mm)

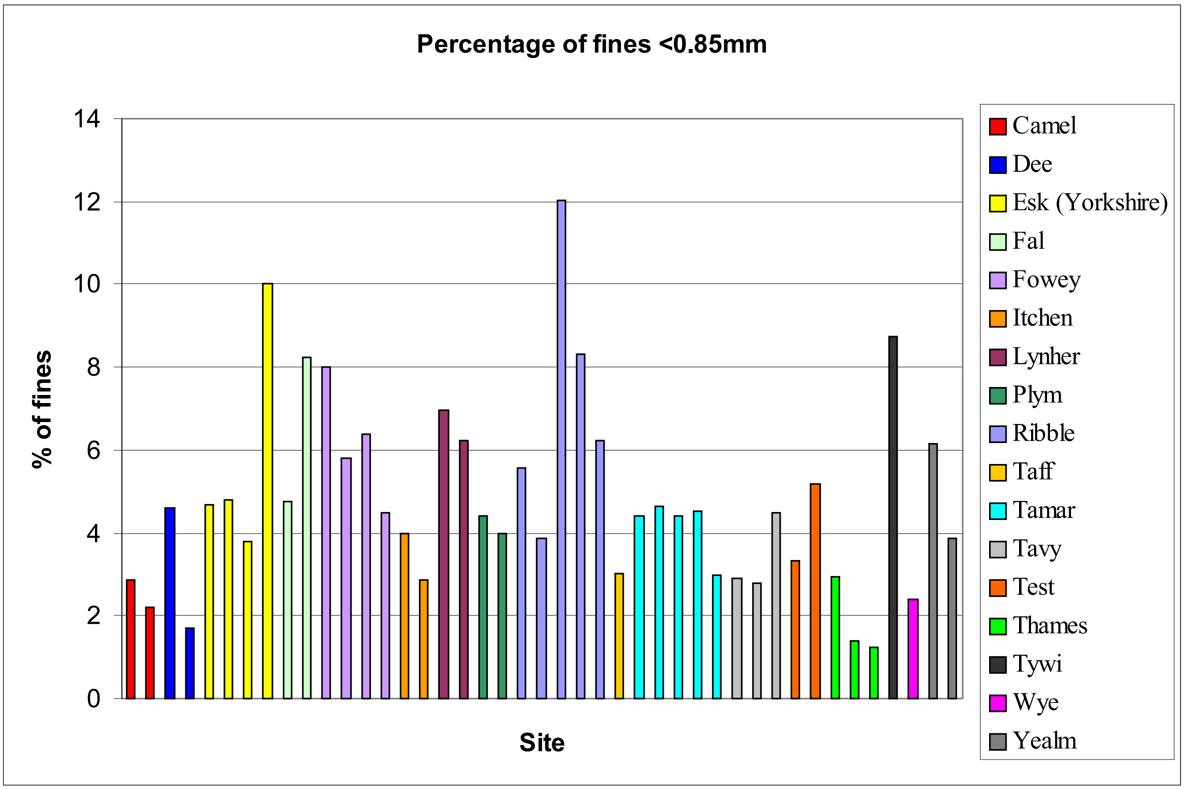
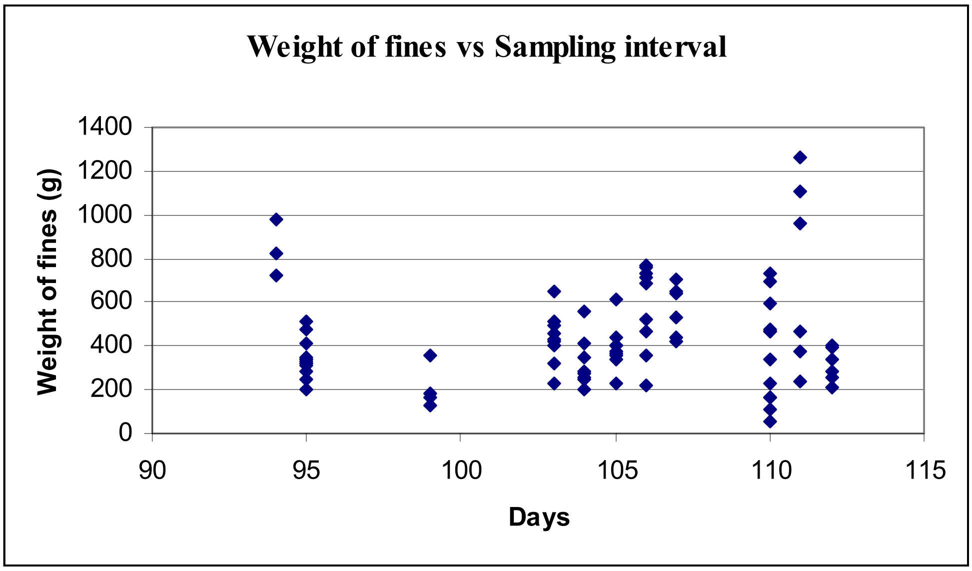


Figure 3.3: Percentage of fines (<0.85mm)

3.2.2 Relationship between quantity of fines and sampling interval.



Pearson correlation of sampling interval and log of the total weight of fines <0.85mm (site average) = -0.038, P-Value = 0.846.

Figure 3.4: Weight of fines <0.85mm against sampling interval (days)

3.2.3 Analysis of variability.

The analysis was carried out on the results from the baskets to assess the levels of variability:

a) Between Rivers
b) Between Sites
c) Between Baskets

The results of the variability assessments are shown in Table 4.2 below.

Table 3.2: Variability within and between sites.

	Fines <0.125mm		Fines <0.85mm	
	Variance	Standard Error	Variance	Standard Error
Between River Variability	0.0952	0.0840	0.1822	0.0835
Between Site Variability	0.1893	0.0898	0.0390	0.0338
Between Basket Variability	0.377	0.0561	0.222	0.0328

3.3 Discussion

3.3.1 The impact of fines

Fine sediments infiltrate salmon redds, filling in gaps within the gravel matrix. This reduces the permeability of the gravel, slowing the through-flow of water and, therefore, the supply of oxygen to the embryos. As the three parameters of gravel composition, permeability and oxygen concentration are closely related, each can be used to assess survival of eggs and alevins. Dissolved oxygen in the interstitial spaces of stream gravels can be measured using a standpipe (Barnard and McBain, 1994). Chapman (1988) showed that survival of eggs and alevins was positively correlated to permeability. Barnard and McBain (1994) found that for "permeabilities greater than 10,000 cm/hr, embryo survival was greater than 85 percent; however, considerable scatter exists for permeabilities lower than 10,000 cm/hr". However, McBain and Trush (2000) noted that the relationship between permeability and salmonid egg survival is not well understood and concluded that permeability "should only be considered an index of gravel quality, and predictions of salmonid reproductive success are tentative." Similarly, gravel composition can be used as an index for egg survival. This is because gravel size composition is the key physical constraint affecting permeability and therefore oxygen supply. The amount of research which has been carried out on these three parameters means that we now have an opportunity to associate local gravel permeability and dissolved oxygen concentrations with physical substrate characteristics. This has lead to the development of models such as SIDO-UK which can predict the effect of fine and coarse sediments on salmonid spawning gravels and redds. This can then be used to assess the changes in the patterns of filling of gravel beds under varying flow conditions, and the effects on intragravel flow rates, dissolved oxygen, and embryo survival (Greig, 2001).

There are numerous ways to describe the complex structure of a gravel matrix. Much of the recent work on salmonid spawning gravels has been devoted to the search for a single statistic drawn or computed from the particle size distribution. Kondolf (2000) states that a natural gravel mixture cannot be fully described by any single statistic (Lotspeich & Everest, 1981; Shirazi & Seim, 1981; Beschta, 1982). Although this seems evident as all summary statistics are meant to give an index and not a complete description, he qualifies this, pointing out that each salmonid life stage has different requirements. His basic proposal is that the size of the framework gravels is important and can be represented by the d50 or d84 value (the size at which 50% or 84% of the fines are smaller), but proposes a nine step, life-stage specific assessment approach.

Within the context of this project, such a complete analysis of the gravel structure was not an objective. The focus was to recover and analyse the fine sediments from the samples. Absolute weight of fines was used for modelling, rather than a percentage of total weight as total weight, and hence the inclusion or exclusion of a single cobble can, significantly affect percentages. A boulder overlying the edge of the basket may be included by some field teams and removed by others. It was therefore felt that absolute weight of fines was the measurement least likely to be affected by different staff or, indeed, different substrate composition, and would therefore be the most appropriate result to use in analyses. Most of the published literature, however, uses percentage fines. This is mainly due to the method of sample collection. Most studies use a freeze coring methodology (e.g. Stocker and Williams, 1972), which results in highly irregular samples. This means that any analysis must be done on a percentage approach to allow inter-comparison of different sized samples. Within this study, it was considered appropriate to use absolute weight of fines, as the samples were volumetrically very similar.

It is however possible to calculate the percentage of fines for comparison with published studies. Recent studies in streams on the Olympic Peninsula in Washington found that if more than 13% fine sediment (<0.85mm) intruded into the redd, no steelhead or coho salmon eggs survived (McHenry *et al*., 1994). McNeil and Ahnell (1964) found that Pink salmon embryo survival is drastically reduced when fines (<0.833mm) exceed 20% by volume of the substrate. These figures are typical of the published literature, which commonly suggests that there will be a significant increase in mortality when fine material accounts for 10-20% of the gravel. These figures come from a diverse range of studies and different salmonid species (see review by Chapman, 1988). Specific figures for Atlantic salmon suggest that significant mortality occurs when fines <0.5mm in diameter rise above 12% of the sediment (Peterson and Metcalfe, 1981).

The results of this study show that the average content of sediment <0.85mm from all samples is only 4.5%. The maximum content from any single sample was 15.5%, from a site on the river Tywi (Cennen catchment). The maximum average content for a site was 12.0% by weight of fines for a site on the River Ribble. Figure 3.3 shows the site on the River Ribble and to a lesser extent one site on the Yorkshire Esk have percentages of fines which may cause concern. All other sites (43 sites, 95%) had levels of fines lower than those suggested in the literature as causing significant egg mortality. It should be noted that the percentages of fines quoted in the literature are generally measured volumetrically, rather than by dry weight, so these results may not be directly comparable. It is therefore important to collect egg survival data in association with sampling basket data in order to clarify the levels of fines which cause egg mortality problems. The chalk rivers do not seem to have high levels of fines recorded despite a widely held belief that these rivers are suffering from siltation. This is in line with other studies (Acornley and Sear, 1999), and suggests that the local geology and hydrological conditions cause the impacts of any silt that is present to be exacerbated.

3.3.2 Comparison with the summer survey (pilot study)

The majority of sediment transport in rivers occurs in the winter months for example in chalk rivers 96% of sediment moves between November and April (Acornley and Sear, 1999). This is because sediment transport is flow dependent (Naden and Cooper, 1999; Acornley and Sear, 1999), with most transport occurring at peak flows. The higher rainfall in winter means that there are more of the peak flows which result in high levels of sediment transport. This is reflected by the levels of fines found in this study being on average over double those found in the pilot study which was carried out in the summer. Samples taken in summer had an average of 161g (2.2%) of fines <0.85mm in diameter, while the samples taken for this study over the winter had an average content of 384g (4.5%). The sources of silt may also change, with a greater proportion coming from arable fields. There has been a recent upward trend in the growing of cereals, and the area of the UK planted with wheat and barley has approximately doubled since the late 1940s. Much of this production is now winter sown (Climate change and agriculture in the UK) meaning that there are now many bare fields in winter allowing greater levels of erosion to take place.

3.3.3 Variability

The between-river, between-site and between basket variability of the samples was investigated to determine where the biggest differences in silt accumulation occurred. The results in Table 3.2, above, show that the variability between baskets from the same site is larger than the variability between different reaches or rivers. This suggests that the quantity of fines accumulating within different parts of the same riffle can vary widely. This emphasises the need to site the baskets correctly in an appropriate part of the riffle where salmon are likely to spawn, which should minimise this variability. It also suggests that several replicates should be taken from each site as in this study. The variability within a reach is not surprising and is supported by numerous studies (Acornley and Sear, 1999). This variability within small reaches is also reflected in egg survival studies which show large variation in percentage survival over small areas of riffle (Naismith and Wyatt, 1997).

The lower level of variability between rivers means that the siting of the basket within a riffle is more important than the river in which it is placed. This in turn suggests that local hydrological factors in the immediate vicinity of the basket may be more important than upstream characteristics, when assessing the quantity of fine sediment.

3.3.4 Sampling interval

Figure 3.4 shows that there is no clear relationship between the number of days in the sampling interval and the total quantity of fines <0.85mm in the sample. There is almost no correlation (-0.038), and the relationship does not approach significance ($p = 0.846$). This differs from phase 1 of the project where a good relationship was found between the levels of fines and the sampling interval. This may well be because, in this study, a larger quantity of silt accumulated in the samples. It is possible that the sediments had all reached some level of equilibrium with the surrounding gravels before they were removed, so that the sampling interval was no longer an important factor. Alternatively, the small range in the sampling interval (94-112 days), and high variability between samples, may have masked any effect.

3.4 Conclusions

The greatest variability in weight of fines <0.85mm was found between sampling baskets recovered from the same site. This suggests that catchment features and land use may be less important than the exact hydrological conditions surrounding individual baskets. This highlights the importance of correct siting of the baskets, and the necessity of repeat samples.

The weight of fines <0.85mm recovered from the sampling baskets was on average 2-3 times larger than recorded in the summer survey. This confirms that siltation is of a higher magnitude over the winter months, and that the summer baskets were not saturated by fines.

Although comparisons with published literature may be unreliable due to different methodologies used, two sites rivers have levels of fines high enough to cause concerns about the survival of salmonid eggs, one on the Yorkshire Esk, and one on the River Ribble.

Although chalk streams are perceived to suffer from problems of siltation, the sites examined had relatively low levels of fines <0.85mm recorded. Problems within the chalk streams are likely to be linked to a combination of siltation and local hydrological and geological factors.

4 TO USE GIS TO QUANTIFY ENVIRONMENTAL FACTORS WHICH MAY AFFECT THE SILTATION OF SALMON REDDS

4.1 Introduction

The extraction of site-specific information from a GIS is relatively straightforward procedure. A sampling point can be used to extract information from any data set which intersects with it. This means that a value such as height can be read from a suitable topographic data set and added to the attribute table of a sampling point.

When looking at the effects of environmental factors such as land use on the in-river environment, the procedure is more complex. In this scenario it would be more appropriate to extract data for the entire subcatchment upstream of the sampling point. This is because silt will stay in suspension for a long period of time, so an integration of upstream impacts is therefore likely to give a better indication of silt loadings than any site specific measurements. This is confirmed by research which shows that diffuse catchment sources are the most important providers of silt to watercourses (Theurer et al., 1998). The automatic creation of a subcatchment requires hydrological modelling to be carried out in the GIS.

4.2 Method

Within this project a combination of the ArcGIS 8.0 and ArcView 3.1 software packages were used. ArcGIS 8.0 was used for the advanced hydrological modelling procedures. ArcView 3.1 was used for other parts, as the software was more readily available and the techniques had been developed as part of the pilot study.

The following steps were carried out:

1. ArcGis 8.0 was loaded with the ArcHydro hydrological modelling extension.
2. The 50m Digital Elevation Model (DEM) from the ordnance survey was loaded. This is a grid data set of elevation values, with each cell in the grid representing a 50m x 50m area on the ground.
3. 1:50,000 river network from CEH was loaded.This is a vector (line) data set representing the river network.
4. Slope was then calculated from the DEM, which can be done simply within ArcGIS.
5. Each of the sampled catchments was then isolated and treated separately i.e. the catchment data sets were cut out. This made subsequent processing much quicker.
6. The river network was then rasterised to a 50m grid, compatible with the DEM. Again this can be done automatically within the software.
7. The AGREE surface reconditioning algorithm was run on each of the catchment DEMs with a 5 cell buffer, smooth offset value of 10m and sharp offset of 10m. This algorithm is included in the ArcHydro extension. More explanation of this approach is contained in the discussion.
8. The flow direction and the flow accumulation data was derived from the agree DEM, again using the functions within the ArcHydro extension.

The next steps were then carried out within ArcView 3.1 for this project, although there is nothing to prevent a similar process being carried out within ArcGIS 8.0.

9. ArcView 3.1 was loaded, and the spatial analyst, hydrological modelling and ‘basin’ hydrological tools extensions were added.
10. The datasets generated within ArcGIS 8.0 were added.
11. The actual sediment sampling points were then added as an event theme, and converted to a shape file.
12. The ‘basin’ tools were used to automatically generate the catchment upstream of each sampling point. As part of this process, summary statistics for altitude, distance to source, distance to estuary, slope as well as averages for the upstream catchment were calculated.
13. The CEH Landcover 2000 data was loaded. This is a grid data set of 25m x 25m cells representing the dominant landcover, derived from satellite data.
14. Summary land cover data extracted for catchments upstream of data points, using the tabulate area command.
15. All data were collated to a single table structure and exported to statistical software.

4.3 Results

The results of the data extraction process are shown in the raw data in appendix 2, and are used in the analysis procedures in Section 5.

4.4 Discussion

4.4.1 Hydrological modelling

Many commercially available GIS systems have hydrological modelling capabilities. Most modelling applications use a grid of elevation values as a base model, which is known as a Digital Elevation Model (DEM). These are widely used due to the simplicity of use and wide data availability. The simplest and most frequently applied hydrological model is the Eight Direction Pour Point Model (D8) (O’Callaghan and Mark, 1984) which uses the difference in height between a cell and its neighbours to calculate flow direction. The flow from one cell passes to one and only one of the eight neighbouring cells, where the drop in height value is greatest. Surface flow becomes a watercourse when draining greater than a user - defined number of cells.

General problems with Digital Elevation Models (DEMs)

This set approach can cause problems when different geologies are crossed by a watercourse, as the permeability and therefore flow patterns are affected. This means that the model may have to be adjusted for different subcatchments.

Hydrological modelling with DEMs does have other limitations. Flow direction is limited to one of 8 values, and if the DEM is based on an integer grid, there are a limited number of values that the slope can have. This causes inaccuracies to occur particularly in relatively flat areas, where the actual slope may be too small to be represented by the integer grid, giving areas which are perfectly flat according to the DEM.

Hydrologic modelling is dependent on the quality of the DEM used, and most GIS have limited functionality for controlling or eradicating errors. (Choudray and Morad, 1998). Finer resolutions will give better representations of the river network, but at the cost of greatly increased file sizes and greatly increased processing times. Even with fine resolution DEM's, the river network is unlikely to match well with the actual network in lowland alluvial areas. This is not such a problem in the upland areas where the majority of salmonid spawning occurs, but it does cause problems concerning the river length and accuracy of catchment delineation and therefore summary statistics. It will also cause problems in the lowland areas which will be more important for coarse fish.

A common problem when modelling using DEMs is parallel watercourses. These tend to occur on flatter areas, where resolution is too coarse and aspect constrained, so rivers may flow next to each other rather than converging. The same areas cause directional and locational errors within the modelled network. Smoothing or averaging the DEM data does not generally help. It may succeed in hiding the problem, but it does not improve the quality of the data (Garbrecht and Martz, 1999).

Another limitation is that simple modelling can only generate natural flow patterns. Man made drainage systems can control flow patterns in some areas, particularly in urban areas and these cannot be simply modelled within a GIS, although some researchers have managed to compensate for management in more complex models of individual watersheds (Dunn and Ferrier,1999). The standard D8 modelling procedure also fails to model divergent flow over convex slopes and can lead to a bias in flow path orientation.

Dealing with sinks

Sinks are cells in the DEM which are lower than the cells adjacent to them. When modelling river flow, the river will flow into these sinks, but not out, causing the modelling procedure to end. The most common way of dealing with sinks is to 'fill' them. An automated routine finds values on the altitude grid which are lower than all neighbouring cells and increases their values until this is no longer the case, allowing modelling to commence. This approach may not always be the most appropriate. Anomalously high values can also occur in the path of the modelled flow, in which case lowering the high point (obstruction) may be a neater solution than raising the values of many cells behind it. This process is called breaching and may be applied along with filling in order to create a suitable DEM for hydrological modelling (Cluis *et al*., 1996; Maidment *et al*., 1996).

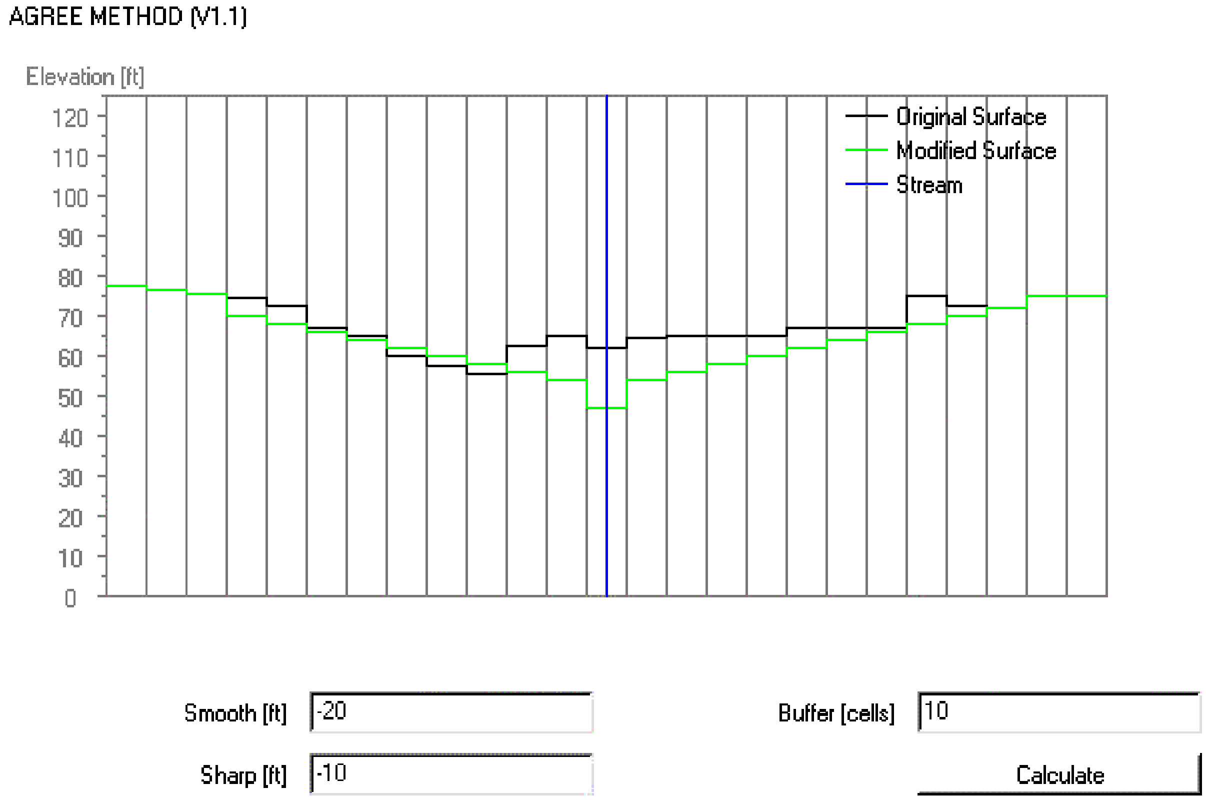
Stream burning

Using a standard D8 hydrological approach, there will be many instances where the modelled flow differs from the mapped 'true' river network which may be available as a vector dataset, as is for the U.K.

One approach is to integrate the DEM with the vector river network data set, a process commonly referred to as 'stream burning' (Jenson and Dominique, 1988). The simplest form of this approach is to raise the elevation of all grid cells that are not on the stream network by a user defined value. This has the effect of placing the river network in a gully, which constrains the hydrological modelling.

The results of stream burning can still have problems such as irregular watershed delineation or the creation of parallel streams, but are still likely to improve the accuracy of the modelled features. It may also be necessary to carry out some pre-processing of the DEM to remove channel braiding and any artificial drainage networks which would cause inaccuracies in the modelling process (Saunders and Maidment, 1996; Saunders, 1999).

Saunders (1999) compared the performance of several stream burning algorithms, and found a method called 'agree' was very efficient and accurate when compared to other approaches. Agree was recommended for extracting information from transient points as the only method which was more accurate took 20-30 times more processing time. 'Agree' (Hellweger and Maidment, 1997) is actually a surface re-conditioning algorithm, rather than stream burning. It effectively smoothes the cells to a point on the stream network within a user defined buffer. The buffer distance is defined first. This should be slightly larger that the locational difference between the vector network and the valley bottom of the DEM. The stream network is then burned in by a user specified amount (smooth offset) and the profile of the DEM is smoothed between the river network and the edge of the buffer zone. A sharp offset value can then be applied to burn the network into a trench, within the buffered zone. An example of this process can be seen in Figure 4.1, below.



Smooth [ft] -20

Sharp [ft] -10

Buffer [cells] 10

Figure 4.1: Example of the AGREE surface reconditioning process
from http://www.ce.utexas.edu/prof/maidment/GISHydro/ferdi/research/agree/agree.htm

The Agree algorithm has been made available in the hydrological modelling extension for ArcGIS 8, ArcHydro, and has therefore been used for this project.

Once this hydrological modelling has been completed, subcatchment delineation can be easily carried out using tools available in ArcView. The 'basin' set of tools were used in this project to automatically generate the subcatchment above each sampling point. This allows summary statistics to be generated for each of the subcatchments, by intersecting the subcatchment shape with the data set of interest, such as landcover. This was the real goal of the hydrological modelling process, and the high quality of the hydrological modelling undertaken, leads to accurate delineation of the subcatchments.

4.5 Conclusions.

The most appropriate available hydrological techniques were used in definition of the stream network and catchments upstream of the sampling sites. The river network and generated subcatchments were therefore accurate.

The data extracted for each sampling point and subcatchment was the most appropriate and up to date available in digital format.

5 TO CREATE AN EMPIRICAL MODEL OF SILTATION USING ENVIRONMENTAL AND LAND USE DATA

5.1 Introduction

Environmental data was available from two different sources, the field sheets filled out on site by the fisheries officers, and from GIS sources. The GIS data can be further subdivided into variables relating to the site itself and those relating to the catchment upstream of the site. As outlined above, the variables relating to the catchment upstream are likely to be more important than the variables at that specific site. This was confirmed by extensive analysis in the pilot study. Variables from both the site and the catchment upstream of the site were, however, included in the analysis to test the assumptions outlined above. The variables recorded and generated are shown in Table 5.1, along with their source.

Table 5.1: Environmental variables examined during analyses

Source	**Variable**
GIS – Site Specific	Gradient
GIS – Site Specific	Altitude
GIS – Upstream catchment	Catchment Area
GIS – Upstream catchment	Catchment Perimeter
GIS – Upstream catchment	Maximum, Minimum and Average gradient
GIS – Upstream catchment	Maximum, Minimum and Average altitude
GIS – Upstream catchment	% Landuse by category

5.2 Method

These datasets were examined and analysed using:

1. Bivariate plots (Excel)
2. Correlation matrix (MINITAB)
3. Best subsets regression(MINITAB)
4. Stepwise regression (MINITAB)

5.2.1 Bivariate plots

Bivariate plots were used to examine simple relationships between the variables, and to determine which results should be used in subsequent modelling. From the outputs of these plots and the previously discussed problems with using percentage weight it was decided to use the absolute weight of the silt fractions (<0.85mm) in subsequent analysis. An example plot is shown in Figure 5.1 below.

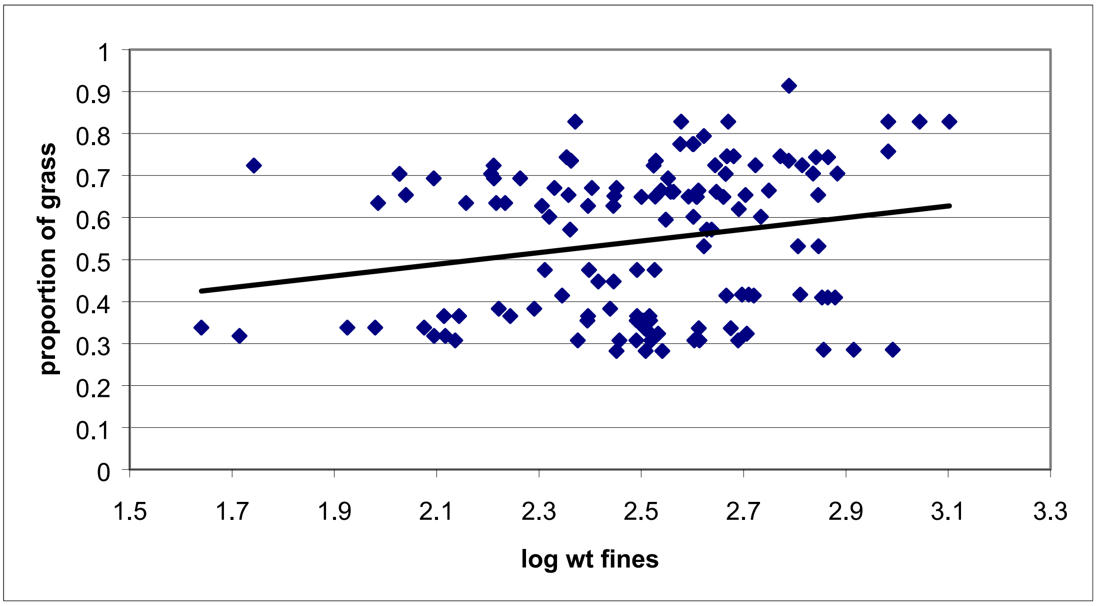


Figure 5.1: **Example bivariate plot: grassland upstream v's log weight of fines <0.85mm.**

5.2.2 Correlation matrix

It became apparent when creating the bivariate plots that the relationships between the variables were complex. A correlation matrix is a good way to examine a large number of variables and determine which relationships are significant and which variables are linked. Table 5.2 shows the matrix describing the correlations between the variables studied. It can be seen that there is a high degree of correlation between the variables. We would expect a significant correlation between some of the variables, as they are not all independent. An example is average elevation (m) and the mean gradient, which are related variables and show a significant correlation. This means that either one of these two measurements could be used in a model, but there may be little to choose between them.

The correlation matrix also shows that land use is related to both gradient and average altitude. This is not surprising, as uplands will have a higher average altitude and steeper gradients. They will also have very different land uses, with arable farming, for example, being confined to lowland areas with shallow slopes. This does make it difficult to separate physical factors from land use issues within a simple model, with a physical factors often acting as a surrogate for land use within empirical models, or vice versa.

Table 5.2: Correlation Matrix for site averages

	log <0.85mm	Log <0.125mm	Av. Elevation (m)	Area (hect)	Mean gradient	Cereals	Horticulture	Bare ground	Urban	Total arable
Log <0.125mm	0.318 0.038									
Av. Elevation (m)	-0.273 0.077	-0.162 0.298								
Area (hect)	-0.156 0.317	0.159 0.307	-0.116 0.46							
Mean gradient	0.247 0.11	-0.06 0.704	0.439 0.003	-0.279 0.07						
Cereals	-0.416 0.005	-0.003 0.984	-0.503 0.001	0.453 0.002	-0.693 0					
Horticulture	-0.397 0.008	0.082 0.603	-0.485 0.001	0.482 0.001	-0.752 0	0.9 0				
Bare ground	0.088 0.573	-0.146 0.349	-0.203 0.192	0.071 0.653	-0.06 0.702	0.099 0.53	0.143 0.36			
Urban	0.184 0.237	-0.078 0.621	-0.394 0.009	0.21 0.176	0.006 0.97	0.14 0.372	0.146 0.35	0.119 0.445		
Total arable	-0.416 0.006	0.04 0.799	-0.508 0.001	0.484 0.001	-0.74 0	0.976 0	0.973 0	0.122 0.434	0.148 0.343	
grassland	0.256 0.097	-0.127 0.418	0.114 0.465	-0.565 0	0.265 0.086	-0.495 0.001	-0.591 0	-0.366 0.016	-0.126 0.421	-0.556 0

Cell Contents:	Pearson correlation P-Value

Significant correlations are shown in red.

5.2.3 Variable selection procedures

Variable selection procedures within a package such as Minitab can be valuable tools in the early stages of building a model. However these procedures must be treated with caution. Since the procedures automatically check many models, the model selected may fit the data “too well.” That is, the procedure can look at many variables and select ones which, by pure chance, happen to fit well giving a type 1 error. Automatic procedures cannot take into account special knowledge the analyst may have about the data. Therefore, the model selected may not be the best from a physical process point of view. The construction of such a model should be based on 'best fit' tempered with specialist knowledge that can remove any relationships, which are thought to be spurious. Based on existing knowledge and experience from the pilot study, only a few key land uses and physical factors were used in the development of the model (see Table 5.1).

5.2.4 Best subsets regression

The first variable selection procedures used to examine the data was the best subset regression. This analysis gives a good indication of which factors best explain variability. An example output from the best subsets regression is shown in Figure 5.2 below. The variables used in each model are written vertically in columns, with different options for models written in the rows. The first model listed has an ‘X’ under the arable column only, denoting that this model contains only one parameter, the proportion of arable land upstream. The R^2 of this model is 17.3, which means that this single variable explains 17.3% of the variability between the sites. Alternative models with increasing numbers of parameters used are listed below.

```
Weight of fines <0.85mm, site averages, N=43.

                                                A A G U A G
                                                l r r r r r
                                                t e a b a a
                                                i a d a b s
                                                t   i n l s
                                                u   e   e
                                                d   n
Vars   R-Sq    R-Sq(adj)        C-p         S   e   t

   1   17.3         15.3       22.8   0.21349           X
   1    7.4          5.2       30.2   0.22588   X
   2   48.9         46.4        1.2   0.16991   X       X
   2   24.1         20.3       19.7   0.20709   X   X
   3   51.2         47.4        1.5   0.16819   X X     X
   3   50.0         46.1        2.4   0.17023   X       X X
```

Figure 5.2: Example output from the best subsets regression in Minitab.

The drawback of this approach is that it is not restricted to significant relationships. As a result a single outlying point may exert an undue influence in this analysis. It was felt that this analysis was not ideal, as we have a small data set and require the robustness of statistical rigour. It was however useful in highlighting factors which explain a large amount of the variability between sites. These factors were carried forward into the next stage of the analysis.

5.2.5 Stepwise regression

The next variable selection procedure used was a stepwise regression. The automatic procedures are heuristic algorithms, which often work very well but which may not select the model with the highest R-squared value for a given number of predictors. They will however select only significant relationships. Minitab adds variables in a way which is equivalent to choosing the variable with the largest partial correlation or to choosing the variable that most effectively reduces the error sum of squares. The regression equation is then calculated, results are displayed, and the procedure goes to a new step. When no more variables can be entered into the model, the stepwise procedure ends.

5.3 Results

The stepwise regression procedure allowed options to be trialed and an eventual model to be generated which had a relatively high R-squared value, significant relationships, and seemed realistic. The output for this model is shown in Figure 5.3 below. This shows a two step model using the proportion of arable land upstream and the average altitude upstream which together explain 48.9% of the variation between sites (the R^2 value). The significance of each of the variables is shown by the P value.

```
Response is (Log weight of fines) on  6 predictors, with N =   43


    Step           1        2
Constant       2.626    3.051

Arable         -0.59    -1.05
T-Value        -2.93    -5.70
P-Value        0.006    0.000

Altitude              -0.00160
T-Value                  -4.97
P-Value                  0.000

S              0.213    0.170
R-Sq           17.32    48.91
R-Sq(adj)      15.30    46.35
C-p             22.8      1.2
```

Figure 5.3: Output from the stepwise regression in Minitab showing the model that was used

The equation generated by this model is therefore:

log(weight of fines <0.85mm) = 3.051- 1.05*(proportion of arable land U/S) -0.00160*(average elevation of US catchment)

This model was then applied to all the sites used, and the actual v's the generated results were plotted as shown in Figure 5.4, below.

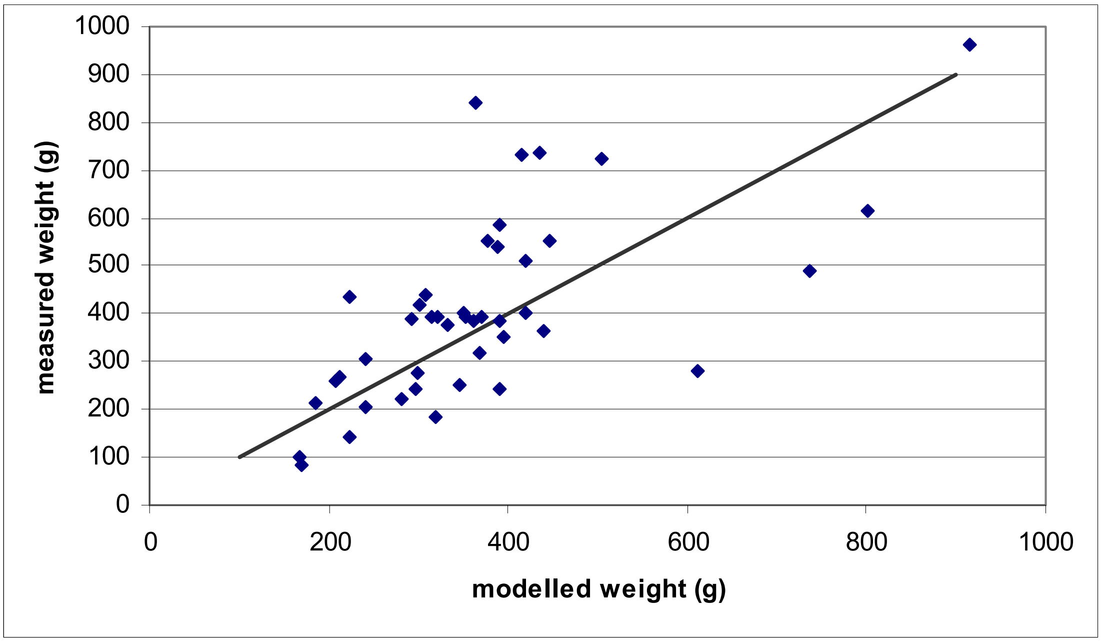


Figure 5.4: The relationship between the observed and the expected results.

5.4 Discussion

The model generated is the most realistic found using the above techniques. The model uses the proportion of arable land in the catchment upstream of the site, and the average elevation of the catchment upstream to explain 48.9% of the variation between sites. This is a reduction when compared to the summer survey, when an empirical model was able to explain 95% of the variability between samples. The reasons for this are the greater variability in samples from the winter survey, the increase in the number of samples and the geographic spread of the winter survey, which mean that it is harder to fit a single model which fits all circumstances.

The model generated for the winter survey differed from the model generated for the summer survey. In the summer survey, the sampling interval, the percentage of grazed land upstream and the average gradient upstream were the parameters in the model. For the winter survey, arable land and the average upstream gradient were found to be the most important variables. In the winter survey, the sampling interval no longer had an impact, as discussed in Section 3.2 (see Figure 3.4). One model used gradient and the other altitude, and these two variables are linked, as high altitude catchments will be in steep upland areas, with lowland catchments having lower gradients. The difference in the land use parameters used in the two models could be due to simple data variability, the additional sites used in the winter survey, or could reflect a variable impact of different land uses through the seasons.

It is interesting to note that arable land had a negative correlation with the quantity of fines. This is at odds with common understanding, which suggests that the majority of fines come from arable land (Theurer *et al.,* 1998, Walling *et al.*, 2002)

The stepwise regression analysis was carried out on the 43 separate sites, using average results from each site. This was necessary to prevent problems of pseudo-replication. As samples from the same site shared environmental factors in common, the 131 samples were not independent and including all samples would have artificially reinforced the relationships found in Minitab. This method of analysis is not ideal, as it ignores the fact that samples from different sites within the same catchment are likely to be related. This is particularly true where one site is downstream of another site, where there will be overlap of their upstream catchment areas. This relationship was ignored within the model, as it could not be included without specialised statistical software and analysis, which were outwith the remit of this project. The analysis presented here is however a reasonable, if not perfect, representation of the data and represents the best approach within the resources available to the project.

The equation generated can be used to calculate an expected silt accumulation value at any site using data from GIS. This was carried out for the 43 sites used in the development of the model. The relationship between the observed and the expected results for each site are shown in Figure 10 above. There is a good relationship between the expected and the observed results. This is to be expected as we are comparing the model to the data used to create the model. The relationship shown does not necessarily mean that this model is widely applicable, and hence it was applied only in catchments that supplied the source data.

5.5 Conclusions.

The model generated uses the proportion of arable land upstream and the average altitude of the catchment upstream to generate an expected silt loading using the equation:

log(weight of fines <0.85mm) = 3.051- 1.05*(proportion of arable land U/S) -0.00160*(average elevation of US catchment)

The model explains 48.9% of the variability in weight of fines <0.85mm between sites.

The statistical approach used to generate this model is not ideal, as it does not account for the true nesting of the data. It is however acceptable, and represents the best approach available within the constraints of this project.

The land use and physical features extracted from GIS are highly inter-related. This will cause difficulties in trying to separate the effects of physical features from the impacts of land management.

6 TO APPLY THE MODEL ACROSS UNSAMPLED AREAS USING GIS

6.1 Introduction

As all the data used in the generation of the model were derived from digital data sets within GIS, there was an opportunity to extrapolate this model to unsampled areas. This approach allows us to highlight potential problem areas even when they were not sampled. It also allows relationships between expected silt accumulation to be examined in relation to fisheries surveys which are widely distributed around the catchment.

6.2 Method

For the purposes of this modelling exercise a raster river network was derived from a 50m Digital Elevation Model (DEM), as described in Section 4.2. This approach allows easy modelling, as different data layers can be easily combined and weighted, allowing models to be easily implemented. A stepwise procedure to the implementation of this model is outlined below, which was implemented in ArcView 3.1.

1. Load ArcView 3.1
2. Load the 50m DEM covering target catchment.
3. Load the hydrological analysis extension.
4. Load the hydrological models generated in Section 4.2 (flow accumulation, flow direction).
5. Adjust the display of the flow accumulation dataset, until the model network approximates to the 1:50,000 river network. The display threshold was set to 100cells for this project.
6. Compute the average altitude upstream for each cell on the river network grid using the formula:
   ([Flow Direction] . flowaccumulation ([altitude])) / [Flow Accumulation] * [Derived River Network]
7. Isolate arable land from the CEH Landcover 2000 data layer. This is done by using the reclassify command and setting the value of arable land to 1 while all other land cover types are set to the ‘no data’ category.
8. Compute the proportion of grazed land upstream for each cell on the river network grid using the formula:
   ([Flow Direction] . flowaccumulation ([arable land])) / [Flow Accumulation] * [Derived River Network]
9. Apply the model to the river network. Within ArcView 3.1 this is implemented as:
   (([Derived River Network] * 3.051) – (1.05*(proportion of arable land U/S) –(0.00160* [average elevation US])). EXP10

This approach gives a level of silt expected in every cell of a river network. Some cells were found to give exceptionally high values of expected silt. This was found only to be the case where the values for either the average elevation upstream or the proportion of arable land upstream were outside the range of values used as inputs to the models. The model was run again, this time limiting the input elevation and proportion of arable land data layers to the range of values observed at the sampling sites. Thus, the elevation data was constrained to values between 41.8m and 447.9m, and arable land was constrained to values between 0 and 0.517. The reduced river network, which met these criteria, was then substituted for the derived river network in step 8, and the modelling procedure repeated.

6.3 Results

Examples of outputs from this model are shown in Figures 11 and 12.

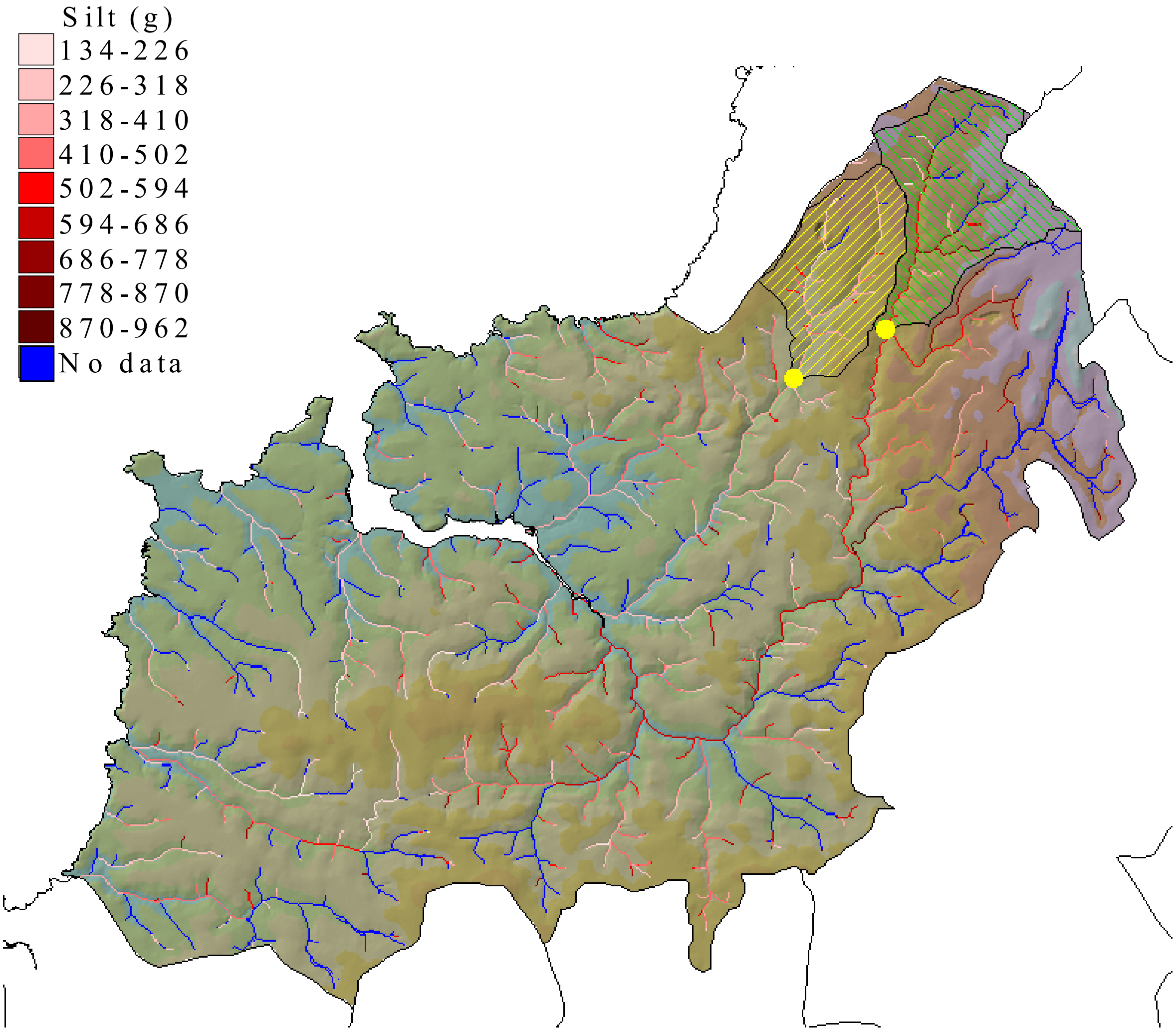


Figure 6.1: The river Camel, showing generated catchment upstream of a survey site.

6.4 Discussion

The application of the model to unsampled areas is important for making best use of the data and the model generated. The application of the model to the previously modelled river network means that there is good agreement between the silt model and the mapped vector river network. The large spread of sampling sites around the catchments mean that the model can be applied to the most areas. The areas of the river network which are outside the range of the parameters of the model, and cannot therefore be modelled with confidence are displayed in blue in Figure 6.1. For all the catchments used in this project, 74% of the river network can be modelled with the remainder outside the range of the model. This actually represents a slight underestimation of the applicability of the model as it includes the tidal areas and a small distance out to sea. The extreme headwaters are often outside the range of the models, as these are rarely sampled being small and often remote. The applicability of the model to ‘target area’ where we would expect spawning to take place is therefore greater than the 74% quoted above.

It should be noted that the GIS model of silt accumulation was created by extrapolating data derived from potential spawning sites. This means that the model will only be giving an accurate prediction when applied to riffle areas. The model as it is displayed in Figures 6.1 and 7.1 implies that we have realistic predictions for the whole river network. In actual fact, there will be pool and glide features from which data was not collected, and for which the predictions will be inappropriate. Ideally a GIS layer would be created identifying potential spawning sites and used to mask the predictions to appropriate areas. It is unlikely that such a data layer could be created easily from available data sets. Some of these inappropriate areas will be removed as they were outside the input parameter of the model, but many areas will be left where the prediction of the model would not give a true indication of the likely silt accumulation.

6.5 Conclusions

The application of the model to experimental catchments was carried out successfully, and should allow a comparison of expected silt accumulation with fisheries survey results from other sites.

A total of 74% of the river network is within the model input parameters. More than 74% of the actual spawning reaches will be within the model parameters.

This application of the model is slightly misleading, as the ‘expected’ silt accumulation values are those that would be expected at suitable spawning sites, equivalent to those where the sampling baskets were placed. The modelled silt accumulation values would not be correct in deep or pooled areas, but these areas are not currently excluded from the model.

7 TO INVESTIGATE RELATIONSHIPS BETWEEN THE MODELLED SILT ACCUMULATION AND FISH DENSITIES

7.1 Introduction

Around ten thousand individual fishery survey results were collated in phase 1 of this project, with the intention of comparing them to land use characteristics. The model developed to generate expected silt accumulation within a redd is an integration of the average upstream altitude and the upstream proportion of arable land. This was therefore compared to the fry densities of salmon and trout, as these are the life stages that are most likely to be affected by siltation of gravels through the process of egg mortality. In order to do this is was necessary to overcome inaccuracies associated with the use of a generated, rather than digitised river network, and grid references for fisheries survey sites which were not accurate or precise, and may therefore not fall exactly on the watercourse. A procedure was therefore needed to align the fisheries sampling sites with the modelled river network, before reading the modelled silt accumulation value from the grid underlying the survey sites.

7.2 Method

The stages carried out were

1. Load ArcView GIS and load the hydrological models generated in Section 4.2 and the silt accumulation model generated in Section 6.2.
2. Generate a vector river network from the hydrological model grid. This generates a series of lines which pass through the centre of each square within the grid.
3. ‘Snap’ the fisheries survey points to the new vector network. There is an extension available within ArcView 3.1 which automates this process. This snapping has been carried out to align the fisheries survey points with the river network in Figure 7.1 below. This avoids problems occurring when survey points do not fall exactly on the modelled river network. Snap tolerance was set to 100m.
4. Retrieve information from the silt accumulation grid and add it as a field in the attributes table of the fisheries survey points. A script is available to do this within ArcView (getgridvalue.ave).
5. Export the fisheries survey table to Excel and plot survey results against the silt accumulation values. Fisheries results are recorded as densities per 100m^2, and these values were logged to normalise the data. Quantitative survey results only were used for this analysis.
6. Carry out a regression analysis within Excel to test the significance of any relationships.

7.3 Results

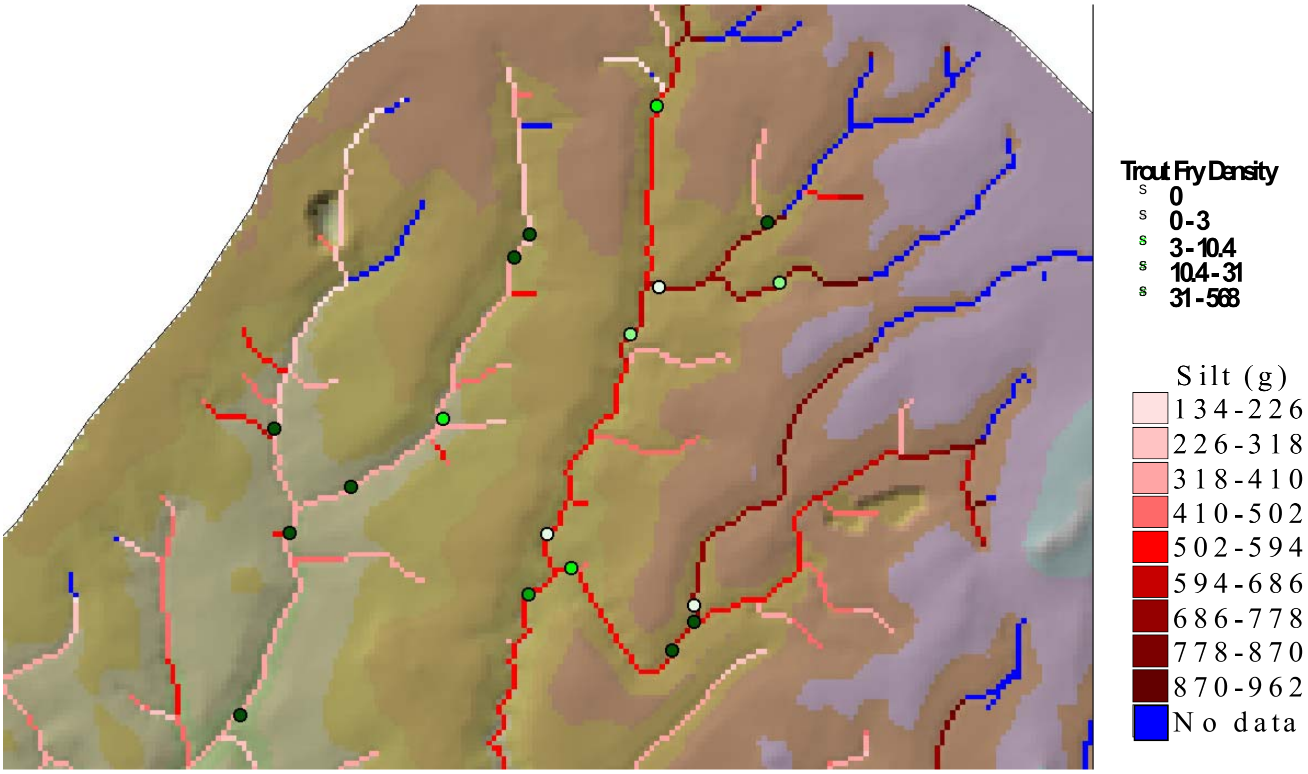


Figure 7.1: Close up of the river network showing trout fry densities.

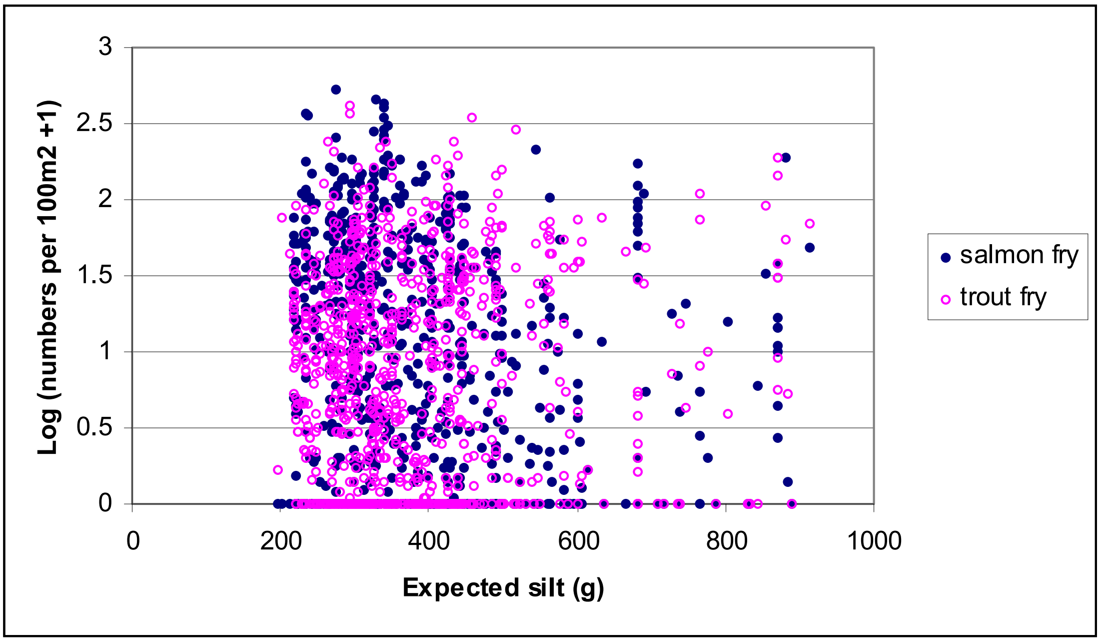


Figure 7.2: Log of Salmon and trout fry density +1 plotted against the expected silt accumulation.

Table 7.1: Statistical outputs from regression analysis of salmonid fry vs estimated silt.

		Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Trout	Intercept	0.74	0.04	16.86	0.00	0.65	0.83
Fry	X Variable 1	0.00	0.00	0.40	0.69	0.00	0.00
Salmon	Intercept	1.04	0.06	17.33	0.00	0.92	1.16
Fry	X Variable 1	-0.0004	0.00	-2.62	0.01	0.00	0.00

7.4 Discussion

Only quantitative fisheries surveys were used in this analysis, as they give much more precise population estimates than can be calculated from semi-quantitative surveys. Not all of the catchments which had been modelled had quantitative fisheries survey data available, so only the catchments from Wales and Cornwall contributed to the final analysis. This means that the chalk streams of the Test, Itchen and Thames catchments as well as the Yorkshire Esk and the River Ribble were excluded due to lack of suitable fisheries data. A total of 1742 fisheries survey results were used in this analysis.

The graph (Figure 7.2) showing densities of salmon and trout fry against the modelled silt accumulation does show a very slight trend for salmon fry, with increasing silt values correlating with decreasing fry densities. There is however a large scatter of points. This is not surprising, as fisheries survey results vary widely, both spatially and temporally. This means that any trends in fisheries data are generally well masked by noise in the data and are therefore difficult to detect. Despite this, the results of a regression analysis carried out on the data show that the trend is significant, although very slight, for salmon (Table 7.1, P value = 0.01). This result is encouraging, but we should not read too much into the fact that the trend is significant. This is because a key assumption of a regression analysis is that the x variable is known. In this analysis it is modelled.

The other consideration is that behavioural factors could be having an influence. Salmon must migrate to and from the sea and cannot pass all obstructions, and are therefore likely to be excluded from many upland areas. Salmon also show a preference for wider streams, so again behavioural considerations may mean that they are not present in high densities in the smaller high altitude streams. This is important, as average altitude upstream is one of the variables used in the model. The fact that trout, which do not need to migrate, and are present in small streams, do not show a significant relationship suggests that the behavioural aspects may be important. This was tested by removing all sites where no salmon were recorded, and re-running the analysis. There was little difference in the results, and the trend, although slight, was still significant. This implies that land use may be having a slight impact, but the effects of low densities of salmon at high altitudes may still be due in part to behavioural preferences rather than siltation.

The results for trout fry are much less conclusive with no real trend evident (Figure 7.2), and the relationship is not significant (Table 7.1, P value = 0.69). However, as mentioned above, the high spatial and temporal variability of fisheries data, and the uncertainty surrounding the modelled silt accumulation with which the densities are being compared may obscure any relationship. The extrapolation of the siltation model from very few sites to whole catchments may also cause problems. The transportability of the model has not been tested against independently collected data, and therefore the underlying validity of this approach has not been tested.

7.5 Conclusions

There is a significant relationship between the modelled silt accumulation and salmon fry densities, with lower densities occurring at high silt levels.

There is no evident relationship between trout fry densities and silt accumulation.

The fit or otherwise of these models should not be used to draw any further conclusions as no causal relationship between silt accumulation and fish densities can be proved. There are questions about possible behavioural bias influencing the results, as well as concerns about the transportability of the model to unsampled areas.

8 TO PUT THIS PROJECT INTO CONTEXT WITH OTHER MODELLING APPROACHES UNDERTAKEN IN THE UK

Hydrological modelling applications within GIS are becoming more widespread, as the equipment and necessary data sets become more widely available. The most basic input required is a Digital Terrain Model (DTM), which can be used to calculate the slope and aspect. A flow path of water from upstream areas downstream can then be calculated. A combination of slope, information on soil characteristics, land use and flow paths can give information on likely erosion rates. GIS offers benefits over traditional erosion models, as spatially distributed models and data are more suitable than conventional lumped ones (Lenzi and Di Luzio, 1997).

Recent developments have seen GIS being used to model the effects of the land on the aquatic environment within the UK. Modelling the effect of the land on water relies on both land use data and an understanding of how the different land uses impact on watercourses. This information can be collected by field surveys, or derived theoretically, but remains sparse for the UK (McHugh *et al.,* 2002).

In the UK both empirical and process based models have been used to model the siltation of watercourses.

8.1 Empirical Modelling

Naden and Cooper (1999) carried out a large study in the Yorkshire area to model the quantity of sediment in watercourses. This study used automatic watershed delineation to describe points upstream of sampling points and to extract subcatchment summary statistics. This study was particularly interested in the impacts of land uses on the suspended sediment within the rivers. They combined the Institute of Terrestrial Ecology 1990 land cover data set with the DEFRA agricultural statistics to gain a refined estimate of land use for the model.

They found that the percentage of cropped land and suburban \ urban land accounted for 71.5% of the variation between catchments in terms of suspended sediment concentration. They also found that the load of suspended sediment within a watercourse is heavily flow dependent, which is in line with expectations, as from a process point of view, it is only excess runoff which tends to carry suspended sediment. Excess runoff is always associated with heavy rainfall and therefore high flows. Channel bank erosion also occurs at high flow, further increasing sediment delivery to the watercourse.

The approach outlined above is analogous to this project, with both producing models based on an empirical relationship between environmental factors chosen from an extensive list of candidates. It is possible that a factor could have a good correlation by chance, the likelihood of which increases as more candidates are considered. This is known as a type 1 error. Another problem is that many of the candidate environmental factors which could be used in the model are related to each other, as they are not totally independent. Examples such as altitude and gradient are related variables and show a significant correlation (Table 5.2). This means that in terms of explaining the variability in silt delivery, these two measurements would perform approximately equally.

It would seem logical that gradient would be a controlling factor in silt delivery. One possible reason why it was not used in the study by Naden and Copper (1999) is that there was little variation in the gradient for their sampling sites. Alternatively it is also possible that the land use was acting as a surrogate for gradient as outlined above. Land use is undoubtedly important in its own right, but is highly correlated with other physical characteristics such as gradient, altitude and soil type. Any relationship found may therefore be acting as a surrogate for the true controlling factor.

Existing approaches often have such embedded empirical relationships. This means that it is possible to create a model which works well at explaining the variability in silt delivery between sites, but does not actually use controlling factors within the model. This type of approach can lead to transportability problems, with a model developed in one location performing poorly in a different area. This does cause concern about the transportability of the model developed within the current project.

Naden and Copper (1999) found that the load of suspended sediment within a watercourse is heavily flow dependent. Flow was omitted from the current study as a possible explanatory variable for a number of reasons. The key reason for omitting flow was the complexity of the subject. Flow is constantly variable, so reducing a three-month hydrograph to a single statistic, which we can relate to our samples, is very difficult. It is complicated by the fact that there are 'threshold values' over which sediment transport becomes active, but these are not straightforward, as hysteresis occurs. This means that sediment load is not related directly to the flow, but is affected by whether the hydrograph is falling or rising. Hysteresis results from changing availability of sediment (Dunne and Leopold, 1978), resulting in high levels of transport on the rising arm, but lower levels at the same flow on the falling arm. Bank erosion, in contrast, tends to occur in a series of large failures on the falling arm of the hydrograph, with failures more likely if they follow other recent high flow events (Lawler *et al.*, 1997). The other limiting factor was the fact that flows are only readily available for gauging stations, not our sampling points. This would make it difficult to calculate the necessary model (methods are available for estimating flow at ungauged locations), and impossible to apply in GIS to extrapolate to unsampled areas. This aspect should be considered further in any future work.

8.2 Process Based Modelling

Another study which has been carried out within the UK has addressed the problem of silt delivery using a process based model (McHugh *et al.,* 2002). This differs from the previous two studies in that it is a process-based model which does not integrate all sources of silt. It attempts to describe silt delivery from the catchment surface only, excluding silt from field drains and riverbank erosion. Riverbank erosion can be a significant input in some areas of the country (Walling *et al.*, 2002), so this model will not be as useful for estimating quantities of silt within the watercourse, merely that delivered from the land surface. A further process based model for assessing riverbank erosion may be useful from an ecological assessment point of view.

A key part of this project was a process based assessment of the connectivity of the land with the watercourses, that is, how much sediment eroded from a particular piece of land is likely to end up in the river. This is the piece of work which allows models of erosion to be transformed into quantities of silt in the river. The first value calculated was a qualitative connectivity index which represents a relative quantity of silt delivered. This was the converted to the connectivity ratio, an actual estimate of the proportion of fines delivered from one land parcel to the watercourse.

The first stage undertaken was to identify the key factors which control the efficiency of sediment delivery from hill slopes to watercourses. There were several obstacles to this process. Firstly, there is only limited understanding of the sediment delivery process, which is a complex dynamic system characterised by a high degree of both temporal and spatial variability. Secondly, spatially explicit sediment delivery models are limited by the availability of suitable spatial data sets. Current understanding suggests that there are three primary controls on sediment delivery to watercourses: the transport capacity of surface runoff, the spatial distribution of the receiving watercourses and the characteristics of the mobilised sediment. These three controls can be represented by six factors used to derive the connectivity index:

- Runoff potential factor

Surface runoff is the ultimate driver of sediment transfer. It was estimated by combining the Surface Potential Runoff (SPR), derived from soil hydrology data, with the Hydrological Effective Rainfall (HER) to give the runoff potential factor.

- Slope steepness factor

Derived from the 50m DEM Using slope and curvature functions within ArcInfo. For a more accurate analysis than available from just averaging the values from the 50m DEM into the 1km^2 grid, focal functions were used including 'focalsum' and 'focalmajority' to derive the overall slope gradient.

- Slope shape factor

A convex slope profile is more efficient in terms of sediment delivery, because sediment transport capacity increases down slope. Concave surfaces are usually associated with deposition of sediment as the slope levels out. Slope shape was therefore derived from the DEM within ArcInfo.

- Drainage pattern factor

This represents the spatial distribution and density of the drainage network. The river length per km^2 is a common descriptor of drainage pattern, but does not account for the spatial distribution of watercourses within the area. For this project an improved methodology which takes the average distance from all land cells at 50m resolution to the nearest watercourse.

- Land use factor

The land use was used as a base layer to estimate the surface roughness of the soil, which is the process by which land use affects runoff.

- Sediment characteristics factor

The silt and clay % from the soils data was used to gain an idea of the transportability of the soil, which is controlled by the particle size.

Each of the factors was scaled to a value of between 0 and 1, and the factors were then combined. The factors are unlikely to be equally important in accounting for sediment delivery. They were therefore weighted using an objective formula which gave greatest weighting to those factors which showed the greatest spatial variability, as these are likely to account for the greatest differences observed between different areas.

This connectivity index can now be combined with a model of erosion to provide sediment delivery data. Unfortunately few models of erosion have been derived and tested for the UK, and empirically collected data is sparse. For this project, existing data from a network of approximately 700 field sites was used to assess erosion. Unfortunately erosion rates were assessed by measuring the amount of material missing from rills and gullies. Arable land is ploughed on an annual basis, which means that the results have a time scale associated with them, meaning that erosion rates can be calculated. For the other two land uses, grassland and upland, no such temporal information is available. This means that the data sets for different land uses are not equivalent, and cannot be combined. The arable section is very useful, as quantities of silt reaching the watercourse per year can be calculated. For the other two categories, the final output is a qualitative assessment of risk.

There are several parts of this project which leave scope for improvement. The most obvious is the incompatibility of the different land use components, which seriously limits the usefulness of the outputs. This is currently being examined as a possible next phase of the project. Another is the resolution of the data, as the modelling has been done on a coarse 1km^2 grid, with much of the input data being deliberately generalised to this scale. However, De Roo (1998) found that more resolved grids do not necessarily lead to more accurate erosion estimates. Processes occurring at a larger scale than the cell size of the DEM smooth out the streamflow and erosion response. The concern is that as the DEM becomes more detailed, so the number of parameters increases. This may actually increase, rather than decrease the overall uncertainty of the model. The expectation that the highest resolution data should always give the best result may not be valid in all circumstances.

8.3 Summary

Clearly there is a great deal of work still to be done to improve our understanding of silt delivery. Given the increasing interest in diffuse pollution and farming being shown by policy makers, it would seem imperative that this is taken forward. Soil has been given relatively little attention in environmental policy to date, but new proposals mean that there should now be an EU "thematic strategy" on soil protection by 2004, with erosion being considered a priority threat (Ends Daily,19/04/02).

A key problem which needs to be addressed, is the lack of raw data as input to UK models. This project has provided some integrated data on the incidence and source of siltation of gravels, but the UK still lacks vital data on the quantity of silt produced by different land management practices, making process based or predictive modelling very difficult. It is also difficult to separate chance correlations from actual controlling factors within the empirical modelling approach.

The dearth of information does however make modelling exercises such as this one very useful, as it highlights areas where the risks of sediment delivery are high, allowing targeted sampling and remediation to be carried out. As a result, there are likely to be many more UK projects using GIS to model siltation in the future.

9 RECOMMENDATIONS

Refine model by

- land use * connectivity to watercourse (from R&D Project P2-209, Prediction of sediment delivery to watercourses from land, Phase II).
- Scaling the influence of land use by the proportion of fines from catchment sources (from sediment fingerprinting results, Walling *et al.,* 2002)

Repeat the modelling procedure using data on the source of fines from Walling *et al.,* 2002. Examining the relationship between landuse characteristics and the source of fines would be a useful exercise, and may allow a prediction of the dominant source of fines in unsampled areas. Such a prediction would be of use in tackling any perceived siltation problems.

An attempt should be made to include some measure of flow into future projects, as flow is a major control on sediment delivery.

Compare 'risk of sediment delivery' model (from R&D Project P2-209, Prediction of sediment delivery to watercourses from land, Phase II) to actual levels of fines recovered from this project. This could help to validate the model, and provide insights to the processes controlling sediment accumulation within salmonid spawning gravels. A comparison with the models generated with this project, and recorded fish densities would also be instructive, although risk of sediment delivery will differ from silt accumulation within river gravels.

Work should be carried out to link the levels of fines accumulating in salmonid spawning gravels to the turbidity of the water. Although the calibration of turbidity meters is time consuming, they do offer the possibility of continuous, real time monitoring.

More information is needed on the relationship between the quantity of silt in sampling baskets and egg mortality. Some of this information is currently being collected as part of a DEFRA project (Greig, 2001) and should be analysed to give more information on the levels which cause reproductive problems for salmonids.

Future monitoring using sampling baskets should be co-ordinated and results compiled centrally.

More information is needed on siltation. Although this project represents the largest co-ordinated study of its kind, the number of samples taken is tiny on a national scale, particularly when compared to e.g. biological or chemical samples of which many thousands are taken each year.

There is a need to have a better understanding of the particular land management practices which are causing problems. This is best achieved through the sediment fingerprinting work, which should be supported as the best route to provide evidence of particular agricultural practice causing measurable damage to spawning gravels.

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MAFF \ WOAD

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APPENDIX 1

THE EXTENT AND IMPACT OF SEDIMENT DEPOSITION ON SALMON AND TROUT SPAWNING GRAVELS.

R&D PROJECT REFERENCE: W2-046

NOTE ON SURVEY DESIGN, WINTER 1999 / 2000

1. Introduction

At the project board meeting on 5/8/99, it was agreed to provide a written rationale for the survey design. This note outlines the rationale and the scope of the survey.

2. Aims and Approach:

2.1. To use a standard retrievable sampling basket in a representative range of British rivers to determine the extent of siltation of spawning gravels.

Approach: The retrievable sampling basket allows a measurement to be taken of the level of intrusion of fines into an area of cleaned gravel over the time period critical to egg survival. This will be done using a standardised sampling protocol, based on trials conducted in summer 1999 in seven catchments in England and Wales.

2.2. To obtain information on the physical and chemical properties of sediments deposited in salmonid redds.

Approach: A fingerprinting approach will be used to provide a preliminary assessment of the source of fine sediments within the artificial redds to determine whether catchment or channel bank sources are most important.

2.3. To use the resulting data and experience to produce National picture of:

- the proportion of rivers in which salmonid spawning gravels are affected by siltation
- the location of impacted rivers.
- the predominant source of the sediments causing problems
- the factors most commonly associated with siltation problems e.g. land use, geology, gradient

2.4. To use the results of this survey to determine the need for, and extent of, future work.

2.5. To use results as evidence to support policy, planning and management actions to reduce impacts of siltation on fisheries.

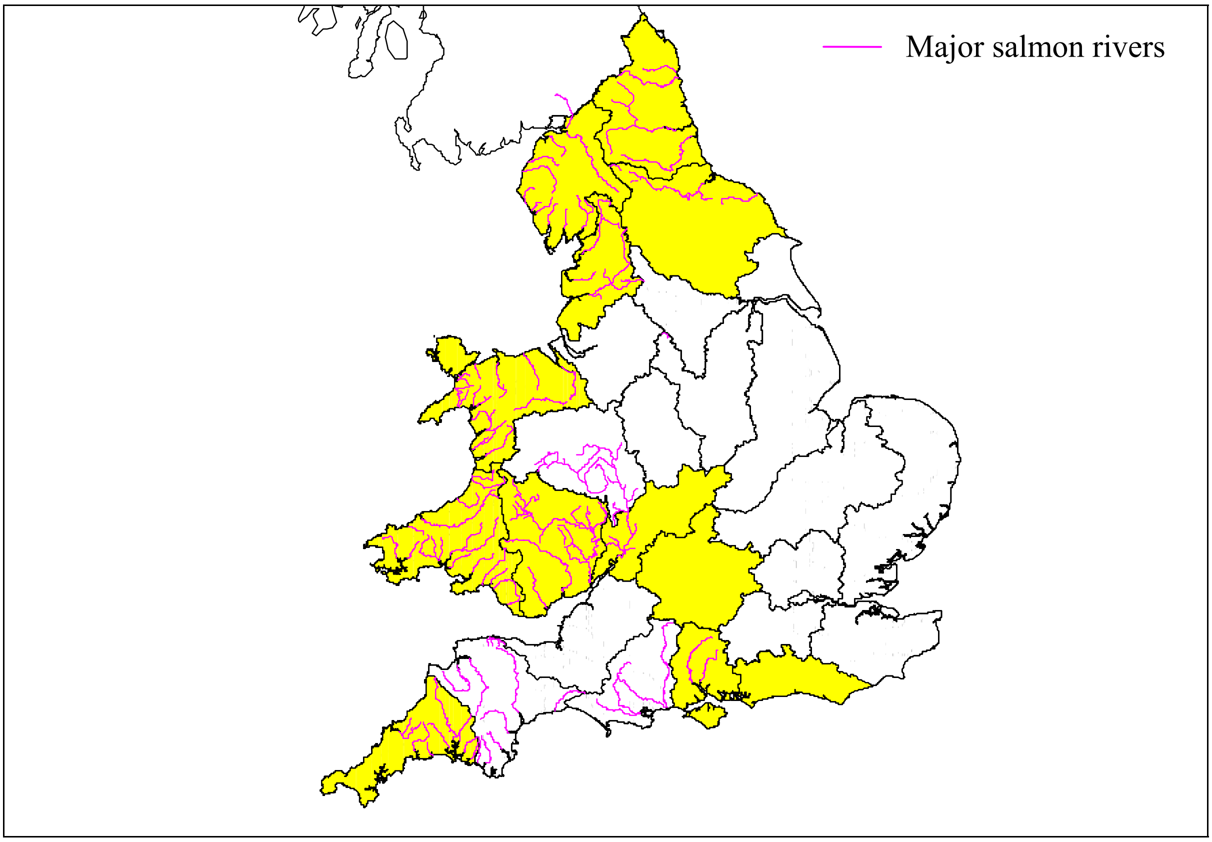
3 Representativeness of Participating Areas:

It was proposed to sample a representative range of river types in order to get a clear picture of the extent of the problem, with the survey restricted to:

- salmon and sea trout rivers
- spawning reaches within these rivers.

Not all Agency Areas, however, are able to provide support. To date, twelve Areas have offered to support the project (Figure 1). The Areas that have offered to support the project show a good geographical spread, and cover the majority of major salmon rivers in England and Wales. This is shown in Figure 1, with Areas offering support in yellow and the major salmon rivers displayed in pink.

Figure 1: **Areas offering to support the winter survey.**



It was decided that the survey should sample a wide range of river types. River types can be classified in a variety of ways. The River Habitat Survey (RHS) database has been used to examine different river type classifications in an attempt to relate them to the physical characteristics of the river. Five different river classification schemes have been examined using the RHS, and in all cases variation within river types was larger than between river type variation. As a result of this testing, it has been found that gradient and altitude are the only parameters that can be used consistently to identify river characteristics, with geology playing a secondary role.

It was therefore decided to stratify the sampling on this project according to altitude and gradient. The rivers of England and Wales were classified using GIS which showed that the majority of river length in England and Wales is grouped in the lowest altitude \ gradient class. This is due to the spatial dominance of relatively flat, lowland areas. Many of these large lowland areas will not support salmonid spawning areas, so it was decided to remove the bias that these rivers impose. This was done by classifying river lengths only from Agency Areas supporting major salmonid rivers as represented in the “Annual Assessment of Salmon Stocks and Fisheries in England and Wales” report. The results of this are shown in Table 1.

Table 1: Percentage of river lengths in altitude - gradient classes for major salmonid areas in England and Wales.

		Altitude (m)					
		0 - 100	**100 - 200**	**200-300**	**300-400**	**400+**	**Total**
	0-50	32.8	11.1	3.7	1.4	1.1	**50.0**
Gradient	**50-100**	7.2	7.9	4.7	2.6	2.1	**24.5**
m/km	**100-150**	2.6	3.5	2.7	2.0	1.7	**12.4**
	150-200	1.1	1.5	1.4	1.2	1.0	**6.2**
	200+	0.9	1.4	1.7	1.6	1.4	**7.0**
	Total	**44.5**	**25.5**	**14.1**	**8.7**	**7.2**	**100.0**

To find out if the Areas volunteering to undertake work were representative of salmon areas across England and Wales, the classification was carried out again using only on those areas who had volunteered to undertake the work. The results of this classification are shown in Table 2.

Table 2: Percentage of river lengths in altitude - gradient classes for areas in England participating in the winter survey

		Altitude (m)					
		0 - 100	**100 - 200**	**200-300**	**300-400**	**400+**	**Total**
	0-50	36.7	10.2	3.6	1.3	1.1	**52.9**
Gradient	**50-100**	7.0	7.0	4.4	2.5	2.2	**23.1**
m/km	**100-150**	2.3	3.1	2.5	1.9	1.7	**11.5**
	150-200	1.0	1.4	1.3	1.1	1.0	**5.8**
	200+	0.8	1.4	1.6	1.5	1.5	**6.8**
	Total	**47.7**	**23.0**	**13.4**	**8.4**	**7.5**	**100.0**

The distribution of river types within the volunteer Areas (Figure 3) shows a very similar distribution of river types to that of the major salmon areas in England and Wales (Figure 2).

Figure 2: Percentage of River Length in Gradient Categories

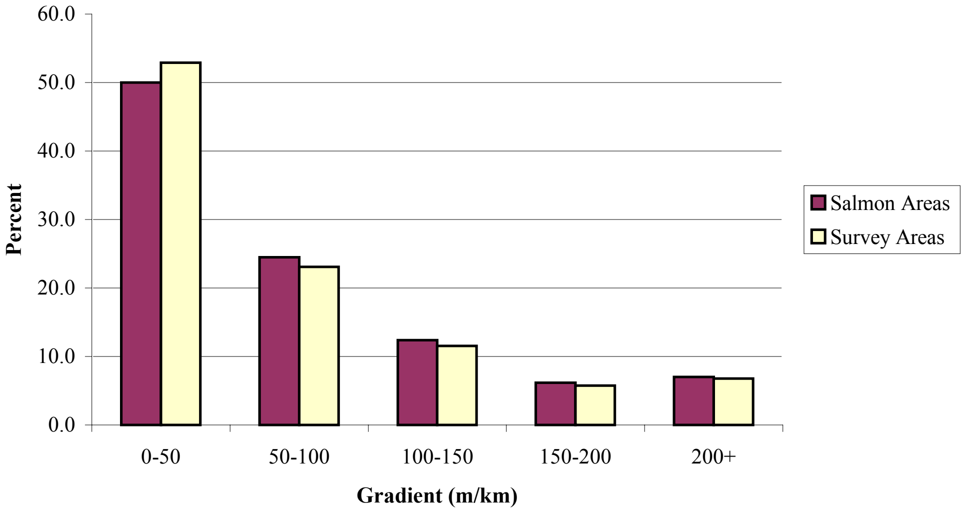
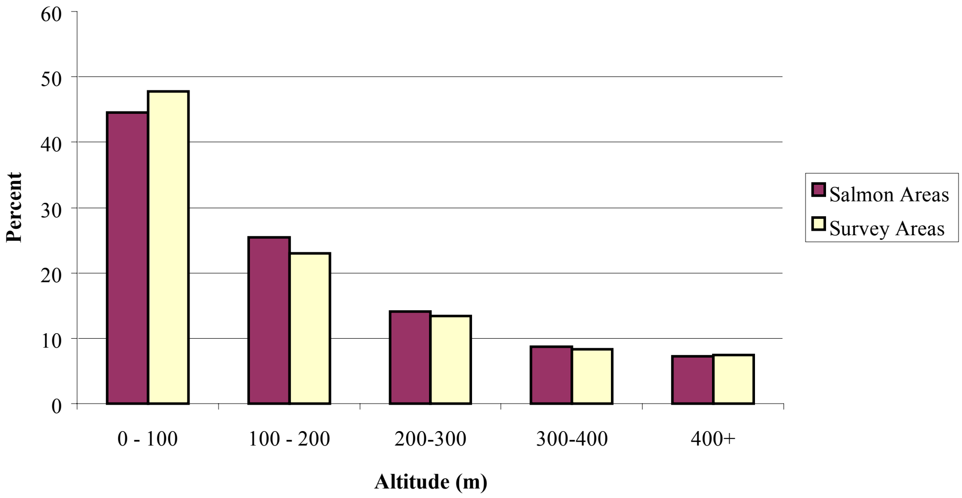


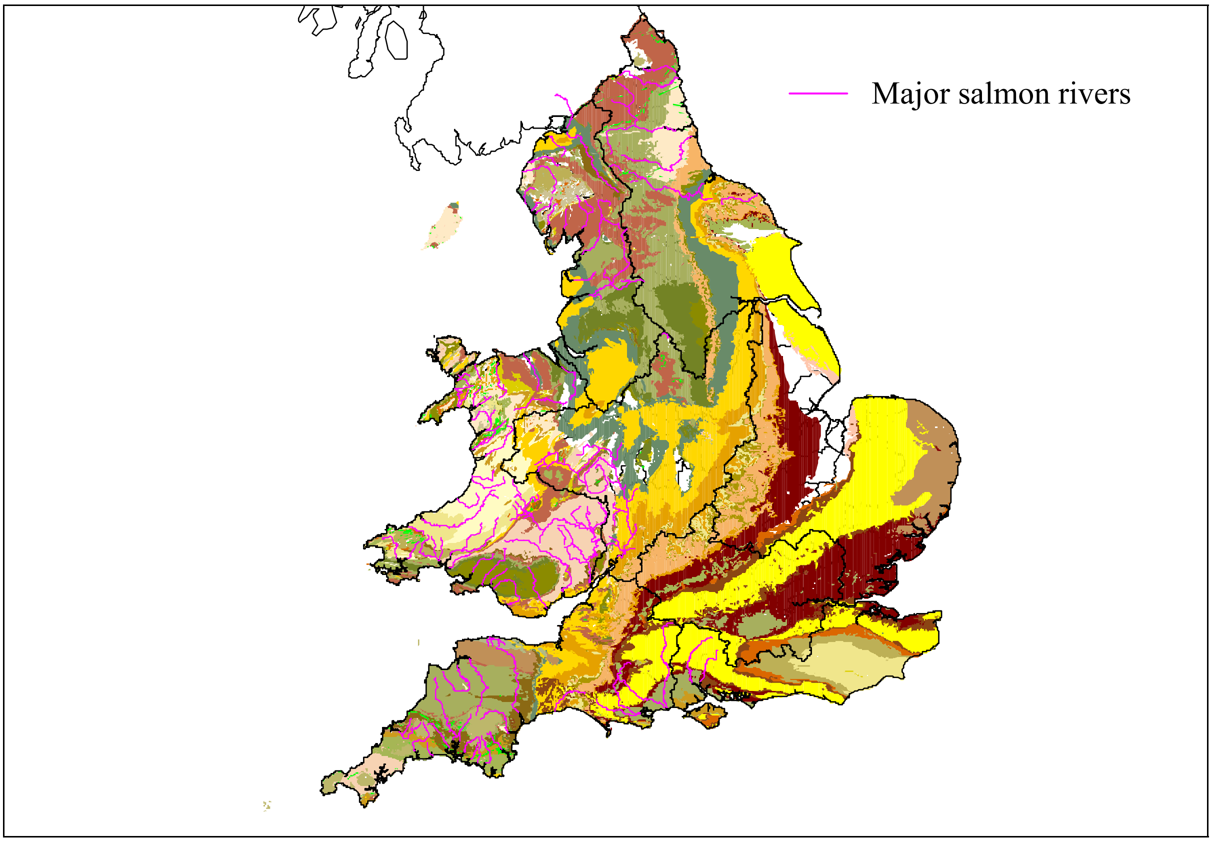
Figure 3: Percentage of River Length in Altitude Categories



The river within the volunteer areas can therefore be said to be representative of the major salmon rivers of England and Wales. This shown more clearly by Figures 2 and 3 above.

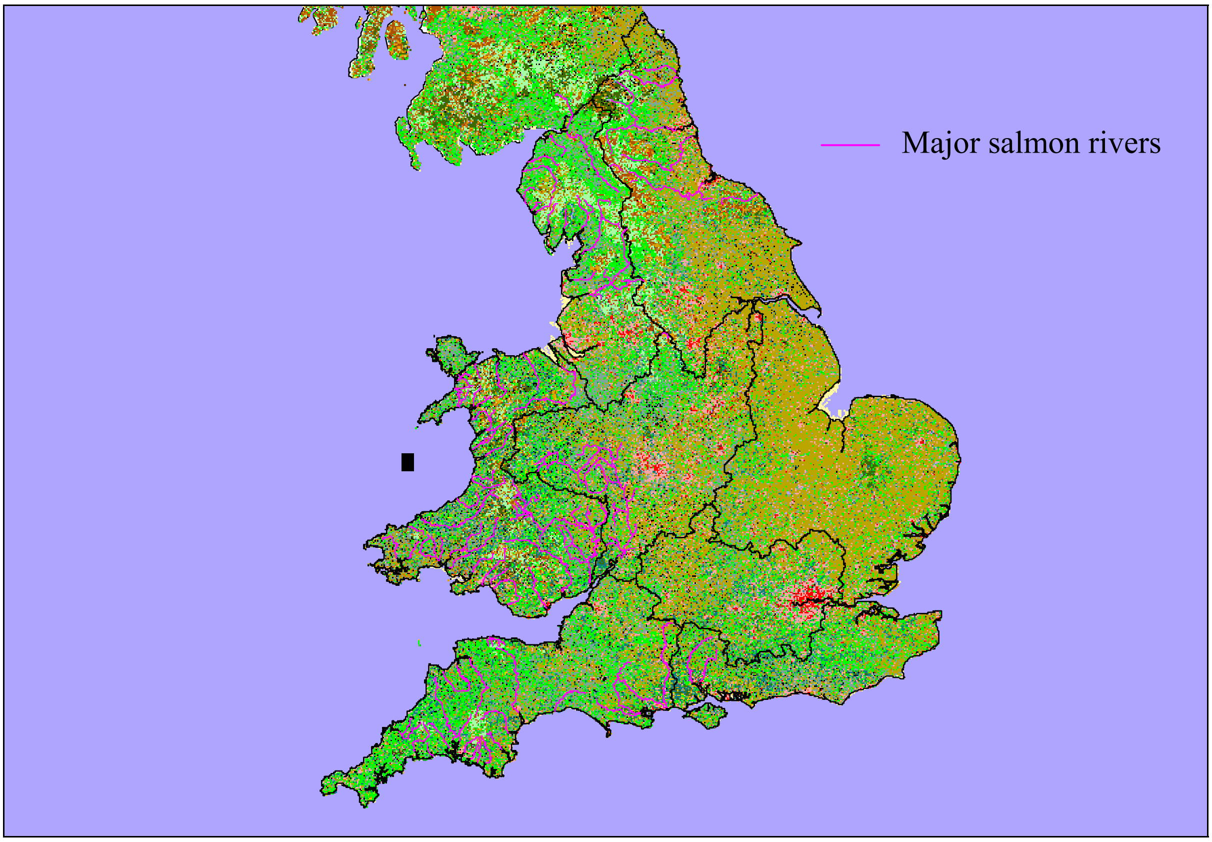
Geology was also found, by the RHS analysis, to have an impact on the nature of rivers. Geology tends to be on a large scale, with rivers in similar Areas cutting across similar rock types (Figure 4). As a result, rivers within the same area run off similar geology, eg most of the rivers in the North of England and North Wales run through drift geology dominated by boulder clay and morainic drift. The large geographic spread between the Areas carrying out the surveys, and the way that geology varies around the country mean that the sampling will represent many different geology types. The most important distinction brought about by geology is that between chalk rivers and others. Approximately 13% of England and Wales is on a chalk geology, but this is situated mainly to the South and East of England, meaning that few major salmon rivers occur on chalk. Approximately 5% (land area)of major salmon areas are on chalk. Due to the fact that these rivers have greater perceived problems, interest in these areas has been greater. 15% to 20% of the samples in this study will be taken from chalk rivers. Chalk rivers therefore over represented within the sampling strategy, which will be taken into account in any extrapolation of findings to create a National picture.

Figure 4: Solid geology of England and Wales



Landuse shows definite trends related to geographic location (Figure 5). As a result the geographic spread of Areas offering support again covers a range of land use patterns.

Figure 5: Land use across England and Wales



3.2 Site Selection Within Participating Areas

A pragmatic approach has been applied to the actual site selection. It is impractical for the National Centre to choose individual sites, as information is not readily available on factors such as accessibility to migratory fish or the availability of spawning gravels. In addition such considerations as site accessibility for sampling and travel times from the office must be taken into account. The National Centre has therefore ensured that a representative sample of catchments has been selected, while Areas will be left to determine the most applicable reaches in which to place the baskets, taking into account the above considerations.

Once selections have been made the exact nature of these sites will be determined in terms of land use, geology, gradient and altitude. Any shortfall in the sampling of river types will be adjusted after areas have nominated sites. It is however recognised that spawning gravels may not be found across the full range of altitude \ gradient classes.

4 Summary

The Areas selected for sampling are representative of salmon rivers in England and Wales in terms of their distribution across the altitude/gradient classes. Geology, in terms of its impact on river type, is best split into chalk and other for salmon rivers. Both of these categories are well sampled in the strategy set out above. In addition the Areas selected cover a wide range of land uses.

APPENDIX 2

Table 1: Weight of Fines Summary

Catch-ment	Tributary	NGR	Weight (g)	wt>4.0 mm	wt>2.0 mm	wt>0.85 mm	wt>0.125 mm	wt<0.125 mm	Wt of fines <0.85mm	% fines <0.85mm
Camel	Allen	SX066791	8829.3	247.2	369.9	653.4	438.8	23.8	462.7	5.2
Camel	Allen	SX066791	8012.7	262.0	1073.7	468.7	89.7	16.8	106.6	1.3
Camel	Allen	SX066791	8005.0	325.0	408.3	451.5	156.1	4.8	160.9	2.0
Camel	Camel	SX096807	7572.4	272.6	525.5	362.7	49.2	6.1	55.3	0.7
Camel	Camel	SX096807	8575.0	289.0	611.4	506.8	282.1	52.3	334.4	3.9
Camel	Camel	SX096807	8383.2	485.4	1028.6	542.4	152.6	10.1	162.6	1.9
Dee*	Alyn	SJ358568	8400.0	40.9	91.7	422.4	202.4	25.6	228.0	2.7
Dee*	Alyn	SJ358568	8400.0	37.0	61.0	77.5	694.1	6.7	700.8	8.3
Dee*	Alyn	SJ358568	8400.0	24.9	49.6	430.0	83.6	26.0	109.6	1.3
Dee*	Alyn	SJ358568	8400.0	5.4	11.4	47.3	342.3	163.4	505.7	6.0
Dee*	Ceiriog	SJ233378	8400.0	168.3	235.7	283.5	139.0	32.3	171.3	2.0
Dee*	Ceiriog	SJ233378	8400.0	198.9	180.7	152.1	72.9	23.8	96.7	1.2
Dee*	Ceiriog	SJ233378	8400.0	152.3	357.6	181.4	112.9	30.8	143.7	1.7
Dee*	Ceiriog	SJ233378	8400.0	136.6	173.9	147.4	140.3	24.2	164.6	2.0
Esk *	Esk	NZ764076	8400.0	292.2	334.5	321.9	284.3	57.1	341.4	4.1
Esk *	Esk	NZ764077	8400.0	354.9	360.7	135.1	447.5	61.0	508.5	6.1
Esk *	Esk	NZ764078	8400.0	289.8	364.8	452.2	282.2	47.2	329.4	3.9
Esk *	Esk	NZ781055	8400.0	187.1	193.3	274.7	361.7	48.0	409.7	4.9
Esk *	Esk	NZ781056	8400.0	261.1	241.2	511.4	426.6	46.8	473.4	5.6
Esk *	Esk	NZ781057	8400.0	217.4	382.7	571.4	291.1	30.2	321.3	3.8
Esk *	Esk	NZ826055	8400.0	385.7	243.8	131.5	263.5	84.0	347.5	4.1
Esk *	Esk	NZ826056	8400.0	298.8	400.3	223.6	263.2	59.1	322.3	3.8
Esk *	Esk	NZ826057	8400.0	436.2	402.4	249.0	208.4	74.4	282.8	3.4
Esk *	Esk	NZ863078	8400.0	182.1	279.7	256.1	647.6	70.7	718.3	8.6
Esk *	Esk	NZ863079	8400.0	181.3	209.1	357.3	734.0	88.9	822.9	9.8
Esk *	Esk	NZ863080	8400.0	92.5	387.3	851.2	915.8	64.4	980.2	11.7
Fal	Fal	SW922450	8580.6	284.0	278.0	341.5	514.8	10.3	525.1	6.1
Fal	Fal	SW922450	7581.2	281.3	270.6	264.6	219.9	1.5	221.4	2.9
Fal	Fal	SW922450	8870.3	438.2	518.0	491.4	461.3	2.7	463.9	5.2
Fal	Fal	SW929468	9223.7	248.1	359.7	544.2	643.8	88.5	732.4	7.9
Fal	Fal	SW929468	8620.3	262.1	351.7	358.6	579.3	133.6	712.9	8.3
Fal	Fal	SW929468	8957.7	233.8	380.7	670.0	699.6	57.3	756.9	8.5
Fowey	Fowey	SX111664	8301.8	126.2	141.1	192.6	606.9	78.0	684.9	8.3
Fowey	Fowey	SX111664	9846.1	407.6	404.7	947.2	714.8	49.2	764.1	7.8
Fowey	Fowey	SX158676	9263.7	242.7	644.8	711.4	403.9	61.1	465.0	5.0
Fowey	Fowey	SX158676	8163.5	202.5	675.9	667.0	427.0	52.2	479.2	5.9
Fowey	Fowey	SX158676	9001.1	234.0	800.2	982.9	548.2	43.2	591.4	6.6

Catch-ment	Tributary	NGR	Weight (g)	wt>4.0 mm	wt>2.0 mm	wt>0.85 mm	wt>0.125 mm	wt<0.125 mm	Wt of fines <0.85mm	% fines <0.85mm
Fowey	Fowey	SX202661	8600.1	156.5	287.2	485.9	712.9	20.6	733.6	8.5
Fowey	Fowey	SX202661	8877.6	466.1	538.9	980.1	664.0	30.2	694.2	7.8
Fowey	Fowey	SX202661	8072.4	351.2	963.8	448.0	209.9	16.1	226.0	2.8
Fowey	St. Neot	SX185654	7880.5	193.9	346.7	424.8	328.6	24.4	353.0	4.5
Itchen		SU480281	7601.5	3.6	15.4	44.6	278.6	32.4	311.0	4.1
Itchen		SU480282	7676.2	0.5	1.9	9.8	294.0	35.2	329.3	4.3
Itchen		SU480283	7892.8	1.8	1.3	1.0	153.3	167.3	320.5	4.1
Itchen		SU480284	7751.6	1.4	2.4	37.6	227.7	20.4	248.1	3.2
Itchen		SU480285	7482.0	5.1	5.1	4.1	280.4	29.5	309.9	4.1
Itchen		SU480286	7575.1	6.6	5.5	7.0	284.6	33.5	318.0	4.2
Itchen	Itchen	SU461171	8151.9	165.8	167.7	112.1	295.1	33.2	328.4	4.0
Itchen	Itchen	SU461172	7316.6	71.2	121.4	115.9	265.0	45.0	310.1	4.2
Itchen	Itchen	SU461173	7775.7	32.9	94.6	300.7	101.2	28.9	130.1	1.7
Itchen	Itchen	SU461174	7688.4	135.2	233.7	116.2	100.2	39.0	139.2	1.8
Itchen	Itchen	SU461175	7874.8	153.8	211.5	143.9	151.8	23.4	175.2	2.2
Itchen	Itchen	SU461176	8031.9	173.5	197.3	121.0	218.3	30.4	248.7	3.1
Lynher	Deans Brook	SX382623	8620.3	467.2	458.6	638.8	681.0	21.6	702.6	8.2
Lynher	Deans Brook	SX382623	8507.8	303.7	338.6	482.4	623.6	17.0	640.6	7.5
Lynher	Deans Brook	SX382623	8128.9	368.2	371.5	861.7	408.9	10.6	419.5	5.2
Lynher	Lynher	SX286749	8477.3	212.8	425.6	628.2	415.4	25.4	440.8	5.2
Lynher	Lynher	SX286749	8381.5	220.4	459.3	609.3	630.3	21.8	652.1	7.8
Lynher	Lynher	SX286749	9295.9	309.6	640.5	759.5	506.6	22.3	528.9	5.7
Plym	Meavy	SX526655	8902.9	263.5	142.4	827.1	390.8	15.1	406.0	4.6
Plym	Meavy	SX526655	9511.0	261.6	657.2	876.9	428.0	29.5	457.5	4.8
Plym	Meavy	SX526655	8306.4	221.8	315.6	492.6	303.2	13.3	316.5	3.8
Plym	Plym	SX526618	10013.7	283.4	576.8	742.0	526.7	15.0	541.7	5.4
Plym	Plym	SX526618	9725.2	182.8	354.0	605.9	391.9	7.8	399.7	4.1
Plym	Plym	SX526618	8432.8	280.8	172.0	184.7	177.1	32.0	209.1	2.5
Ribble		SD793759	8840.6	416.4	601.2	668.3	461.5	29.2	490.7	5.6
Ribble		SD807720	7270.2	368.6	339.5	288.6	250.8	29.1	279.9	3.9
Ribble		SD811632	7994.2	316.6	343.8	618.0	926.5	35.2	961.7	12.0
Ribble		SD841580	7389.6	315.5	459.6	461.1	580.1	34.7	614.8	8.3
Ribble		SD852552	6716.7	139.0	148.4	309.0	407.0	12.1	419.1	6.2
Taff	Taff	ST088881	8453.6	323.8	426.1	595.1	313.6	22.0	335.6	4.0
Taff	Taff	ST088882	9016.6	402.1	534.7	423.8	228.1	21.6	249.8	2.8
Taff	Taff	ST088883	10136.0	543.3	648.7	631.5	302.1	8.1	310.2	3.1
Taff	Taff	ST088884	8906.7	373.2	549.5	621.7	191.5	13.4	204.9	2.3
Tamar	Inny	SX260815	9273.8	186.4	378.4	568.5	581.5	32.5	613.9	6.6
Tamar	Inny	SX260815	8502.1	206.6	399.6	508.4	323.9	13.6	337.5	4.0
Tamar	Inny	SX260815	8764.8	248.0	639.0	660.9	215.6	14.9	230.5	2.6

Catch-ment	Tributary	NGR	Weight (g)	wt>4.0 mm	wt>2.0 mm	wt>0.85 mm	wt>0.125 mm	wt<0.125 mm	Wt of fines <0.85mm	% fines <0.85mm
Tamar	Lew	SX458874	9063.5	370.7	451.4	499.4	340.8	36.3	377.0	4.2
Tamar	Lew	SX458874	8683.5	371.7	526.2	346.5	336.9	63.4	400.3	4.6
Tamar	Lew	SX458874	7783.3	311.3	343.2	279.4	335.5	63.0	398.5	5.1
Tamar	Lyd	SX429838	8036.7	386.6	411.5	266.0	281.3	55.5	336.7	4.2
Tamar	Lyd	SX429838	9076.9	371.2	451.1	499.2	341.3	49.9	391.2	4.3
Tamar	Lyd	SX429838	8580.1	276.3	379.2	631.5	338.9	66.1	405.0	4.7
Tamar	Ottery	SX229917	8540.8	249.4	620.9	554.3	374.9	68.3	443.3	5.2
Tamar	Ottery	SX229917	8768.9	332.3	626.1	698.0	316.6	49.1	365.7	4.2
Tamar	Ottery	SX229917	8650.4	327.8	617.6	688.6	312.3	48.4	360.7	4.2
Tamar	Tamar	SX289994	8417.6	357.7	324.9	180.1	197.0	85.9	282.8	3.4
Tamar	Tamar	SX289994	8297.1	326.1	252.2	177.6	196.6	56.4	253.1	3.1
Tamar	Tamar	SX289994	8392.7	202.3	210.7	158.6	143.5	70.5	214.0	2.6
Tavy	Tavy	SX477733	7720.1	141.3	119.7	74.1	240.9	37.8	278.7	3.6
Tavy	Tavy	SX477733	8641.9	166.8	175.4	124.4	229.9	19.0	248.9	2.9
Tavy	Tavy	SX477733	8942.3	261.1	533.0	347.0	187.8	14.3	202.1	2.3
Tavy	Tavy	SX511786	9461.5	433.3	675.5	526.1	259.2	19.9	279.1	3.0
Tavy	Tavy	SX511786	9829.4	487.5	723.4	548.5	245.7	14.7	260.5	2.7
Tavy	Walkham	SX488709	10157.2	387.0	503.8	1112.2	546.5	15.2	561.7	5.5
Tavy	Walkham	SX488709	10734.0	517.4	926.3	1187.2	331.7	14.0	345.6	3.2
Tavy	Walkham	SX488709	8736.4	255.1	449.0	616.8	395.8	13.1	408.9	4.7
Test	Test	SU331301	7711.8	4.6	14.0	41.6	214.1	23.5	237.6	3.1
Test	Test	SU331302	7929.9	26.4	83.5	160.4	297.2	33.4	330.6	4.2
Test	Test	SU331303	7675.8	13.2	87.8	120.6	252.5	56.7	309.2	4.0
Test	Test	SU331304	7902.4	37.8	102.1	33.5	117.2	19.7	136.9	1.7
Test	Test	SU331305	8122.3	19.3	86.8	27.6	265.8	20.8	286.6	3.5
Test	Test	SU351161	7969.7	41.7	134.1	143.7	328.1	73.2	401.3	5.0
Test	Test	SU351162	8209.5	67.1	116.7	103.7	346.8	64.2	410.9	5.0
Test	Test	SU351163	8903.9	48.2	65.4	51.9	426.1	63.2	489.3	5.5
Thames	Kennet	SU323635	7565.5	152.1	91.5	84.7	121.0	45.4	166.4	2.2
Thames	Kennet	SU323635	6989.5	210.4	102.0	88.8	229.3	45.4	274.7	3.9
Thames	Kennet	SU323635	7423.5	386.8	227.9	237.6	179.6	15.6	195.2	2.6
Thames	Kennet	SU341693	7035.1	45.7	32.4	42.9	85.1	39.4	124.5	1.8
Thames	Kennet	SU341693	7749.7	44.9	19.4	41.8	87.6	43.4	131.0	1.7
Thames	Kennet	SU341693	7004.3	85.5	59.5	45.5	44.8	7.0	51.8	0.7
Thames	Lambourne	SU414726	7127.9	24.9	12.1	32.8	73.4	22.1	95.5	1.3
Thames	Lambourne	SU414726	6963.2	58.5	20.2	18.8	70.3	13.9	84.3	1.2
Thames	Lambourne	SU414726	7533.0	172.5	85.1	38.4	37.7	6.0	43.7	0.6
Thames	Lambourne	SU414726	6689.1	22.1	18.1	28.8	90.3	28.8	119.1	1.8
Tywi	Cennen	SN619181	8047.1	370.2	321.1	339.6	198.0	37.0	235.0	2.9
Tywi	Cennen	SN619182	9316.7	201.2	316.8	715.5	1056.5	50.3	1106.8	11.9
Tywi	Cennen	SN619183	8716.2	363.5	480.3	434.9	946.6	13.9	960.5	11.0

Catch-ment	Tributary	NGR	Weight (g)	wt>4.0 mm	wt>2.0 mm	wt>0.85 mm	wt>0.125 mm	wt<0.125 mm	Wt of fines <0.85mm	% fines <0.85mm
Tywi	Cennen	SN619184	7968.1	466.1	515.5	289.2	423.9	43.8	467.7	5.9
Tywi	Cennen	SN619185	8163.1	453.0	427.7	355.1	1217.9	48.2	1266.1	15.5
Tywi	Cennen	SN619186	7381.9	169.0	248.8	200.8	323.3	55.4	378.7	5.1
Wye	Marteg	SO002753	8760.6	593.1	509.0	374.1	316.3	40.3	356.6	4.1
Wye	Marteg	SO002754	8991.2	601.5	495.4	355.2	152.8	30.6	183.4	2.0
Wye	Marteg	SO002755	8072.5	459.3	395.6	173.6	96.9	27.4	124.3	1.5
Wye	Marteg	SO002756	8398.4	708.0	499.7	335.9	141.1	21.8	162.9	1.9
Yealm	Piall	SX599576	8963.6	414.1	579.9	449.1	461.6	35.9	497.5	5.6
Yealm	Piall	SX599576	8620.4	334.5	488.8	330.2	488.8	24.1	512.9	6.0
Yealm	Piall	SX599576	9262.7	296.4	518.7	780.8	617.8	28.7	646.5	7.0
Yealm	Yealm	SX595538	9038.4	269.3	461.0	576.6	209.7	19.9	229.6	2.5
Yealm	Yealm	SX595538	9629.1	219.5	443.9	624.0	384.2	40.4	424.6	4.4
Yealm	Yealm	SX595538	9399.0	253.8	619.4	654.2	387.2	47.0	434.2	4.6

* Average total weight applied due to data omissions.

Table 2: Upstream Catchment Statistics

NGR	Area (km2)	Proportion urban	Proportion arable	Proportion grass	Mean slope	Av. elevation (m)
SX066791	20.4	0.1	0.2	0.7	4.9	171.2
SX066791	20.4	0.1	0.2	0.7	4.9	171.2
SX066791	20.4	0.1	0.2	0.7	4.9	171.2
SX096807	27.8	0.0	0.1	0.7	3.2	249.3
SX096807	27.8	0.0	0.1	0.7	3.2	249.3
SX096807	27.8	0.0	0.1	0.7	3.2	249.3
SJ358568	235.2	0.1	0.1	0.7	5.9	252.7
SJ358568	235.2	0.1	0.1	0.7	5.9	252.7
SJ358568	235.2	0.1	0.1	0.7	5.9	252.7
SJ358568	235.2	0.1	0.1	0.7	5.9	252.7
SJ233378	94.1	0.0	0.0	0.6	10.6	439.4
SJ233378	94.1	0.0	0.0	0.6	10.6	439.4
SJ233378	94.1	0.0	0.0	0.6	10.6	439.4
SJ233378	94.1	0.0	0.0	0.6	10.6	439.4
NZ764076	135.4	0.0	0.1	0.3	6.8	278.8
NZ764077	135.4	0.0	0.1	0.3	6.8	278.8
NZ764078	135.4	0.0	0.1	0.3	6.8	278.8
NZ781055	159.0	0.0	0.1	0.3	6.5	268.9
NZ781056	159.0	0.0	0.1	0.3	6.5	268.9
NZ781057	159.0	0.0	0.1	0.3	6.5	268.9
NZ826055	289.1	0.0	0.1	0.3	5.8	257.1
NZ826056	289.1	0.0	0.1	0.3	5.8	257.1
NZ826057	289.1	0.0	0.1	0.3	5.8	257.1
NZ863078	303.4	0.0	0.1	0.3	5.9	251.8
NZ863079	303.4	0.0	0.1	0.3	5.9	251.8
NZ863080	303.4	0.0	0.1	0.3	5.9	251.8
SW922450	88.8	0.0	0.2	0.4	4.5	127.0
SW922450	88.8	0.0	0.2	0.4	4.5	127.0
SW922450	88.8	0.0	0.2	0.4	4.5	127.0
SW929468	85.4	0.1	0.2	0.4	4.4	129.8
SW929468	85.4	0.1	0.2	0.4	4.4	129.8
SW929468	85.4	0.1	0.2	0.4	4.4	129.8
SX111664	16.5	0.0	0.1	0.7	6.7	173.1
SX111664	16.5	0.0	0.1	0.7	6.7	173.1
SX158676	25.4	0.0	0.1	0.7	5.1	219.3
SX158676	25.4	0.0	0.1	0.7	5.1	219.3
SX158676	25.4	0.0	0.1	0.7	5.1	219.3
SX202661	54.5	0.0	0.1	0.7	5.6	251.2
SX202661	54.5	0.0	0.1	0.7	5.6	251.2
SX202661	54.5	0.0	0.1	0.7	5.6	251.2

NGR	Area (km2)	Proportion urban	Proportion arable	Proportion grass	Mean slope	Av. elevation (m)
SX185654	23.5	0.0	0.1	0.6	4.5	227.0
SU480281	299.5	0.1	0.5	0.4	2.9	114.3
SU480282	299.5	0.1	0.5	0.4	2.9	114.3
SU480283	299.5	0.1	0.5	0.4	2.9	114.3
SU480284	299.5	0.1	0.5	0.4	2.9	114.3
SU480285	299.5	0.1	0.5	0.4	2.9	114.3
SU480286	299.5	0.1	0.5	0.4	2.9	114.3
SU461171	405.3	0.1	0.4	0.4	2.9	100.5
SU461172	405.3	0.1	0.4	0.4	2.9	100.5
SU461173	405.3	0.1	0.4	0.4	2.9	100.5
SU461174	405.3	0.1	0.4	0.4	2.9	100.5
SU461175	405.3	0.1	0.4	0.4	2.9	100.5
SU461176	405.3	0.1	0.4	0.4	2.9	100.5
SX382623	10.7	0.0	0.3	0.5	6.3	93.5
SX382623	10.7	0.0	0.3	0.5	6.3	93.5
SX382623	10.7	0.0	0.3	0.5	6.3	93.5
SX286749	5.0	0.1	0.2	0.7	3.7	158.6
SX286749	5.0	0.1	0.2	0.7	3.7	158.6
SX286749	5.0	0.1	0.2	0.7	3.7	158.6
SX526655	39.4	0.0	0.0	0.6	5.9	286.9
SX526655	39.4	0.0	0.0	0.6	5.9	286.9
SX526655	39.4	0.0	0.0	0.6	5.9	286.9
SX526618	76.6	0.0	0.0	0.6	5.7	283.2
SX526618	76.6	0.0	0.0	0.6	5.7	283.2
SX526618	76.6	0.0	0.0	0.6	5.7	283.2
SD793759	57.9	0.0	0.0	0.6	6.2	114.6
SD807720	77.1	0.0	0.0	0.7	6.0	164.6
SD811632	3.2	0.2	0.0	0.8	7.6	41.8
SD841580	16.0	0.0	0.0	0.9	7.3	91.9
SD852552	225.3	0.0	0.0	0.8	5.7	351.3
ST088881	461.9	0.1	0.0	0.5	9.0	343.3
ST088882	461.9	0.1	0.0	0.5	9.0	343.3
ST088883	461.9	0.1	0.0	0.5	9.0	343.3
ST088884	461.9	0.1	0.0	0.5	9.0	343.3
SX260815	26.5	0.0	0.1	0.7	4.5	263.2
SX260815	26.5	0.0	0.1	0.7	4.5	263.2
SX260815	26.5	0.0	0.1	0.7	4.5	263.2
SX458874	0.4	0.0	0.2	0.8	3.5	215.0
SX458874	0.4	0.0	0.2	0.8	3.5	215.0
SX458874	0.4	0.0	0.2	0.8	3.5	215.0
SX429838	79.2	0.0	0.1	0.7	6.8	257.2
SX429838	79.2	0.0	0.1	0.7	6.8	257.2

NGR	Area (km2)	Proportion urban	Proportion arable	Proportion grass	Mean slope	Av. elevation (m)
SX429838	79.2	0.0	0.1	0.7	6.8	257.2
SX229917	51.1	0.0	0.2	0.7	3.4	206.5
SX229917	51.1	0.0	0.2	0.7	3.4	206.5
SX229917	51.1	0.0	0.2	0.7	3.4	206.5
SX289994	78.5	0.0	0.2	0.7	2.7	170.9
SX289994	78.5	0.0	0.2	0.7	2.7	170.9
SX289994	78.5	0.0	0.2	0.7	2.7	170.9
SX477733	101.8	0.0	0.0	0.6	5.7	341.4
SX477733	101.8	0.0	0.0	0.6	5.7	341.4
SX477733	101.8	0.0	0.0	0.6	5.7	341.4
SX511786	47.0	0.0	0.0	0.4	5.7	447.9
SX511786	47.0	0.0	0.0	0.4	5.7	447.9
SX488709	49.7	0.0	0.0	0.7	6.3	323.4
SX488709	49.7	0.0	0.0	0.7	6.3	323.4
SX488709	49.7	0.0	0.0	0.7	6.3	323.4
SU331301	839.5	0.0	0.5	0.3	2.8	144.4
SU331302	839.5	0.0	0.5	0.3	2.8	144.4
SU331303	839.5	0.0	0.5	0.3	2.8	144.4
SU331304	839.5	0.0	0.5	0.3	2.8	144.4
SU331305	839.5	0.0	0.5	0.3	2.8	144.4
SU351161	1037.0	0.0	0.5	0.3	2.8	136.2
SU351162	1037.0	0.0	0.5	0.3	2.8	136.2
SU351163	1037.0	0.0	0.5	0.3	2.8	136.2
SU323635	4.6	0.0	0.5	0.4	3.3	160.9
SU323635	4.6	0.0	0.5	0.4	3.3	160.9
SU323635	4.6	0.0	0.5	0.4	3.3	160.9
SU341693	318.3	0.0	0.5	0.3	3.6	181.5
SU341693	318.3	0.0	0.5	0.3	3.6	181.5
SU341693	318.3	0.0	0.5	0.3	3.6	181.5
SU414726	160.4	0.0	0.5	0.3	3.6	174.3
SU414726	160.4	0.0	0.5	0.3	3.6	174.3
SU414726	160.4	0.0	0.5	0.3	3.6	174.3
SU414726	160.4	0.0	0.5	0.3	3.6	174.3
SN619181	24.7	0.0	0.0	0.8	6.9	249.6
SN619182	24.7	0.0	0.0	0.8	6.9	249.6
SN619183	24.7	0.0	0.0	0.8	6.9	249.6
SN619184	24.7	0.0	0.0	0.8	6.9	249.6
SN619185	24.7	0.0	0.0	0.8	6.9	249.6
SN619186	24.7	0.0	0.0	0.8	6.9	249.6
SO002753	18.9	0.0	0.0	0.7	6.6	418.3
SO002754	18.9	0.0	0.0	0.7	6.6	418.3
SO002755	18.9	0.0	0.0	0.7	6.6	418.3

NGR	Area (km2)	Proportion urban	Proportion arable	Proportion grass	Mean slope	Av. elevation (m)
SO002756	18.9	0.0	0.0	0.7	6.6	418.3
SX599576	11.1	0.0	0.1	0.4	6.1	185.3
SX599576	11.1	0.0	0.1	0.4	6.1	185.3
SX599576	11.1	0.0	0.1	0.4	6.1	185.3
SX595538	42.4	0.1	0.1	0.6	5.8	191.0
SX595538	42.4	0.1	0.1	0.6	5.8	191.0
SX595538	42.4	0.1	0.1	0.6	5.8	191.0