# LAND USE AND FISHERIES

Report of the Pilot Study

R&D Technical Report W2-046/TR1

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This report describes a pilot study carried out to assess the quantity and source of fine sediments accumulating in salmonid spawning gravels. It also examines the use of GIS as a possible tool for the investigation of relationships between siltation and land-use practices. The results were used to develop a standard methodology manual, which is attached to the report as Appendix 1. 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 project was initiated on recommendation of the report “sedimentation and salmonids in England and Wales”, which expressed concern that there was little quantitative data on the impact or extent of siltation in England and Wales.

Collaborative work was undertaken between the Environment Agency and Exeter University to develop and test a method for assessing the quantity and source of fines accumulating in salmonid spawning gravels. The use of geographical information systems were also assessed as a possible tool for the investigation of relationships between siltation and land-use practices.

It was decided to use a retrievable sampling basket method to assess the quantity and source of fines accumulating within an area of cleaned gravel. This area of cleaned gravel is analogous to a salmon redd, allowing data to be collected on the conditions faced buy a salmon egg within the gravels. Eighty-four basket were installed in seven catchments, split equally between sites thought to be impacted and sites thought to be clean. Fifty-one of the baskets were successfully recovered at the end of the sampling interval of approximately 90 days.

The weight of fines was very variable within individual sites and between catchments. There was a significant difference between the weight of fines recovered from sites thought to be impacted and those thought to be clean. The quantities of fines recovered were low compared to the levels thought to cause egg mortality. However, this trial was carried out in the summer, and the majority of sediment transport occurs over winter, so these results are unlikely to be directly comparable with those quotes in the literature.

The source of the finest fraction (<0.125mm) was investigated using a simple fingerprinting approach based on a range of physical and chemical properties. This suggested that catchment sources were more important than channel bank sources in most cases.

The results of this practical work were used to develop a standard methodology manual, which is enclosed as Appendix 1.

A Geographical Information System (GIS), ArcView, was delivered and populated with relevant environmental data sets. Environmental data was extracted from the GIS for every gravel sampling site and used to develop a Bayesian model of silt accumulation. This model used average upstream gradient and the percentage of grazed land as the inputs. The model was then applied within the GIS to all points on the river network, extrapolating the model to unsampled areas.

Fisheries survey data for the river Tamar was then examined in relation to the modelled silt accumulation data. A significant relationship was found between silt the modelled silt accumulation values and the densities of both salmon and trout fry.

Recommendations for future work are included.

## 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. This project is concerned 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 to mainly to the inputs of fertilisers and pesticides. 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 or cause gill abrasion, which may increase 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 waste products are not removed from the eggs and oxygen is not brought to 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 land use change 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 uses tend 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). This leads to a phenomenon called capping where water runs off the surface of fields taking silt with it, rather than being absorbed by the soil. 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. This was carried out by Fred Theurer who 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.

As a response to these recommendations, the Agency initiated this R&D project.

### 1.2 Methods of Assessing Siltation

There are several different approaches to the collection of data on siltation, most of which rely on an assessment of the size distribution of the sediments within the spawning 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 and a sample of the gravel is extracted (McNeil and Ahnell, 1964). Shovel samples may be used instead of a core sampler and similar results 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 method 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 $CO_2$ 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 give 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). 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 examine the conditions likely to be experienced by a salmon egg.

Work had recently been undertaken at Exeter University using a retrievable sampling basket in this way, to measure the quantity of fines accumulating in an artificial salmon redd (Nicholls *et al*, 2000). The fine sediment recovered from the samples was subjected to a series of analyses to determine their source. As a result of their expertise in this area, the Agency contracted Exeter University to assist in the development of the sampling methodology, and subsequent analysis of the fine sediment recovered. This refinement and testing of the methodologies was carried out in the hope of producing a workable method and a standard methodology manual for future assessments of siltation.

### 1.3 Geographical Information Systems (GIS) and Fisheries Science

The use of GIS in 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 (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 which are essential for ICM.

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 predictive modelling capabilities of GIS are currently under-utilised in fisheries science (Fisher and Toepfer, 1998), but examples do exist. Keleher and Rahel (1996) used GIS to model the effect of climate change on salmonid populations in Wyoming, while more complex predictive modelling of hydrological habitat change has been carried out by Evans *et al.* (1994).

From the studies outlined above, have been carried out to date, it is clear that GIS has great potential for applications within fisheries science. It is particularly well suited for large scale integration of environmental data, which offers great potential for investigations 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. This project will use GIS in order to investigate these effects and to demonstrate the application of GIS in land use studies.

# 2 OBJECTIVES

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

- **To transfer protocols for sampling gravel siltation to allow Area staff to conduct preliminary field trials**

- **To determine the source of fine sediments accumulating within salmonid spawning gravels**

- **To scope out data availability and GIS requirements for the fisheries input to a larger land-use and soil erosion risk assessment project.**

As the objectives of this project were to test and modify the experimental protocols, and to assess whether the approach 'worked', it was necessary to assess whether actual results met expectations in terms of perceived siltation status. To this end samples were analysed, as they would be in a full survey, to see whether results matched expectations. Once the GIS requirements had been scoped, they were applied to enable modelling of the catchment to take place.

The three headline objectives are handled in separate sections of this report.

# 3 SAMPLING PROTOCOL

- **To transfer protocols for sampling gravel siltation to allow Area staff to conduct preliminary field trials**

## 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 was based on the approach described by Davey *et al* (1987) and Sear (1993), which was further developed during the course of a PhD studentship at Exeter University (Nicholls 2000). This method allows measurement of silt intrusion into an artificial redd by using a retrievable sampling basket. This basket has a waterproof skirt, which is compressed around the base when the basket is buried in the artificial redd. The skirt is raised around the basket when it is removed, preventing fine sediments being washed away by the current. Designs for the manufacture of the sampling baskets, which were developed from experience during the PhD, were delivered to the Agency. The baskets were then manufactured by an external supplier.

A workshop was organised to provide background information and a practical demonstration to Area fisheries staff of the sampling methodology. A brief standard methodology manual was also supplied outlining procedures and containing relevant field sheets. This was carried out in conjunction with Exeter University and involved a practical demonstration of the installation of a sampling basket in a local river.

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 another output of this project, enclosed as Appendix 1.

### 3.1.1 Experimental design.

Exeter University submitted a project outline for the measurement and investigation of silt within artificial salmon redds which involved using retrievable sampling baskets to assess levels of silt intrusion. It was proposed that 60 retrievable sampling baskets would be distributed between 5 trial catchments. Within each experimental catchment, two contrasting reaches were required:

1) One reach perceived to be suffering from siltation problems.
2) One reach perceived to be clean in the same catchment.

The protocol involved placing six sampling baskets in each of the reaches in areas *where salmonids were known to spawn*. Fisheries staff were then contacted to explain the project and to try to identify catchments with suspected siltation problems. This resulted in a final list of seven catchments being selected for trials. Exeter University agreed to this slightly expanded programme of work. The catchments and sampling sites were not stratified in any way, but were well spread across the country. The suggested sites were checked to ensure there was no obvious bias in terms of topography, land use or location, which there was not. It was concluded that the proposed sampling covered diverse range of rivers and would be suitable for testing the methodology.

The sampling baskets were placed by the Area staff according to the sampling methodology manual and left for approximately 90 days 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.

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 >6.4mm. 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 and flow regime.

## 3.2 Results

A total of 72 sampling baskets were installed at twelve sites spread through six catchments. Of these 51 baskets were successfully recovered, a recovery rate of 71% (table 3.1).

**Table 3.1: Sites and numbers of sampling baskets installed**

| Region | Area | Catchment | No. Baskets installed | No. Baskets Retrieved |
|---|---|---|---|---|
| North West | North | Leven | 12 | 7 |
| Wales | South West | Tywi | 12 | 2 |
| Wales | North | Dee | 12 | 2 |
| Midlands | Lower Severn | Severn | 12 | 9 |
| Southern | Hampshire | Test | 12 | 12 |
| Southern | Hampshire | Itchen | 12 | 11 |
| South West | Cornwall | Tamar | 12 | 10 |
| **Total** | | | **84** | **53** |

The losses were not evenly distributed around the test catchments, with losses being greatest in the Tywi catchment (South Wales), where only 17% of baskets were recovered.

## Particle size analysis

The results of individual samples can be seen in Appendix 2. A summary of the results is shown in Figure 3.1, below. The results from the Dee catchment are not included in this analysis, as the sieved samples were sent to Llanelli laboratory, and the weight of the >6.4mm sample was not recorded.

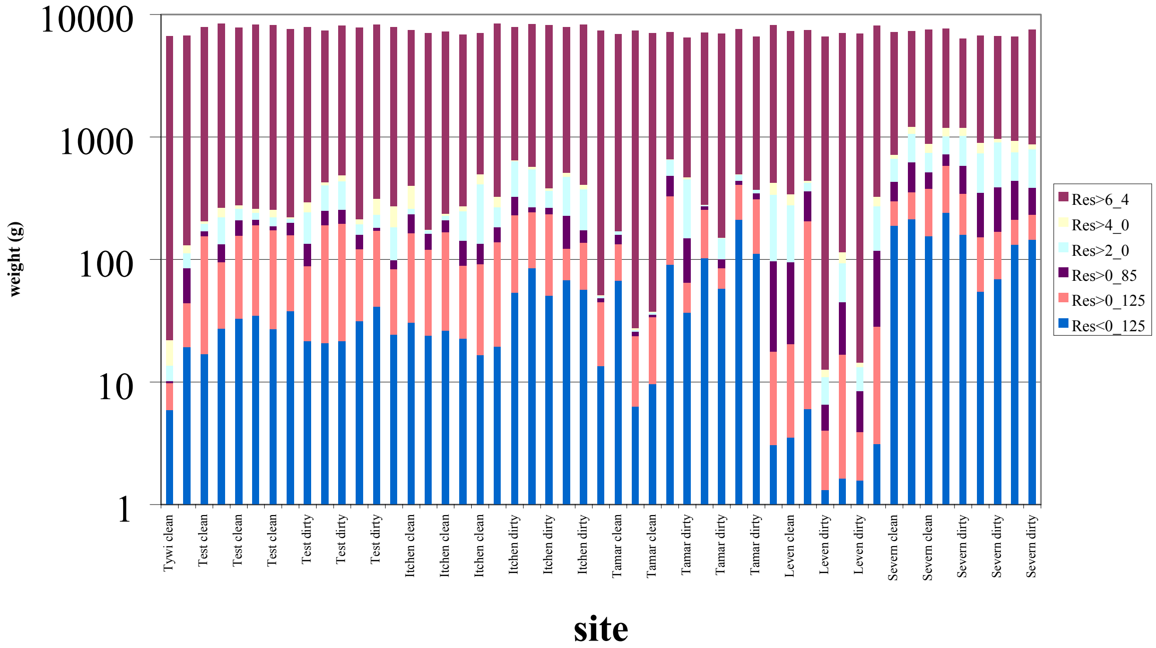


**Figure 3.1: Log results of the particle size analysis**

Figure 3.2 is on a logarithmic scale, as in all samples the vast majority of weight in the sample was made up of particles of >6.4 mm in size (range 81.3% to 99.8%, mean 94.3%). The weight of fines is very low compared to the overall weight of the sample.

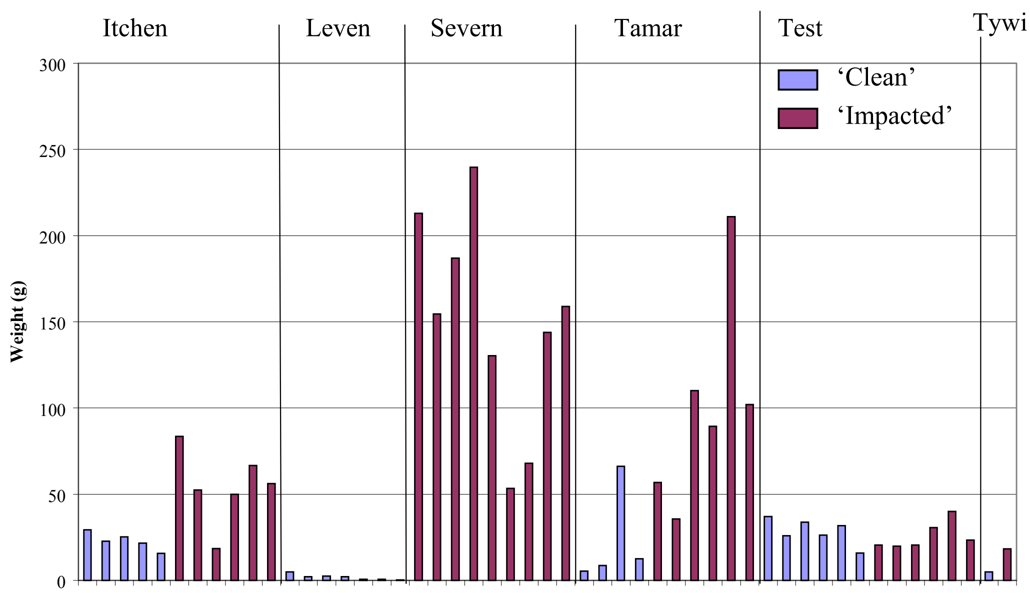


**Figure 3.2: Weight of fines (<0.125mm)**

**Particle size analysis results**

The analysis was carried out on the results from the baskets with the following aims:

- To assess the levels of variability:
  a) Between baskets within a site (within reach variability)
  b) Between sites (between reach variability)

- To examine whether the perception of whether a site is clean or impacted is borne out by the results of the study.

The variability in the weight of fines recovered from baskets installed in the same reach was calculated. This was carried out in order to see how important the siting of a basket was within an individual reach, and also to give an indication of how many samples should be taken at a site to give confidence in the findings.

The variability between reaches was carried out to see how much different sites vary. If site specific factors are important, a high degree of variability would be expected between sites.

Both the within and the between reach variability results were calculated using the Bayseian model which is described in Section. 5.2.2.

The results of the variability assessments are shown in table 3.2 below.

**Table 3.2: Variability within and between sites**

| | 2.50% | median | 97.50% |
|---|---|---|---|
| Within Reach Variability | 0.04 | 0.05 | 0.09 |
| Between Reach Variability | 0.01 | 0.05 | 0.24 |

A simple two-sample T-test was carried out on the weight of fines retrieved from those sites that were thought to be impacted and those that were thought to be clean. This was carried out to see whether the sampling protocol gave results which agreed with the perceived status of river reaches.

**Table 3.3: Results of the two-sample T-test.** The samples from the river Severn were excluded, as field staff found both sites were impacted.

| | *'Impacted' Sites* | *'Clean' Sites* |
|---|---|---|
| Mean | 48.2 | 20.7 |
| Variance | 2313.2 | 247.7 |
| Observations | 23 | 19 |
| Pooled Variance | 1383. 8 | |
| Df | 40 | |
| t Stat | 2.4 | |
| P(T<=t) one-tail | 0.01 | |
| t Critical one-tail | 1.68 | |

### 3.3 Discussion

#### 3.3.1 Installation

In most locations, installation of the baskets was straightforward, taking approximately 20 minutes per basket. Installation could be a problem depending on the depth and type of substrate. Some intended locations did have to be altered by a few tens of metres when the depth of the gravel was found to be insufficient for complete burial of the basket. The chalk streams of the Kennet and Lambourne (Thames catchment) caused particular problems due to the presence of a concreted armour layer. In practice, some of the gravels were broken up and cleaned using a pressure washer prior to basket installation. This was outside of the suggested protocol, but was a pragmatic solution employed by field staff in the area.

#### 3.3.2 Recovery

A total of 53 sampling baskets were successfully recovered, with the overall recovery rate of 63% being lower than anticipated. Most Areas lost some baskets, while the two trial catchments in Wales each lost ten of the twelve sampling baskets that were installed. The baskets are thought to have been removed through curiosity (some missing baskets were located on land adjacent to the watercourses), buried by shifting gravels or swept away. In Wales, where the biggest losses were sustained, the baskets went missing after heavy rainfall and large-scale spates. In Cornwall, however, similar conditions were encountered and the baskets were recovered. This was due to the addition of brightly coloured electrical flex to the top of the basket, which was left in the current. These baskets were found, buried to the point of near invisibility, but were located due to the flex being visible in the water column. It is therefore likely that most of the missing baskets were buried rather than swept away, and the problem is one of relocation.

As a result of this trial, some changes were made to the material used for basket construction and in the sampling methodology to aid relocation. These changes have been incorporated in the standard methodology manual, enclosed as Appendix 1.

#### 3.3.3 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 alevin 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 (Whitcombe, 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, a full analysis of the gravel structure was not a key objective. The focus was to recover and analyse the fine sediments from the samples. Absolute weight of fines was used 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 2.2%. The maximum content from any single sample was 7.6 % from a site on the river Leadon. The maximum average content for a site was 5.4 % by weight of fines for the same site on the River Leadon. It is surprising that all of these values are substantially lower than any of the figures quoted in the literature as causing significant mortality. However, the vast majority of sediment transport occurs in the winter months, and this study was carried out in summer. This variation in sediment movement is well illustrated in chalk rivers where 96% of sediment transport occurs between November and April (Acornley and Sear, 1999). The percentage of fines within a sampling basket are therefore likely to be higher when the sample taken over a true spawning season in the winter months. The results of the proposed winter survey will allow a much more viable comparison with results from the published literature.

**Variability**

The between-reach and within-reach variability of the samples was investigated to determine whether the biggest differences in silt accumulation were between samples in the same reach or between different reaches. The results in Table 3.2 show that the variability within samples from a single site is that same as the variability between sites. 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) placed sampling baskets, similar to the ones used in this study, across the width of a chalk stream and found the average variation in the quantity of fines to be 21% between samples with individual samples varying by up to 58% from the mean. This variability within small reaches is reflected in egg survival studies which show large variation in percentage survival over small areas of riffle (Naismith and Wyatt, 1997).

Table 3.3 shows that there are significant differences between the mean weights of silt recovered from sites perceived to be clean and those perceived to be dirty. This adds weight to the methodology, as results appear to be in line with expectations.

# 4 FINGERPRINTING

- **To determine the source of fine sediments accumulating within salmonid spawning gravels**

## 4.1 Method

**Further analysis of the finest fraction**

The finest silt, <0.125mm, was retained from the sampling and forwarded to Exeter University staff who undertook a fuller investigation of this fraction. This analysis aimed to provide further information on the grain size composition of this finest fraction, to use the sediment properties to provide a preliminary assessment of its likely source and to assess the potential for more detailed work on sediment source fingerprinting.

**Particle size composition**

Because of the relatively small mass available for most samples (range <1g to 239g, mean 56g), grain size analysis was undertaken on a composite sample representative of each group of samples from the same reach. The grain size analyses were performed on the chemically-dispersed mineral fraction of the sediment using a Coulter laser granulometer. The results are presented in Table 4.1.

**Radionucleide analysis**

It is possible to make some preliminary inferences concerning the likely source of the accumulated fine sediment based on a consideration of its properties in relation to the likely properties of potential sources. The environmental fallout radionuclides caesium-137 ($^{137}Cs$) and excess lead-210 (excess $^{210}Pb$) are particularly useful in this context, since their concentrations are not greatly influenced by local terrain characteristics, such as soil type, and clear distinctions should exist between the concentrations associated with different potential sources.

Since the source of such radionuclides is atmospheric fallout and the radionuclides reaching the land surface will be rapidly adsorbed by the surface soil, their concentrations in undisturbed topsoil will be relatively high. Where soils are cultivated, the radionuclides will be mixed into the plough layer and the concentration at the surface will be significantly reduced compared to that found in undisturbed soils. It will thus be possible to draw inferences regarding the relative importance of undisturbed soils, such as found in pasture areas, and cultivated soils as sources of the sediment accumulated in the basket baskets. Equally, sediment derived from river banks, ditches and other subsurface sources will be characterised by greatly reduced radionuclide concentrations since there is only limited opportunity for the radionuclides to accumulate in such materials. Concentrations of organic carbon and organic nitrogen and the associated C/N ratio may similarly be used to make general distinctions between material from undisturbed, cultivated and subsurface sources.

To afford a basis for making some inferences regarding the source of the sediment accumulated in the basket baskets, all samples of the <0.125mm fraction of this sediment were analysed for $^{137}Cs$, excess $^{210}Pb$, organic carbon and organic nitrogen. The presence of chalk ($CaCO_3$) particles in the sediment from the Rivers Test and Itchen interfered with the measurements of organic C on sediment from these rivers and these results have not been reported. The values have been averaged for the samples obtained from individual sites and the results are presented in Table 4.2.

## 4.2 Results

**Table 4.1: The grain size composition of the <0.125 mm fraction of the sediment recovered from the baskets**

| River and Site | $d_{50}$ (median diameter µm) | % <63 µm | %<2 µm |
|---|---|---|---|
| Tamar at Crawford | 7.1 | 95.1 | 20.6 |
| Lyd at Sydenham | 7.1 | 96.4 | 19.1 |
| Leadon at Bosbury | 8.8 | 94.0 | 17.5 |
| Leadon at Dymock | 8.3 | 97.1 | 17.5 |
| Upper Test at Bossington | 11.7 | 93.1 | 19.5 |
| Lower Test at Broadlands | 8.1 | 94.9 | 21.9 |
| Upper Itchen at Winchester | 15.9 | 87.1 | 16.5 |
| Lower Itchen | 7.5 | 94.6 | 23.7 |
| River Leven | 30.7 | 72.5 | 11.5 |
| Rivers Dee and Tywi | 6.9 | 97.4 | 19.5 |

**Table 4.2: Concentrations of $^{137}$Cs, excess $^{210}$Pb and organic carbon and nitrogen associated with the samples of fine sediment retrieved from the baskets**

| River and Site | Fingerprint property | | | | |
|---|---|---|---|---|---|
| | $^{137}$Cs (mBq $g^{-1}$) | excess $^{210}$Pb ( mBq $g^{-1}$) | C (%) | N (%) | C/N |
| Tamar at Crawford | 4.6 | 10.3 | 2.9 | 0.31 | 9.4 |
| Lyd at Syndenham | 15.5 | 16.7 | 6.8 | 0.60 | 11.3 |
| Leadon at Bosbury | 8.0 | 6.2 | 2.6 | 0.22 | 12.1 |
| Leadon at Dymock | 7.7 | 13.2 | 3.6 | 0.26 | 15.7 |
| Upper Test at Bossington | 4.0 | 28.1 | - | 0.63 | - |
| Lower Test at Broadlands | 7.3 | 44.4 | - | 0.94 | - |
| Upper Itchen at Winchester | 6.1 | 22.0 | - | 0.63 | - |
| Lower Itchen | 5.4 | 36.7 | - | 0.85 | - |
| River Leven | 82.4 | 178.8 | 9.6 | 1.16 | 8.4 |
| River Alyn | 20.8 | 95.1 | 6.9 | 0.46 | 14.9 |
| River Tywi | 11.1 | 42.3 | 7.7 | 0.67 | 11.1 |

## 4.3 Discussion

### 4.3.1 Particle size composition

The results presented in Table 4.1 demonstrate a number of important points:

1) The <0.125mm fraction of the sediment accumulated in the retrievable sampling baskets contains a substantial proportion of very fine sediment. The median diameters ($d_{50}$) of the composite sediment samples range between 6.9 and 30.7μm, although in the majority of cases the values are <10μm.
2) The <63μm fraction accounts for between 72.5 and 97.4% of the sediment mass, although the values are typically >90%. This again emphasises the fine-grained nature of this sediment.
3) The fine sediment within this fraction contains a significant amount of clay-sized (<2μm) material.. The clay fraction accounts for between 11.5 and 23.7% of the total mass.
4) The sediment from the River Leven in north west England is significantly coarser than that from the other sites in terms of its $d_{50}$. However, there is still a significant clay fraction at this site (11.5%) and this suggests that the coarser sediment found here reflects the local soil and geology rather than an hydraulic effect resulting in the preferential accumulation of coarser particles.
5) The grain size composition of these samples is closely analogous to the typical grain size composition of suspended sediment in British rivers. As such the sediment is therefore likely to represent suspended sediment that has been deposited on the bed or that has been transported through the gravel matrix by the local flow and deposited. The presence of substantial quantities of clay-sized material reflects the importance of flocs or composite particles in the suspended sediment load. Thus, although there may be preferential deposition of the larger particles, these composite particles will contain substantial proportions of clay-sized material.
6) The large proportion of very fine sediment within the <0.125mm fraction recovered from the basket traps has important implications for degradation of the spawning gravels, since it is the fine sediment which will have the greatest impact on clogging the gravel matrix and reducing flow velocities, thereby causing reduced levels of dissolved oxygen within the egg zone. Fine sediment is also known to be of greatest importance in carrying contaminants, such as heavy metals and pesticides, which may also have a detrimental effect on the spawning environment.
7) In the case of the Rivers Itchen and Test, where there are upstream and downstream sites, there is clear evidence of a downstream fining of the sediment associated with the <0.125mm fraction. This is likely to reflect the preferential deposition of coarser material during downstream transport, and suggests that the dominant source of coarser materials is towards the headwaters.

### 4.3.2 A preliminary assessment of sediment sources

Existing work undertaken at the University of Exeter and elsewhere has demonstrated the potential for using a comparison of suspended sediment properties with those of potential sediment sources to establish the relative importance of those sources (e.g. Walling and Woodward, 1995; Walling, Owens and Leeks, 1999). Such source fingerprinting exercises require the collection of samples of both suspended sediment and potential source materials as the basis for the fingerprinting. The collection of source material samples was beyond the scope of the present study and it is therefore not possible to provide a definitive assessment of the source of the fine sediment collected in the baskets. Such source information is clearly important in terms of planning sediment management strategies for reducing gravel siltation. It is, nevertheless, possible to make some preliminary inferences concerning the likely source of the accumulated fine sediment based on a consideration of its properties in relation to the likely properties of potential sources.

Looking firstly at the values of $^{137}$Cs and excess $^{210}$Pb concentration, the high values reported for the River Leven are worthy of comment. This area of the country will have received significant inputs of fallout from the Chernobyl accident in 1986 and this undoubtedly accounts for the higher values recorded for this river in Table 3. A similar explanation applies to the River Alyn. The increased levels of excess $^{210}$Pb recorded for sediment from the River Leven cannot be attributed to Chernobyl fallout and reflect the high rainfall and local geology of this area.

Existing information from sediment fingerprinting studies undertaken in the UK indicates that the $^{137}$Cs and excess $^{210}$Pb content of fine sediment (<63μm) mobilised from river banks, ditches and other subsurface sources is low and typically of the order of 1-2mBq $g^{-1}$ for $^{137}$Cs and 2-4mBq $g^{-1}$ for excess $^{210}$Pb. The values reported in Table 4.2 are all considerably in excess of these values, indicating that river banks and subsurface sources are not the dominant sediment source. A significant proportion of the sediment is undoubtedly derived from surface sources. In the absence of additional fingerprint properties and more precise characterisation of potential source materials, it is difficult to indicate the relative importance of arable and pasture areas as sources of the sediment. As the surface concentrations found in pasture areas are typically double those found in cultivated areas and the values obtained for the sediment are close to, although a little lower than, those typically associated with cultivated topsoils, it seems likely that cultivated areas represent the major sediment source. The reduction in the concentrations below that associated with cultivated soils suggests that bank sources make a significant, although relatively small, contribution to the fine sediment found in the baskets. The results therefore suggest that surface sources are dominant, although bank sources are likely to provide a significant contribution. In most cases, the dominant surface source is likely to be cultivated areas, but in the case of the Rivers Lyd, Alyn and Leven the relatively high $^{137}$Cs concentrations suggest that pasture areas also represent a significant source.

The tentative conclusions drawn from examination of the radionuclide data are consistent with the evidence provided by the values of organic C and N content and C/N ratio for the sediment from the baskets. Values of C and N content for river banks are typically 2.0 % and 0.20 %, respectively, whereas values for surface soils are significantly higher. The values reported for the sediment from the baskets are higher than those associated with equivalent fine sediment from river banks and closer to the values associated with topsoil from cultivated and pasture areas. Again, therefore, the fingerprint evidence suggests that river banks are unlikely to be the dominant sediment source, and that surface materials represent the major source.

The source fingerprinting results presented above strongly suggest that catchment surface sources represent an important source of the sediment collected in the baskets from the study rivers. Detailed sampling of source materials would be required to confirm and refine these findings but they are seen to provide clear evidence that future efforts to reduce the siltation of spawning gravels will need to focus on the reduction of sediment inputs from the wider catchment, as well as reducing the incidence and severity of bank erosion and bank trampling by livestock.

#### 4.3.3 The potential for further work on sediment source fingerprinting

The findings presented in Section 4.2 provide a clear indication of the potential for using sediment fingerprinting to assess the relative contribution of potential sediment sources to the sediment collected in the sampling baskets. Such information will be an important requirement for the future development of sediment management strategies, in order to permit the targeting of remedial actions and measures. However, the results obtained from examination of the properties of the sediment collected can only provide a tentative and essentially subjective assessment of the nature and relative importance of the sediment sources involved. More detailed work is required to produce definitive results. This would involve collection of representative samples of potential source materials from the individual study catchments, in order to permit precise comparisons between sediment and source material properties and the application of multiparameter mixing models to establish the relative contributions of the potential sources (cf. Walling, Owens and Leeks, 1999). The data presented in Table 4.2 indicate that fallout radionuclide concentrations (i.e. $^{137}$Cs and excess $^{210}$Pb) and measurements of the organic C and N content are capable of providing effective source fingerprints, but other sediment properties should also be included to improve source discrimination and the application of a multiparameter mixing model. Contrasts in particle size composition between the sediment and the source material must also taken into account in order to provide high-resolution results. Procedures for applying such corrections have already been successfully applied in other studies (cf. Walling, Owens and Leeks, 1999).

# 5 GIS MODELLING

- **To scope out data availability and GIS requirements for the fisheries input to a larger land-use and soil erosion risk assessment project.**

This section goes beyond the original objective which was a data scoping study. Additional time allowed experimental application of GIS modelling procedures to be carried out.

## 5.1 Method

One of the key objectives of this project was to scope out data availability for, and uses of, Geographical Information Systems (GIS) to this type of work. After initial delays a GIS system, ESRI ArcView 3.1, was delivered. Data scoping was carried to establish data availability and suitability.

Two discrete data types are needed for an investigation into the effects of land use on fisheries, fisheries data and data on sediment delivery to rivers. Relationships between land-use, soil types, soil erosion and particularly the link between erosion from land and delivery to watercourses are not simple or clearly understood (Walling, 1983). Many different data types could act as surrogates for sediment delivery to rivers. Of these, six options were identified and evaluated for possible use.

- Soil vulnerability surveys.
- Soil erosion maps.
- Plotting average annual suspended solids or turbidity on maps.
- Modelling Approach.
- Examining fisheries data in relation to MAFF (now DEFRA) Agricultural census data.
- Examining fisheries data in relation to land cover class from the ITE (now CEH) land cover data layer.

Of these, only two were found to be in a readily accessible format. These were the turbidity and ITE land cover maps. All other options would require a large amount of work to get them into GIS compatible format. It was decided to progress the most cost effective, quickest and simplest option for the first evaluation. This involved analysing juvenile salmonid data in relation to ITE land cover data.

The choices for fisheries data to use in this investigation are electrofishing data (juvenile surveys), catch statistics, counter data and trapping data. It was decided to look at juvenile data as this life stage is most closely related to gravel quality. It is also the most widespread and of fairly consistent quality. Catch statistics are also widespread and of consistent quality, but are only available for whole catchments, are heavily dependant on fishing effort and conditions, and cannot be related to an individual site. It was therefore decided to investigate the availability of juvenile salmonid data around the Agency.

Areas were contacted and asked to provide juvenile salmonid survey data. The data received was in held in a variety of forms, and was reformatted to a standard, database compatible structure. A simple database was created and populated with the data from all areas, which amounted to approximately 10,000 survey results. These results are heavily skewed to Wales as the three Welsh Areas had put all historical data onto databases, making it easily accessible and easy to import. In other Regions the data is patchy and dependant both on the salmonid surveys carried out and whether that data was held in electronic format.

For the GIS system to be used effectively, relevant datasets must be installed. Datasets showing Coast, Regions, Leap Areas, catchments, Hydrometric Areas, Land use, altitude, OS maps, river network, Habscore sites, fisheries data, geology, towns and GQA Water Quality were collected and installed on the GIS.

The ‘simple’ approach to assessing land use data still requires a considerable amount of work to be carried out before any analysis can begin. It is important to be able to provide unique catchment summary statistics at each electrofishing survey site. The alternative is to apply whole catchment statistics to all survey sites within that catchment. In an extreme example one sub-catchment could be entirely forested, while another is entirely arable. If analysis were carried out on two survey sites, one in each sub-catchment, it would be desirable to have unique characteristics for each site, rather than analysing both survey sites as impacted equally by agriculture and forestry.

The drawback of this approach is that it uses a generated river network rather than the actual river network. The generated river network is created using gradient, slope aspect and drainage data from a GIS terrain model. In most places the generated river network closely matches the actual river network but problems arise where there are very low gradients, lakes, or unusual geology involved such as chalk.

In the first attempt at modelling the effects of land-use, the fisheries data was effectively ignored. The silt accumulation data were modelled using a wide variety of environmental variables generated from GIS or recorded in the field. It should be noted that the aim of this exercise was to develop methodology, rather than to actually carry out a detailed investigation of fisheries data.

## 5.2 Results

All detailed analyses were carried out on the weights of the finest fraction isolated, less than 0.125mm. A log transformation was carried out on the weights in order to normalise their distribution as shown in Figure 5.1. It can be seen that the log transformation was successful in normalising the data in order to allow further statistical analyses to be carried out.

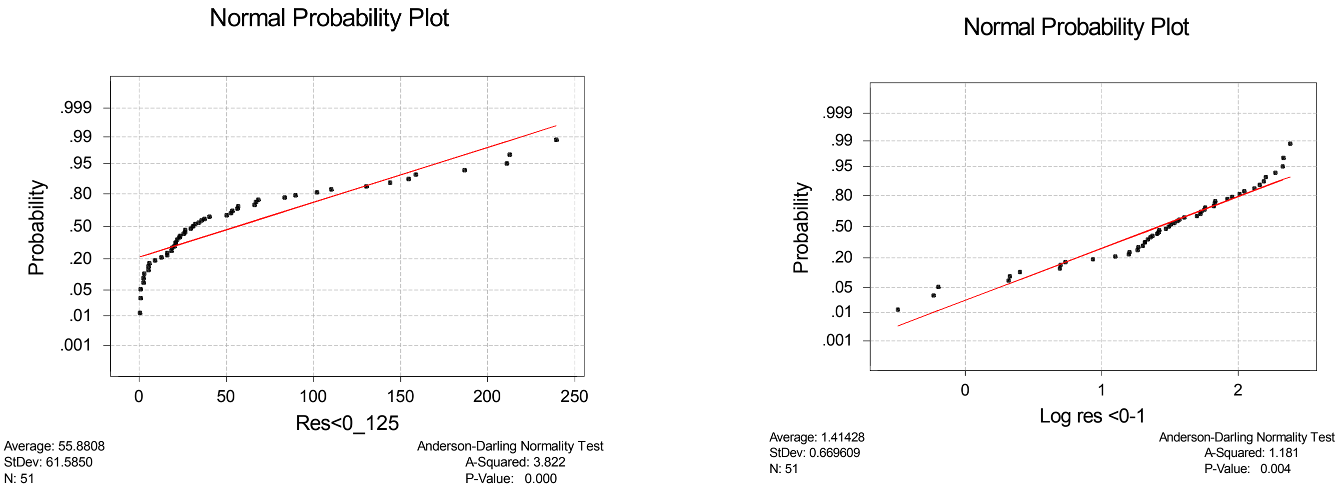


**Figure 5.1: Untransformed and Log Transformed weight of fines data**

### 5.2.1 To determine the environmental factors which are important in explaining the variation in silt accumulation between sites.

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. The variables relating to the catchment upstream are likely to be more important than the variables at that specific site. This is true because silt stays in the water column for an extended period of time. An integration of upstream impacts is therefore likely to give a better indication of silt loadings than any site specific measurements. An additional factor is that a great deal of research has shown that diffuse catchment sources are the most important providers of silt to watercourses (Theurer *et al,* 1998). Again this suggests that upstream characteristics are likely to be of more importance than adjacent characteristics. 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 |
|---|---|
| Site sheet | Substrate by category |
| Site sheet | Width |
| Site sheet | Average depth |
| Site sheet | Visible bankside erosion |
| GIS - Site Specific | Gradient |
| GIS - Site Specific | Underlying Geology |
| GIS - Site Specific | Drift Geology |
| GIS - Site Specific | Altitude |
| GIS - Site Specific | Stream Order |
| GIS - Site Specific | Distance from Source |
| GIS - Site Specific | Distance to Estuary |
| 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 |
| GIS – Upstream catchment | % Geology by category |
| GIS – Upstream catchment | Average long term rainfall |

These datasets were examined and analysed using :

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

**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 finest fraction (<0.125mm) in subsequent analysis. An example plot is shown in Figure 5.2 below.

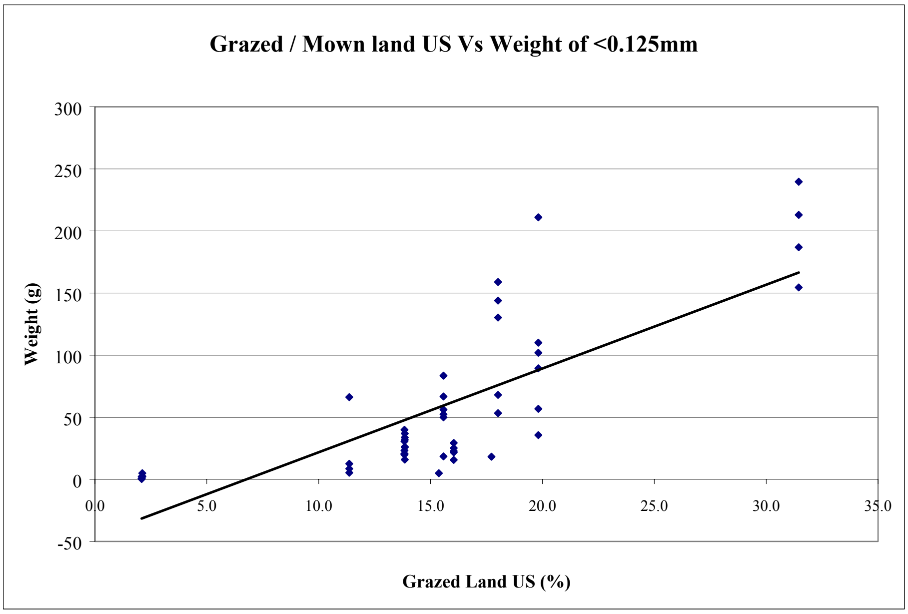


**Figure 5.2: Example bivariate plot: grazed land vs weight of fines.**

## 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 the distance to source and the distance to estuary, which are related variables and show a significant correlation. This means that in terms of explaining the variability between the samples these two measurements would perform approximately equally.

## Table 5.2: Correlation matrix

| | TimeIn | AvDepth | AvgOfWid | AREA_KM2 | SL_AVE_P | EL_AVE_M | GrassCla | %Trees | %Urban | %Tilled | Mean Rainfall | Altitude | Slope_mk | D_source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AvDepth** | 0.04 | | | | | | | | | | | | | |
| | 0.902 | | | | | | | | | | | | | |
| **AvgOfWid** | -0.162 | 0.787 | | | | | | | | | | | | |
| | 0.615 | 0.002 | | | | | | | | | | | | |
| **AREA_KM2** | 0.134 | 0.728 | 0.698 | | | | | | | | | | | |
| | 0.677 | 0.007 | 0.012 | | | | | | | | | | | |
| **SL_AVE_P** | -0.766 | -0.037 | 0.174 | -0.365 | | | | | | | | | | |
| | 0.004 | 0.909 | 0.588 | 0.244 | | | | | | | | | | |
| **EL_AVE_M** | -0.8 | -0.322 | -0.066 | -0.47 | 0.876 | | | | | | | | | |
| | 0.002 | 0.308 | 0.838 | 0.123 | 0 | | | | | | | | | |
| **GrassCla** | 0.418 | -0.625 | -0.679 | -0.287 | -0.537 | -0.159 | | | | | | | | |
| | 0.176 | 0.03 | 0.015 | 0.366 | 0.072 | 0.622 | | | | | | | | |
| **%Trees** | -0.61 | -0.087 | 0.055 | -0.087 | 0.372 | 0.471 | -0.162 | | | | | | | |
| | 0.035 | 0.787 | 0.865 | 0.789 | 0.233 | 0.123 | 0.616 | | | | | | | |
| **%Urban** | 0.826 | 0.035 | -0.166 | 0.071 | -0.653 | -0.824 | 0.103 | -0.497 | | | | | | |
| | 0.001 | 0.914 | 0.606 | 0.827 | 0.021 | 0.001 | 0.75 | 0.1 | | | | | | |
| **%Tilled** | 0.722 | 0.439 | 0.23 | 0.589 | -0.791 | -0.899 | -0.013 | -0.523 | 0.7 | | | | | |
| | 0.008 | 0.153 | 0.472 | 0.044 | 0.002 | 0 | 0.968 | 0.081 | 0.011 | | | | | |
| **Mean Rainfall** | -0.825 | -0.007 | 0.181 | -0.316 | 0.937 | 0.809 | -0.472 | 0.347 | -0.697 | -0.818 | | | | |
| | 0.001 | 0.983 | 0.574 | 0.316 | 0 | 0.001 | 0.121 | 0.269 | 0.012 | 0.001 | | | | |
| **Altitude** | -0.116 | -0.772 | -0.548 | -0.673 | 0.129 | 0.496 | 0.64 | 0.169 | -0.276 | -0.583 | 0.109 | | | |
| | 0.719 | 0.003 | 0.065 | 0.016 | 0.689 | 0.101 | 0.025 | 0.599 | 0.384 | 0.046 | 0.737 | | | |
| **Slope_mk** | 0.038 | -0.416 | -0.309 | -0.365 | 0.105 | 0.046 | 0.03 | -0.328 | 0.203 | -0.024 | 0.103 | 0.151 | | |
| | 0.908 | 0.179 | 0.329 | 0.243 | 0.745 | 0.887 | 0.927 | 0.298 | 0.528 | 0.942 | 0.751 | 0.638 | | |
| **D_source** | -0.078 | 0.764 | 0.63 | 0.888 | -0.174 | -0.392 | -0.459 | 0.058 | 0.03 | 0.406 | -0.051 | -0.796 | -0.288 | |
| | 0.809 | 0.004 | 0.028 | 0 | 0.589 | 0.208 | 0.134 | 0.859 | 0.927 | 0.19 | 0.874 | 0.002 | 0.365 | |
| **D_estuar** | -0.099 | -0.79 | -0.564 | -0.526 | -0.066 | 0.364 | 0.664 | 0.321 | -0.21 | -0.409 | -0.12 | 0.912 | 0.028 | -0.696 |
| | 0.761 | 0.002 | 0.056 | 0.079 | 0.838 | 0.244 | 0.019 | 0.31 | 0.512 | 0.186 | 0.711 | 0 | 0.932 | 0.012 |

Key

Cell Contents

Pearson correlation
P-Value

| Title | Description |
|---|---|
| TimeIn | Number of days the basket was left in the river |
| AvDepth | Average depth of the river at the site, recorded on the field sheet at time of installation |
| AvgOfWid | Average width of the river at the site, recorded on the field sheet at time of installation |
| AREA_KM2 | Area ($Km^2$) of the catchment upstream of the sample site, calculated from GIS |
| SL_AVE_P | Average slope (%) of the catchment upstream of the sample site, calculated from GIS |
| EL_AVE_M | Mean elevation (m) of the catchment upstream of the sample site, calculated from GIS |
| GrassCla | Area of grassland in the catchment upstream of the sample site, calculated from GIS |
| %Trees | Percentage of the catchment upstream of the sample site covered by trees, calculated from GIS |

| | |
|---|---|
| %Urban | Percentage of the catchment upstream of the sample site covered by urban development, calculated from GIS |
| %Tilled | Percentage of the catchment upstream of the sample site covered by tilled land, calculated from GIS |
| Mean Rainfall | Mean annual rainfall in the catchment upstream of the site, based on long term records. |
| Altitude | Altitude (m) of the sample site, from GIS |
| Slope_mk | Slope (meters per km) of the sample site, calculated from GIS |
| D_source | Distance to source from the sample site, calculated from GIS |

One problem which was highlighted by this correlation matrix was that the time that the trap was left in situ was significantly correlated with mean depth of water, average upstream gradient, average upstream elevation, % trees upstream, % urban upstream, and mean rainfall upstream. This causes problems in the interpretation of statistical outputs as it is apparent that time that the baskets were left in situ should be entirely independent of the environmental variables. The result is that, with the data set that we have, we cannot determine whether baskets had more silt in them because they were left in longer, or because of some landuse, rainfall or depth consideration. Had the length of time been truly independent we could have corrected for it in our analysis to allow a more subtle investigation of the impacts of other variables to be carried out.

**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 practical 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. It was felt intuitively that the amount of time for which a basket had been buried would have a large impact on the levels of fines recovered from it. Time was therefore used in all variable selection procedures, with the remaining variables being selected automatically by Minitab.

**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 Table 5.3 below. This shows the fitting of the best model for a given number of variables, with the 'best' model appearing on the second last line. The output shows that this model includes three variables (in addition to time in, which is included in all models), which are percentage of tilled land upstream, percentage of urban land upstream and the mean rainfall. This model accounts for 94.9% of the variation between the samples as shown by the $R^2$ value. However due to the inter-relationships between the factors, another model, which explains 93.6% of the variability has no factors in common with the previous model. Judgement is therefore needed to assess which suite of variables is most likely to represent a causal relationship, and therefore likely to be the best data representation of the physical processes we are attempting to model.

**Table 5.3: Example output from the best subsets regression in Minitab**

**Best Subsets Regression: LogRes<0_125 versus AvDepth, AvgOfWidth, ...**

```
Response is LogRes<0
The following variables are included in all models:  TimeIn

                                                  A S       M D D
                                                A v L %     e _ _
                                                v g _ T % % a s e
                                                D O A i T U n o s
                                                e f V l r r   u t
                                                p W E l e b R r u
                                                t i _ e e a a c a
Vars   R-Sq    R-Sq(adj)        C-p         S   h d P d s n i e r

   1   77.5         72.5      536.7   0.83629               X
   1   74.4         68.7      611.4   0.89203                   X
   2   89.8         86.0      242.1   0.59732   X           X
   2   88.4         84.0      276.1   0.63730     X         X
   3   94.9         92.0      121.2   0.45187         X   X X
   3   93.6         89.9      152.9   0.50661   X   X   X
```

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.

### 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 SS. 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.

This procedure allowed options to be trialed and an eventual model to be generated which had a good R-squared value, significant, or close to significant results, and seemed realistic. The output is shown in Table 5.4 below.

**Table 5.4: Output from the stepwise regression in Minitab showing the model that was used**

```
Stepwise Regression: LogRes<0_125 versus TimeIn, Slope_mkm, ...


  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

 Response is LogRes<0 on  9 predictors, with N =   12


    Step          1        2        3
Constant    -0.5807  -0.4388   2.5147

TimeIn        0.048    0.020   -0.001
T-Value        3.79     1.53    -0.09
P-Value       0.004    0.161    0.933

%Grazed                0.127    0.113
T-Value                 3.11     3.68
P-Value                0.012    0.006

SL_AVE_P                       -0.111
T-Value                         -2.90
P-Value                         0.020

S              1.07    0.783    0.581
R-Sq          58.94    80.24    90.35
R-Sq(adj)     54.83    75.85    86.73
C-p            11.5      3.4      0.6
```

This model is the most realistic which was found using the above techniques. The model uses the amount of time the basket was left in situ, the percentage of grazed land upstream of the site and the average slope upstream of the site to explain 87% of the variation between sites.

The above analysis was done on the twelve 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 51 samples were not independent and including all samples would have artificially reinforced the relationships found in Minitab.

A more sophisticated model was therefore created out which took account of the individual samples and the relationships between them.

### 5.2.2 To use the factors identified above to generate a model for predicting silt accumulation within a basket based on map based features

**BUGS**

BUGS is a program that carries out Bayesian inference on complex statistical problems for which there is no exact analytic solution, and for which even standard approximation techniques have difficulties. It was used to generate a model using the same parameters identified by Minitab, but taking into account the true number of samples.

The model generated is shown in Figure 5.3 below. This figure is a graphical representation of the relationships between the known variables (grazed land upstream, time in, average gradient upstream and weight of fine material recovered), and the unknown parameters (between reach variability, within reach variability, and coefficients for time, grazed land and gradient). The unknown parameters are estimated by the modelling procedure, allowing an equation to be generated. This equation allows the accumulation of fines to be predicted for a given set of time, gradient and grazed land data.

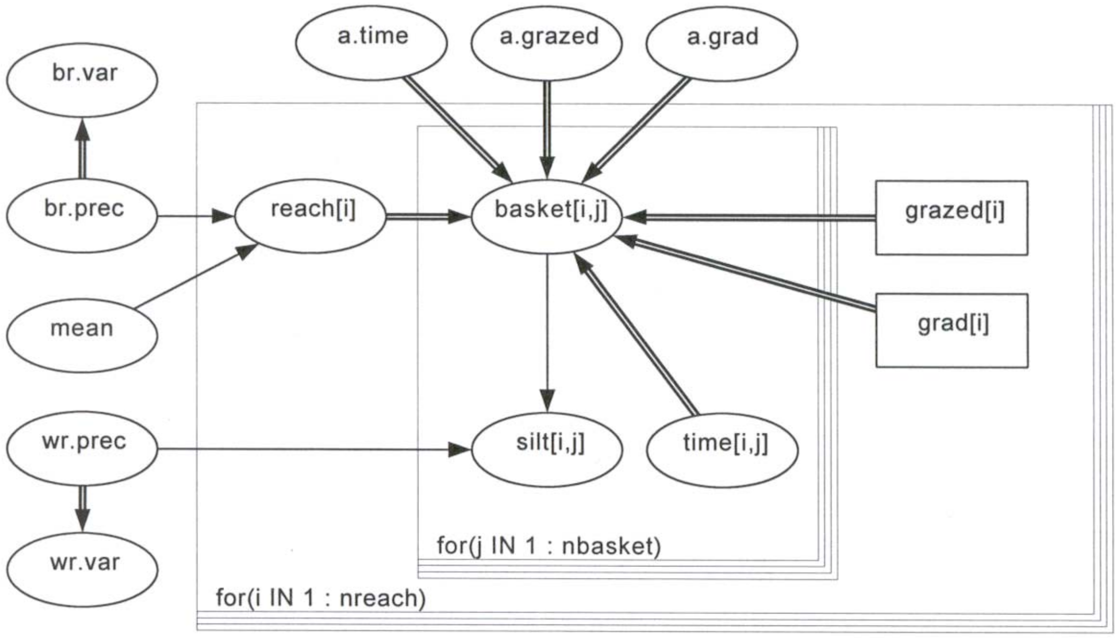


**Figure 5.3: The siltation model developed in BUGS**

The equation generated by this model was:

Log 10 Expected Silt = 1.324 + 0.004481(time - 80) + 0.04283(%Grazed - 15.3467)
- 0.03813 (Average Upstream Gradient - 10.667).

This equation can be used to generate an expected silt accumulation value at any site using data from GIS. This was carried out for the 12 sites used in the development of the model. The relationship between the observed and the expected results for each site are shown in Figure 5.4 below.

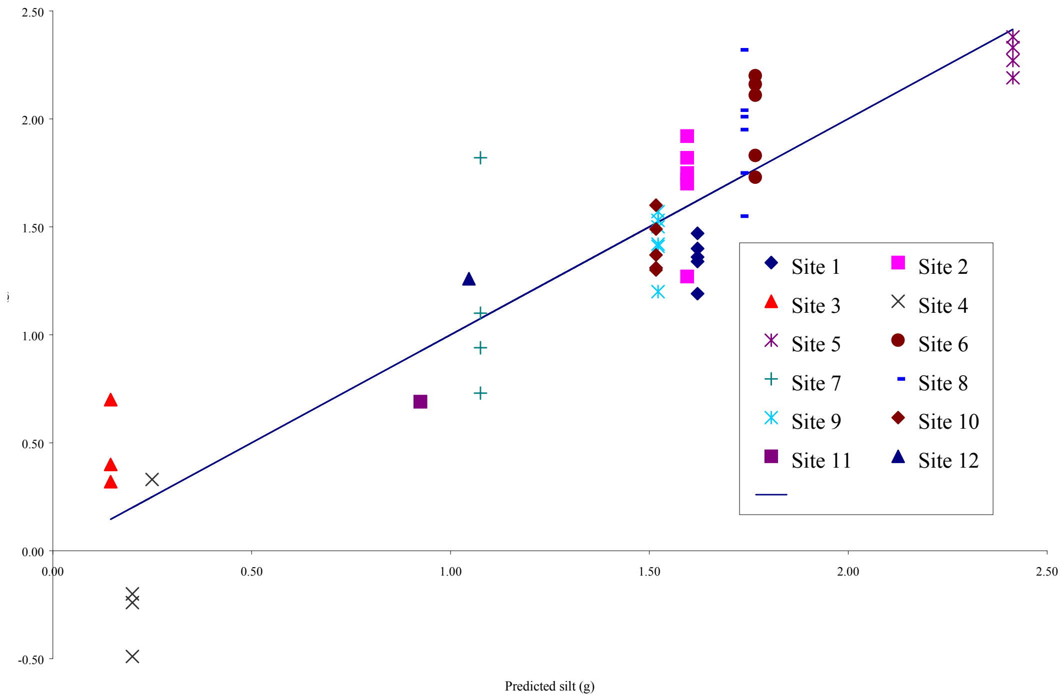


**Figure 5.4: The relationship between the observed and the expected results.**

**Fitting of the model using ArcView GIS**

The fit of this model is reasonable, although in this instance it is being compared to the sites which created the model. It was however felt that it would be useful to apply this model to a catchment as an example of how GIS can be used to extrapolate results around a catchment.

The river Tamar catchment was used as an example for the application of this model. Although the number of sites is small (12 for model generation) and therefore the validity of extrapolating this model to unsampled sites must be questioned, it was felt that this was a good opportunity to test the procedure.

For the purposes of this modelling exercise a raster river network was derived from a 50m Digital Elevation Model (DEM). 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

1. Load 50m DEM covering target area.
2. Load the hydrological analysis extension in ArcView
3. In the hydrological modelling menu:
   - Fill Sinks
   - Compute slope
   - Compute flow direction
   - Compute flow accumulation

4. Flow accumulation was adjusted so that it was displayed only when the value was >500. This means that only cells that drain over 500 other cells are displayed. This figure of 500 was found after iteration as a value, which approximated to the 1:250,000 river network.
5. Compute the average slope upstream for each cell on the river network grid using the formula: ( [Flow Direction] . flowaccumulation ( [Slope])) / [Flow Accumulation] * [Derived River Network]
6. Isolate Grazed land from the ITE land cover data layer. Convert to a new data layer where grazed land has a value of 1 and all other land cover types are given a 'no data' category.
7. Compute the average percentage of grazed land upstream for each cell on the river network grid using the formula:
   ( [Flow Direction] . flowaccumulation ( [grazed land])) / [Flow Accumulation] * 100 * [Derived River Network]
8. Apply the model to the river network:
   (1.324 + ((%Grazed - 15.3467) * 0.04283)- (( Av. Upstream Gradient - 10.667) * 0.03813)) EXP10

This approach gives a level of silt expected in every cell of a river network after a standardised 80 day period. This is an approximation of the salmon egg incubation period, and by standardising it in this way, we can gain a more direct comparison of silt accumulation rates in different sampling sites. 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 gradient or the % of grazed land were outside the range of values used as inputs to the models. The model was run again, this time limiting the input slope and % grazed land data layers to the range of values observed at the sampling sites. Thus, the slope data was constrained to values between 4.6% and 22.1%, and grazed land was constrained to values between 2.1% and 31.5%.

Examples of outputs from this model are shown in Figures 5.5 and 5.6.

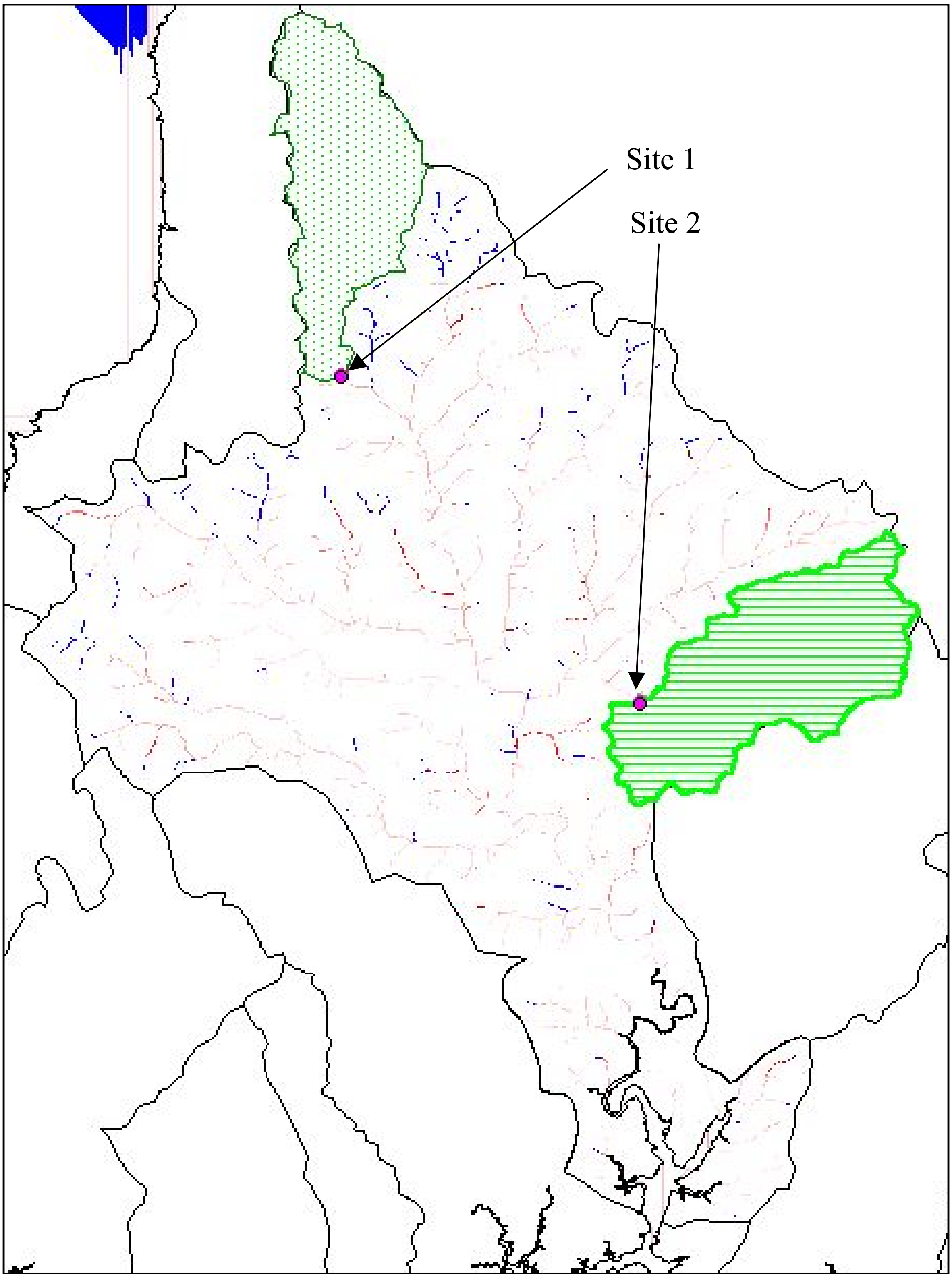


**Figure 5.5: The river Tamar, showing generated catchments upstream of each survey site**

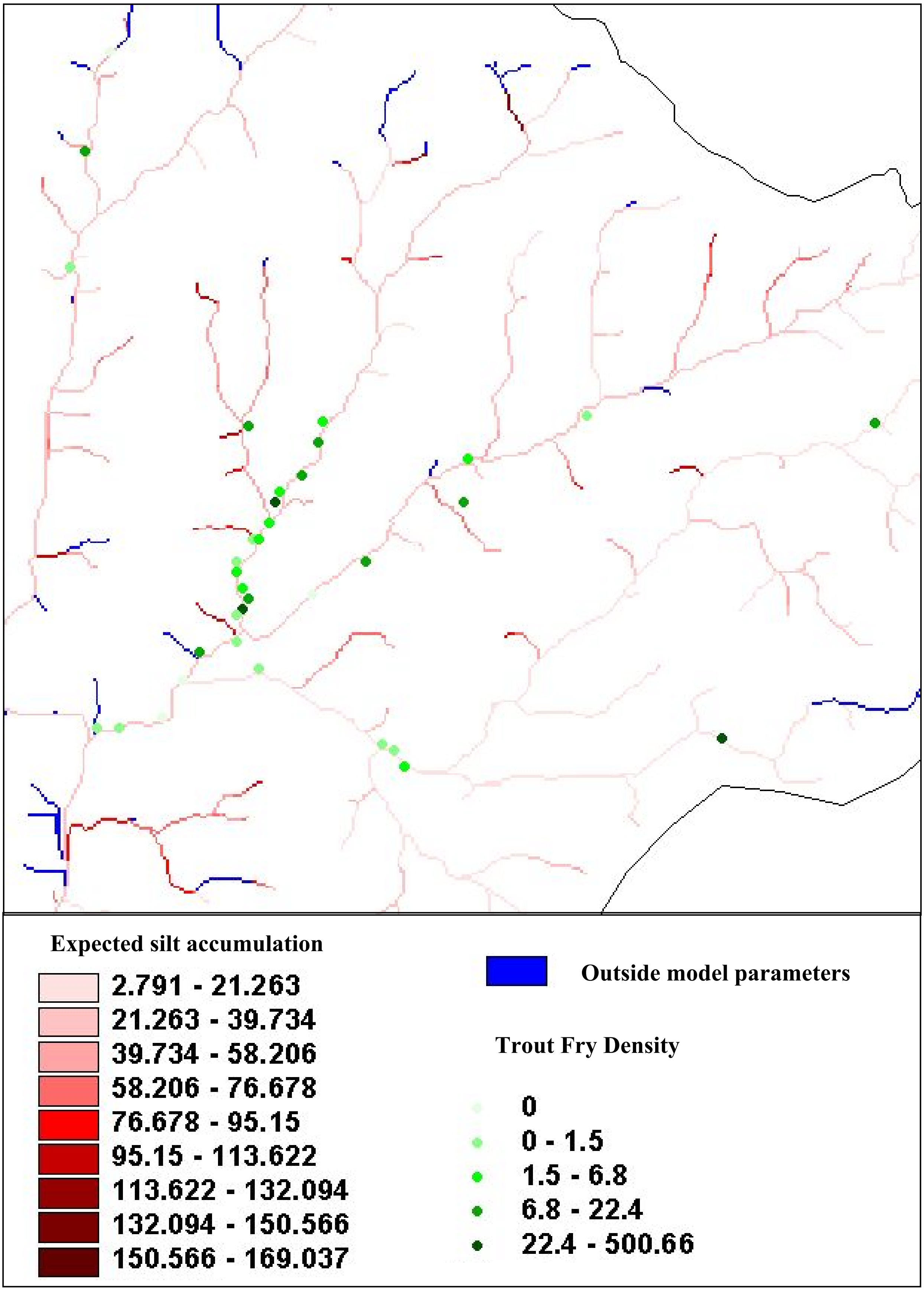


**Figure 5.6:** **Close up of the river network showing trout fry densities**

### 5.2.3 Analysis of estimated silt accumulation in relation to trout fry density

The 10,000 individual fishery survey results were collated 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 upstream gradient and the upstream percentage of grazed 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 user defined grid references which were not accurate or precise, and may therefore not fall on the watercourse.

The stages carried out were

1. Generate a vector river network from the generated silt accumulation grid. This generates a series of lines which pass through the centre of each square within the grid
2. 'Snap' the fisheries survey points to the new vector network. There is an extension available within ArcView which automates this process. An example of this stage is shown in Figure 5.6 above.
3. Retrieve information from the silt accumulation grid and add it as a field in the attributes table of the fisheries survey points.
4. Export the fisheries survey table to Excel and plot survey results against estimates silt accumulation values.

The results of this process are shown in Figure 5.7.

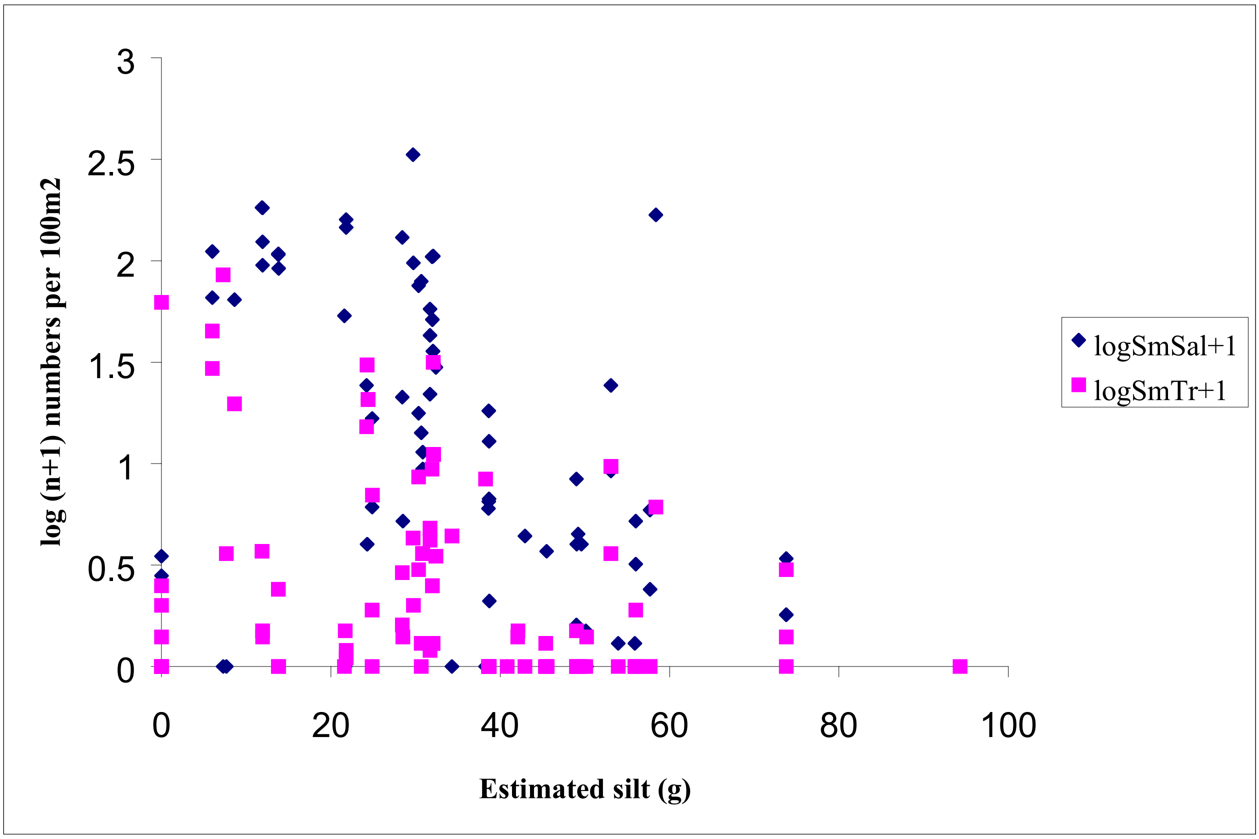


**Figure 5.7: Log of salmon and trout fry density +1 plotted against the expected silt accumulation**

**Table 5.5: Statistical outputs from regression analysis of salmonid fry vs estimated silt**

| | | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* |
|---|---|---|---|---|---|---|---|
| Trout | Intercept | 1.319 | 0.155 | 8.504 | 0.000 | 1.011 | 1.627 |
| Fry | X Variable 1 | -0.010 | 0.004 | -2.526 | 0.013 | -0.018 | -0.002 |
| Salmon | Intercept | 0.677 | 0.101 | 6.727 | 0.000 | 0.477 | 0.876 |
| Fry | X Variable 1 | -0.008 | 0.003 | -2.994 | 0.004 | -0.013 | -0.003 |

## 5.3 Discussion

### 5.3.1 Uses of GIS in salmonid fishery science

Most of the applications of GIS to fisheries science have been carried out in the USA. The UK is lagging behind, partially because of data availability problems. The potential user community within the UK is still restrained by data sharing problems and corporate cultures which do not promote the idea of shared data (Craglia 2000).

Despite these problems there are examples of large GIS applications which have been implemented in the British Isles. In Scotland the Dee Catchment Management Planning (DeeCAMP) GIS has been used to model salmon habitat for the river Dee catchment (Webb and Bacon, 1999), while in the Republic of Ireland GIS has been used to model smolt outputs from the Mayo Region (McGinnity *et al*. 1999). Although the project carried out in the Mayo region was well resourced, the GIS model accounted for only around 10% of the spatial variability in juvenile numbers. This compares unfavourably with field based models such as HABSCORE which is able to explain between 60-95% of the spatial component of variability by using both field and map-based variables. (Milner *et al.* 1995).

Within the confines of this project, GIS was used to extract attributes associated with the sampling sites, and implementing the derived model to parts of the catchment which had not been sampled. One of the key decisions to be taken was how to model river-network data, as there are two fundamentally different approaches, vector and raster.

### 5.3.2 Vector vs raster for river network modelling

There are two principal ways to handle river network data within GIS, raster or vector. Vector river networks are made of individual lines and are very precise. Raster networks are based on a grid of cells. Within a vector network, direction and other data must be added to the table of attributes. This makes setting up such a network a major undertaking in its own right. Never the less this has been carried out over wide geographic scales. In the Mayo region of the Republic of Ireland, 41,656 individual sub-reaches were identified, classified, and given attributes (McGinnity *et al*. 1999). Attributes given to each vector reach included some which were calculated manually, such as stream order, and some which were calculated within GIS, such as distance from source. In Scotland too, a vector river network was used for the Aberdeenshire Dee. Each reach in the river network was given direction to allow upstream or downstream calculations to be carried out (Webb and Bacon, 1999).

In this project the alternate approach was used. Instead of using a vector data set, the hydrological modelling capabilities of ArcView have been used to generate stream networks. This saves a considerable amount of time in generating directional networks. It is important for catchment modelling that GIS can answer questions such as 'what are the catchment characteristics upstream or downstream of this point?' Automation of this process allows a large amount of relevant catchment information to be extracted, which is very difficult for fisheries scientists to obtain by other methods. It also allows sub-catchment boundaries to be generated automatically, instead of digitised, as they were in Scotland and Ireland. Factors such as flow accumulation can be automatically computed, which is a more useful input that distance from source for modelling flow and width criteria. Distance from source does not change greatly when a large tributary enters the river, whereas flow accumulation does. It is therefore more closely linked to the real habitat variables of flow and width, which are important for fish.

Another benefit of the raster modelled approach to river networks is the ease with which raster coverages such as land use and altitude or slope data can be utilised. This allows river gradient to be easily calculated on a square by square basis, meaning that the river network does not have to be split into reaches and these parameters handled as reach attributes. Strahler stream orders can also be automatically calculated, and flow accumulation can be used instead of distance from source as a surrogate for flow levels.

The modelling of river networks using the hydrologic functions within ArcView relies as its base input a Digital Elevation Model (DEM). The accuracy and resolution of this DEM will have a major impact on the accuracy of the modelled river network. 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 statistics. It will also cause problems in the lowland areas which will be more important for coarse fish.

Further problems can occur when different geology is considered. Generation of the river network assumes that the pour point draining greater than a given number of cells (defined by the user) becomes a river. This approach would be acceptable if all geology was equally permeable and rainfall across all areas was equal. This of course is not the case leading to the modelled river network having to be tailored to the specific catchment or subcatchment being dealt with.

One approach to the problems caused by the use of raster data is to rasterise the vector data layer, and force the river model to follow this new data layer as outlined by Saunders (1999). This gives in some ways the best of both worlds, with the benefits of the raster approach without the inherent inaccuracies of a normally modelled river network, and may be a good approach for the next phase of this project.

### 5.3.3 The model

The model developed to explain the variability in the quantities of fines recovered from the sample sites was a reasonably good fit. This is to be expected as the model was based on relatively few samples, allowing a reasonable fit to be applied. A knowledge-based approach was taken to the modelling. This means that only factors which we could be reasonably confidant of having an impact on silt accumulation were included in the analysis. Any spurious results which were against expectations, were removed, if it was felt there were reasonable grounds for doing this. With so few independent sampling sites and so many possible environmental variables to choose from significant correlations are bound to crop up as type I errors. A knowledge-based audit of the final model was therefore felt to be the best approach, and follows normal modelling procedure (Gilchrist, 1984).

It was found that the GIS derived variables gave better results than those collected at the site. There were two reasons why this should be so:

- The GIS data allows an integration of all upstream effects, which should be more important that on site descriptions when considering silt transport.
- There are more GIS variables to choose from, therefore more chance of having finding good correlations.

The fact that the GIS derived environmental data was more suitable for generating the model also allowed GIS to be used to apply the model to unsampled parts of the catchment.

The final model took into account 3 variables:

- The average slope in the catchment upstream of the sample point
- The time that the basket had been left in position
- The percentage of grazed land in the catchment upstream

All three of these parameters are intuitively reasonable. Grazed land was the significant only land use variable which seemed to have a positive correlation with the amount of fines recovered.

Naden and Cooper (1999) 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. These findings were for suspended sediment rather than sediment delivered to spawning gravels. Urban land could have been used within this model, but as it accounted for very small portions of the test catchments, it was not considered as useful as the alternatives of pasture and gradient. Within this project it was found that there was an inverse correlation between cropped land and levels of silt. This was counter to our expectations and the findings of Naden and Cooper (1999), which does raise some concerns about the data used. This finding could, however, be due to the relationship between cropped land and gradient, with cropped land tending to be in lowland areas, where less active erosion occurs.

Naden and Copper (1999) also found that the load of suspended sediment within a watercourse is heavily flow dependent. Flow was omitted from this pilot 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.

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 5.5 and 5.6 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.

The use of this model to investigate real fisheries results was trialed on the Tamar catchment. Only quantitative fisheries surveys were used, as they give much more precise population estimates than can be calculated from semi-quantitative surveys. The graph (Figure 5.7) showing densities of salmon and trout fry against the modelled silt accumulation does show a slight trend, with increasing silt values correlating with decreasing fry densities in both species. 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 always 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 for both salmon and trout fry (Table 5.5). 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 key consideration is that one of the variables, gradient, which was used in the model is well known to influence the densities of salmonids (Wyatt *et al*, 1995). This means that the significance found in this analysis may be attributable to gradient rather than silt accumulation, although clearly the two are connected.

It should be remembered that the results being displayed here are from a summer survey of silt accumulation. The picture during the actual spawning season may be very different. The quantity of sediment that moves over winter is different, for example in chalk rivers 96% of sediment moves between November and April (Acornley and Sear, 1999). The sources of silt may also change, with a greater proportion coming from arable filed where winter cereals are grown. The recent upward trends in the growing of winter cereals means that there are now many bare fields over winter allowing greater levels of erosion to take place (DEFRA, 2000).

It is therefore vital that this type of study is repeated over an actual spawning season, if a true picture of siltation in salmon redds is to be gained.

The process was however successful, with the GIS providing a quick and easy way of retrieving environmental and modelled data associated with individual fisheries survey points.

# 7 CONCLUSIONS

## 7.1 Sampling Methodology

This trial has demonstrated that the proposed sampling methodology is effective in collecting samples of silt from artificial salmon redds.

Care must be taken to ensure that baskets can be retrieved. A floating marker or precise measurements are vital in areas subject to gravel movement

Results were in line with peoples perceptions i.e. sites thought to be impacted had more silt accumulation than those thought to be 'clean'.

The quantities of fines recovered from the gravels were low compared to the levels which cause egg mortality in the published literature. However, these trials were carried out over the summer so these findings should not really be compared to trials carried out over the winter spawning season. A winter trial would provide a much more realistic comparison.

## 7.2 Fingerprinting

The simple sediment fingerprinting approach taken in this project was successful in indicating the most likely source of the fines recovered from each site.

More detailed information on the source of the silt could be gained if catchment sampling of possible sediment sources was carried out.

The results suggest that surface sources are dominant, although bank sources are likely to provide a significant contribution. In most cases, the dominant surface source is likely to be cultivated areas, but in the case of the Rivers Lyd, Alyn and Leven the relatively high $^{137}Cs$ concentrations suggest that pasture areas also represent a significant source.

## 7.3 Modelling

This approach clearly demonstrates the potential of GIS to both improve and simplify modelling, and to extrapolate results to unsampled areas.

The model developed for estimating silt accumulation took into account the amount of time the sample had been left in situ, the average gradient of the catchment upstream, and the percentage of grazed land in the catchment upstream.

There is a significant relationship between the numbers of both trout and salmon fry and the estimated accumulation of fines on the Tamar catchment.

# 8 RECOMMENDATIONS

1. A larger scale survey should be carried out over the actual spawning season of salmon.

2. Efforts should be made to make the baskets more visible for re-location via a floating marker.

3. A more detailed quantitative fingerprinting study should be carried out to identify possible source material

4. GIS modelling shows great potential for both identifying the source of variability in the sediment samples and extrapolating the results to unsampled parts of the catchment. The GIS modelling procedure should therefore be carried out on any future surveys.

5. A similar modelling exercise should be carried out to model the source of the fines to see if the pasture\bankside relationship is influenced by physical and land-use factors.

6. Flow data should be examined as a possible variable for inclusion in future modelling exercises.

7. A larger juvenile data study should be carried out on the future models to see if juvenile surveys results correlate to expected silt results.

8. The results of this and any future studies should be used to validate the models developed as part of the ‘Risk of sediment delivery to rivers’ project.

9. The maps generated as outputs from the ‘Risk of sediment delivery to rivers’ project should be investigated against the fisheries data collated as part of this project. This would examine relationships between areas thought to have a high risk of sediment delivery, to see if they have lower than expected fish densities.

10. Further work could refine the approach used here and produce more detailed and reliable results relating to sediment sources and the variation in such sources both spatially and temporally.

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# APPENDIX 1: STANDARD METHODOLOGY

# Assessing the quality of salmonid spawning gravels using a retrievable sampling basket methodology


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# 1 INTRODUCTION

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. This is because salmon and trout lay need clean river gravels in which to lay their eggs. 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, waste products are not removed from them. This can dramatically decrease egg survival (Turnpenny and Williams, 1980; Crouse *et al.,* 1981; Rubin, 1998).

Liaison with fisheries staff has shown that there are perceived problems across the majority of Environment Agency Areas. 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 (<60μm). Silt remains in suspension for long periods of time and can therefore be transported for long distances. Runoff from fields can contain a high proportion of such fines, so erosion from a field may impact spawning gravels well downstream. Eroding riverbanks, although a much more visible source of suspended material, contain only a small proportion of the very fine sediment fractions which are thought to be causing the problems.

The land use issue has also emerged through routes such as an OECD Fellowship which reported in 1997 (Theurer *et al.,* 1998) on the impacts of siltation on fisheries in England and Wales. 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.

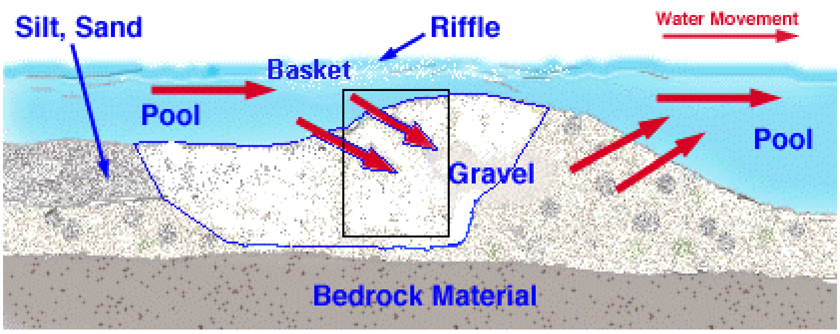
As a response to these recommendations, the Agency initiated an R&D project to ascertain the extent of siltation problems around England and Wales. The National perspective is difficult to obtain because the problem has previously only been investigated locally, and has not been systematic, consistent or extensive. Freeze coring is the only standard method which has been applied extensively. Methods such as freeze coring are labour intensive, and only assess the current state of gravels. When a salmonid creates a redd, the gravels are cleaned and fine sediments are washed downstream. It is therefore important to find a method which will describe the rate of accumulation of silt within a redd after its creation, as it is this parameter which is of primary importance to egg survival. This method has been developed to meet that need.

## 2 SITE SELECTION AND BASKET INSTALLATION

### 2.1 Site Selection

Within each of the study catchments, artificial redds should be constructed at sites where salmonids have been observed to have spawned in the recent past. If information concerning the siting of previous salmonid redds is unavailable then artificial redds should be constructed in areas of significant downwelling or upwelling in the flow where incubating embryos are supplied with oxygenated water. Such conditions occur, for example, at the downstream edge of a pool, as water flows into a riffle (see Figure 1).

**Figure 1: Siting of retrievable sampling basket**




### 2.2 Basket Installation

Stream-spawning salmonids bury their eggs in a redd dug into the stream gravel. The cutting of the redd involves the female turning on her side above the substrate and vigorously waving her tail. (Fig 2). This mobilises sediment into the fast flowing main current which transports it downstream creating a hollow and a mound within the gravel. The female then lays her eggs in the hollow, while the male fertilises them. Cutting is started again slightly upstream in order to bury the eggs. Again fine sediment is washed downstream, leaving eggs deposited in an area of cleaned gravel, containing little fine sediment (Kondolf *et al.,* 1993; McNeil and Ahnell, 1964; Crisp and Carling 1989). This process may be repeated several times, with most salmonid redds containing at least two egg pockets.

**Figure 2: Spawning behaviour of salmonids**

This methodology attempts to replicate the natural spawning process detailed above by constructing artificial redds with a depth of 220mm, a length of 1500mm and width of 500mm. These dimensions are based on representative dimensions for salmonid redds (Crisp and Carling, 1989). The methodology for constructing an artificial redd and the installation of a retrievable sampling basket within the redd is detailed below, and shown in figure 3.

1. A garden fork is used to create a hollow in the spawning gravel to a depth 220mm and diameter 500mm. The displaced gravel is lifted into the main current which will winnow out the fines and deposit the coarser particles downstream creating the tail of the redd.
2. A second hollow is created immediately upstream of the first hollow, such that the axis of the redd is parallel to the direction of flow. The displaced gravel is deposited into the first hollow, with the finer sediment being transported downstream in the main current, mimicking the cleansing, of gravel by salmonids during redd cutting.
3. A third hollow is created immediately upstream of the second hollows in order to fill the second hollow with clean gravel.
4. A fourth hollow is created more vigorously than the previous hollows to fill the third hollow and transport gravel over the whole redd. The successive excavation of the hollows creates an artificial redd with a depth of 220mm, a width of 500mm and a length of 1500mm.
5. The retrievable sampling basket is filled with representative gravel taken from the middle of the constructed artificial redd, with gravel<6.4mm having been removed by sieving. Collection of the gravel creates a hollow in the middle of the redd into which the retrievable sampling basket is placed. The waterproof skirt should be collapsed and folded at the base of the sampling basket, with the drawstrings tied to the top of the basket. Some restructuring of the redd may be required to return the artificial redd to its original shape.

**Figure 3: Installation of a sampling basket**

# 3 SITE DESCRIPTION

For each sampling basket installed a it is recommended that a brief site description form is filled in, to allow a degree of site characterisation to be carried out. A template site description form is shown in section 3.2.

## 3.1 Environmental Variables Required for Field Sheet

**Stream Width**

The stream width should be measured to the nearest 10cm across the cross section of the stream where the sampling basket has been placed, at right angles to the direction of flow. The width recorded should be the width of the water surface rather than the channel width. Widths should be measured whenever possible, but estimates may be necessary for particularly wide and deep rivers.

**Depth**

Depth measurements should be taken to the nearest 1cm across the same cross section as the width measurements. Depths should be taken at roughly 1/6, 1/3, 1/2, 2/3, and 5/6 of the width. A representative depth should be taken at each sampling point across the width of the stream. This means that if the sampling point falls on a large boulder, the depth should be taken from the nearest representative point instead. Standard right bank / left bank conventions should be used i.e. right hand and left hand banks are designated when facing downstream.

**Substrate**

The substrate assessment scheme follows that of HabScore. The area around the installation site should be assessed using the 'Absent', 'Scarce', 'Common', 'Frequent' and 'Dominant' system as shown in table 1. The Area assessed should be that in which the sampling basket is sited, hence if it is placed at the tail of a pool, in a riffle the substrate of the riffle should be assessed. The pool, although close to the basket would not be representative of the conditions experienced around the basket, and should therefore be excluded from the substrate assessment.

**Table 1: Codes for cover categories**

| Estimated % of bed Area within section | | | | |
|---|---|---|---|---|
| 0%<br>Absent<br>A | >0 &<5%<br>Scarce<br>S | ≥5& <20%<br>Common<br>C | ≥20 & <50%<br>Frequent<br>F | ≥50<br>Dominant<br>D |

The abundance categories should be assigned strictly according to the percentage area. This means that the most abundant substrate type will not necessarily score as 'Dominant', but achieve this only if the area of stream bed covered is > 50%.

For discrete areas of substrate it is helpful to try to estimate the area of that patch, and relate this to the reach area. For areas of mixed substrate types, a direct estimate of proportion, rather than area may be more straightforward.

Emergent instream substrates such as large boulders breaking the surface should be included, large dry shoals or permanent islands should not.

**Channel Bank Height**

The height from the water surface to the top of the channel bank should be noted for both the left and right hand banks. The top of the channel bank should be taken as the first significant break in slope, marking the point where floodwater spills out of the channel. If the river runs through a very steep valley or gorge, with no obvious break in slope this should be noted. The bank top in these cases should be taken as the height of the annual flood level, usually marked by debris in trees.

**Riparian Zone Description**

This should be a general description of the land use adjacent and upstream of the survey site. It should include reference to all of the land use types to a distance of approximately 200m upstream.

### 3.2 Site Description Form

| | |
|---|---|
| Catchment:______________________<br>Tributary:<br>Sample Number: | Clean \ Dirty<br>Date:<br>NGR: |

**Section Width (m)** [ ]

**Depth Profile (cm)** Left Bank [ ] [ ] [ ] [ ] [ ] Right Bank

1/6 1/3 1/2 2/3 5/6

**SKETCH CROSS SECTION AND POSITION OF ARTIFICIAL REDD**

**SUBSTRATE**

| Absent | Scarce | Common | Frequent | Dominant |
|---|---|---|---|---|
| 0% | >0 <5% | $\geq$5& <20% | $\geq$20 & <50% | $\geq$50 |
| A | S | C | F | D |

What percentage of the spawning gravel area in each section is composed of the following substrate types? Enter A,S,F,C and D as appropriate.

Bedrock [ ]

Boulders >25.6 cm [ ]

Cobbles 6.4 – 25.6 cm [ ]

Gravel / Coarse sand 0.2 – 6.4 cm [ ]

Fine Sand and Silt <0.2 cm [ ]

Compacted Clay [ ]

**Channel Bank and Riparian Area**

Average Height of channel bank along reach (m) Left Bank [ ] Right Bank [ ]

Actively eroding banks within reach YES / NO

Description of riparian zone

# 4 RETRIEVAL OF SAMPLING BASKET

## 4.1 Re-Locating the Sampling Basket

As the sampling baskets are almost completely buried during installation, they can be difficult to relocate. This was shown by a low retrieval rate during the pilot study with only 51 of 84 baskets being successfully recovered. When first installed the baskets are likely to be visible as they are surrounded by an area of cleaned gravel, like natural salmonid redds. When they have been installed for the notional incubation period of around ninety days, relocation can be much more problematic. This can be due to algal overgrowth of the clean gravels, or burial by shifting gravels during high water events. During the pilot study some traps were also found to have been removed by curious members of the public, as they were found on the riverbank nearby. It is possible that some baskets were lost due to scour and washout, but most losses are thought to be due to difficulties in relocating the actual sample point rather than by the actual loss of baskets from the site.

In all rivers careful notes should be taken on the exact location of the baskets within the river, utilising measurements and bankside markers as appropriate. A one meter length of brightly coloured floating line should also be attached to the rim of the basket to allow relocation in the event of burial or excessive algal overgrowth.

## 4.2 Retrieving the Sampling Basket

The sampling baskets should be retrieved from the gravel after the 90 day sampling interval. The procedure used for retrieving the sampling baskets is detailed below.

1. The drawstrings are untied from the top of the sampling basket and sequentially pulled to gradually ease the waterproof skirt up around the basket until it extends just above the top of' the basket. Careful pulling of' the individual drawstrings should allow the skirt to move up through the gravel smoothly without significant movement of the basket.

2. The sampling basket is removed from the redd by holding the waterproof skirt against the top of the basket and slowly lifting the basket into a waterproof crate or onto a flat surface on the channel bank. The weight of the gravel should be taken by the basket and not the drawstrings or the waterproof skirt.

3. The water contained within the basket will gradually seep out, but if necessary it can be slowly released by gradually lowering the waterproof skirt down around the sides of the basket. The slow release of water reduces the loss of fine sediment collected in the basket.

# 5 SAMPLE PROCESSING

## 5.1 Basket Sample

The table below depicts the important sediment particle sizes and their impact upon incubating embryos within salmonid redds. The overlap of the particle size classes highlight the uncertainty within the literature of the critical particle sizes for salmonid spawning (Table 2).

**Table 2: Sediment particle sizes and their impact upon salmonid embryos**

| | |
|---|---|
| 0-0.125mm | Suspended sediment fraction responsible for reducing throughflow and adhering to and abrading eggs |
| 0-0. 85mm | Sediment responsible for reducing throughflow and supply of oxygen to embryos (McNeil and Ahnell, 1964, Hall, 1984, Chapman. 1988). |
| 0-2mm | Sediment responsible for reducing throughflow and supply of oxygen to embryos (Platts et al., 1979; Tappel and Bjornn, 1983;). |
| 2-6.4mm | Sediment responsible for entombment (Bjornn and Reiser. 1991) |

Sediment <6.4mm collected within the sampling basket needs to be separated from the original gravel placed within the basket and sieved to determine its particle size distribution. The procedure for processing, the sediment collected by the sampling baskets is detailed below.

1. The contents of the sampling basket are tipped onto a 6.4mm sieve which separates the original gravel, used to fill the basket, from sediment which infiltrated into the basket during the sampling period.
2. The spawning gravel (>6.4mm) is weighed to determine the weight of the gravel contained in the sampling basket. This will permit the infiltrated sediment to expressed as a percentage of the total weight of the gravel.
3. The <6.4mm fraction collected from the basket is wet sieved through a series of sieves, namely 0.125mm. 0.85mm, 2mm, and 4mm. The resulting fractions are allowed to dry and are then weighed. Sediment <0.125mm will need to be separated from water by sedimentation and decanting under centrifuging and is then dried and weighed.
4. Sediment <0.125mm should be bagged, sealed and retained for further laboratory analysis. Analysis can be carried out to determine the physical and chemical properties of the sediment. These data will provide a preliminary assessment of the key controls on rates of sediment deposition, the selectivity of the deposition mechanisms and the relative importance of catchment surface and channel bank sediment sources.

### 5.2 Additional Information

When using this method, there is an opportunity to gather additional information which will give more information on the processes and impact of sediment infiltrating salmonid redds. Depending upon the scope of the study being undertaken, it may be worth collecting information on some of the following parameters:

**1. Suspended sediment**

Several 1 litre suspended sediment samples should be collected during high flow events to provide information on the properties of the suspended sediment transported by the study rivers and their relationship to those of the sediment deposited in the baskets. These samples should be allowed to settle and reduced in volume by decantation. The resulting small volume samples should be stored in individual plastic bottles and forwarded to Exeter for analysis as soon as possible after collection.

**2. Suspended sediment concentration and discharge data**

Where feasible, suspended sediment concentration and discharge data should be recorded to determine the suspended sediment load transported through the study reaches during the sampling period. The rate of sediment infiltration into salmonid redds will be related to the suspended sediment load and this relationship will provide a useful insight into the infiltration process and variations both within and between the study catchments.

**3. Dissolved oxygen concentration**

Dissolved oxygen is an important indicator of the potential survival of embryos incubating within salmonid redds. Although dissolved oxygen requirements vary throughout egg development, 5mg $l^{-1}$ is usually taken as the critical level below which it can be assumed that there will be significant egg mortality.

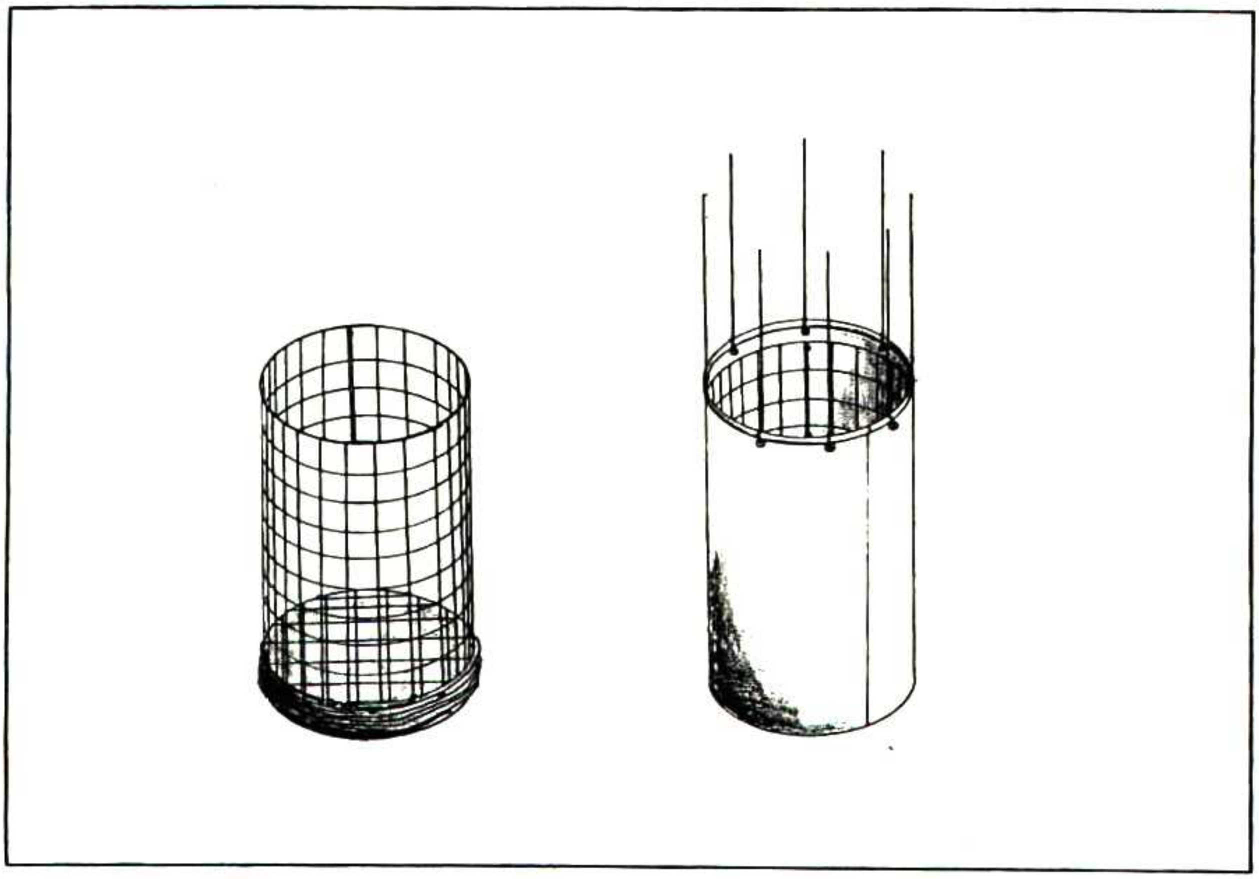
To measure dissolved oxygen within the artificial redd a tube is fastened to the inside of the basket. The diameter of this tube should be just large enough to permit the insertion of the finest oxygen probe available. The tube should reach down to near the base of the basket, where the egg zone would be in a natural redd. The upper end of the tube is corked during the sampling period to stop sediment deposition within the tube, and is uncorked to allow the oxygen probe to be inserted to the base of the basket where the level of dissolved oxygen is measured. The probe is left in the basket for 10 minutes before a reading is taken, to allow time for the oxygen readings to stabilise. When readings are taken within the basket a measurement of the ambient dissolved oxygen level in the river water should also be made, so that the reduction in dissolved oxygen within the spawning gravel can be calculated.

**4. Freeze coring data**

To determine the representativeness of the sediment collected by the retrievable sampling baskets, an adjacent artificial redd could be freeze cored, at the end of the sampling period, and the results obtained compared to those provided by the retrievable sampling basket. To make this possible, an additional artificial redd that will be used for freeze coring should be constructed at the time that the baskets are installed.

# 6 DESIGN AND SUPPLY OF RETRIEVABLE SAMPLING BASKET

**Figure 4: The retrievable sampling basket**



## 6.1 Construction of Basket

- 559 x 256mm Galvanised Steel Mesh (25 x 25mm x l0gauge) is rolled to form a cylinder with height 256mm- and diameter ca. 178mm (to outside edge). The 10gauge steel runs vertically on the outside of the cylinder to facilitate the upward movement of the waterproof skirt. The steel mesh cylinder should be welded together if possible, although it is possible to finish the cylinder using four cable ties.
- A 3mm thick PVC sheet should be cut to form two circles, each with the same diameter as the cylinder (approx. 175mm).
- One plastic disc is secured 25mm above the base of the cylinder with 6 cable ties. It is important that the cable ties are fitted so that the outside of the cylinder remains as smooth as possible.
- 175 x 175 x 25mm Expanded Polystyrene is cut to form a disc with diameter 175mm. This is inserted into the base of the cylinder under the plastic disc.
- The second plastic disc is secured on the base of the cage. The plastic base should be flush with the sides of the cage.

A plan of this can be seen in Figure 5 (below).

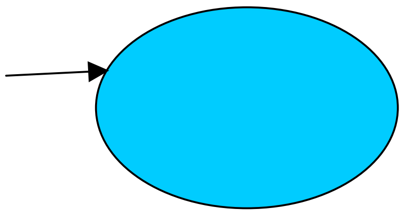
## 6.2 Construction of Waterproof Skirt

- 640 x 310mm Rip-Stop Nylon is machined with Polyester Thread to form a cylinder with diameter ca. 1971mm and height 310mm. 20mm has been allowed for the hem. The stitching is sealed with a Waterproof Sealant. A pilot waterproof skirt should be used to determine the most suitable diameter for the skirt. This would allow adjustments to be made so that the skirt fits the basket as tightly as possible, but allows for the skirt to be drawn down to 25mm at the base of the basket. If separate firms are constructing the basket and waterproof skirt a basket should be made available to check the dimensions of the waterproof skirt.
- 217 x 217mm RipStop Nylon is cut into a circle with a diameter of 217mm. This circle of fabric is machined with Polyester thread to the base of the cylinder constructed above. 10mm of material at the bottom of the cylinder and around the circle of fabric is used to attach the cylinder to the circle of fabric. The stitching is sealed with a Waterproof Sealant.
- 620mm length of 5mm diameter 'O-Ring' Rubber is sewn into the top of the skirt using Polyester thread. 30mm of fabric at the top of the skirt is used to attach the rubber to the skirt.
- 8 x 6mm Brass Eyelets are punched under the 'O-Ring' Rubber at equal distances at the top of the skirt.
- 2000mm Polypropylene Cord (diameter 3mm) is cut into six equal sections and attached to the skirt through the eyelets.

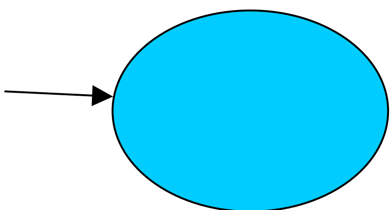
The waterproof skirt should be fitted around the basket to operate as shown in Figure 4.

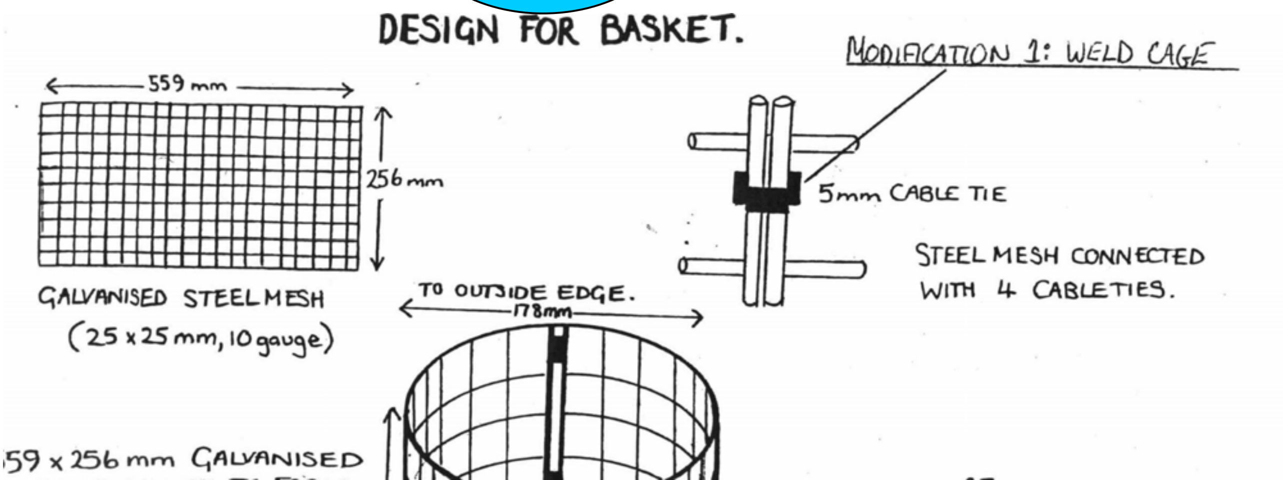
**Figure 5: Design for retrievable sampling basket**

PVC Disc
Diameter 175mm



PVC Disc
Diameter 175mm





**Supply of retrievable sampling baskets**

Sampling baskets were constructed to the above specifications by:

Peter Harding C.O.
Duncan and Associates
Jeeves Bank
Fernleigh Road
Grange over sands
Cumbria
LA11 7HT

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## APPENDIX 2: DATA

| Catchment | Perceived status | NGR | Sampling Interval (days) | Fraction Weight (g) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | >6.4 mm | >4.0 mm | >2.0 mm | >0.85 mm | >0.125 mm | <0.125 mm | Total |
| Itchen | Clean | SU48032808 | 86 | 6515 | 81.81 | 277.38 | 42.38 | 75.35 | 15.66 | 7007.58 |
| Itchen | Clean | SU48032808 | 86 | 6576 | 25.41 | 103.9 | 53.73 | 66.41 | 21.7 | 6847.15 |
| Itchen | Clean | SU48032808 | 86 | 6989 | 6.73 | 20.39 | 40.39 | 141.82 | 25.27 | 7223.6 |
| Itchen | Clean | SU48032808 | 86 | 6838 | 1.54 | 9.42 | 43.12 | 95.94 | 22.73 | 7010.75 |
| Itchen | Clean | SU48032808 | 86 | 7027 | 140.3 | 25.13 | 69.71 | 133.71 | 29.34 | 7425.19 |
| Itchen | Dirty | SU46061704 | 85 | 7374 | 38.26 | 247.21 | 105.22 | 54.57 | 66.71 | 7885.97 |
| Itchen | Dirty | SU46061704 | 85 | 7898 | 33.12 | 202.32 | 35.84 | 79.93 | 56.13 | 8305.34 |
| Itchen | Dirty | SU46061704 | 85 | 7225 | 10.33 | 308.78 | 93.83 | 177.15 | 52.49 | 7867.58 |
| Itchen | Dirty | SU46061705 | 85 | 8055 | 58.3 | 81.55 | 46.29 | 118.96 | 18.48 | 8378.58 |
| Itchen | Dirty | SU46061705 | 85 | 7779 | 20.85 | 280.25 | 23.8 | 158.9 | 83.48 | 8346.28 |
| Itchen | Dirty | SU46061705 | 85 | 7806 | 15.51 | 101.72 | 29.42 | 182.96 | 49.94 | 8185.55 |
| Leven | Clean | SD346837 | 40 | 6960 | 64.38 | 181.48 | 74.46 | 16.96 | 2.51 | 7299.79 |
| Leven | Clean | SD346837 | 40 | 7000 | 16.85 | 58.94 | 157.23 | 200.56 | 4.99 | 7438.57 |
| Leven | Clean | SD346837 | 40 | 7790 | 84.8 | 242.69 | 78.62 | 14.63 | 2.07 | 8212.81 |

| Catchment | Perceived status | NGR | Sampling Interval (days) | Fraction Weight (g) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | >6.4 mm | >4.0 mm | >2.0 mm | >0.85 mm | >0.125 mm | <0.125 mm | Total |
| Leven | Dirty | SD367863 | 64 | 7800 | 54.59 | 153.34 | 89.24 | 25.09 | 2.12 | 8124.38 |
| Leven | Dirty | SD367863 | 53 | 6950 | 1.15 | 4.71 | 4.56 | 2.32 | 0.58 | 6963.32 |
| Leven | Dirty | SD367863 | 53 | 6950 | 21.21 | 48.37 | 28.43 | 15.02 | 0.63 | 7063.66 |
| Leven | Dirty | SD367863 | 53 | 6600 | 1.71 | 4.4 | 2.51 | 2.7 | 0.32 | 6611.64 |
| Severn | Dirty | SO69444310 | 127 | 6404 | 43.69 | 237.36 | 134.77 | 109.53 | 186.92 | 7116.27 |
| Severn | Dirty | SO69444310 | 127 | 6503 | 178.65 | 290 | 137.11 | 343.37 | 239.57 | 7691.7 |
| Severn | Dirty | SO69444310 | 127 | 6125 | 159.29 | 438.1 | 264.72 | 139.7 | 212.94 | 7339.75 |
| Severn | Dirty | SO69444310 | 127 | 6618 | 132.88 | 230.28 | 139.7 | 221.23 | 154.48 | 7496.57 |
| Severn | Dirty | SO70023142 | 99 | 5704 | 60.67 | 520.36 | 220.67 | 99.43 | 67.98 | 6673.11 |
| Severn | Dirty | SO70023142 | 99 | 6671 | 79.29 | 410.05 | 151.72 | 87.06 | 143.93 | 7543.05 |
| Severn | Dirty | SO70023142 | 99 | 5154 | 169.13 | 438.19 | 238.2 | 184.34 | 158.91 | 6342.77 |
| Severn | Dirty | SO70023142 | 99 | 5695 | 178.33 | 313.47 | 228.86 | 79.59 | 130.29 | 6625.54 |
| Severn | Dirty | SO70023142 | 99 | 5770 | 156.91 | 385.36 | 200.46 | 96.72 | 53.37 | 6662.82 |
| Tamar | Clean | SX429838 | 69 | 7350 | 0 | 1.63 | 3.7 | 31.25 | 12.51 | 7399.09 |
| Tamar | Clean | SX429838 | 69 | 6720 | 0 | 10.13 | 25.38 | 66.57 | 66.2 | 6888.28 |
| Tamar | Clean | SX429838 | 69 | 7025 | 0 | 1.22 | 1.57 | 24.27 | 8.61 | 7060.67 |
| Tamar | Clean | SX429838 | 69 | 7360 | 0 | 0.69 | 2.15 | 17.34 | 5.36 | 7385.54 |
| Tamar | Dirty | SX287994 | 69 | 5965 | 17.61 | 301.29 | 84.57 | 28.17 | 35.68 | 6432.32 |
| Tamar | Dirty | SX287994 | 69 | 6250 | 0 | 25.06 | 36.01 | 199.26 | 110.14 | 6620.47 |

| Catchment | Perceived status | NGR | Sampling Interval (days) | Fraction Weight (g) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | >6.4 mm | >4.0 mm | >2.0 mm | >0.85 mm | >0.125 mm | <0.125 mm | Total |
| Tamar | Dirty | SX287994 | 69 | 6800 | 0 | 6.29 | 18.05 | 151.69 | 102.03 | 7078.06 |
| Tamar | Dirty | SX287994 | 69 | 6470 | 0 | 175.87 | 149.5 | 239.21 | 89.42 | 7124 |
| Tamar | Dirty | SX287994 | 69 | 6850 | 1.28 | 48.19 | 16.13 | 27.35 | 56.78 | 6999.73 |
| Tamar | Dirty | SX287994 | 69 | 7100 | 5.64 | 48.21 | 35.6 | 194 | 211 | 7594.45 |
| Test | Clean | SU33073006 | 84 | 7674 | 9.34 | 26.32 | 14.6 | 138.15 | 15.88 | 7878.29 |
| Test | Clean | SU33073006 | 84 | 7362 | 5.37 | 17.11 | 40.86 | 120.15 | 37.01 | 7582.5 |
| Test | Clean | SU33073006 | 84 | 7903 | 33.29 | 34.18 | 13.5 | 146.61 | 25.88 | 8156.46 |
| Test | Clean | SU33073006 | 84 | 8016 | 19.73 | 28.92 | 22.34 | 155.21 | 33.74 | 8275.94 |
| Test | Clean | SU33073006 | 84 | 7558 | 20.07 | 49.85 | 52.58 | 123.58 | 31.8 | 7835.88 |
| Test | Clean | SU33073006 | 84 | 8174 | 44.35 | 86.54 | 38.73 | 68.02 | 26.27 | 8437.91 |
| Test | Dirty | SU35061605 | 83 | 6935 | 24.2 | 154.94 | 58.13 | 170.84 | 19.87 | 7362.98 |
| Test | Dirty | SU35061605 | 83 | 7629 | 50.32 | 109.78 | 45.49 | 66.86 | 20.56 | 7922.01 |
| Test | Dirty | SU35061605 | 83 | 7636 | 56.78 | 176.3 | 59.8 | 174.68 | 20.56 | 8124.12 |
| Test | Dirty | SU35061605 | 83 | 7554 | 18.88 | 36.08 | 37.19 | 89.45 | 30.62 | 7766.22 |
| Test | Dirty | SU35061605 | 83 | 7965 | 80.97 | 51.29 | 8.61 | 131.41 | 39.95 | 8277.23 |
| Test | Dirty | SU35061605 | 83 | 7606 | 90.95 | 83.69 | 16.24 | 58.74 | 23.34 | 7878.96 |

| Catchment | Perceived status | NGR | Sampling Interval (days) | Fraction Weight (g) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | >6.4 mm | >4.0 mm | >2.0 mm | >0.85 mm | >0.125 mm | <0.125 mm | Total |
| Tywi | Clean | SN75873906 | * | 6614 | 8.41 | 3.41 | 0.39 | 3.9 | 4.91 | 6635.02 |
| Tywi | Dirty | SN75693320 | * | 6608 | 18.71 | 27.25 | 41.01 | 24.65 | 18.26 | 6737.88 |

* Date of removal not recorded.