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# River Leven Freeze Coring Report

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Study of hydrodynamics and sediment in fluvial, coastal and lacustrine environments

**FINAL PROJECT REPORT**

# RIVER LEVEN (at NEWBY BRIDGE) FREEZE CORING

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## 1. Executive Summary

Most sites contain a sufficiently high fine content to be considered detrimental to successful salmonid spawning. All the freeze cores contained distinct horizontal strata down through their length. The cores often penetrated into a highly compacted layer of light grey coloured material. The upper surface of this highly compacted layer is considered as a boundary between fine materials of different origin. Considerable variability was observed in the median grain size ($D_{50}$) of the gravels from the cores. In addition variability was observed in the thickness of the upper less compacted layers. The role of regulated river flow across the weir in clearing fines from river gravels is briefly considered.

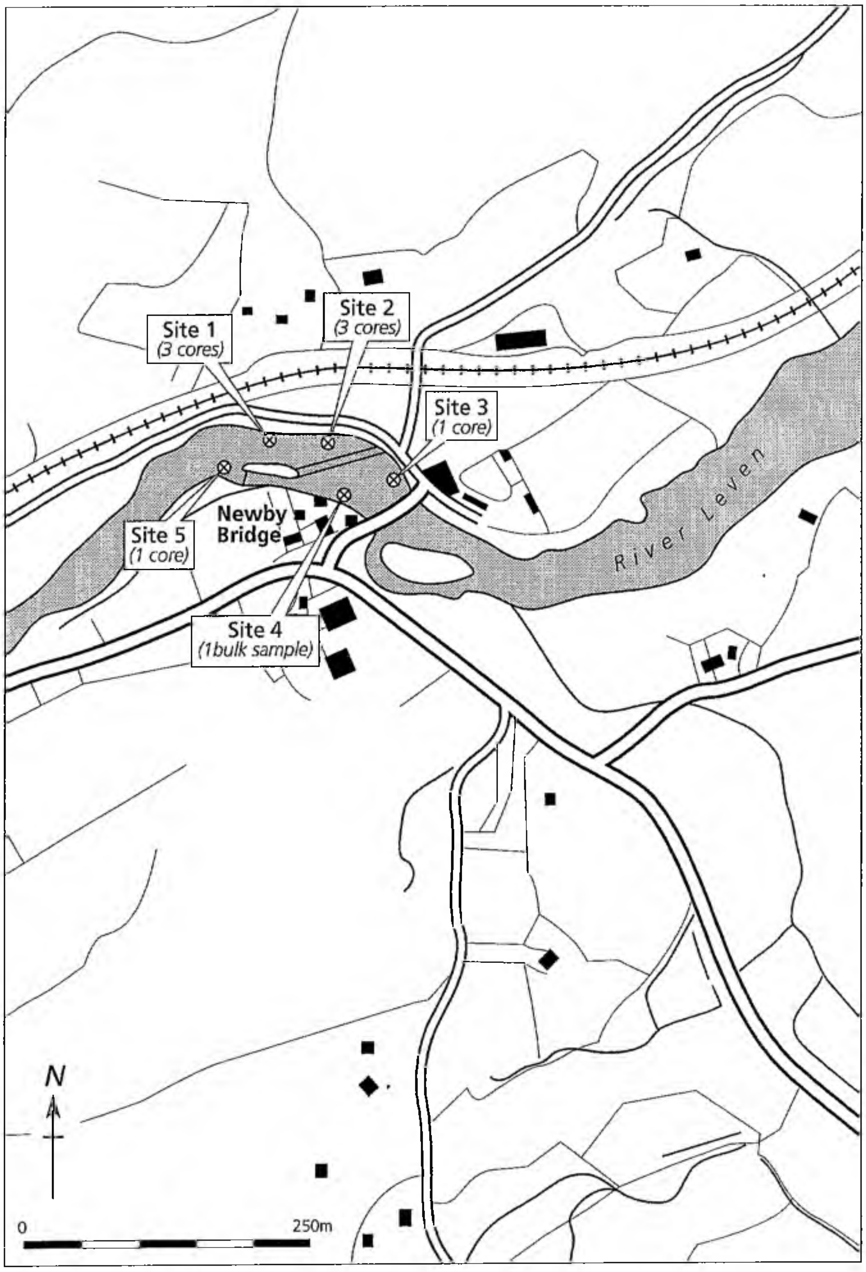
## 2. Project Background

Following an observed decline in quality of salmonid fisheries at the site an investigation was initiated to assess the extent of ingress of fine sediments into the spawning gravels. A broader picture was sought by sampling both above and below the weir and close to both banks of the river. A comparison of the fine sediment from each sample site was undertaken.

## 3. Site Details (NGR: SD 369 865)

Five sites on the river Leven where sampled situated both upstream and downstream of the weir complex at Newby Bridge (**Plate 1**). In the region identified as the main area of redds, close to the north bank downstream of the weir, two clusters of three freeze cores where obtained. A further freeze core was obtained upstream of the weir close to the north bank at a point close to the road bridge. An area identified for sampling close to the southern bank upstream of the weir proved to be unsuitable for freeze coring and a bulk sample was collected instead. The final site is found immediately downstream of the sluice gates from which a final freeze core was obtained.

A total of eight freeze cores and one bulk sample were taken as shown in **Map1** and **Plates 2,3 and 4**. These where retained for the sediment analysis which forms the bulk of this report. Sites were chosen in consultation with Ms. Jo, Barrett, Fisheries Officer with the Environment Agency (Penrith Office), during a preliminary site visit during January2000.



River Leven Sample Sites

# PRINCIPAL PARTICLE SIZE DIVISIONS

## Particle Diameter

| Units | | Division | Class | Group |
|---|---|---|---|---|
| | | V Large | | |
| - 11 | 2048mm | | | |
| | | Large | | |
| - 10 | 1024mm | | Boulders | |
| | | Medium | | |
| - 9 | 512mm | | | |
| | | Small | | |
| - 8 | 256mm | | | |
| | | Large | | |
| - 7 | 128mm | | Cobbles | GRAVEL |
| | | Small | | |
| - 6 | 64mm | | | |
| | | V Coarse | | |
| - 5 | 32mm | | | |
| | | Coarse | | |
| - 4 | 16mm | | | |
| | | Medium | Pebbles | |
| - 3 | 8mm | | | |
| | | Fine | | |
| - 2 | 4mm | | | |
| | | V Fine | | |
| - 1 | 2mm | | | |
| | | V Coarse | | |
| 0 | 1mm | | | |
| | | Coarse | | |
| +1 | 500μ | | | |
| | | Medium | Sand | |
| +2 | 250μ | | | |
| | | Fine | | |
| +3 | 125μ | | | |
| | | V Fine | | |
| +4 | 62μ | | | |
| | | V Coarse | | |
| +5 | 31μ | | | |
| | | Coarse | | |
| +6 | 16μ | | | |
| | | Medium | Silt | MUD |
| +7 | 8μ | | | |
| | | Fine | | |
| +8 | 4μ | | | |
| | | V Fine | | |
| +9 | 2μ | | | |
| | | | Clay | |

**Table 1.**

**Summary of Sample and Site Details**

| SAMPLE SITE | LOCATION | SAMPLE IDENTITY |
|---|---|---|
| 1 | North bank downstream of the weir | FREEZE CORE 1A |
| 1 | North bank downstream of the weir | FREEZE CORE 1B |
| 1 | North bank downstream of the weir | FREEZE CORE 1C |
| 2 | North bank downstream of the weir | FREEZE CORE 2A |
| 2 | North bank downstream of the weir | FREEZE CORE 2B |
| 2 | North bank downstream of the weir | FREEZE CORE 2C |
| 3 | North bank upstream of the weir | FREEZE CORE 3A |
| 4 | Southern bank upstream of the weir | BULK SAMPLE 1A |
| 5 | Downstream of the sluice gates | FREEZE CORE 4A |

## 4. Methodology

Cores were collected using standard freeze coring methods a summary of which follows. Sediment samples were extracted by using a copper standpipe inserted into the river bed, liquid nitrogen is decanted down into the stand pipe to freeze the pipe and the surrounding interstitial water within the river bed sediments. The pipe is then extracted from the bed complete with an undisturbed bed sample using a winch. Details of freeze coring equipment are given in Carling and Crompton (1988). Intact cores were then photographed (**Plates 5-12**) and inspected for stratigraphic divisions. In addition core lengths were taken and the whole core weight measured in order to calculate void ratios.

Samples were then dried at room temperature and then sieved mechanically using a Fritch Analysette. Sieving time was 15 minutes using an intermittent mode of amplitude sufficient to mobilise the coarsest fractions. As grain size distributions approach a logarithmic distribution samples were sieved at 1phi (Ø) intervals in the range <0Ø (<1mm) to –6Ø (64mm). The use of the phi scale is common practice in sedimentological investigations. and the relationship to the mm and Wentworth scales is shown in Table 1. The fine fractions (<0Ø (<1mm)) from each core, in addition to the bulk sample were then analysed with a Coulter LS230 Laser Particle Size Analyser to determine detailed particle size distribution and cumulative frequency curves.

# 5. Results

## 5.1. Sample Descriptions

All the cores appeared to contain sediments from the fluvial regime of the river. All samples contained gravels of varying sizes within a finer matrix and appeared to be compacted to some degree. All of the cores where structured vertically throughout their lengths. They ranged in length from 32cm to 57cm

**Core 1A:** Total core length 57cm that was clearly divided into two strata, no bed armour layer of uncompacted gravels was present. The upper stratum, 20cm thick, contained gravels of varying sizes within a finer matrix of dark brown and grey material and appeared to be compacted. The lower stratum, 37cm thick, contained gravels of varying sizes within a matrix of very dense and highly compacted fine light grey coloured material. Photograph **Plate5.**

**Core 1B**: Total core length 50cm, no armour layer was present. The core was highly structured vertically differentiated into four clear strata; compaction appeared to increase down the core. The upper stratum, 17cm thick, was similar to the upper stratum of core 1A. The second stratum, 15cm thick, was again compacted. Larger gravel clasts (over 64mm) are largely absent from this layer but the remaining smaller gravels are again found in a finer matrix similar to the matrix in the layer above. The third stratum was a narrow (5cm) band of gravels in a matrix of fine material of light brown material. The fourth stratum was similar in appearance to the lower section of core 1A. Due to the stratified nature of this core it was chosen for more detailed examination of the individual stratum. Photograph **Plate 6.**

**Core 1C**: Total core length 35cm with two clear strata, upper layer 12cm thick and lower 23cm, again no clearly defined armour layer. The two sections of this core where similar in appearance to those of core 1A. Photograph **Plate 7.**

**Core 2A**: Total core length 32cm divided into two compacted strata with no clear armour layer. The upper layer, 12cm, is similar in appearance to the upper strata of the cores from site 1. The lower layer, 20cm, gravels of varying size within a matrix of a finer light brown material similar in appearance to level three of core 1B. Photograph **Plate 8.**

**Core 2B**: Total core length of 40cm. Similar in appearance to core 2A with the upper layer 15cm thick and the lower 25cm. Photograph **Plate 9.**

**Core 2C**: Total core length 51cm divided into two strata. The upper stratum, 17cm, is similar to the upper layers of the previous cores. The lower stratum, 34cm, contains gravels of varying sizes within a matrix of finer material that appears to be a mixture of the light grey material found in the lower sections of the cores from site 1 and the light brown material found in the lower sections of cores 2A and 2B and the third layer of core 1B. Photograph **Plate 10.**

**Core 3A**: Total core length 38cm. The large individual clast shown on the photograph **Plate 11** has been discounted from this core as it appeared to be part of some small scale 'engineering' on the bank of the river and therefore not part of the natural fluvial regime of the river. Two compacted stratum where visible in this core. The upper layer, 22cm contained a mixture of fluvial gravels and debris from human activity (tiles and pottery) in a matrix of finer material similar to that found in the upper sections of the cores from sites 1 and 2. The lower layer, 16cm contained fluvial gravels in a dark matrix of fine material.

**Core 4A**: Total core length 52cm divided into three distinct strata. The upper stratum was a thin (10cm) relatively uncompacted layer of gravel similar to that expected in a natural bed armour layer. The second stratum, 20cm, consisted of gravels in a finer matrix similar to that found in the upper layers of the previous cores. The lower layer, 20cm, contains gravels in a matrix similar to the light brown material found in the narrow third layer of core 1B and the lower layers of cores 2A and 2B. Photograph **Plate 12.**

**Bulk Sample 1A**: Dark mud, no larger sized material was observed at this section of the river.

### 5.2. Whole Core Data

| Core | 1A | 1B | 1C | 2A | 2B | 2C | 3A | 4A |
|---|---|---|---|---|---|---|---|---|
| Total length (cm) | 57 | 50 | 35 | 32 | 40 | 51 | 38 | 52 |
| Number of Sections | 2 | 4 | 2 | 2 | 2 | 2 | 2 | 3 |
| Top of Lowest Section | 20cm | 37cm | 12cm | 12cm | 15cm | 17cm | 22cm | 30cm |
| Total Dry Weight (g) | 17301 | 15989 | 16402 | 7147 | 9339 | 12981 | 9830 | 18661 |
| Total Wet Weight (g) | 17900 | 16500 | 17750 | 12000 | 13250 | 16750 | 13423 | 22000 |
| % Weight <0Ø (1mm) | 8.1 | 13.3 | 14.0 | 11.1 | 11.5 | 7.6 | 17.8 | 3.9 |
| % Weight >0Ø (1mm) | 91.9 | 86.7 | 86.0 | 88.9 | 88.5 | 92.4 | 82.2 | 96.1 |

### 5.3. Median Grain Size ($D_{50}$)

| Core | 1A | 1B | 1C | 2A | 2B | 2C | 3A | 4A |
|---|---|---|---|---|---|---|---|---|
| $D_{50}$ (mm) | 24.4 | 11.1 | 20.6 | 6.1 | 9.9 | 9.3 | 5.9 | 28.1 |

### 5.4. Percentage of Fines (% Weight <0Ø (1mm)) Within the Cores

| Core | 1A | 1B | 1C | 2A | 2B | 2C | 3A | 4A |
|---|---|---|---|---|---|---|---|---|
| % Weight <0Ø (1mm) | 8.1 | 13.3 | 14.0 | 11.1 | 11.5 | 7.6 | 17.8 | 3.9 |

PLATE 1:The River Leven at Newby Bridge

PLATE 2: Location of Cores 1A, 1B, 1C, 2A, 2B and 2C (viewed left to right)

PLATE 3: Location of Core 3A

PLATE 4: Location of Core 4A


Plate 5: Core 1A


Plate 6: Core 1B


Plate 7: Core 1C

Plate 8: Core 2A

Plate 9: Core 2B

Plate 10: Core 2C


Plate 11: Core 3A


Plate 12: Core 4A

### 5.5. Modal Values of Fines (<0Ø (1mm))

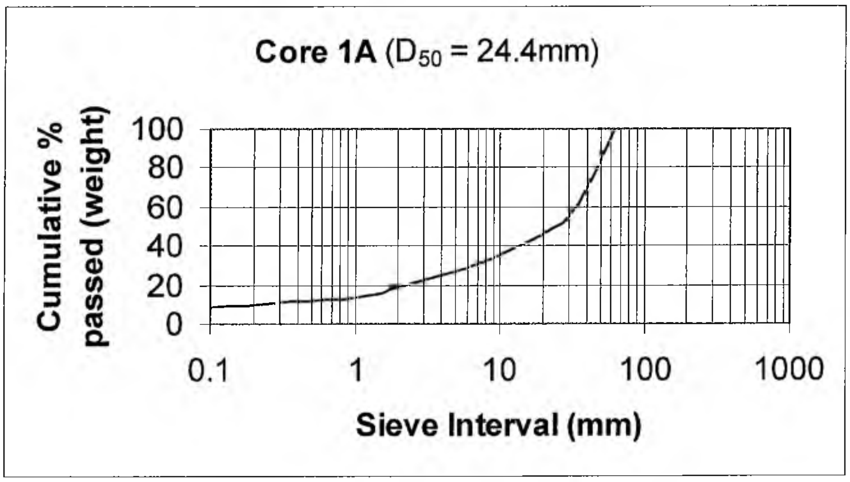
All the samples were found to have particle size distributions that indicate the presence of two populations of fine material. This was either a clearly bimodal distribution or the presence of a 'bulge' on the fine limb of the distribution curve. Particle size distributions and cumulative frequency curves are located in the appendix of this report.

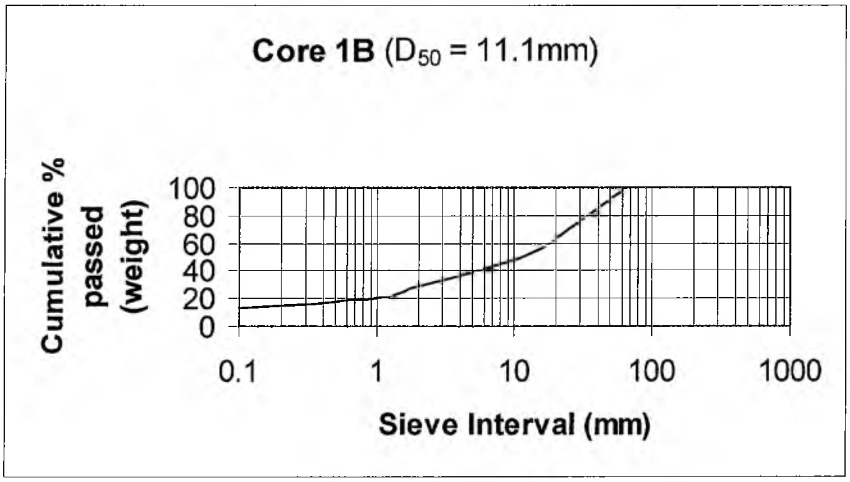
| Core | 1A | 1B | 1C | 2A | 2B | 2C | 3A | 4A | Bulk Sample 1A |
|---|---|---|---|---|---|---|---|---|---|
| Modal Value (µm) | 3.4 | n/a | 5.9 | 2.1 | 2.5 | 2.8 | 5.9 | 3.7 | 6.5 |
| 2nd Mode (µm) | n/a | n/a | n/a | 0.6 | 0.7 | 0.7 | n/a | 0.8 | n/a |
| Position of 'Bulge' (µm) | 1 | n/a | 1 | n/a | n/a | n/a | 0.9 | n/a | 0.8 |

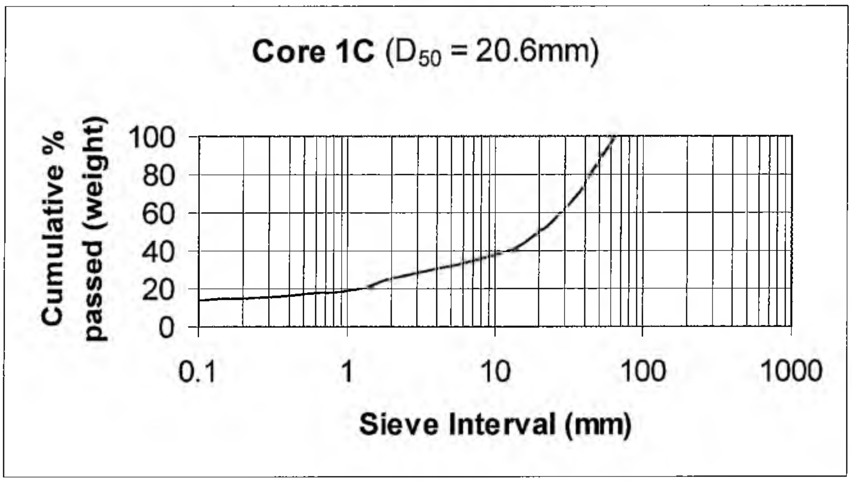
### 5.6. SECTIONED CORE DATA (Core 1B)

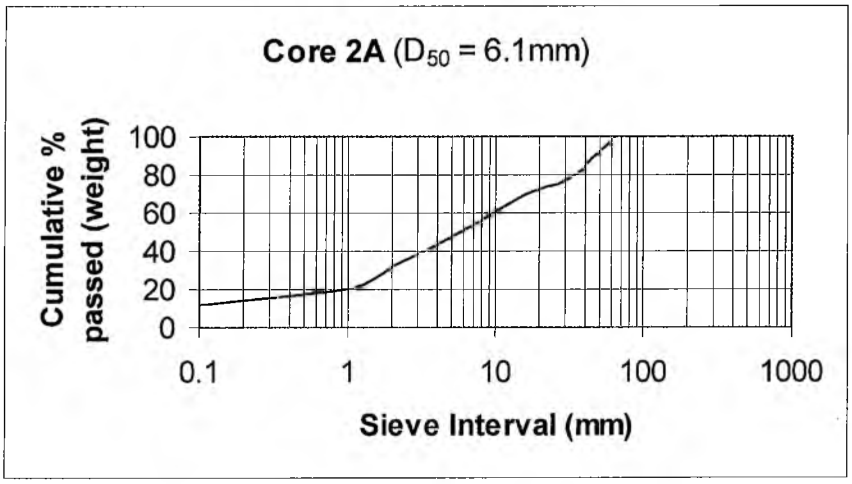
| SECTION | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| LENGTH (cm) | 17 | 15 | 5 | 13 |
| DRY WEIGHT (g) | 6950 | 3488 | 1965 | 3585 |
| % Weight <0Ø (1mm) | 4.9 | 10.3 | 16.3 | 30.8 |
| % Weight >0Ø (1mm) | 95.1 | 89.7 | 83.7 | 69.2 |
| $D_{50}$ (mm) | 22.4 | 6.2 | 11.1 | 2.0 |
| Modal Value (fines) (µm) | 4 | 5.8 | 3 | 5.4 |
| 2nd Mode (fines) (µm) | 0.9 | 1 | 0.9 | n/a |
| Position of 'Bulge' (fines) (µm) | n/a | n/a | n/a | 1.1 |

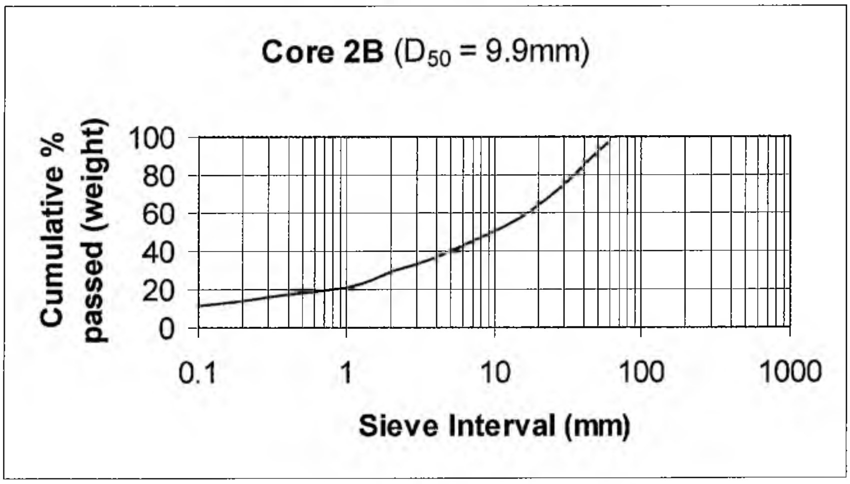
### 5.7. Cumulative Frequency Curves

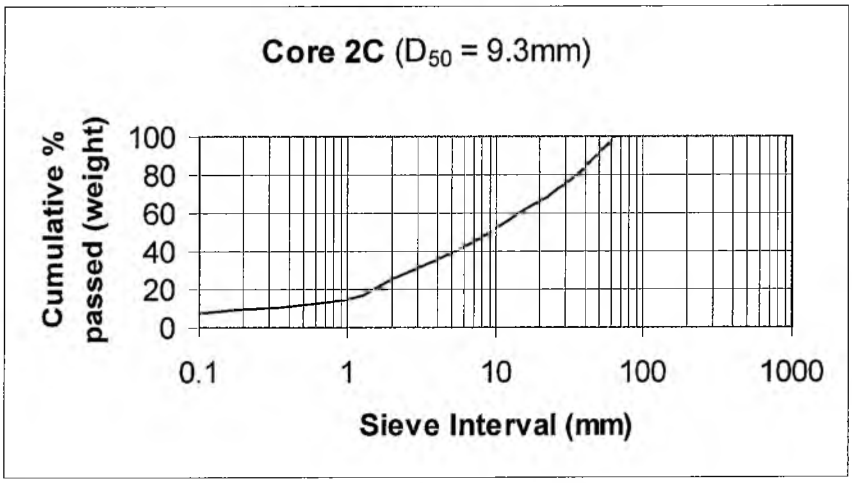


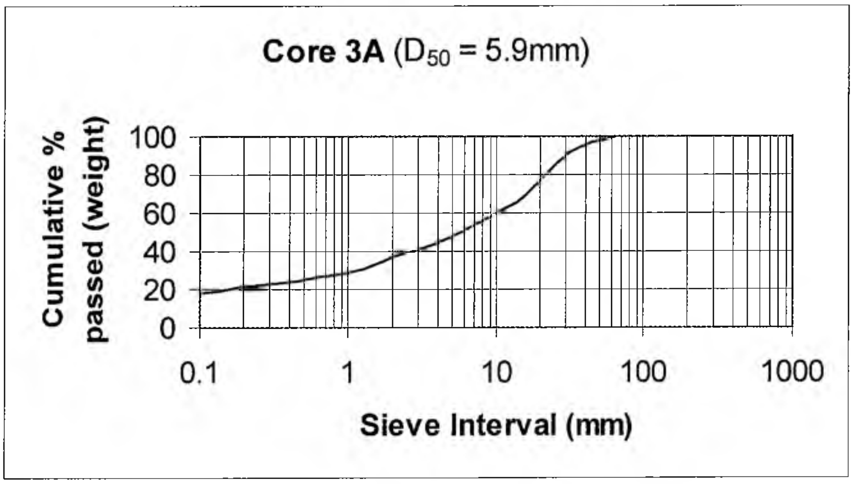

Core 1B (D50 = 11.1mm)
Cumulative % passed (weight)
100
80
60
40
20
0
0.1
1
10
100
1000
Sieve Interval (mm)

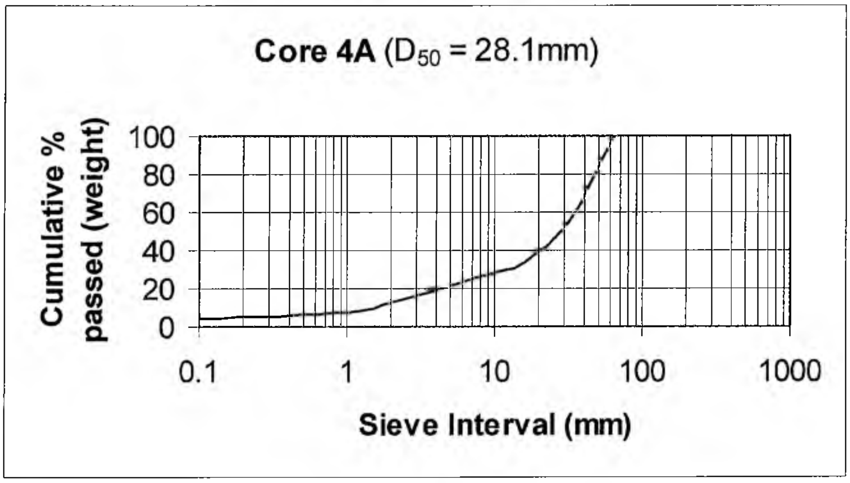

Core 1C (D50 = 20.6mm)
Cumulative % passed (weight)
100
80
60
40
20
0
0.1
1
10
100
1000
Sieve Interval (mm)

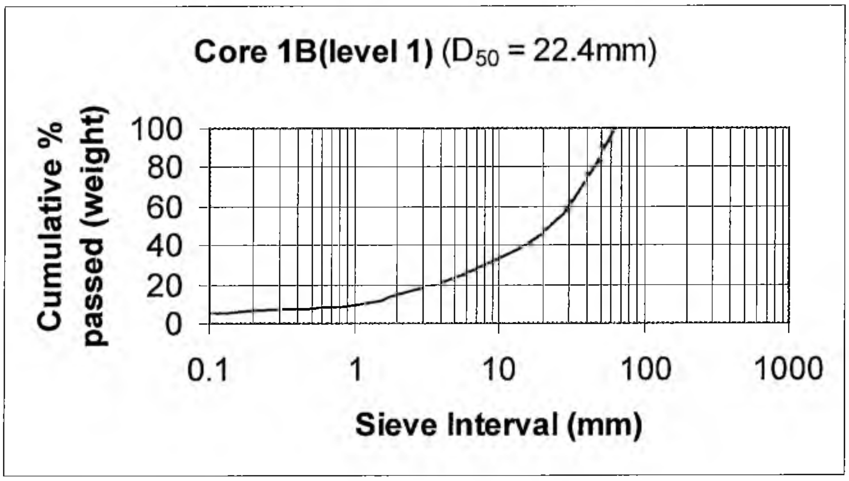

Core 2A (D50 = 6.1mm)
Cumulative % passed (weight)
100
80
60
40
20
0
0.1
1
10
100
1000
Sieve Interval (mm)

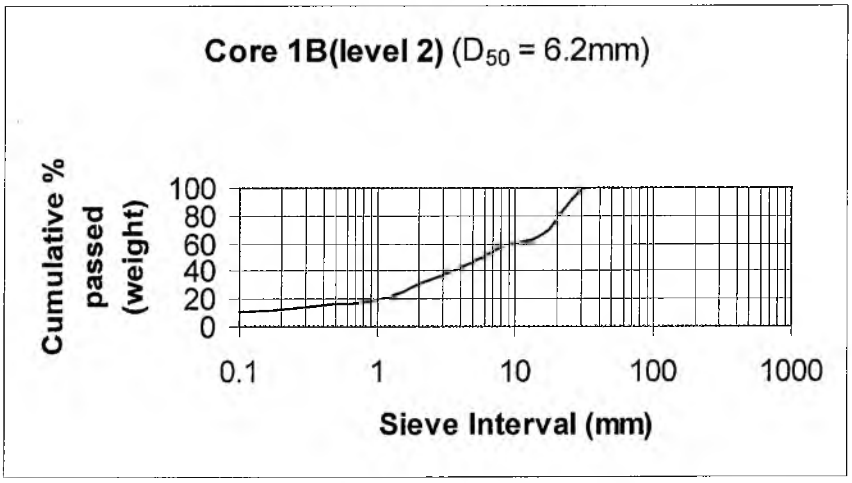

Core 2B ($D_{50}$ = 9.9mm)
Cumulative % passed (weight)
100
80
60
40
20
0
0.1
1
10
100
1000
Sieve Interval (mm)

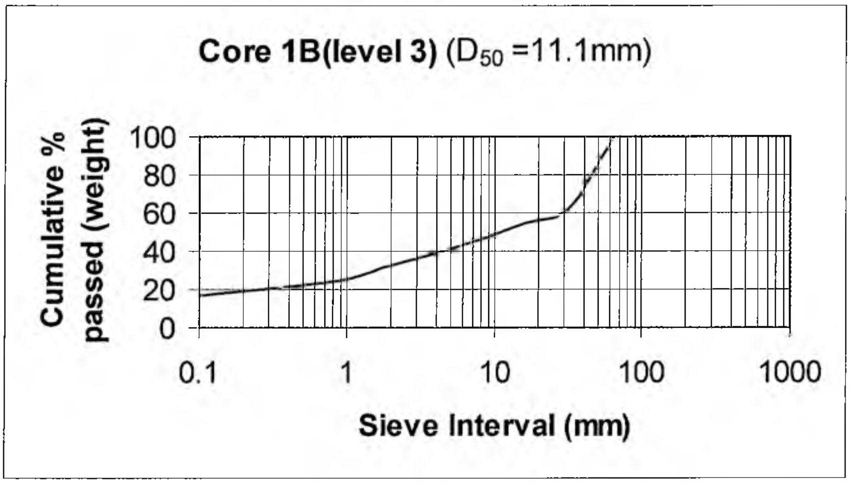

Core 2C ($D_{50}$ = 9.3mm)
Cumulative % passed (weight)
100
80
60
40
20
0
0.1
1
10
100
1000
Sieve Interval (mm)

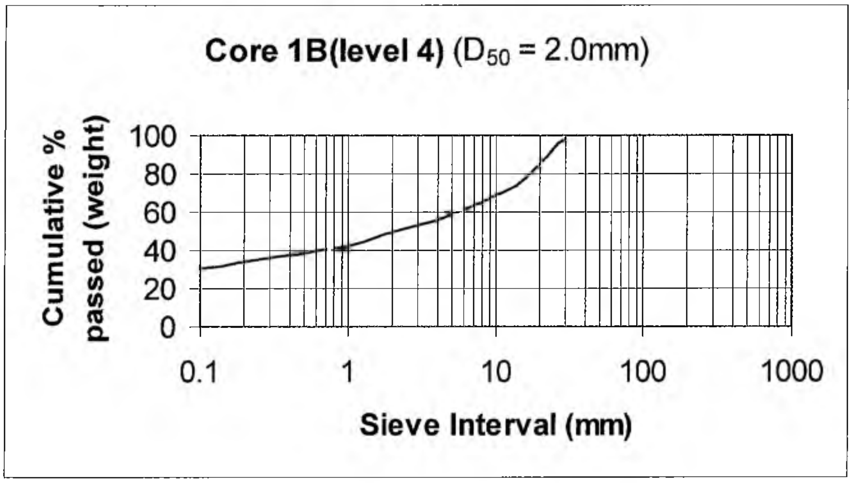

Core 3A ($D_{50}$ = 5.9mm)
Cumulative % passed (weight)
100
80
60
40
20
0
0.1
1
10
100
1000
Sieve Interval (mm)


Core 4A (D50 = 28.1mm)
Cumulative % passed (weight)
100
80
60
40
20
0
0.1
1
10
100
1000
Sieve Interval (mm)


Core 1B(level 1) (D50 = 22.4mm)
Cumulative % passed (weight)
100
80
60
40
20
0
0.1
1
10
100
1000
Sieve Interval (mm)


Core 1B(level 2) (D50 = 6.2mm)
Cumulative % passed (weight)
100
80
60
40
20
0
0.1
1
10
100
1000
Sieve Interval (mm)




## 6. Interpretation

A common feature of the core samples was the clear stratification noted down core. This often terminated in a layer heavily compacted with a fine grey material, above which were found strata containing varying degrees of fine material. The overall nature of the fine material in the cores and bulk sample was again similar. Significant variations were however found in the relatively low median grain sizes ($D_{50}$) of the cores (5.9mm in Core3A to 28.1mm in Core 4A) and the depth of the upper surface of this compacted layer (12cm in cores 1C and 2A to 37cm in core 1B).

Initially we shall consider the six cores taken from sites 1 and 2; the main zone identified as containing redds. Whole core data was obtained for cores 1A, 1C, 2A, 2B and 2C whilst a more detailed picture of down core changes was determined for core 1B. Overall the whole cores presented a consistent picture with fine contents varying from 7.6% (core 2C) to 14% (core 1C). Median grain sizes ($D_{50}$) of the core material were found to be in the range of 6.1mm (core 2A) to 24.4mm (core 1A) whilst the fine material was consistently found to contain fine silts and clay. The two populations of fines, as indicated by their particle size distributions, had modal values in the ranges of 0.6-1μm and 2.1-5.9μm. The data from the sectioned core, Core 1B, is consistent with these data with an overall fines content of 13.3% and a $D_{50}$ value of 11.1mm. The data from the sectioned core does however highlight changes down core. The upper three strata of core 1B relatively low values for percentage of fines and overall $D_{50}$, 4.9-16.3% and 6.2-22.4mm respectively. The lower, light grey coloured, layer however contained up to 30.8% fines and a low $D_{50}$ value of only 2mm for the gravel content. The nature of all the fines however was similar to the other layers and core sites with modal values 3-5.8μm.

The core taken above the weir Core 3A had a relatively high fine content (17.8%) and a relatively low overall $D_{50}$ value (5.9mm). The character of the fines was once again consistent with other cores with a modal value of 5.9μm and the presence of a second population at 0.9μm.

The final core, taken from downstream of the weir, contained a low concentration of fines (3.9%) and the highest D50 value (28.9mm) of all the samples. The fines where again however similar in character to the other sites, with a bimodal distribution with populations of fines centred at 3.7μm and 0.9μm.

The bulk sample of fines collected showed a similar particle size distribution to other fines from other cores with a modal value of 6.5μm and evidence of a second population at 0.8μm.

## 7. Conclusions

Several factors investigated within the remit of this report could be adversely affecting the success of salmonid spawning on the River Leven. These can be broadly divided into two, those concerning the presence of fine material and the overall calibre of the gravels.
Excessive fines within a salmonid spawning ground are known to be detrimental to the success and health of both spawning fish, egg development and emerging fry. Suspended sediments can directly affect the health of adult fish by physically damaging gills and scales. In addition areas of gravel compacted by fines can impair the progress of female fish excavating a suitable redd. The deposition of fine material after eggs have been emplaced can reduce the oxygen available for normal egg development by reducing the flux of oxygenated water past the eggs and if organic material is present within the fines remove available oxygen from the water by increasing the BOD in the vicinity to the eggs. In addition fine material can physically impair the emergence of alevins. The problems of fines in salmonid spawning grounds have been highlighted by various authors including Acornley and Sear (1999); Crisp and Carling (1989); Crisp (1993); Kondolf et al. (1993) and Turnpenny and Williams (1980).

Gravel compacted with fines of a similar character were found across the sampling area. There appears to be two classes of this material, highlighted by their physical appearance. The light grey highly compacted layer found at the base of core samples and the brown coloured material located towards the surface of the cores. These will be considered separately. The material found in the upper strata of the cores is likely to be that deposited due to a contemporary hydrological process associated with the movement of silt and clay through the fluvial system. Mobilisation of such material is often associated with catchment land use changes possibly coupled with increasing rainfall intensity. A wider ongoing investigation of catchment characteristics combined with a program of continuous suspended sediment monitoring would help to quantify the scale of this process. It is harder to envisage such a process being responsible for the deposition of the lower strata of the cores. One potential explanation for the presence of this material is that it is the result of an earlier depositional regime. The highly compacted nature and physical characteristics of this material suggest that it may be associated with a glacial or fluvio-glacial environment. The present day River Leven may be down cutting into an underlying glacial till or fluvio-glacial outwash deposit. As an addition to this study we are investigating the surface texture of this material by means of a scanning electron microscope as a way of assessing the validity of this suggestion. These results will not be available however until later in the year and will be forwarded to the Environment Agency.
The median grain size $D_{50}$ of riverbed material is also of importance to the success of salmonid spawning. Ideally $D_{50}$ values between 18mm and 62mm with a preference for the 20mm-30mm range have been suggested for UK salmonids, Crisp and Carling (1989). The $D_{50}$ values obtained for the cores in this study are quite varied (5.9mm(Core 2B) – 28.1mm(Core4A)) and often fall below the minimum 18mm value stated by Crisp and Carling. The variability of the median gravel size could also be problematic for spawning fish.
The overall character of the core taken below the sluice gates (site5, Core4A) appears to much more readily suitable for spawning fish, a low fine content 3.9% and a higher $D_{50}$ 28.1mm. The weir structure is obviously used to regulate flow regimes on the River Leven with higher flows being channelled through the sluice gates. Such river management will inevitably have an affect on the overall nature of the river habitat. The matrix of fine material within the gravels at site 5 may be being cleared naturally due to the higher flow rates experienced there.
Gravel bed rivers are highly dynamic in nature and as such consideration should be given to an ongoing programme of monitoring suspended sediment load, flow conditions and periodic freeze core sampling. Such a monitoring programme would provide a much clearer and detailed overview of changing conditions at the site.

## 8. References

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# 9. Appendix

Individual particle size distribution and cumulative frequency curves for the cores 1A; 1C; 2A; 2B; 2C; 3A and 4A.

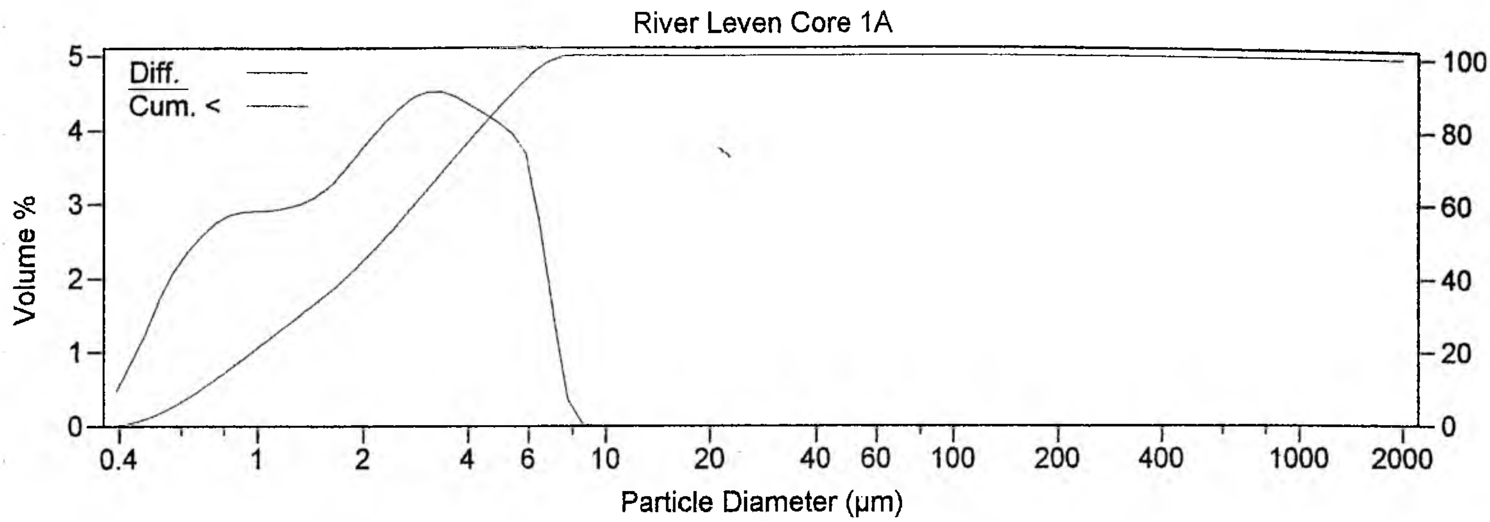
Particle size distribution and cumulative frequency curves for the four sections of core 1B.

Combined particle size distribution curves for cores 1A; 1C; 2A; 2B; 2C; 3A and 4A.

Particle size distribution curve for bulk sample 1A.

( OULTER® LS Particle Size Analyzer

River Leven Particle Size Analysis of the <1mm Fraction



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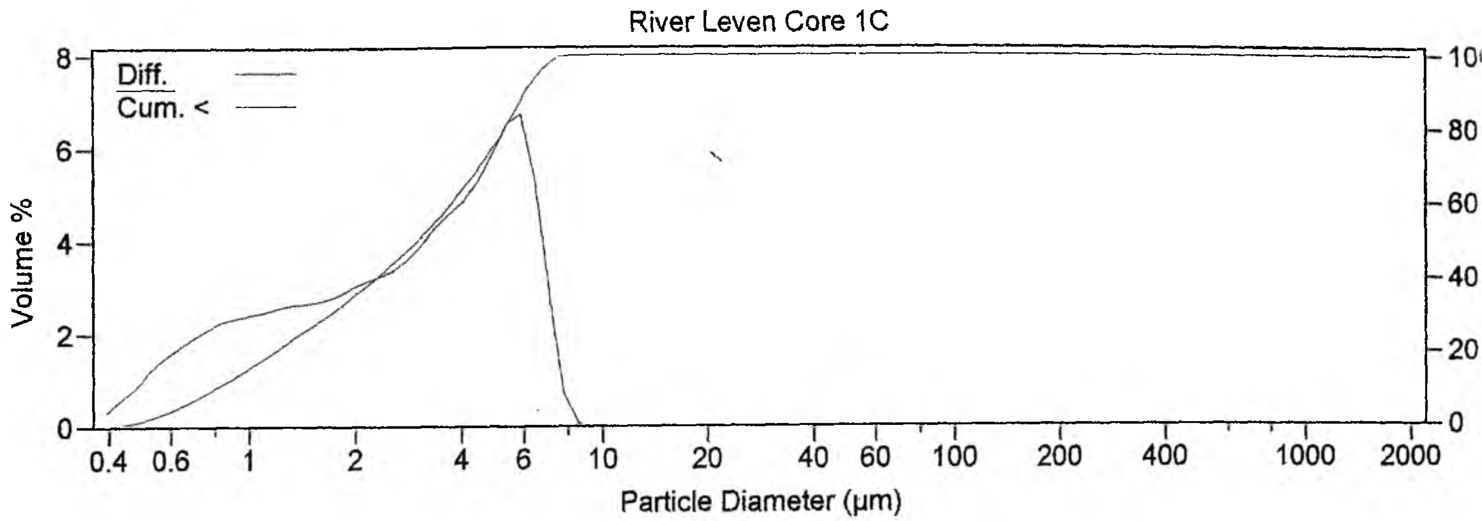
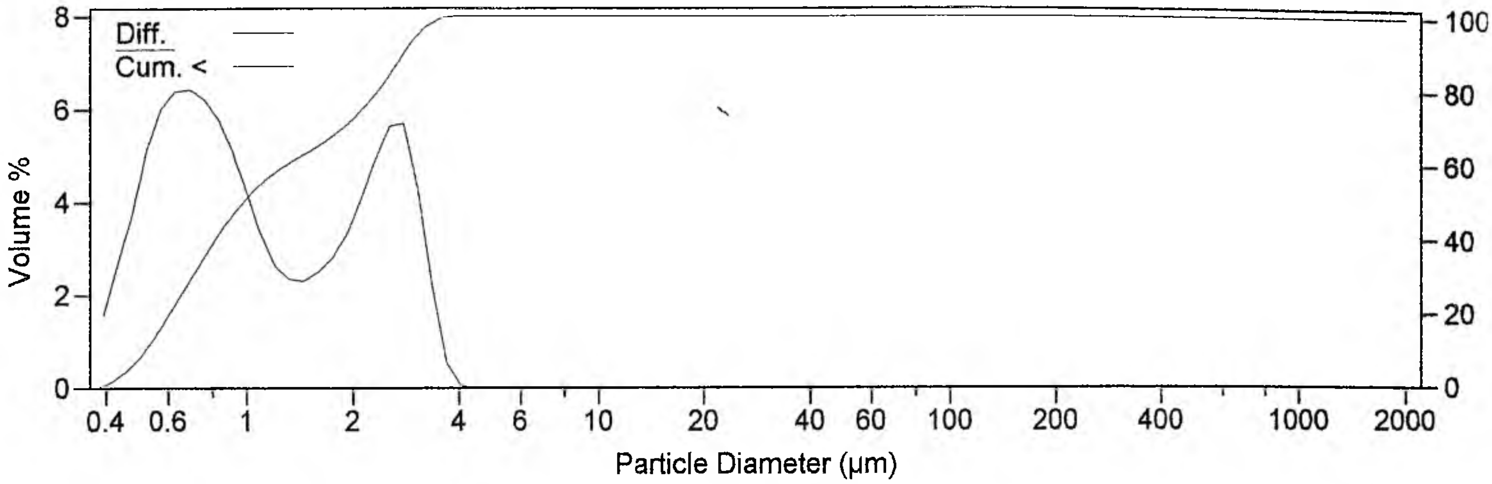
# LS Particle Size Analyzer

## River Leven Particle Size Analysis of the <1mm Fraction



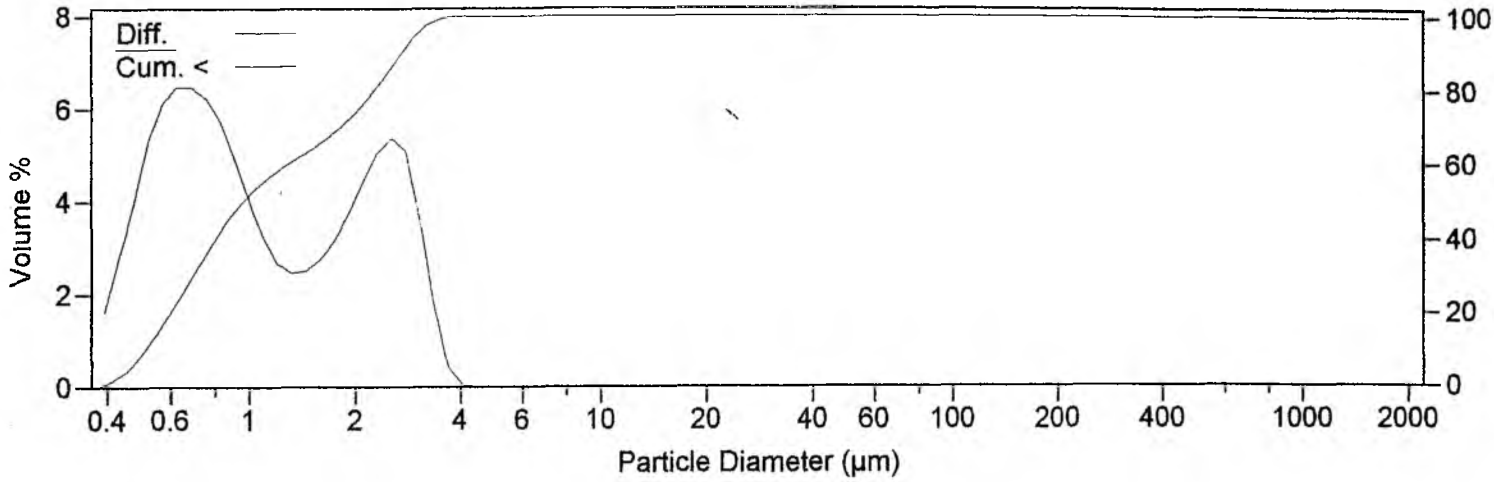
River Leven Particle Size Analysis of the <1mm Fraction

River Leven Core 2A

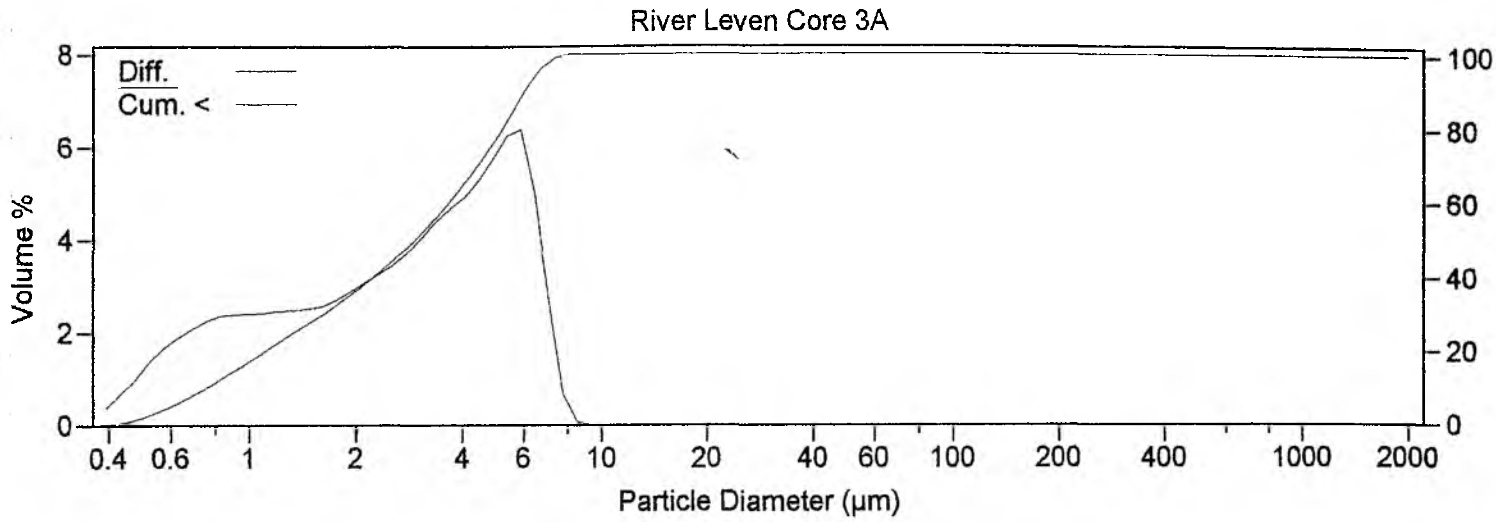


River Leven Particle Size Analysis of the <1mm Fraction

River Leven Core 2B

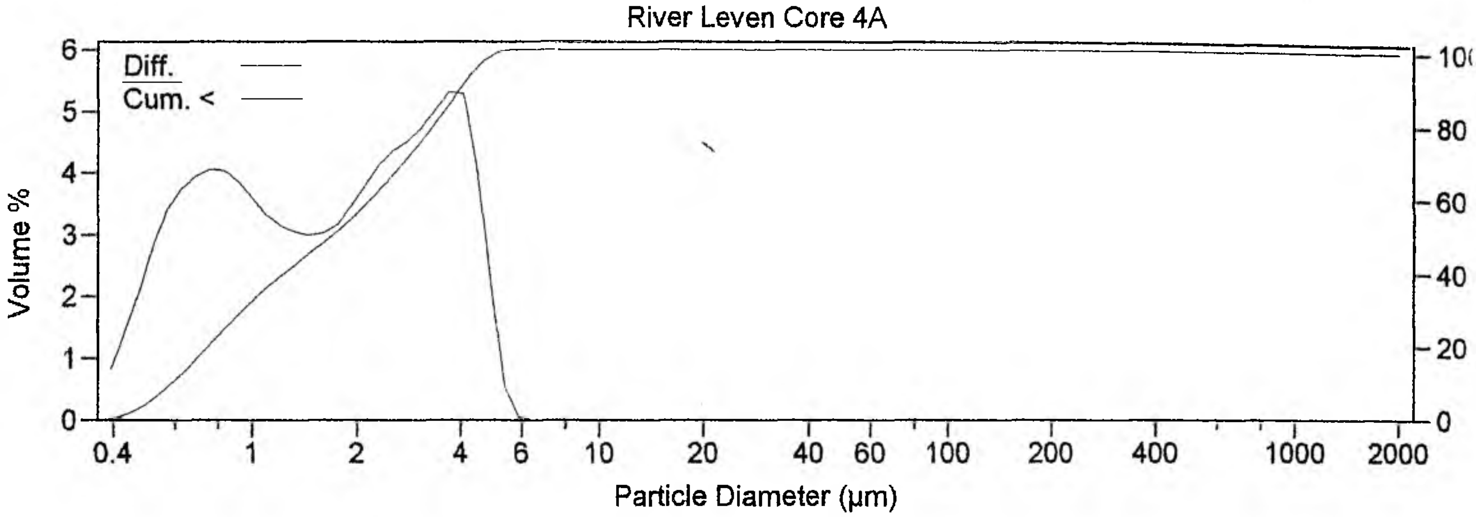


River Leven Particle Size Analysis of the <1mm Fraction



:OULTER® LS Particle Size Analyzer

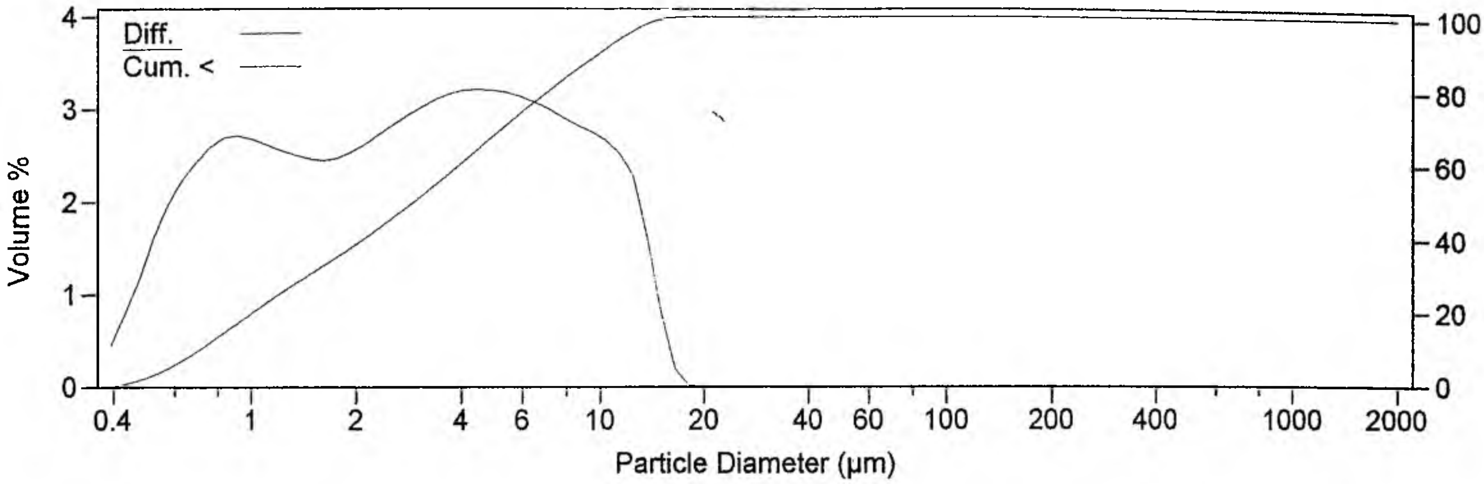
River Leven Particle Size Analysis of the <1mm Fraction



# LS Particle Size Analyzer

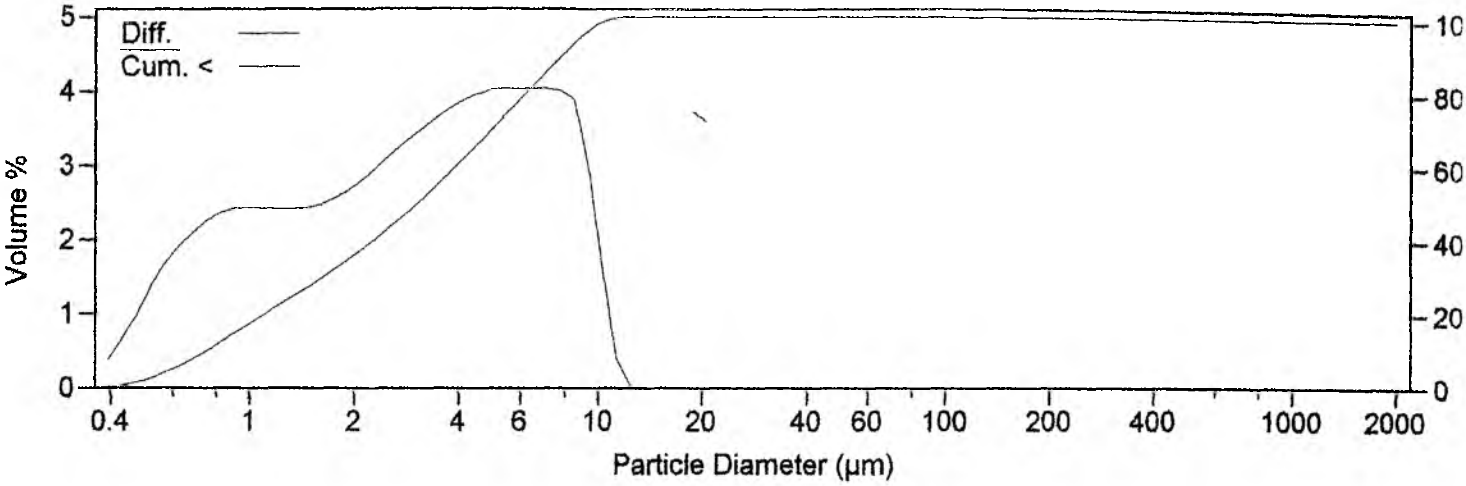
## River Leven Particle Size Analysis of the <1mm Fraction

River Leven Core 1B Level 1

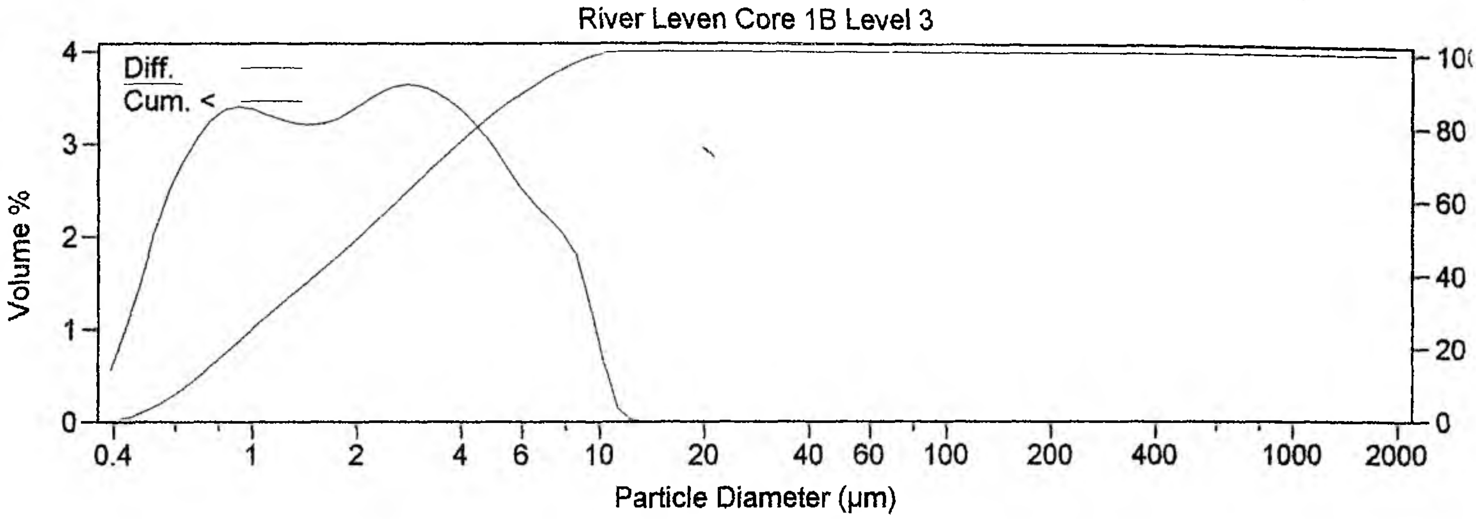


River Leven Particle Size Analysis of the <1mm Fraction

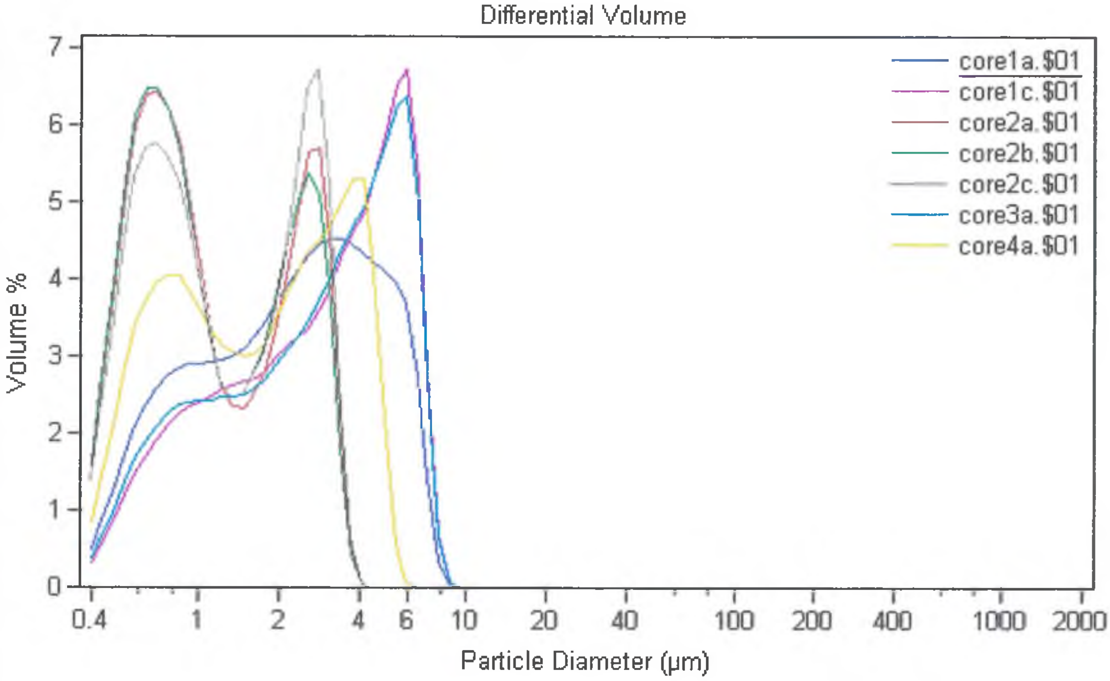
River Leven Core 1B Level 2



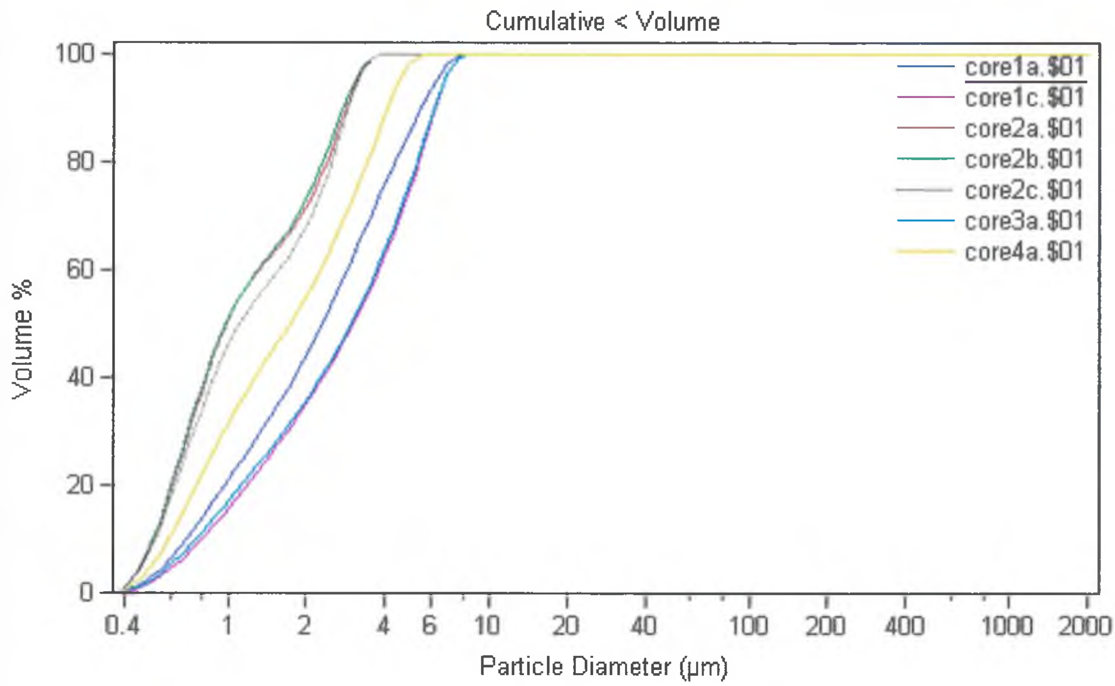
River Leven Particle Size Analysis of the <1mm Fraction



River Leven Particle Size Analysis of the <1mm Fraction

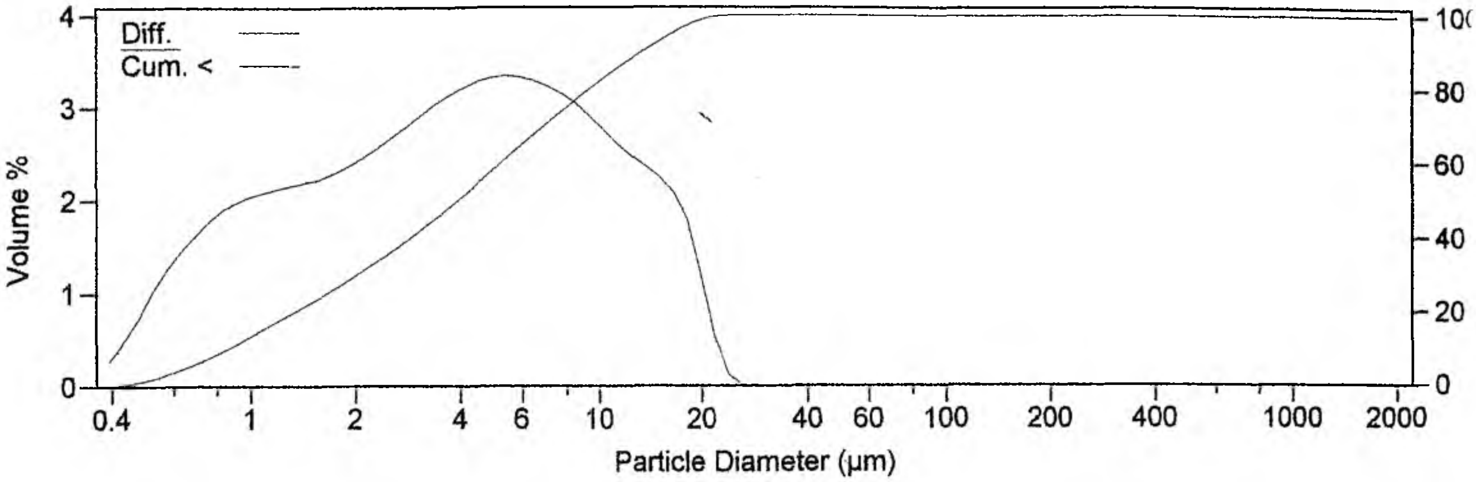


River Leven Particle Size Analysis of the <1mm Fraction



River Leven Particle Size Analysis of the <1mm Fraction

River Leven Core 1B Level 4



# LS Particle Size Analyzer

## River Leven Particle Size Analysis of the <1mm Fraction

River Leven Bulk Sample 1A