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Total sediment transport in the lower reaches of Þjórsá at Krókur

Results from the year 2002

Jórunn Harðardóttir
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Prepared for Landsvirkjun

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Hydrological Service

Report
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Abstract:
This report introduces results from the year 2002 assembled in an extensive sediment sampling program that was initiated in the lower reaches of Þjórsá in 2001. The main objectives of the study were to evaluate the quality of suspended sediment samples taken at Urriðafoss by comparing them to suspended samples taken at a new cableway at Krókur and with a new hydraulic winch on the old cableway at Urriðafoss, and to collect additional suspended and bedload samples on the lower reaches of Þjórsá. The results show that grain size of suspended samples at Urriðafoss and Krókur varies greatly among sediment campaigns and among sampling sites at Krókur. Both the Urriðafoss and the Krókur samples appear to underestimate the sediment concentration of the total and coarse suspended material compared to the samples taken at the old cableway at Urriðafoss. Total bedload transport ranged from 1.3–134.3 kg/s, and was highest at 50 and 70 m stations. Coarsest bedload was transported at 70 m, but the finest material was usually transported at 40 and 140 m.

Key words:
Þjórsá, bedload, suspended sediment, grain size, discharge, Krókur, Urriðafoss,

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1 INTRODUCTION

Þjórsá is one of the largest rivers in Iceland, with watershed at Þjórsártún of 7380 km^2 (Fig. 1) and its mean annual flow for the period 1971–2002 (32 years) 352 m^3/s. About 14% of the watershed (1032 km^2) is covered by glaciers; hence glacial water is an important element of the river during the glacier melting season from June to September.

During the last decades, major hydroelectric power plants have been constructed on the upper reaches of Þjórsá. Most of the coarse river sediment has been deposited in the upstream reservoirs; hence, the sediment transport downstream of the larger reservoirs has been greatly modified (Haukur Tómasson 1982). The mean annual river discharge has stayed similar as before the main power constructions, but the seasonal variation in discharge has stabilized due to the reservoir retention, so that discharge has decreased during summer and increased in winter. Similarly, minor floods have been dampened whereas larger floods have remained more or less unaffected.

The power plant locations proposed on the lower reaches of Þjórsá are two; one at Núpur and the other at Urriðafoss. These options would use the current facilities on the upper reaches of Þjórsá for mitigation of water, although a small reservoir would be built at each power plant on the lower reaches. Discharge has been continuously measured at Þjórsártún for more than 30 years, but information on sediment load in lower Þjórsá has been inadequate. Sediment transport is, however, one of the main concerns for both the environmental impact assessment of the constructions and the design of the hydropower plants including estimation of the fill-in time of the reservoirs.

Reasonably good suspended sediment samples were taken at Urriðafoss between 1962 and 1967 (so-called S1 samples), but since then and until 2002 suspended samples of less quality were taken with a hand sampler from the river bank beneath the main bridge on Highway 1 (so-called S3 samples). The difference in sampling techniques, changes in sediment load due to reservoir constructions, and the large gaps in the data series (up to 23 years) have made sediment evaluations difficult. In addition, bedload measurements have not been performed in this area until 2001 when the National Power Company (Landsvirkjun) initiated an extensive sediment monitoring program at Krókur and Urriðafoss. The program has been carried out by the Hydrological Service (VM) of Orkustofnun (National Energy Authority) with the main objectives: 1) to get additional suspended samples from Þjórsá; 2) to evaluate with greater certainty the suspended sediment transport at Urriðafoss as the older S3 bank samples are thought to underrepresent the sediment load because they are not taken from the main current where the load is greatest; and 3) to make an initial evaluation of the bedload transported in the lower reaches of Þjórsá.

Results from the total sediment program in 2001 were published in a progress report by Jórunn Harðardóttir and Svava Björk Þorláksdóttir (2002), but in this analogous report we focus on the results from 2002.

Figure 2 shows the discharge measured at the Þjórsártún water gauge (vhm 30; V320) during 2002. Most noticeable features on the graph is a large flood peak that reached maximum discharge on January 10 and a smaller discharge peak in mid-April. The January flood was caused by a heavy winter rainstorm, which amplified the discharge by melting a thin snow layer covering frozen ground within the watershed. The high discharge at Þjórsártún in April was caused by great inflow into the Sultartangi reservoir, which at that time was almost full; hence, most of the inflow was directed towards its spillways, causing elevated discharge downsteram. Excluding the two main flood peaks, large and frequent discharge fluctuations of more than 200 m^3/s were seen in Þjórsá from mid-May until October when the river reached normal winter flow close to 300 m^3/s.

The six sediment campaigns were distributed over the year, with the first one during the flood in January and the last one in mid-December (Fig. 2). Table 3 shows how the discharge varied between and within the campaigns. As expected greatest variations within one campaign was during the January flooding, or from 1364 m^3/s on the rising limb of the flood to 544 m^3/s during its waning stage on January 12th.

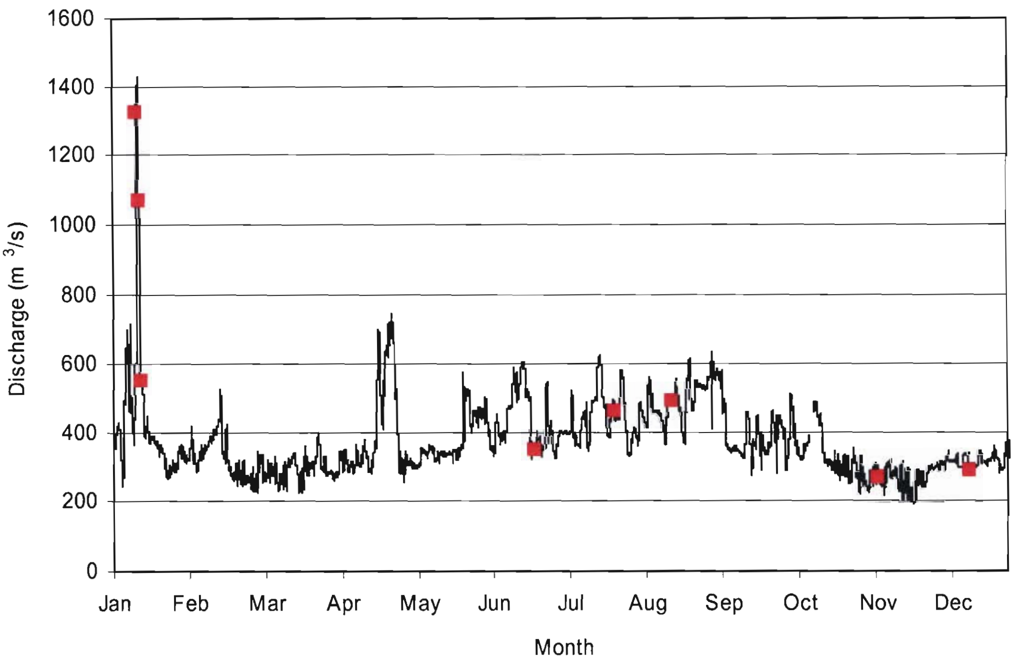


Figure 2: *Discharge at Þjórsártún in 2002 and the timing of the sediment campaigns (red squares). Mean discharge during each day of the 10-12 January flood event is shown.*

Table 3: *Discharge at Þjórsártún during the sample campaigns in 2002.*

Campaign date	Campaign no.	Mean Q (m^3/s)	Minimum Q (m^3/s)	Maximum Q (m^3/s)	Range
10–12 January 2002	1	808	544	1364	820
20–22 June 2002	2	362	331	405	74
23–24 July 2002	3	474	435	496	61
15–16 August 2002	4	494	487	501	14
7–8 November 2002	5	269	254	289	35
15–16 December 2002	6	295	275	303	28

In the other campaigns the discharge difference was much less, i.e. from only 14 m^3/s in August to 74 m^3/s in June. Furthermore, in 2002 the campaigns were carried out over a large discharge range (289–1364 m^3/s), as well as at higher discharge than in 2001 (Table 3) (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002).

2.1 Suspended sediment samples

2.1.1 Sample types

As with other suspended sediment samples taken by the Hydrological Service, the samples are divided into sample types according to the sampler used and the sampling procedures used in the field: 1) the DH48 handsampler, which is fastened to a rod that is dipped into the river from either river bank, and which collects so-called S3 samples; 2) the S49 sampler, which is attached to a winch and is the most frequently used suspended sampler, obtaining so-called S1 samples if they are taken at three or more locations across the river, but S2 samples otherwise; and 3) the point integrated sampler (P61) which is also attached to a winch, but it is heavier than the S49 sampler and has an electronic opening which can be opened with a remote control. These samples are also called S1 samples if they are taken from three or more locations. The first two samplers take integrated samples from the river surface, to the river bottom (or as far down as the sampler reaches) and up to the surface when they are lowered into the river and lifted up again as their intake valves are kept open throughout the sampling procedure. The intake valve on the P61 sampler is in contrast first opened when the sampler is lifted up from the river bed, which results in an integrated sample from the bottom to the surface. Such samplers can thus be used to collect water samples at different depths within the water column as has been done in Jökulsá á Dal, Jökulsá á Fjöllum, and Skaftá in recent years to evaluate the variance of suspended sediment concentration within the channel (Svanur Pálsson and Guðmundur H. Vigfússon 1998, 1999, Jórunn Harðardóttir and Ásgeir Gunnarsson 2001, 2002, Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002).

The samples collected during the sediment campaigns in Þjórsá in 2002 were taken with the three different samplers described above, but were all classified into either S3 samples (taken beneath the Highway 1 bridge with the handheld DH48 sampler), or S1 samples which included both the samples taken from the old cableway downstream of Highway 1 with a S49 sampler and the samples taken from the electric cableway at Krókur with a P61 sampler. However, the Krókur samples only get the S1 status after the weighted mean of each of the seven sample bottles taken at 40, 50, 60, 70, 80, 100, and 140 m has been calculated (see next chapter). In the following text, all reference to stations or locations over the channel width are in meters from the cableway house, which is on average located ca. 18 m from the left (eastern) bank of the river.

2.1.2 Grain size analysis

All the suspended sediment samples were analyzed at the Sedimentological Laboratory at the Hydrological Service, using a combination of a sedimentation method (<63μm) and sieving (>63μm) (Svanur Pálsson and Guðmundur H. Vigfússon 2000). Suspended sediment concentration (mg/l), total dissolved sediment concentration (TDS in mg/l), and grain size distribution were measured on all samples. A slightly different method was, however, used for the Krókur samples on one hand and the samples taken at Urriðafoss (both S1 and S3 samples) on the other. When the Urriðafoss samples were analyzed the water in all the bottles that each sample consisted of were combined into one big sample and analyzed. To get more information from the Krókur samples, which all but one, consisted of seven sample bottles from 40–140 m, each bottle was analyzed separately for grain size. The result from each bottle was then weighted with the volume of each bottle to obtain a S1 comparable to the Urriðafoss samples, using:

Suspended sediment concentration (weighted mean): $$\frac{C_1V_1 + C_2V_2 + \ldots + C_nV_n}{V}$$

where C indicates suspended sediment concentration, V volume, and n number of bottles.

The results from the grain size analysis of the suspended samples are reported in five grain size classes based on a modified Atterberg grain size scale as this as been the standard classification used in publication of sediment data for Landsvirkjun in recent years (Table 4). Due to problems translating the Icelandic terms for size classes into English without confusing them with other grain size scales, such as the widely used Udden-Wentworth scale, the Icelandic names are hereafter used in this report. The near applicable grain size terms according to Udden-Wentworth are, however, also included in Table 4 for comparison.

Table 4: *Grain size classification used in this report.*

Icelandic name used here	English name	Grain size (mm)
Sandur	"Coarse and medium sand"	2–0.2
Grófmór	"Fine sand"	0.2–0.06
Fínmór	"Coarse silt"	0.06–0.02
Méla	"Fine silt"	0.02–0.002
Leir	"Clay"	<0.002

Sediment grains larger than 2 mm are included within the *sandur* fraction; however, only an insignificant part of the suspended sediment is larger than 2 mm. Note that depending on the current velocity, the *sandur* can be transported as bedload at some locations, whereas at other location the same grains are transported in suspension. Sediment coarser than 2 mm is, however, mostly transported as bedload.

2.2 Bedload samples

2.2.1 Sampling procedure

The sampler used for retrieving bedload samples at the cableway at Krókur was of Helley-Smith type, close to 48 kg, with a 7.6×7.6 cm opening, and 3.22 expansion ratio (Fig. 3). In each campaign, samples were collected at the same seven stations as the suspended samples were retrieved from, i.e. 40, 50, 60, 65, 70, 80, and 140 m. In most of the campaigns, additional samples were also taken at 2–4 locations between 80 m and the right bank at ca. 200 m to see how well the bedload at 140 m represented the bedload transport for the extreme width from 80 m and to the bank.

Figure 3: *Bedload sampling at the cableway at Krókur, Þjórsá.*

At each station the Helley-Smith sampler was lowered to the riverbed where it sat for 30 to 300 seconds before it was pulled up again. In the first two campaigns this time varied from one station to another depending on how much bedload was carried at that station, but in the other campaigns the time was kept constant at 120 s. A woven sample bag is positioned behind the opening, into which the bedload is retrieved. The mesh size of the bag is 250 μm which allows the finest suspended material to filter through the bag. On Fig. 3, this bag is being fastened to the opening of the bedload sampler.

Each sample was weighted in the sample bag and then the weight of the bag subtracted from the total weight. If the sample included larger material than sand the size of the largest pebble was measured with a ruler. During each campaign, one sample from each station was collected for grain size analysis at the Sedimentological Laboratory at the Hydrological Service. The number of samples collected in each campaign was between 70 and 79 (Table 1), resulting in at least 10 samples from each station.

2.2.2 Bedload calculations

Like for the 2001 bedload calculations (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002) the total bedload was calculated in several steps. The wet weight of the samples was used although it can deviate considerately from the dry weight of the samples as was seen when some of the samples were analyzed for grain size. The difference was usually less than 30%, but could be higher for the smallest samples, which were most often collected at 40 and 140 m.

First the bedload transport of each sample at each station was calculated by dividing the weight of each sample (in grams) by the time interval the sampler sat at the riverbed and the width of the sampler opening. The mean transport at each station was then calculated.

Mean transport at each station j :

$$q_{bj} = \frac{1}{n_j}\sum_{i=1}^{n_j}\frac{M_i}{t_i d}$$

where M_i is the mass of sample i (in grams), t_i is the sampling time (in seconds) for sample i, d represents the width of sampler opening (0.0762 m), and n_j is the total number of samples at station j.

The total transport through the cross section was then calculated using the following equation:

Total transport through cross section :

$$Q_b = \frac{q_{b1}}{2}x_1 + \frac{q_{b1}+q_{b2}}{2}x_2 + \ldots + \frac{q_{bn-1}+q_{bn}}{2}x_n + \frac{q_{bn}}{2}x_{n+1}$$

where Q_b is in g/s and x represents the distance between sampling points, between a marginal point and the edge of the water surface, or that of the moving strip of stream bed (World Meteorological Organization, 1994).

In this report the transport between stations was also calculated for easier illustration of the data in tables using:

Transport between stations :

$$\psi = q_{bj} \cdot L_j$$

where L_j is the distance between the midpoints between the stations adjacent to station j; however, at each river bank only half the distance from the end station to the bank is used. Summation of these values for the entire cross section provides the same results as shown above for Q_b.

2.2.3 Bedload grain size measurements

Before the samples were analyzed for grain size they were dried at 60°C. The sieve stack that was used ranged from 64 to 0.063 mm, with sieve aperture interval of 0.5 ϕ (phi) (Table 5).

Table 5: *Grain size classes used in bedload sieving.*

mm	phi (ϕ)	mm	phi (ϕ)
64	-6	1.41	-0.5
44.8	-5.5	1	0
32	-5	0.71	0.5
22.4	-4.5	0.5	1
16	-4	0.35	1.5
11.2	-3.5	0.250	2
8	-3	0.177	2.5
5.6	-2.5	0.125	3
4	-2	0.088	3.5
2.83	-1.5	0.063	4
2	-1	<0.063	pan

Both the Udden-Wentworth scale and the linear Phi scale (ϕ) are shown in Table 5 for comparison; however, in the following section the phi scale is used for simplification of statistical analysis. The conversion from Udden-Wentworth values to phi values is given by the following equation:

$$\phi = -\log_2(d)$$

where d is grain diameter in mm.

The grain size data are shown as cumulative graphs on a linear phi scale. In addition, using the method of moments (Krumbein and Pettijohn 1938), the following sedimentological parameters were calculated: mean, sorting, and skewness.

The moment statistics were calculated in the following manner:

$$\textit{Mean}: \quad \bar{x}_\phi = \frac{\sum fm}{n}$$

$$\textit{Sorting}: \quad \sigma_\phi = \sqrt{\frac{\sum f\left(m - \bar{x}_\phi\right)^2}{100}}$$

$$\textit{Skewness}: \quad \overline{Sk_\phi} = \frac{\sum f\left(m - x_\phi\right)^3}{100\sigma_\phi^{\ 3}}$$

where f indicates weight percent in each grain size grade and m the midpoint of each grain-size grade in phi values.

The mean value in moment statistics indicates a simple arithmetic mean, whereas sorting represents the standard deviation of the data. The sorting value represents the slope of the cumulative graph; as the sorting value decreases, the sample is better sorted. Folk (1974) divided the sorting values into seven groups for better verbal expression of the data and those are shown in Table 6.

Table 6: *Description of sorting values.*

Sorting value	Description
<0.35 ϕ	very well sorted
0.35–0.50 ϕ	well sorted
0.50–0.70 ϕ	moderately well sorted
0.71–1.00 ϕ	moderately sorted
1.00–2.00 ϕ	poorly sorted
2.00–4.00 ϕ	very poorly sorted
>4.00 ϕ	extremely poorly sorted

The skewness value describes the form of the frequency curve, i.e. the sorting in the tail of the grain-size population. Negative skewness indicates that distribution of the coarse material is greater than the fine material, and vice-versa. Positively skewed material thus has a tail of excess fine particles (Boggs 1995).

3 RESULTS

3.1 Suspended sediment samples

3.1.1 Urriðafoss samples

Twelve suspended sediment samples were taken from Urriðafoss in 2002; nine samples from the river bank below the bridge on Highway 1 (S3 samples) and three samples from the cableway about 500 m downstream of the bridge (S1 samples). As mentioned before, the bridge samples were taken with a handheld rod sampler (DH48) and the cableway samples with a S49 sampler on a hydraulic winch usually from three locations on the river.

The results from all 12 samples are shown in Table 7. Four of the bridge samples were taken during an integrated chemical, discharge, and sediment study of four rivers in southern Iceland in cooperation between scientists from the Science Institute and Hydrological Service of Orkustofnun. The study is funded by Landsvirkjun (National Power Company), and the Environmental and Food Agency of Iceland (on behalf of the Ministry of Environment) (e.g. Sigurður R. Gíslason *et al.* 2003).

Table 7: *Grain size data on suspended sediment samples from Þjórsá at Urriðafoss both from beneath the bridge on Highway 1 (S3 samples) and the cableway (S1 samples). Samples in bold were taken during a different sediment research program; see text.*

Date	Discharge (m^3/s)	Sediment (mg/l)	Dissolved (mg/l)	Sand % (>0.2 mm)	Grófmór % (0.2–0.06 mm)	Fínmór % (0.06–0.02 mm)	Méla % (0.02–0.002 mm)	Clay % (<0.002 mm)	Largest part. (mm)	Sample type
2002-01-11 15:40	1093	252	31	12	28	18	29	13	4,3	S3
2002-01-30 11:20	323	**23**	**71**	**23**	**11**	**4**	**35**	**27**	**1,5**	**S3**
2002-04-26 12:05	473	**51**	**38**	**26**	**31**	**8**	**29**	**6**	**1,5**	**S3**
2002-06-19 12:45	507	**233**	**47**	**6**	**4**	**3**	**54**	**33**	**1,7**	**S3**
2002-07-22 18:10	436	125	53	3	4	4	37	52	1	S3
2002-07-23 20:30	492	121	47	4	4	4	30	58	0,8	S3
2002-08-16 00:30	491	103	42	20	4	4	35	37	2,7	S3
2002-08-16 01:00	491	177	50	48	3	3	15	31	3,0	S1
2002-08-27 15:40	**537**	**107**	**38**	**4**	**4**	**2**	**30**	**60**	**0,7**	**S3**
2002-11-08 20:58	261	138	54	75	4	2	13	6	2,0	S3
2002-11-08 12:22	282	280	88	86	2	1	7	4	2,6	S1
2002-12-14 23:00	338	67	69	15	7	8	41	29	1,4	S1

Grain size distribution of the Urriðafoss samples is shown on Fig. 4, with separate color for each grain size group. The same trend in grain size variations is seen in the 2002 samples as was evident in the 2001; i.e. the highest percentage of the finest grain size groups, *méla* (0.002–0.02 mm) and *leir* (<0.002 mm), is seen during the summer months June, July, and August, when glacial melting augments the river sedimentation. Grain size is much better distributed between the five grain size groups in the winter samples from January and April, although the November sample appears to have anomalously high sand percentage. There is no indication of a mistake in sample handling so we suggest that abnormal conditions prevailed at Urriðafoss when the sample was taken.

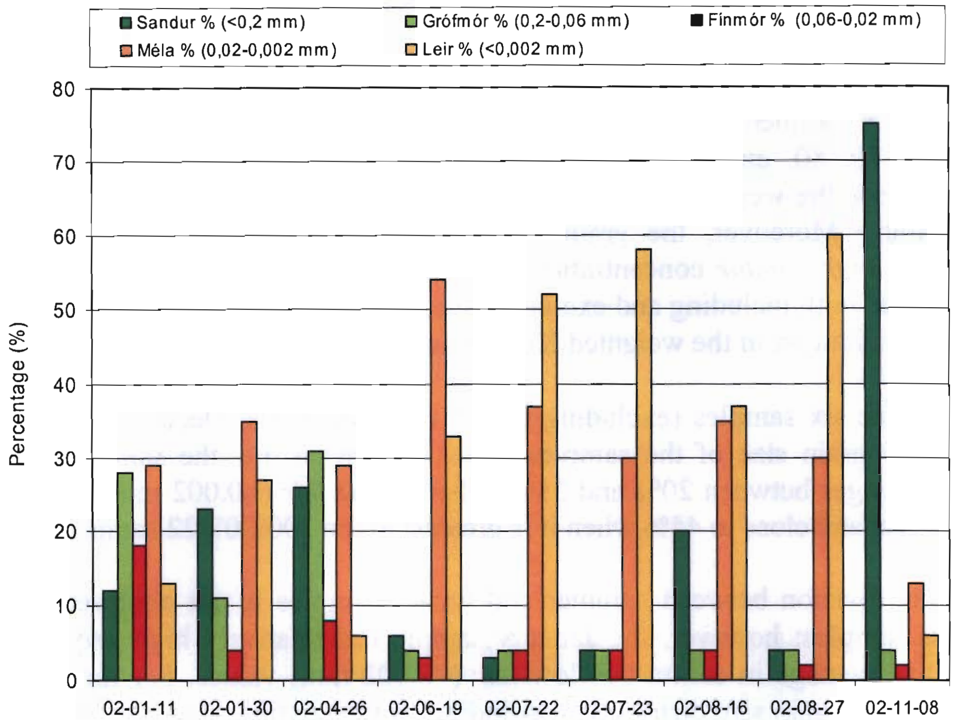


Figure 4: *Grain size distribution in S3 samples from Urriðafoss in 2002.*

Note that due to the closed array problems of such percentage data (when one value decreases, other values increase), the coarser fraction (*sandur* (>0.2 mm) and *grófmór* (0.06–0.2 mm)) is bound to increase as the finer fractions subsequent to the glacial melting season.

It has been believed that the samples taken beneath the Highway 1 bridge underrepresent the coarser fraction of the suspended load in Þjórsá as the handheld sampler does not reach close to the river bed in the main current where the sediment concentration is greatest. Hence, one of the objective with this research was to obtain a better estimate on how well the bridge samples (S3) represent the suspended sediment concentration in Þjórsá.

In 2002, such evaluation was twofold. Firstly, comparisons of sample pairs from the bridge and the cableway at Urriðafoss (S3 and S1 samples) can be used to evaluate the quality of the S3 hand samples. Unfortunately, only two sample pairs exist from last year because the hydraulic winch used at the cableway was not ready until late summer, and a S3 sample was not taken in December. Both pairs show much higher sediment concentration in the S1 cableway sample as is expected (Table 7), i.e. the sediment concentration of the S3 bridge samples is only 58% and 49% of the cableway samples for the August and November sample pairs, respectively. At the cableway the suspended sampler reaches the riverbed where the current is greatest; thus allowing the sampler to collect larger grains in greater concentrations.

With the two sample pairs collected in 2002, the hydraulic winch system showed its potential and justified continuing sampling of such pairs for further understanding of the correlation between these two locations.

Secondly, the Urriðafoss samples can be compared with the Krókur samples as it was done in 2001. The results from that comparison will be discussed in chapter 3.1.3.

3.1.2 Krókur samples

The suspended sediment samples from Krókur were taken in seven sample bottles at 40, 50, 60, 65, 70, 80, and 140 m distance from the house. One bottle broke during transport; hence the weighted mean of the sample from 2002-07-23 did not include the 60 m bottle. Moreover, the grain size of the sample from 2002-12-14 showed anomalously high *sandur* concentration, and thus the weighted mean for that sample was calculated both including and excluding the 60 m sample bottle. Figure 5 shows the grain size distribution in the weighted Krókur samples taken in 2002.

Comparing the six samples (excluding the 60 m bottle in the December sample) it is seen that the grain size of the samples varies somewhat, i.e. the *sandur* (>0,2 mm) percentage ranges between 20% and 35%, whereas the *leir* (<0.002 mm) is about 12% when smallest and close to 45% when it is greatest in the 2002-07-22 sample.

The distinct division between summer and winter samples is not observed as for the Urriðafoss samples; however, the January sample has relatively high *grófmór* (0.02–0.06 mm) percentage in contrast to low *leir* (<0.002 mm) values. For the 2002-12-14 sample both the grain size distribution including and excluding a sample bottle from 60 m is shown as the 60 m bottle included anomalously high concentration of sand. Nothing in the analysing process appears to have been unusual for that sample so it is most likely that the sediment sampler obtained sand from the riverbed.

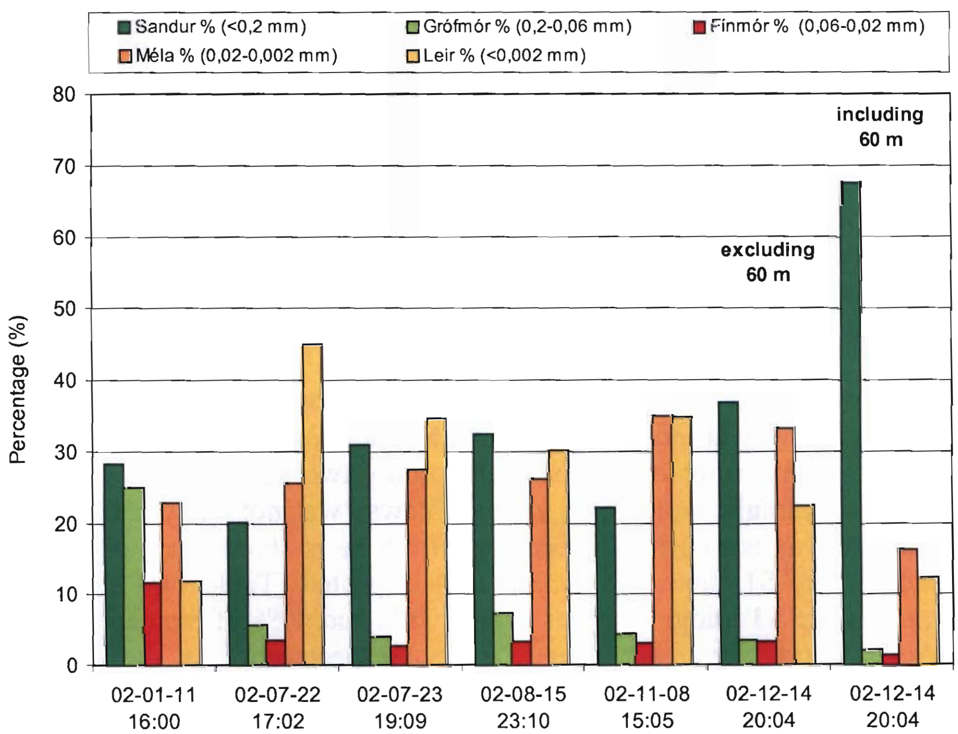


Figure 5: *Grain size distribution in S1 samples from Krókur in 2002. Two grain size distributions are shown for the December sample, including and excluding a sample bottle taken at 60 m, which may include sand from the riverbed.*

One thing to bear in mind when evaluating the weighted Krókur samples is the typically small water volume in the bottles taken closest to the river banks at 40 and 140 m. This results in a larger error in grain size calculations for these bottles, especially for the finer fractions and the TDS. Still, as the integrated result is weighted with the bottle volume the error caused by this is relatively small in the integrated result.

Because each bottle in the integrated sample was analyzed individually, it is possible to look at the grain size at each location across the river (Fig. 7). It is clear from Fig. 7 that the 50, 60, and 65 m stations usually include the highest concentration of *sandur*. However, high *sandur* % is also seen at other stations, i.e. at 140 m in the samples from 2002-01-11 and 2002-08-16, and at 40 m in the sample from 2002-12-14. This highly variable *sandur* fraction in the samples (0 to 90%) is as before readily explainable with the stochastic nature of coarse material that is transported close to the bottom, except when the current is great enough to lift the grains into suspension.

At these locations closest to the river banks, the *leir* (<0.002 mm) and *méla* (0.02–0.002 mm) percentage is relatively high; at 40 m these grain size groups encompass the highest percentage in five out of seven samples, and at 140 m in four out of seven, although the fifth sample includes approximately the same percentage value for *sandur*, *méla*, and *leir* (Fig. 7). In contrast, the *finmór* (0.06–0.02 mm) and *grófmór* (0.2–0.06 mm) percentages are in all samples except the January sample (2002-01-11) less than 12% and in most of the sample bottles less than 5%. Minor current changes can thus determine whether *sandur* is transported in suspension and collected with a suspension sampler, or as bedload and consequently overlooked by the same sampler. Hence, the variable grain size seen in bottles from different stations can be explained by different hydraulic conditions at each location, but as with the Urriðafoss samples, the closed array problem of percentage values can not be ignored.

This concentration of coarse material at 50, 60, and 65 m is somewhat different from the distribution of coarse material in 2001, when the coarsest material was concentrated at 70 m. No obvious reason is recognized for the different *sandur* distribution between the two years, but depth profiles taken during 2001, and a more recent one from May 2003 (Fig. 6), showed a ravine between ca. 70 and 80 m.

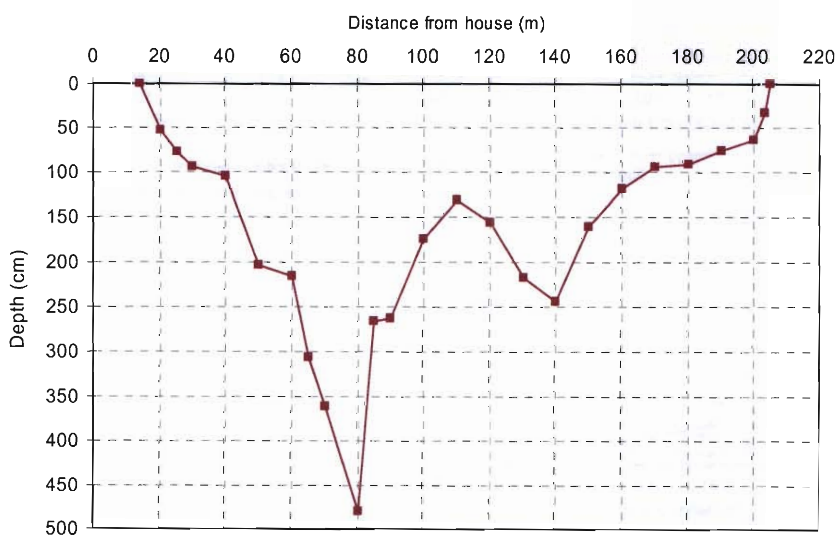


Figure 6: *Depth profile measured during discharge measurement on 2003-05-27 at the Krókur cableway.*

Whereas the greatest concentration of coarse material was within the ravine in 2001, the coarse material appears to be concentrated on the left flank of the ravine, i.e. closer to the house. One speculation is that the large flood in January 2002 changed the hydraulic and sedimentological conditions to some extent, resulting in a shift in the sediment focus; however, a major change in the channel geometry is very unlikely.

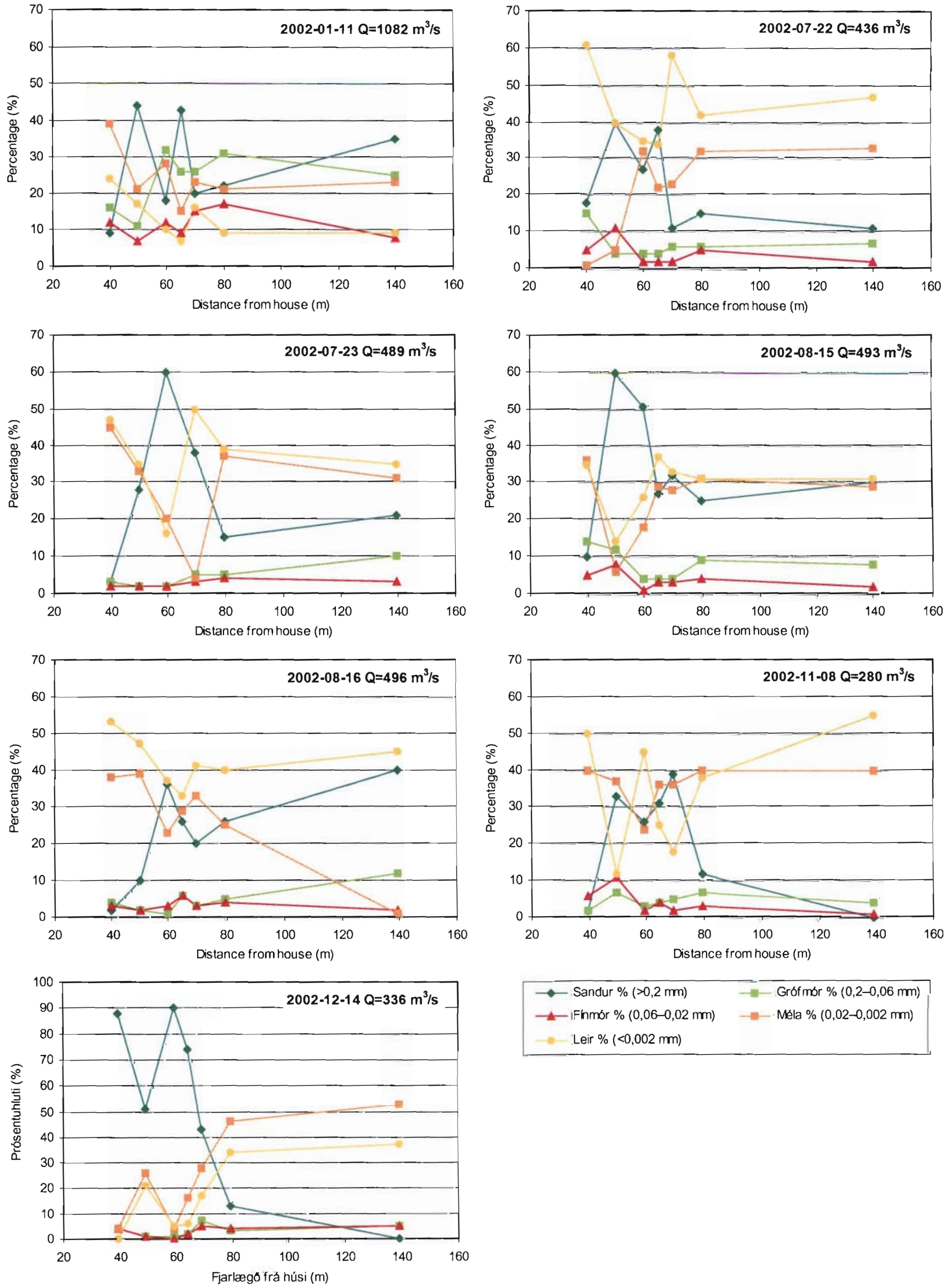


Figure 7: *Grain size distribution of individual Krókur sample bottles. Q represents the mean discharge at Þjórsártún during the suspended sampling interval.*

3.1.3 Comparison between Urriðafoss and Krókur samples

As mentioned in Chapter 3.1.1 one of the objective with the suspended sediment pairs was to evaluate better the error in sediment concentration of the S3 Urriðafoss samples. Hence, grain size analysis of the S3 sample from Urriðafoss and the weighted Krókur samples were compared as it was done in 2001. Table 8 shows the comparison between the different size classes and total and dissolved sediment concentration of each sample pair from these two locations. In the weighted Krókur sample from November, the 60 m sample bottle is excluded due to anomalously high sand content in that bottle and the 2002-07-23 sample also lacked the 60 m bottle as it broke during transport. Moreover, because no S3 sample was taken at Urriðafoss in December we instead use the S1 sample taken from the cableway downstream of the S3 sampling location. However, based on the comparison of the two available Urriðafoss sample pairs (Chapter 3.1.1) the S1 sample has probably double the sediment concentration of the S3 sample.

Table 8: *Comparison of grain size results from suspended sediment samples from Krókur (K-) and Urriðafoss (U-). All Urriðafoss samples were taken from beneath the Highway bridge except the December sample, which was taken from the cableway.*

Time	Discharge (m^3/s)	Sediment (mg/l)	Dissolved (mg/l)	Sandur % (>0.2 mm)	Grófmór % (0.2–0.06 mm)	Fínmór % (0.06–0.02 mm)	Méla % (0.02–0.002 mm)	Leir % (<0.002 mm)	Larg. part. (mm)	Sample type
U-2002-01-11 15:40	1093	252	31	12	28	18	29	13	4,3	S3
K-2002-01-11 16:00	1082	307	70	28	25	12	23	12	2,3	S1
Ratio U/K	*1.01*	*0.82*	*0.44*	*0,.42*	*1.12*	*1.55*	*1.27*	*1.08*	*1.87*	
U-2002-07-22 18:10	436	125	53	3	4	4	37	52	1	S3
K-2002-07-22 17:02	436	159	46	20	6	4	26	45	1,3	S1
Ratio U/K	*1.00*	*0.78*	*1.15*	*0.15*	*0.72*	*1.11*	*1.44*	*1.16*	*0.77*	
U-2002-07-23 20:30	492	121	47	4	4	4	30	58	0,8	S3
K-2002-07-23 19:09	489	230	72	31	4	3	27	35	1,1	S1
Ratio U/K	*1.01*	*0.53*	*0.65*	*0.13*	*1.01*	*1.48*	*1.09*	*1.67*	*0.73*	
U-2002-08-16 00:30	491	103	42	20	4	4	35	37	2,7	S3
K-2002-08-15 23:10	493	160	82	33	7	3	26	30	1,4	S1
Ratio U/K	*1.00*	*0.65*	*0.51*	*0.61*	*0.55*	*1.21*	*1.32*	*1.22*	*1.93*	
U-2002-11-08 20:58	261	138	54	75	4	2	13	6	2,0	S3
K-2002-11-08 15:05	280	166	50	22	4	3	35	35	2,0	S1
Ratio U/K	*0.93*	*0.83*	*1.08*	*3.35*	*0.90*	*0.62*	*0.37*	*0.17*	*1.00*	
U-2002-12-14 23:00	338	67	69	15	7	8	41	29	1,4	S1
K-2002-12-14 20:04	336	140	94	37	4	3	33	23	1	S1
Ratio U/K	*1.01*	*0.48*	*0.73*	*0.40*	*2.00*	*2.34*	*1.23*	*1.28*	*1.40*	

To better visualize the results, the ratio for the Urriðafoss/Krókur (U/K) samples is compared with discharge in Fig. 8. Both the six sample pairs in the 2002 study (orange) and the ten sample pairs from 2001 (black) are shown. The Urriðafoss sample was always, but once, taken before the Krókur sample, with time difference up to six hours. Nonetheless, the difference in discharge was always around 1%, which is very reasonable.

Figure 8 shows that the variability of the U/K ratio is less for the 2002 samples than the 2001 samples, i.e. they are closer to the equal-ratio-line of 1. Still substantial difference is observed between the two sample types in both total suspended sediment concentration as well as in grain size percentage.

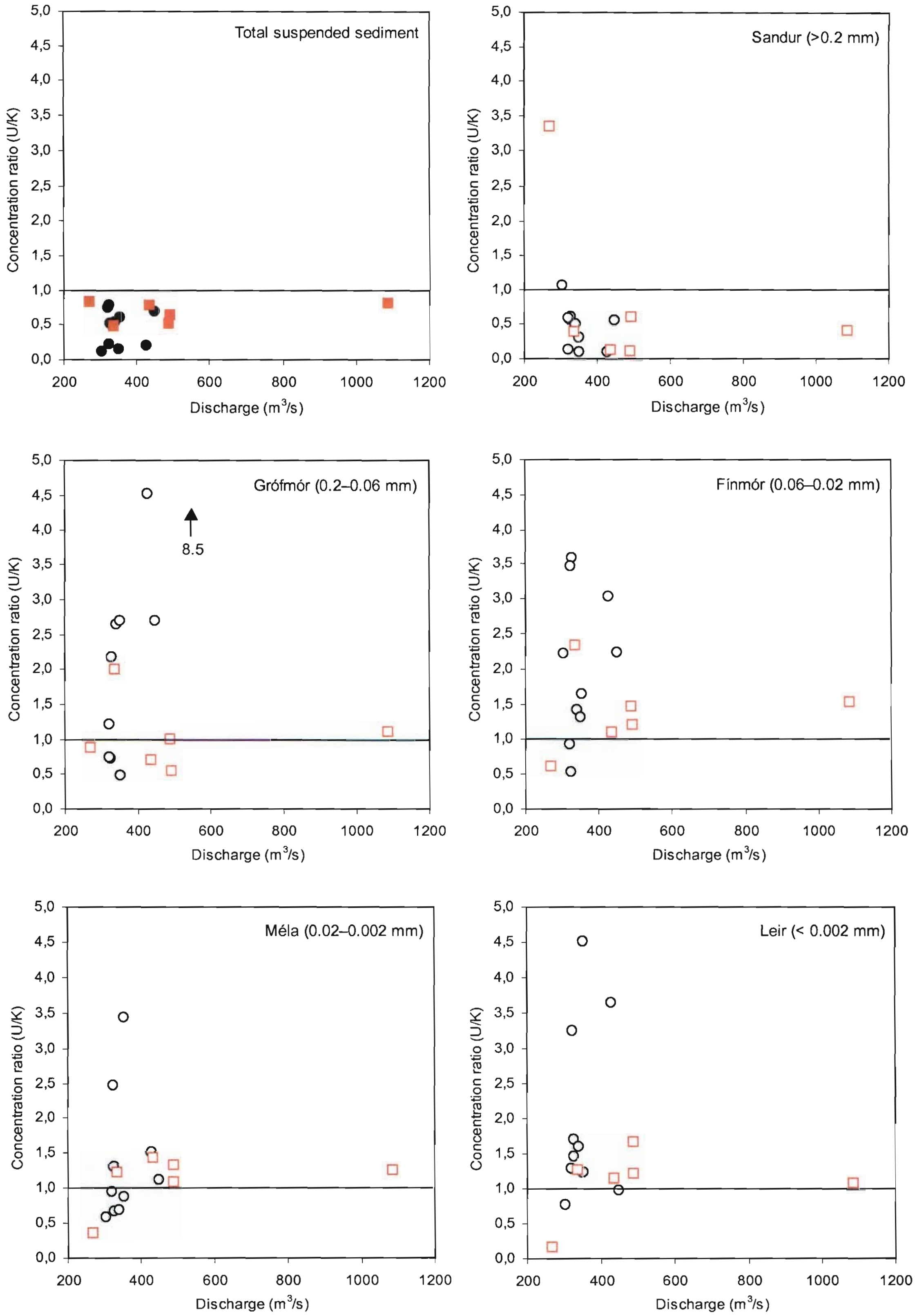


Figure 8: *Sediment ratio of total concentration and individual grain size classes between Urriðafoss samples (U) and Krókur samples (K). Black markers represent samples from 2001 and orange markers show samples from 2002 (this study).*

The total suspended sediment concentration was always greater in the Krókur samples and similarly the *sandur* % was greater in all Krókur samples except one (from 2002-11-08). The comparison is different for the finer sediment fractions where all but one sample pair showed greater percentage of *finmór*, *méla*, and *leir* in all but one Urriðafoss samples. This difference between fine and coarse fraction was also noticeable in the 2001 samples, although, as was said earlier, the variation between sample types was greater in those. Such difference between coarse and fine sediment is partly due to the closed-array problem of dealing with percentage data — the high *sandur* fraction in many of the Krókur samples will decrease percentage of finer fractions as well as increase the U/K ratio of the same fractions.

Although the difference of the fine fraction between the two sample types is much less than in 2001 it is of some concern and raises the question of accuracy and precision of the smaller-volume Krókur samples (especially 40 and 140 m sample bottles). This concern was addressed to some extent in 2001, but disregarded as a major source of error because such error would be minimized in the weighted calculations for each sample.

Comparison of all three sediment sample types taken at Krókur and Urriðafoss in 2002, as well as the Urriðafoss samples from 2001 are plotted against discharge on Fig. 9.

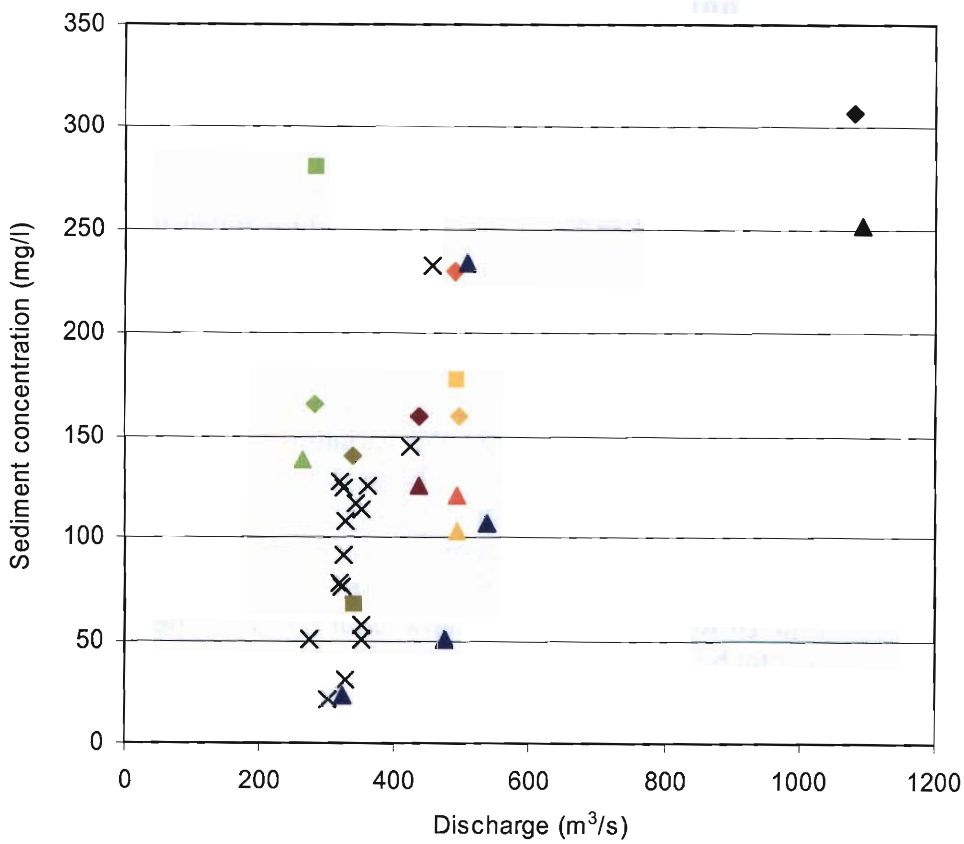


Figure 9: *Relationship between suspended sediment concentration and discharge in Krókur samples (□), Urriðafoss S3 samples (□), Urriðafoss S1 samples (□) from 2002, and Urriðafoss samples in 2001 (crosses). The samples are color-coordinated according to each campaign to ease comparison of sample types in each campaign. The darkblue triangles represent S3 samples taken at Urriðafoss in relation to chemical sampling.*

The minor correlation that was seen in concentration of the S3 Urriðafoss samples with discharge in 2001 (R^2=0.58) is somewhat degraded on Fig. 9 due to the extended scale used to include the high discharge samples from 2002. No such correlation is seen for the Urriðafoss S3 samples taken in 2002 (different colored triangles). Similarly, no such correlation is observed for the Krókur samples (diamonds), or the three Urriðafoss S1 samples (squares).

The high concentration of two of the three S1 samples taken from the cableway at Urriðafoss (lime green and yellow squares) is of special interest. The high concentration suggests that not only the S3 Urriðafoss samples, but also the Krókur samples may underrepresent the total suspended sediment concentration in lower Þjórsá. Due to this result, we have suggested that the sampling program in 2003 should concentrate more on collecting suspended sample pairs from these three locations instead of investigating the suspended sediment variations across the channel at Krókur. To allow for this within the 2003 funding, the sample bottles from each trip to Krókur will be analyzed together instead of separately, which permits an extra suspended sampling trip to Þjórsá in 2003.

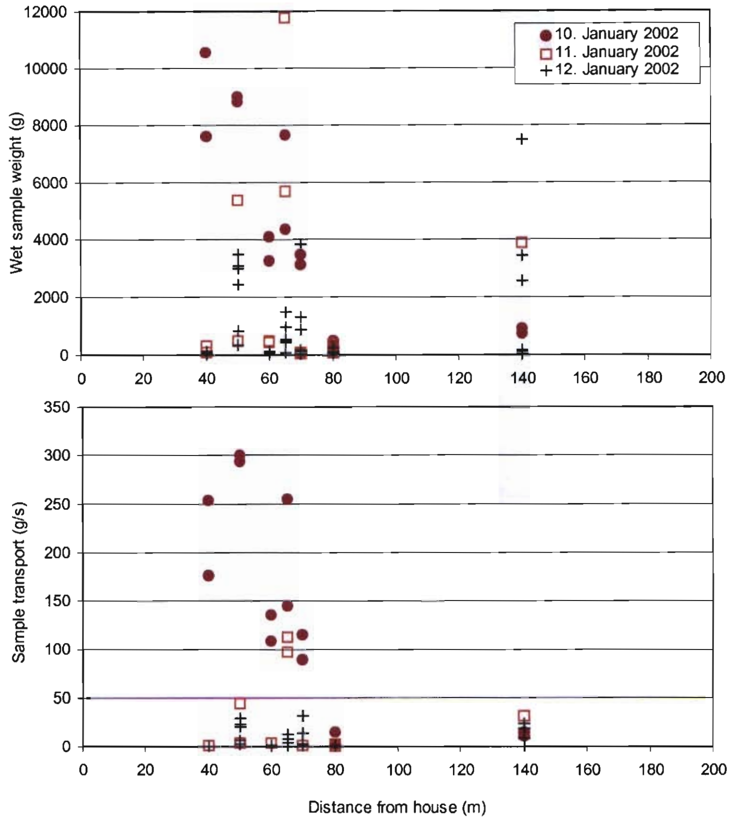
3.2 Bedload samples

3.2.1 Bedload transport

During the six bedload sampling campaigns in 2002 (Table 1), 448 bedload samples were collected from the cableway at Krókur. Samples were collected from seven stations (40, 50, 60, 65, 70, 80, and 140 m) in all campaigns, usually over 10 samples from each station. In addition, extra samples were collected between 80 and 200 m in the four last campaigns to better evaluate the variations in bedload in this 120-m-wide section, which is associated with the 140 m station. Those samples are not included in the bedload calculations, but are used to confirm the integration around the 140 m station.

In some campaigns, the discharge varied significantly over the sampling time, which was sometimes as long as three days. When the variation was substantial the results were divided into smaller data sets for each discharge range, i.e. three sets for January, two sets for June, July, and August, but the November and December data sets were undivided. The results are shown for each campaign with two graphs; one showing the wet sample weight and the other the sample transport, as well as one table for each discharge range (Fig. 10 to 15). The tables show both the mean bedload transport at each station and the total bedload transport between the station's mid-points. In addition, the total bedload transport across the river channel within each campaign range is shown.

The range over which the bedload transport is calculated is from 18 m to 200 m, but this appears to be the mean moving stretch of the river according to channel measurements. These lines are, however, not shown on the following Figures.

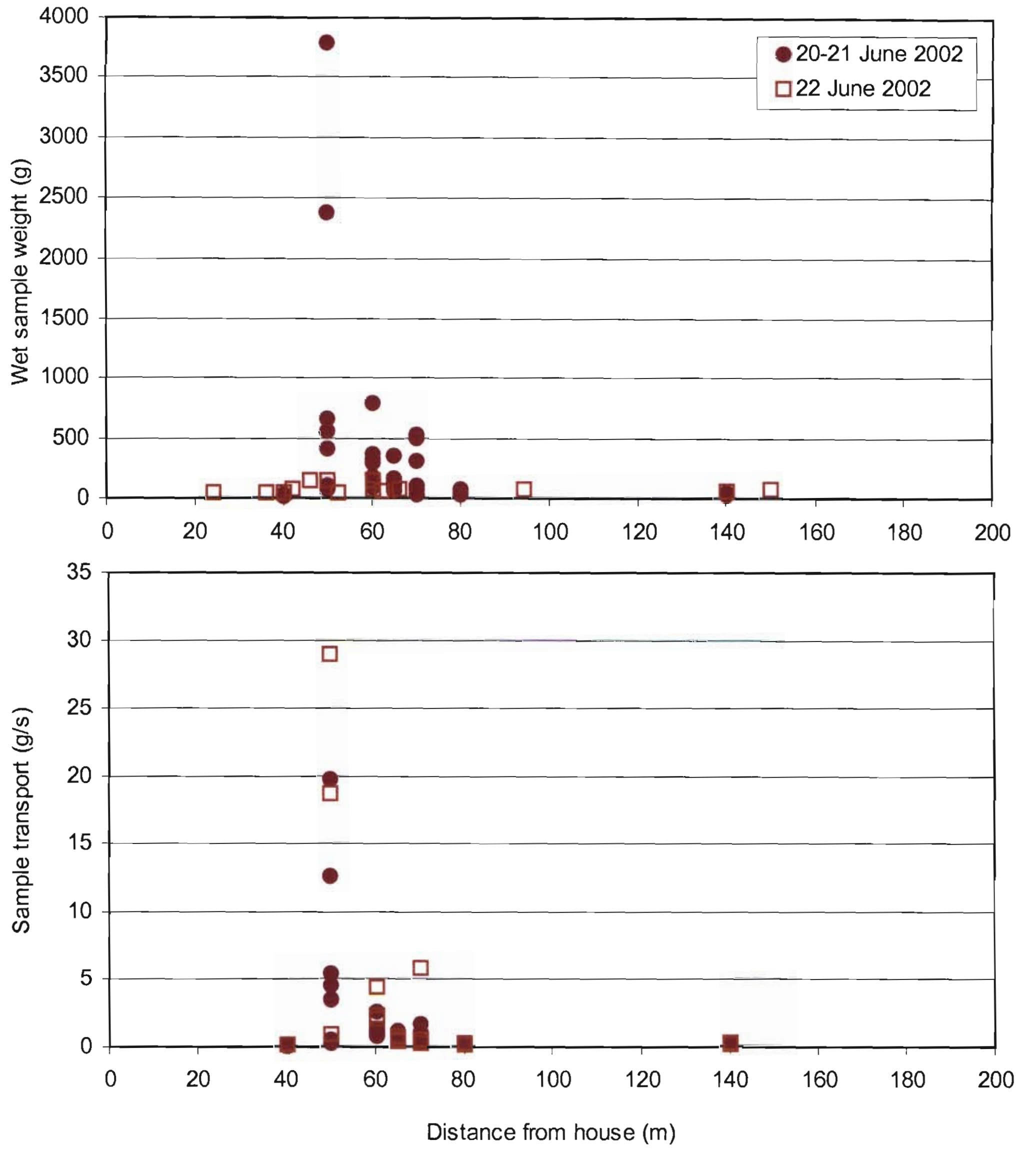


10 January 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=1326 m^3/s
Mean bedload transport at each station (g/s/m)	2820	3899	1608	2626	1350	122	177	
Total transport btw. station midpoints (g/s)	45123	38990	12064	13128	10123	4267	10636	**134.3 kg/s**

10 January 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=1066 m^3/s
Mean bedload transport at each station (g/s/m)	19	320	52	1386	13	16	425	
Total transport btw. station midpoints (g/s)	310	3196	393	6931	95	546	25529	**37.0 kg/s**

10 January 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=550 m^3/s
Mean bedload transport at each station (g/s/m)	4	230	12	71	144	5	118	
Total transport btw. station midpoints (g/s)	58	2301	88	353	1077	190	7080	**11.1 kg/s**

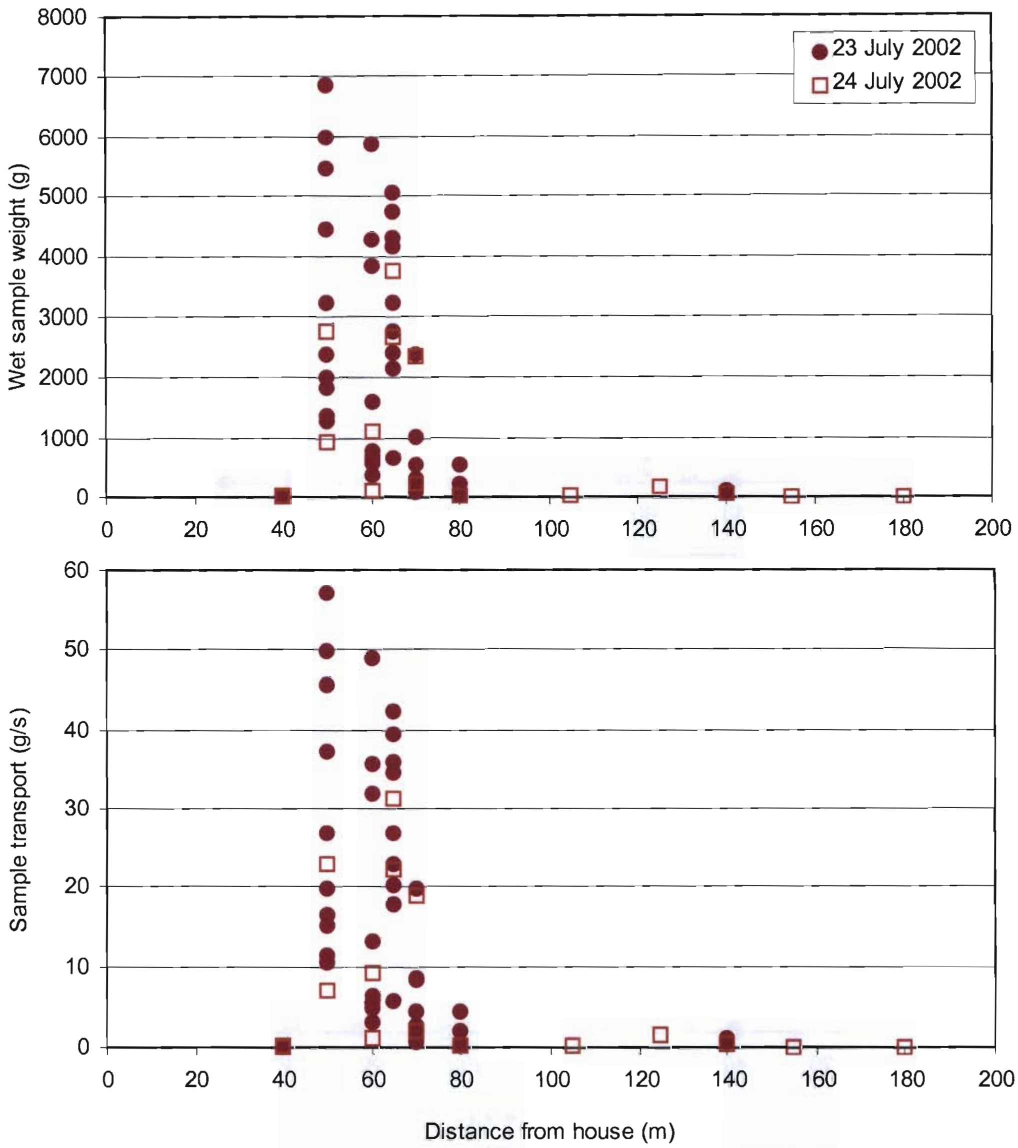
Figure 10: *Results from bedload measurements during 10–12 January 2002.*



20–21 June 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=351 m^3/s
Mean bedload transport at each station (g/s/m)	1	87	17	8	12	2	2	
Total transport btw. station midpoints (g/s)	13	873	124	38	89	62	99	**1.3 kg/s**

22 June 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=399 m^3/s
Mean bedload transport at each station (g/s/m)	1	212	38	7	28	3	2	
Total transport btw. station midpoints (g/s)	23	2116	285	37	213	100	136	**2.9 kg/s**

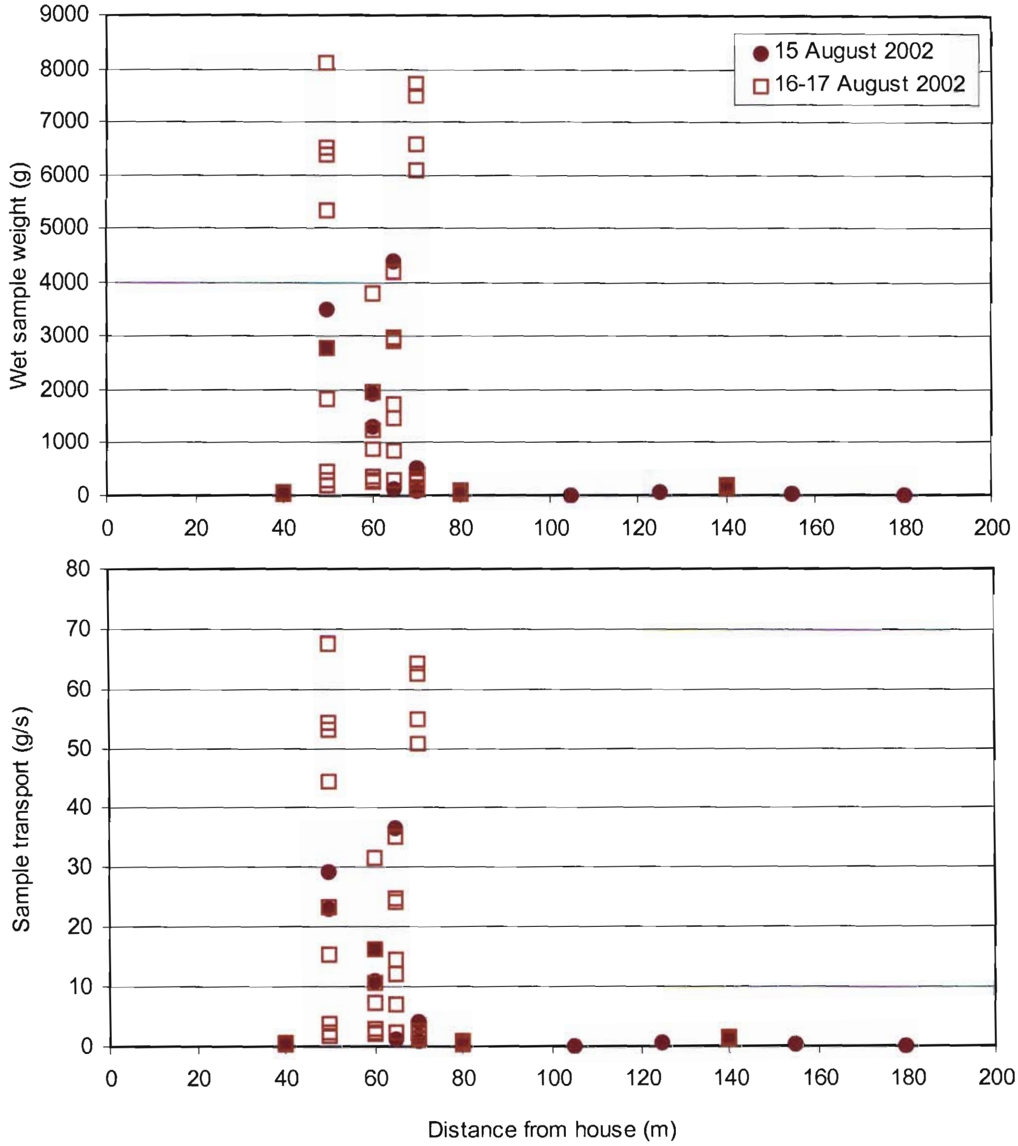
Figure 11: *Results from bedload measurements during 20–22 June 2002.*



23 July 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=485 m^3/s
Mean bedload transport at each station (g/s/m)	3	391	227	359	77	14	11	
Total transport btw. station midpoints (g/s)	43	3909	1705	1794	580	491	643	**9.2 kg/s**

24 July 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=437 m^3/s
Mean bedload transport at each station (g/s/m)	2	197	67	352	137	3	5	
Total transport btw. station midpoints (g/s)	26	1970	504	1762	1029	119	328	**5.7 kg/s**

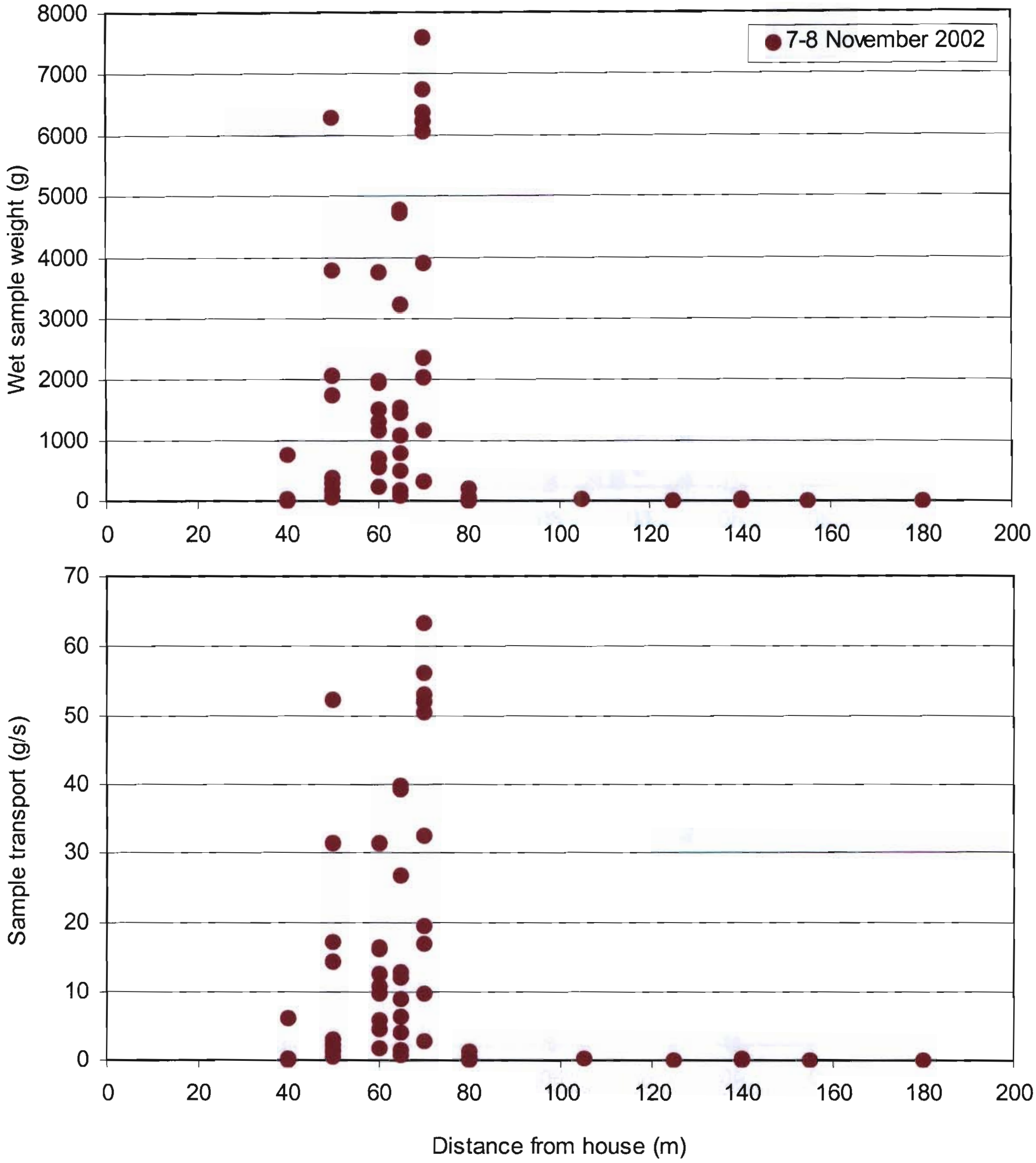
Figure 12: *Results from bedload measurements during 23–24 July 2002.*



15 August 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=488 m^3/s
Mean bedload transport at each station (g/s/m)	5	342	177	247	34	7	15	
Total transport btw. station midpoints (g/s)	77	3422	1326	1234	253	234	919	**7.5 kg/s**

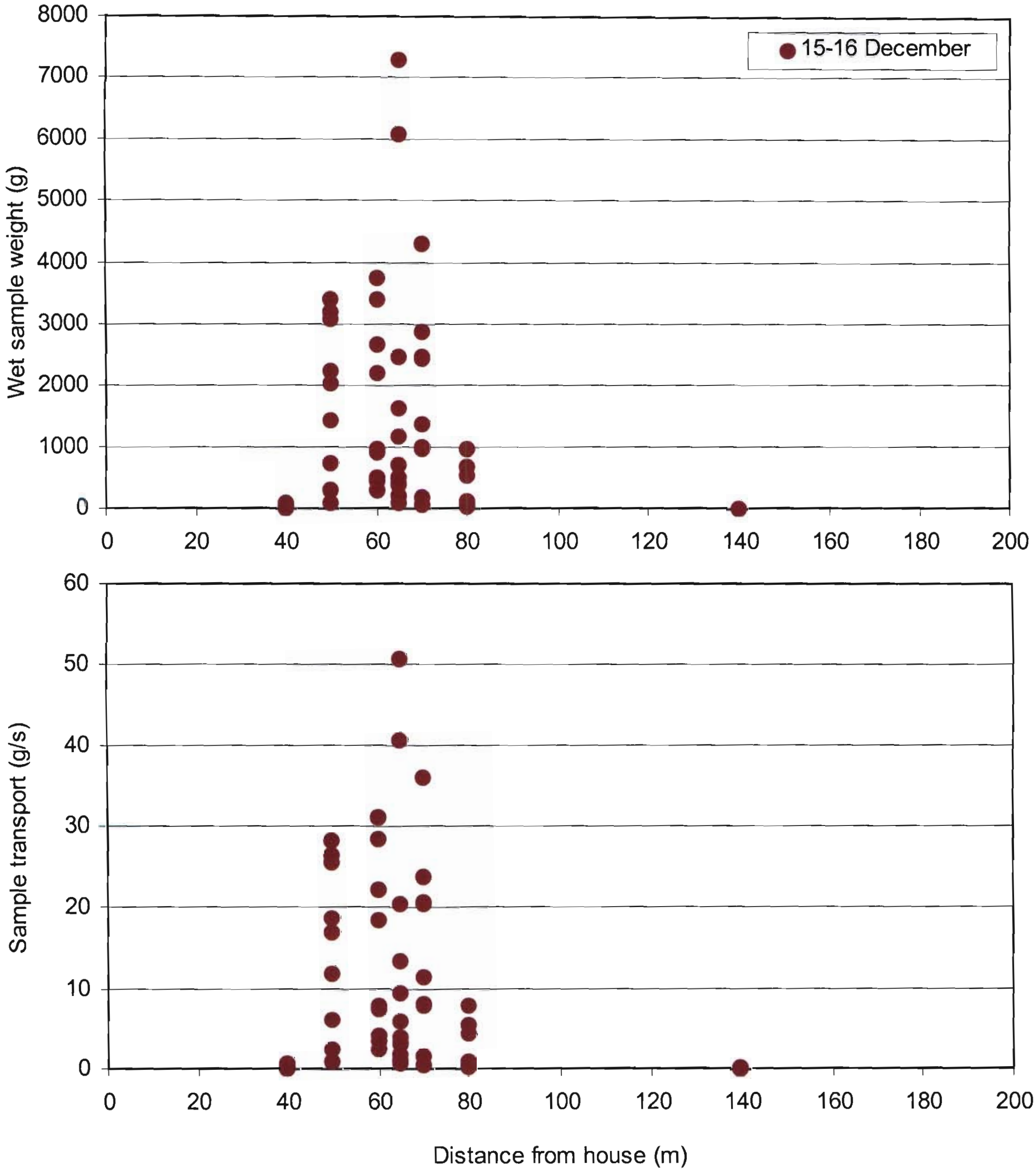
16–17 August 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=496 m^3/s
Mean bedload transport at each station (g/s/m)	5	352	137	237	394	7	16	
Total transport btw. station midpoints (g/s)	74	3522	1031	1187	2953	239	988	**10.0 kg/s**

Figure 13: *Results from bedload measurements during 15–17 August 2002.*



7–8 November 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=269 m^3/s
Mean bedload transport at each station (g/s/m)	9	165	151	200	467	5	2	
Total transport btw. station midpoints (g/s)	151	1651	1135	1001	3506	164	114	**7.7 kg/s**

Figure 14: *Results from bedload measurements during 7–8 November 2002.*



15–16 December 2002	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	8	5	8	35	60	Q=295 m^3/s
Mean bedload transport at each station (g/s/m)	2	181	176	160	172	28	1	
Total transport btw. station midpoints (g/s)	39	1814	1318	799	1291	992	73	**6.3 kg/s**

Figure 15: *Results from bedload measurements during 15–16 December 2002.*

Figures 10 to 15 show that in all campaigns, except the January campaign, the bedload was transported between 50 and 70 m, and much less at 40, 80, and 140 m. In contrast, during the peak of the January flood both the mass of each bedload sample and the transport at each station was up to an order of magnitude higher at some stations than during other campaigns. This difference is better seen visually on Figs. 16 and 17, which show the bedload transport at each station and the total bedload transport between the station's midpoints. Both Figures have A and B parts; including and excluding the January campaign due to the different scales of transport during these campaigns.

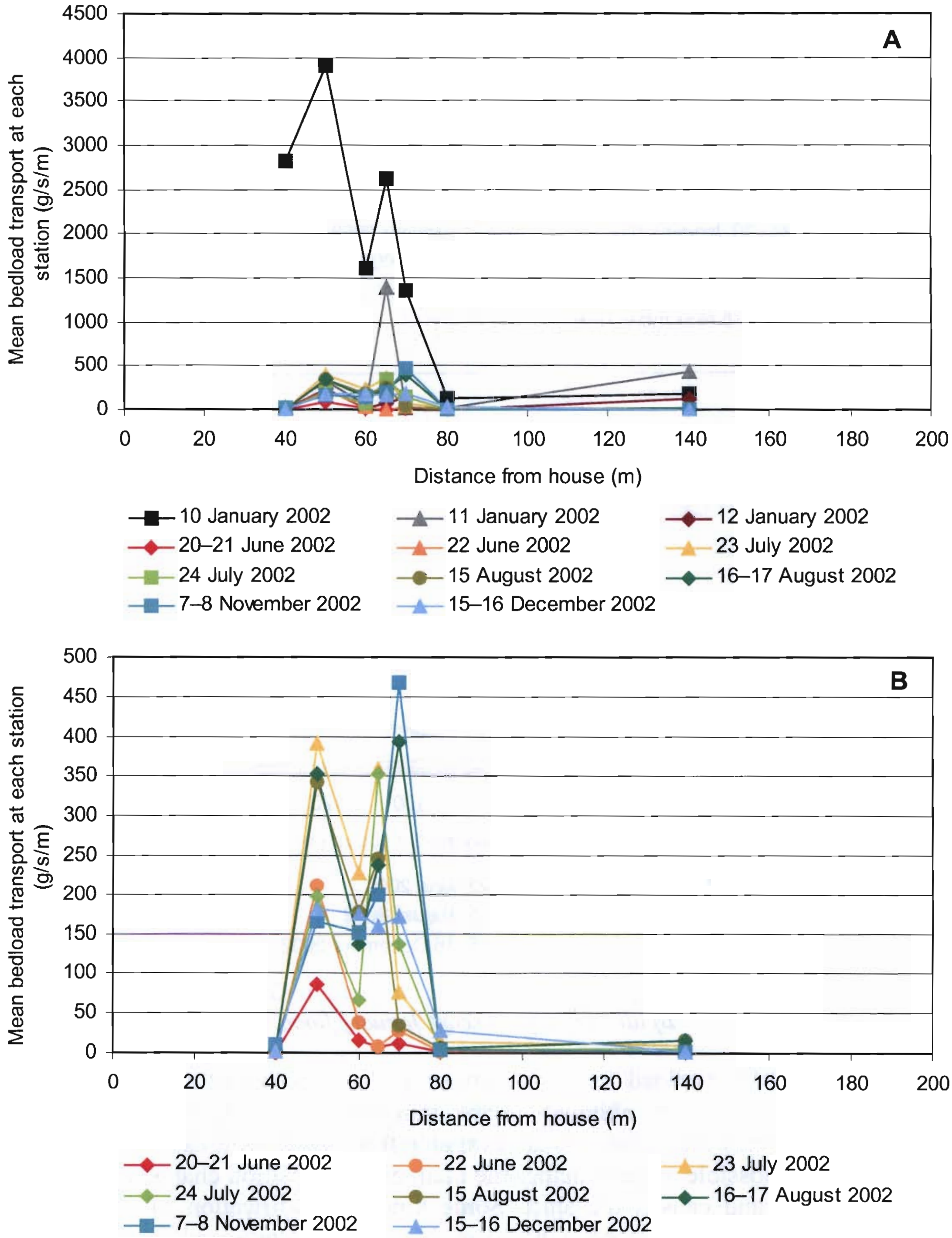


Figure 16: *Mean bedload transport at each station at Krókur. A) All campaigns and B) all campaigns except January flood.*

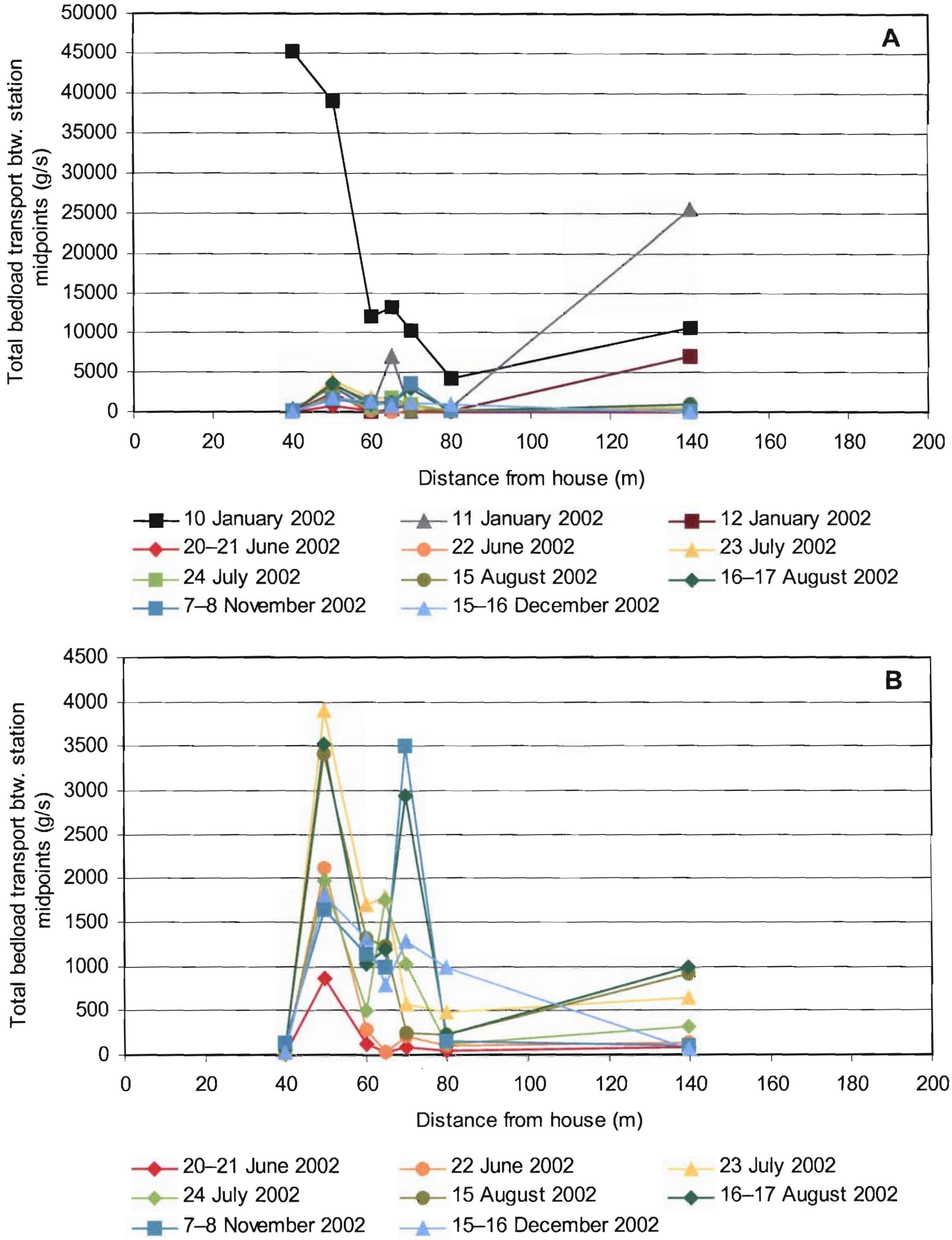


Figure 17: *Total bedload transport between station midponts at Krókur. A) All campaigns and B) all campaigns except January flood.*

During January 10th bedload transport appears to have been shifted towards the left (eastern) bank of the river, although higher transport is seen throughout the whole channel. No discharge measurements are available from the Krókur cableway during the flood so it is not possible to see whether the main current position changed significantly during the flood and caused the shift. Some kind of modification of current speed compared to normal current speed is, however, likely to have occurred.

When looking at Figs. 15 and 16 at higher resolution (B parts), it is noticeable that some variation exists among the campaigns concerning the distribution of mass and bedload transport from one station to another, although most of the bedload is transported between 50 and 70 m. For example, on August 15 most of the bedload was transported at 50 m (3422 g/s), but minor amount at 70 m (253 g/s); in contrast, on August 16 and 17 the transport at 50 and 70 m was much more like with only about 500 g/s more at 50 m.

This high mass and bedload transport at 50 m differs from the situation in 2001 when the majority of the bedload was transported at 70 m and only relatively high transport started at 50 m in late August.

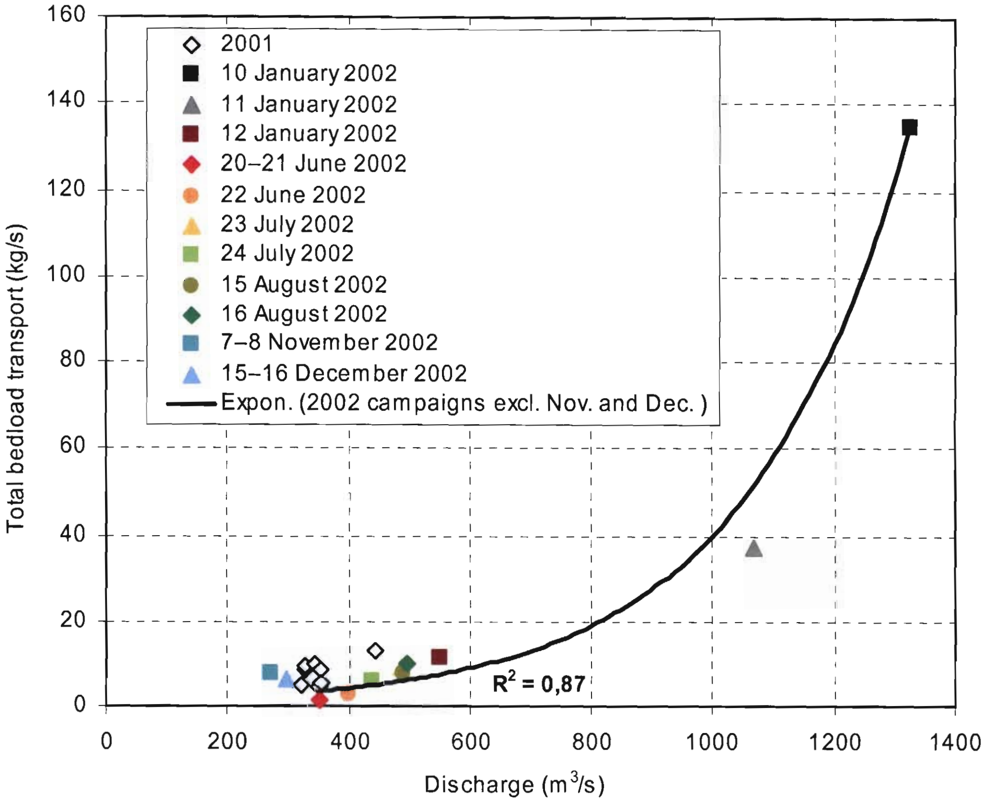
Table 9 shows a summary of the total bedload transport across the river channel at Krókur. The measured total bedload was by far the highest in the January flood, especially on January 10th when the total bedload transport across the channel reached 134.3 kg/s at mean discharge of 1326 m^3/s. As the flood discharge decreased the bedload transport declined as well, but was still relatively high on January 12th when the mean discharge had decreased to 550 m^3/s.

Table 9: *Results from bedload measurements at Krókur in 2002.*

Campaign date	Mean discharge (m^3/s)	Total integrated bedload transport (kg/s)
10 January 2002	1326	134.3
11 January 2002	1066	37.0
12 January 2002	550	11.1
20–21 June 2002	351	1.3
22 June 2002	399	2.9
23 July 2002	485	9.1
24 July 2002	437	5.7
15 August 2002	488	7.5
16 August 2002	496	10.0
7–8 November 2002	269	7.7
15–16 December 2002	295	6.3

Total bedload transported through the channel was small in June, but at that time the discharge was less than 400 m^3/s. There seems to be a reasonable correlation of total bedload transport with discharge. Figure 18 shows all campaigns from 2001 and 2002 as well as an exponential trend-line for the 2002 campaign dates excluding the winter campaigns in November and December. Those are not included as total bedload transport in those campaigns was relatively high compared to the low discharge values of 269 and 295 m^3/s, respectively. The correlation coefficient (R^2) for the trend-line is 0.87 which verifies the correlation indicated in Table 9.

Figure 18 also shows the results from the 2001 campaigns with open diamonds. Most of the campaigns in 2001 were carried out over a relatively narrow discharge range; with only one campaign completed at higher discharge than 400 m^3/s. However, one of the main differences between results from 2001 and 2002 is that the 2002 data shows a good correlation with discharge whereas the 2001 results do not. Furthermore, the 2001 bedload transport appears to have been somewhat higher than the 2002 transport. The reason for this is unknown, although it is possible that the January flood flushed out the sediment in the channel to some extent; leaving less material in the channel for future bedload transport.



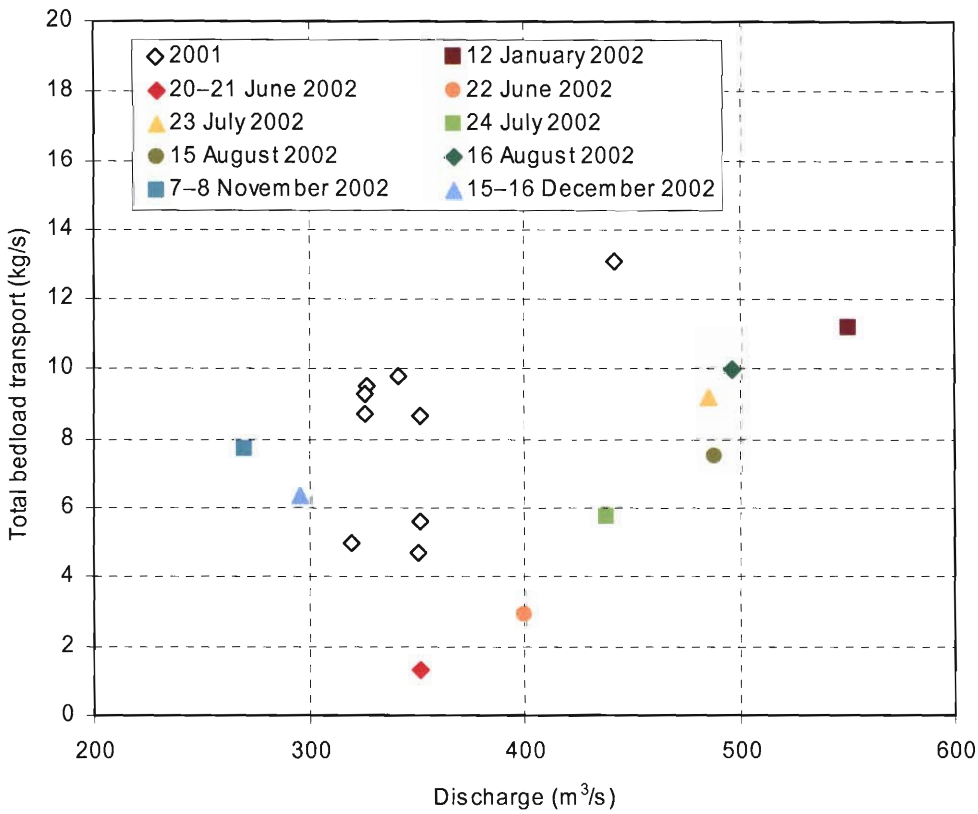


Figure 18: *Total bedload transport and mean discharge during the 2001 and 2002 campaigns. Upper: All data. Lower: All data excluding January 10–11.*

3.2.2 Grain size of bedload samples

In each of the six bedload campaigns in 2002, seven samples, one from each station, were collected and analyzed for grain size analysis at the Sedimentology Laboratory of the Hydrological Service, as described in chapter 2.2.3. The results from each campaign are shown on the following cumulative frequency graphs (Figs. 19 to 24) using the linear phi-scale (Table 5). To improve comparison between the graphs, the same colors are used for each station; however, the 40 m station from December is omitted as the sample was very small and mostly consisted of plant remains.

The finest material was found at 40 and 140 m in three out of six sample campaigns, and in August the 80 m sample included fine material in addition to 40 and 140 m samples (Figs. 19 to 24). The coarsest material was seen in the 70 m samples in all campaigns except in December, when the 80 m sample had by far the coarsest material. The samples from December have somewhat different grain size distribution from the other campaigns. However, the same is true for the samples taken during the January flood, when the 40 m sample was relatively coarse and the 80 m sample much finer than samples from the other stations. Furthermore, the January samples are overall coarser than the rest of the samples, which agrees well with the high discharge prevailing while they were collected.

The results from the moment statistics are shown on Figs. 25 to 27, and these show the grain size variations between stations and campaigns in a better way. Figure 25 shows well how the overall mean grain size was highest in the January flood samples, whereas the December samples usually had the second highest grain size. Figure 25 also shows how the mean grain size differed from one station to another, with the 70 m station including the overall coarsest samples, whereas 40 and 140 m included both the finest and relatively coarse samples. In contrast the 80 m station had generally relatively fine samples.

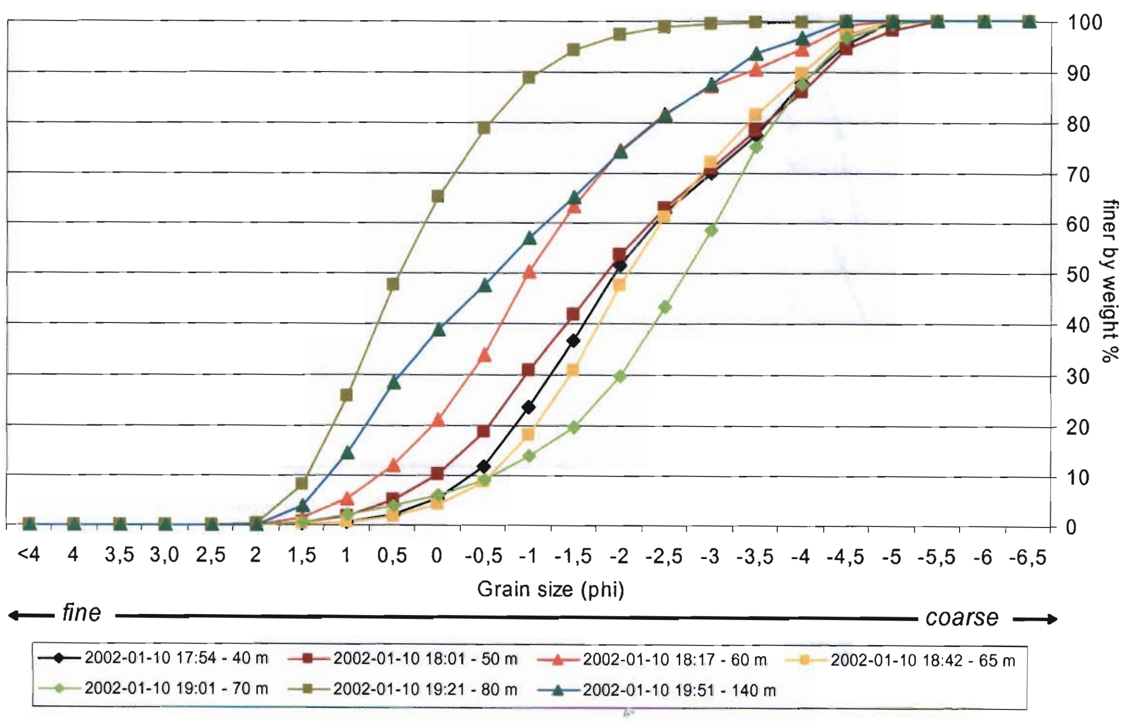


Figure 19: *Cumulative grain size curve for Krókur bedload samples collected January 10.*

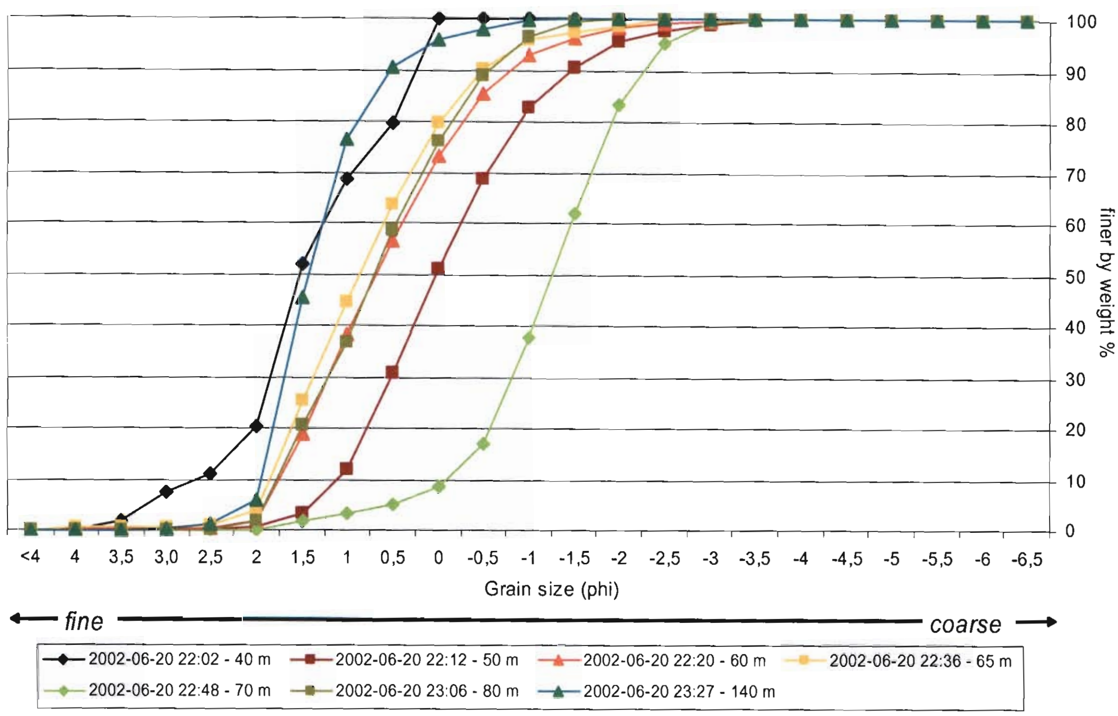


Figure 20: *Cumulative grain size curve for Krókur bedload samples collected June 20.*

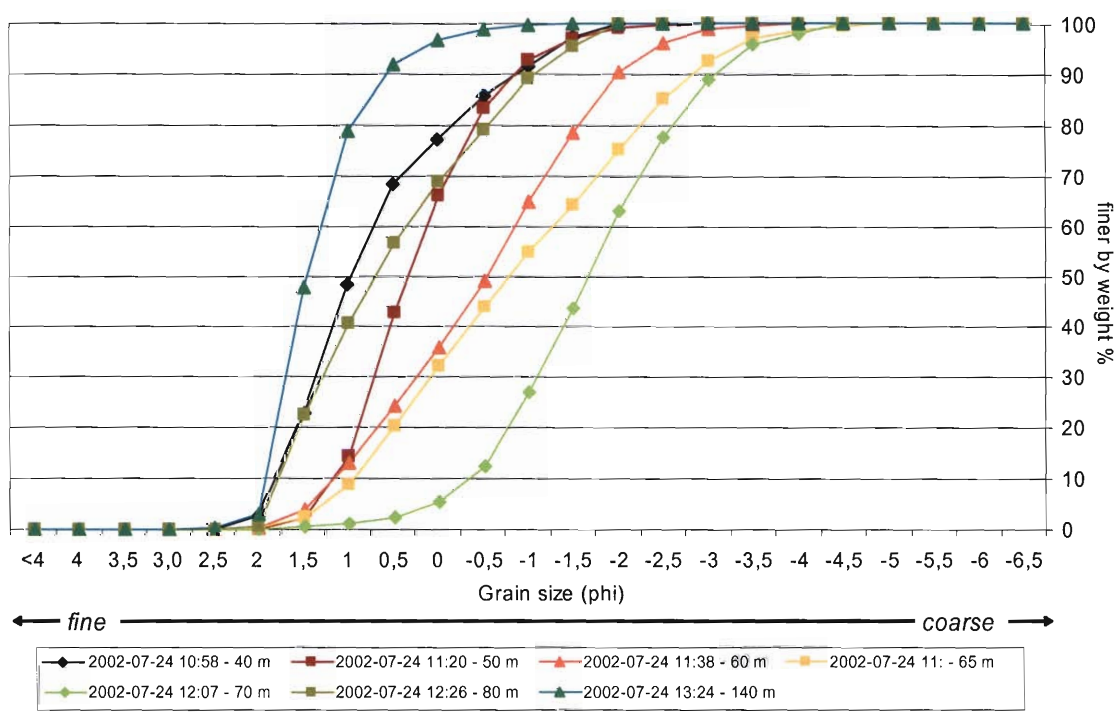


Figure 21: *Cumulative grain size curves for Krókur bedload samples collected July 24.*

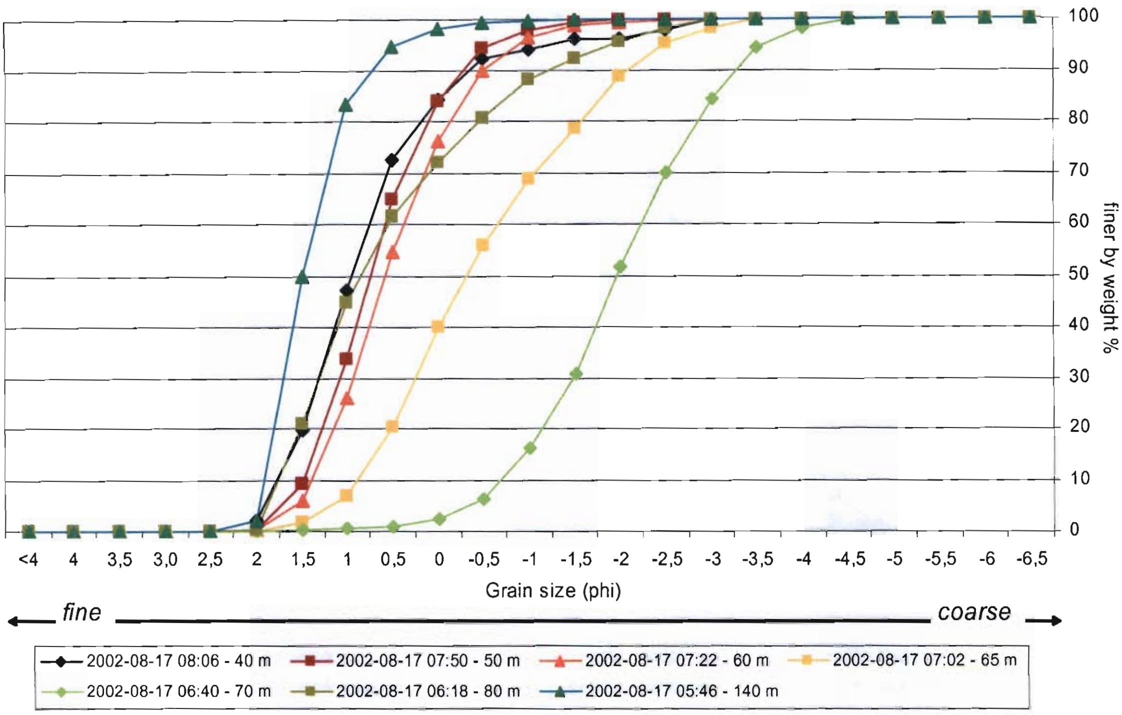


Figure 22: *Cumulative grain size curves for Krókur bedload samples collected August 17.*

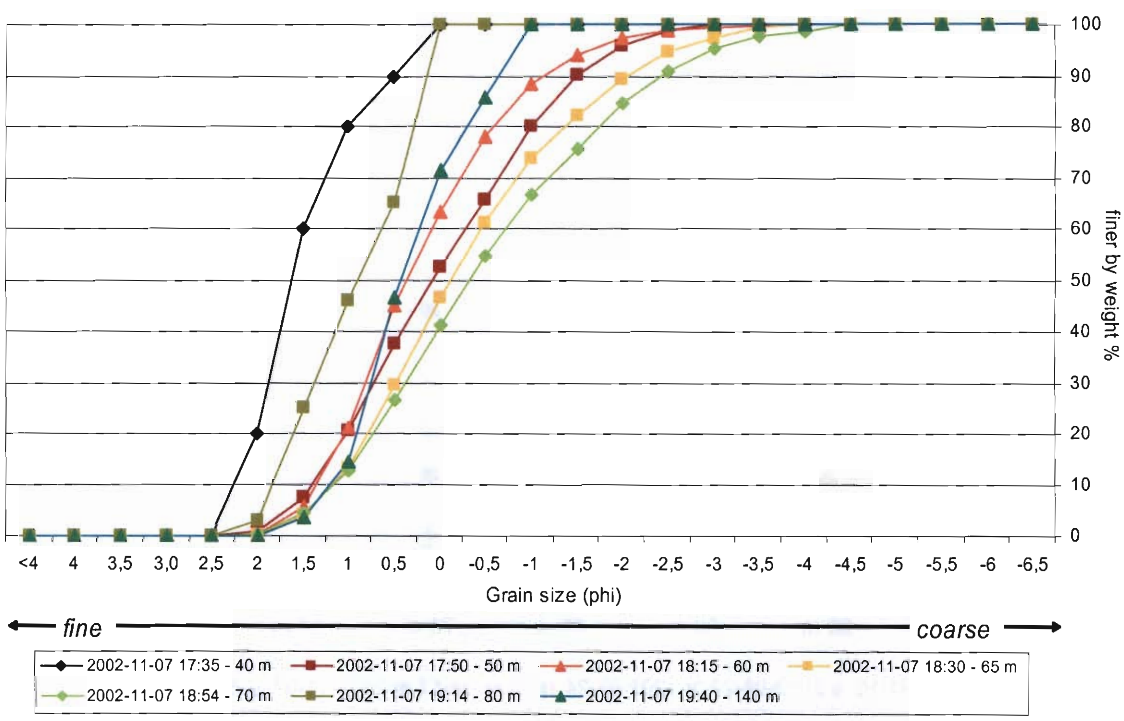


Figure 23: *Cumulative grain size curves for Krókur bedload samples collected November 7.*

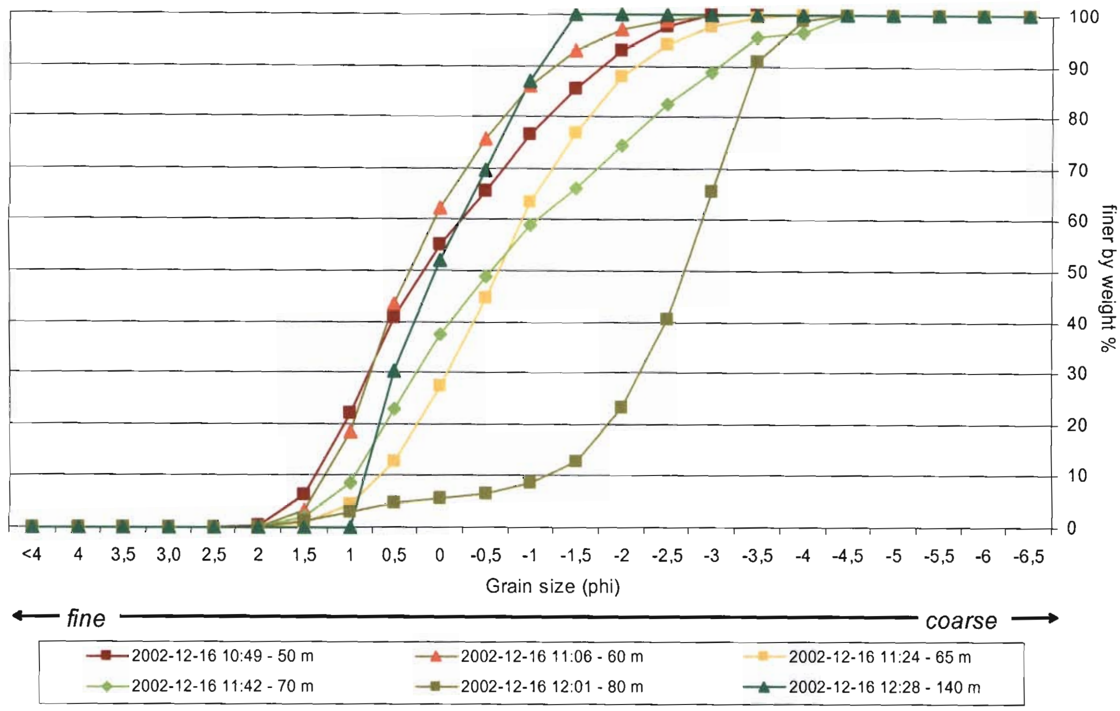


Figure 24: *Cumulative grain size curves for Krókur bedload samples collected December 16.*

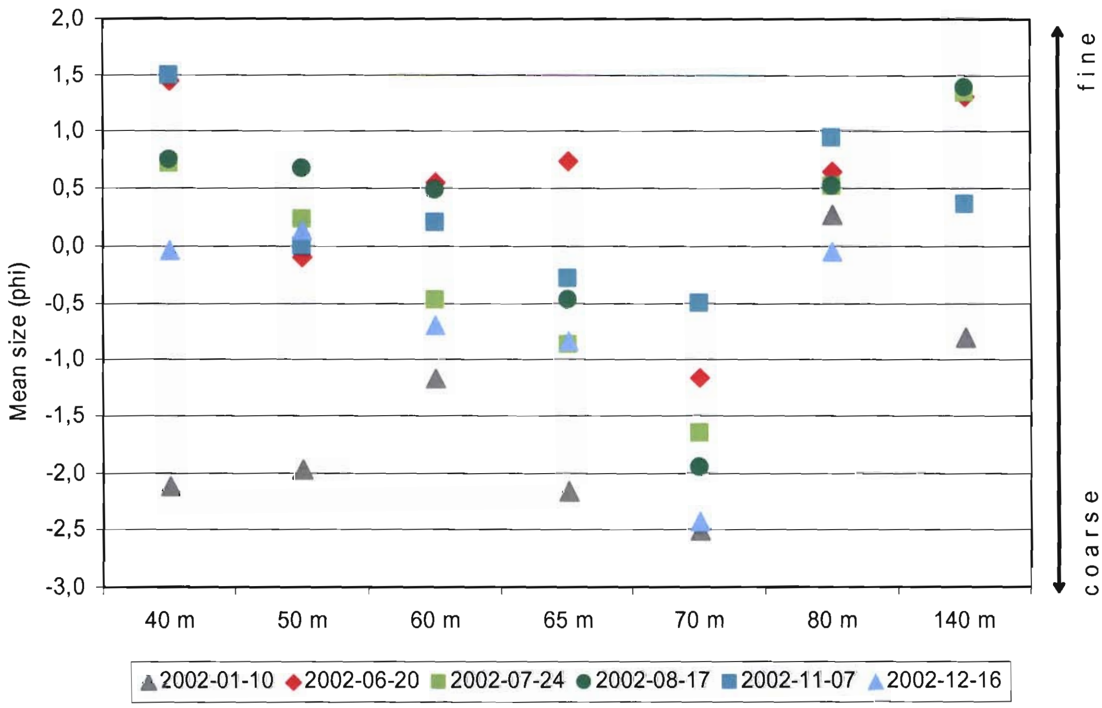


Figure 25: *Mean grain size (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2002.*

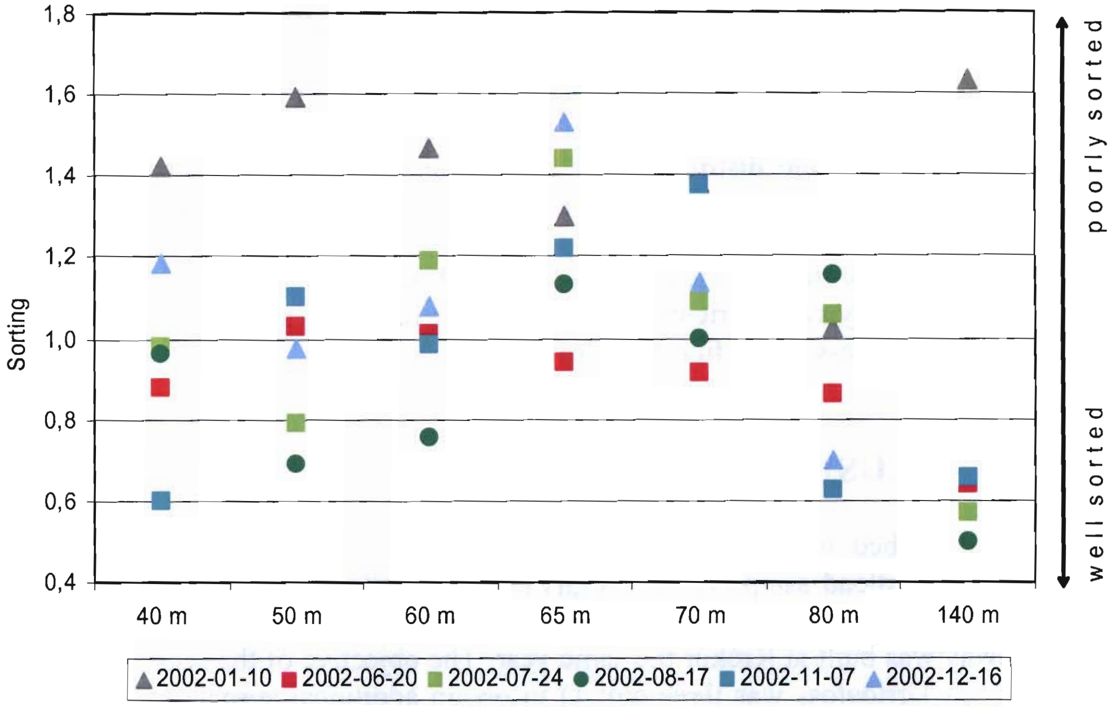


Figure 26: *Sorting values (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2002.*

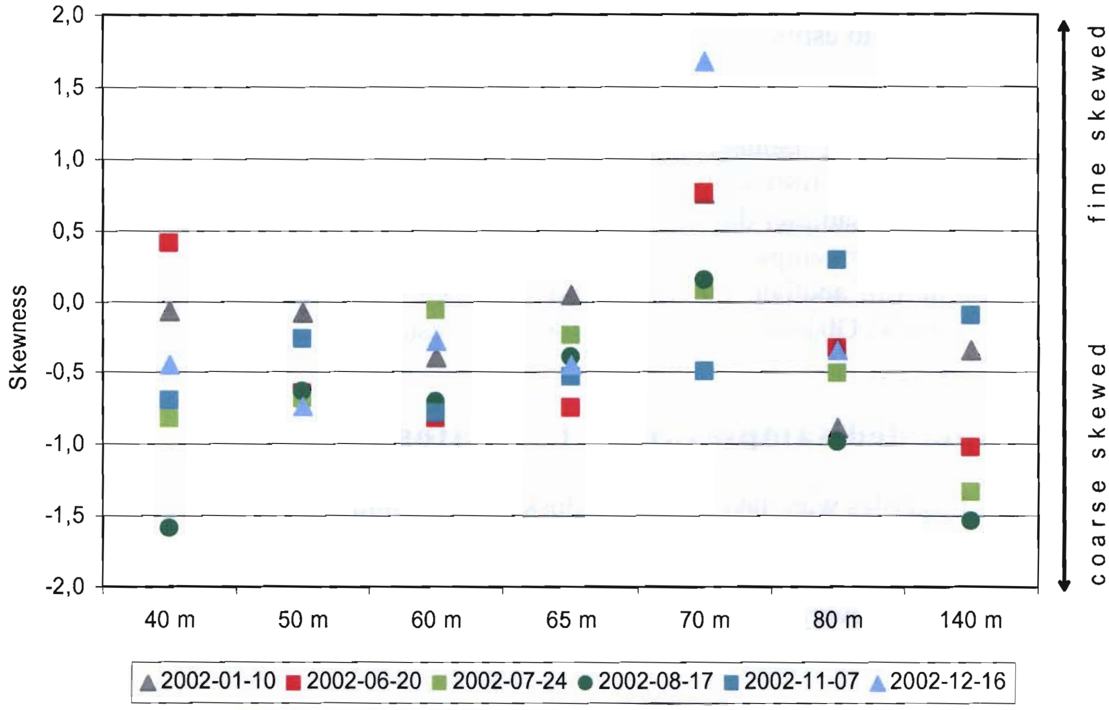


Figure 27: *Skewness values (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2002.*

Sorting values also differ somewhat with campaigns and stations but those indicate the grain size range within in each sample (Fig. 26). The January samples also deviate in this parameter from samples in other campaigns as they are more poorly sorted than the other samples except those from the 65 and 80 m stations. The January sample from 140 m especially differs from 140-m-samples in other campaigns which all are equally well sorted. This deviation in the January samples is due to unusually coarse material being transported at that station along with the typical fine material transported at 140 m. Although sorting values at each station fluctuate to some extent there is a tendency for the values to be greater at 65 and 70 m, and lower closer to the river banks (Fig. 26). This is in contrast to the distribution of mean grain size values; hence, there is a tendency for the coarser samples to be less sorted than fine grained samples.

Figure 27 shows how the skewness values vary with campaigns and stations. Most of the samples are nearly symmetric or coarsely skewed; only four samples are very finely skewed (i.e. with excess tail of fine particles).

4 CONCLUSIONS

The study described in this report shows additional results from the extension of suspended and bedload sampling campaigns initiated at Krókur and Urriðafoss in the lower reaches of river Þjórsá in 2001. Such integrated sampling was first possible after a new cableway was built at Krókur the same year. The objective of the sediment studies at Krókur and Urriðafoss was threefold: 1) to obtain additional suspended samples at variable discharge values in Þjórsá; 2) to compare suspended samples from Krókur and Urriðafoss to evaluate whether the Urriðafoss samples underrepresent sediment concentration in Þjórsá because they are not obtained where the sediment concentration is highest (close to the bottom in the greatest current); and 3) continue the bedload sampling at Krókur to estimate the bedload transport in Lower Þjórsá.

Six major sampling campaigns were carried out at Krókur in 2002, starting with a very important campaign in January when an extensive flooding occurred due to great rainfall and melting of fresh snow in the highlands. During one of those campaigns, the suspended sediment sampler did not work; hence supplementary sediment samples were taken during the other campaigns. Furthermore, four additional suspended samples were obtained as a part of another integrated study on chemical transport in rivers in South Iceland (Sigurður R. Gíslason *et al.* 2003) and those results are also shown here.

4.1 Suspended samples from Urriðafoss

Two kinds of samples were taken at Urriðafoss in 2002; nine samples were taken with a handheld rod-sampler from the river bank beneath the bridge on Highway 1 (S3 samples) and three samples were taken with the normal suspended sediment sampler (S49) from the cableway downstream of the bridge on a newly developed hydraulic winch.

Distinctive change in grain size with seasons was seen in 2002 as was witnessed in samples from 2001; i.e. highest percentage of the fine sediment grain size groups (*méla* 0.002–0.02 mm and *leir* <0.002 mm) were seen during June, July and August when the summer glacial melting augments the river sediment transport. In contrast, the coarser sediment grain size groups (especially *sandur* >0.2 mm and *grófmór* 0.2–0.06 mm) were relatively greater percentage of the suspended sediment concentration in winter time, although the November sample showed anomalously high *sandur* percentage.

It must, however, be stressed that due to the closed array nature of percentage data, one grain size group is bound to increase when another decreases.

Comparison was made between the two cableway samples (S1 samples) and the concurrent bridge samples (S3 samples) from Urriðafoss. This evaluation confirmed that the S3 bridge samples underestimate the sediment concentration at Urriðafoss greatly, in this case they only included 58% and 49% of the sediment concentration of the cableway samples. Continued sampling at the bridge and the cableway will further aid in establishing the relationship between the two locations, and possibly correct the older S3 bridge samples for the underestimation.

4.2 Suspended samples from Krókur

Seven suspended sediment samples were obtained from Krókur in seven sample bottles at 40, 50, 60, 65, 70, 80, and 140 m distance from the house. The weighted mean for the whole sample was calculated based on the analysis of each bottle, although the 2002-07-23 sample excluded the 60 m bottle as it broke during transport and the weighted mean for the 2002-12-14 sample was calculated with and without the 60 m bottle as it showed anomalously high *sandur* concentration.

Some variations between grain size groups is seen from one sample to another, although it is much less than in the Urriðafoss samples and it doesn't show a distinct seasonal variation as the samples from Urriðafoss do. *Sandur* % varied from about 20 to 35%, whereas the finest *leir* fraction ranged from 12% in the 2002-01-11 sample to 45% in the 2002-07-22 sample. In the Krókur samples as well as in the Urriðafoss samples it is necessary to emphasize the nature of percentage data such as our grain size array; when one variable increases another decreases. Hence, high concentration percentage of coarse sediment is bound to result in a low concentration percentage of the fine fraction.

Grain size was measured in the individual sample bottles from the 40, 50, 60, 65, 70, 80, and 140 m stations. The analyses show that the highest *sandur* % was transported at 50, 60, and 65 m and the concentration of fine material (*leir* <0.002 mm and *méla* 0.02–0.002 mm) was highest at 40 and 140 m in most samples. Occasional sample bottles included high percentage of *sandur* like the 140 m bottle from 2002-01-11 and 2002-08-16 and the 40 m bottle from 2002-12-14. These results signify the stochastic nature of the transport of coarse material, although it is necessary to be aware of that greater error is incorporated in the analysis of the 40 and 140 m sample bottles because they include smaller water volume than other bottles due to lower current speed at those locations.

The distribution of the coarsest material is somewhat shifted from 2001 when the coarsest material was concentrated in a ravine at 70 m, instead of being concentrated at 50, 60, and 65 m in 2002. This shift is unexpected and no good explanations are offered here, although the great flood in January may have to some extent modified the hydraulic conditions at the cableway, or the source of sediment upstream of the sampling locations. No major change is though noticed between a depth profile from May 2003 and similar profiles (although not as detailed) from 2001 (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002).

It is suggested that in the sediment campaigns in 2003 the suspended sediment sampling should focus on obtaining integrated samples from Krókur instead of analyzing the individual bottles and calculating the weighted mean. This can be done because a reasonable good knowledge has been gathered on grain size distribution of the suspended sediment across the river channel in the campaigns in 2001 and 2002.

4.3 Comparison of suspended sediment samples from Urriðafoss and Krókur

One of the objectives of the sediment studies at Krókur and Urriðafoss was to evaluate whether the S3 samples from Urriðafoss represent the suspended sediment concentration correctly. The two sample pairs from the bridge on Highway 1 and the downstream cableway suggest that they underrepresent the sediment concentration, but a further comparison can be made between the Urriðafoss samples and the weighted Krókur samples. Six sample pairs were used for the comparison; however, as was portrayed earlier the 2002-07-23 and 2002-12-14 samples from Krókur excluded the 60 m bottles, and the S1 cableway sample from Urriðafoss is used in the December comparison.

Substantial difference is observed between the Urriðafoss and Krókur samples with regard to both grain size variability and total suspended sediment concentration. The Krókur samples always had higher total suspended sediment concentration than the Urriðafoss samples, and similarly, the *sandur* % was higher at Krókur in all, but one, sample. In contrast, but not unexpectedly, the percentages of *finmór*, *méla*, and *leir* were greater at Urriðafoss than Krókur in five out of six sample pairs (all but the November sample with anomalously high *sandur* concentration).

Similar results were seen in the 2001 sample pairs; however, the variability of the Urriðafoss(U)/Krókur(K) ratio was somewhat greater in the 2001 samples than the 2002 samples, indicating that the difference in suspended sediment concentration and grain size percentage between the Urriðafoss and Krókur samples was less in 2002.

The greater concentration and coarse grain percentages in the Krókur samples than Urriðafoss samples must to a large extent be caused by the different sampling strategies used at these two locations. It is impossible, except when discharge is very small, to collect a sample from the bank below the bridge at Highway 1.

Variation of total sediment concentration of all the Urriðafoss and Krókur samples from 2002 was studied with regard to discharge and compared with similar results from 2001. In 2001, a minor correlation (R^2=0.58) was seen between sediment concentration of the S3 samples from Urriðafoss and discharge, but in 2002 no such correlation was obvious. Similarly, no obvious correlation was seen between the three S1 samples from Urriðafoss, or the six Krókur samples with discharge, although the sediment samples from the January flood have relatively high concentration values.

The poor correlation with discharge of the three different sample types may be due to the harnessing characteristics of the Þjórsá river. The natural sediment transport, or at least the coarser fraction of the transport, is greatly hindered in upstream reservoirs as has been discussed by Haukur Tómasson (1982). Hence, the sediment transport in the

Þjórsá channel at Krókur and Urriðafoss is highly unnatural and may be affected by other changes in addition to direct discharge variations, such as the availability of sediment which can alter greatly with major floods like the one in January 2002.

In this comparison it is also observed than two of the three S1 samples from Urriðafoss have higher sediment concentration that the Krókur samples, suggesting that the Krókur samples may also underrepresent the real sediment concentration in Lower Þjórsá. Many more sample pairs are, however, needed before a reasonable relationship can be established.

4.4 Bedload studies

The bedload studies in 2002 at Krókur were a continuation of the measurements initiated in 2001, which were the first bedload studies carried out in Þjórsá downstream of Sandártunga (Haukur Tómasson et al. 1996, Svanur Pálsson 2000). During the six sampling campaigns, samples were taken at seven locations from the new cableway at Krókur, i.e. from 40, 50, 60, 65, 70, 80, and 140 m distance from the house on the left (eastern) bank of the river. Results from 448 samples are used to calculate the total bedload transport during each campaign.

As in 2001, great difference is seen in bedload transport between different locations on the cross-section, with the highest bedload being transported between 50 and 70 m and a relatively small fraction transported at other stations. However, a shift has been observed in regards to which station includes the greatest transport; in 2001 the highest bedload was usually transported at 70 m, but in 2002 the 50 m station showed highest bedload transport in all campaigns except in August and November. This shift in transport towards the left bank is also seen in the suspended sediment results introduced earlier.

The distribution in bedload in the January flood was, however, different from the other campaigns when the highest transport was at 40 and 50 m. This high transport during the January flood close to the left bank may be the cause for the shift in suspended and bedload transport towards the left bank in the 2002 samples compared with the 2001 samples.

Great change was seen in the total bedload transport across the river channel with discharge. By far the greatest is the bedload transport on January 10 when the January flood peak reached its maximum, i.e. 134 kg/s at mean discharge of 1326 m^3/s. The sampling during that day was, however, terminated abruptly when the current was to great for the bedload sampler, which was lost into the river and never to be seen again. The bedload measurements continued the next day, but the transport rapidly declined as the discharge decreased and was already ca. 11 kg/s on January 12 at mean discharge of 550 m^3/s.

Relatively good correlation is observed between bedload transport and discharge, especially if the winter campaigns in November and December are excluded. An exponential fit between all the 2002 campaigns results except those two campaigns shows a R^2 correlation of 0.87, which is a convincingly good correspondance.

The winter campaigns show relatively high bedload compared to the low discharge, i.e. 7.7 and 6.3 kg/s in the November and December campaigns, respectively. The lowest bedload transport, 1.2 kg/s, was in contrast measured on 20–21 June, whereas the day after the transport had increased to 2.9 kg/s with an increase in mean discharge of 48 m^3/s.

Comparing the bedload transport with the 2001 studies it is observed that the bedload was relatively higher during that year than in 2002; however, much less variation was observed in discharge between the sampling campaigns during the previous year. The reason for less bedload transport in 2002 than 2001 is unclear, but one idea may point to the January flood as a cause, i.e. the high discharge during the flood may have flushed out the bedload in the channel leaving less material for transport in the following months. However, such explanations should be taken with caution because the contradictory effect of such a flood would be to erode the bank material upstream and dump it into the channel without clearing the channel. Whichever effect the flood will cause is highly dependent upon the hydraulic conditions and the sediment sources available during the flood.

Grain size was measured from one sample from each station during each campaign, 42 samples in all. The grain size of the bedload was similar as in 2001, *sandur* with occasional pebbles and cobbles. The finest material was seen at 40 and 140 m in half of the campaigns, whereas the 70 m samples were the coarsest except in December when the 80 m sample was coarsest.

The overall coarsest samples were taken on January 11 which is understandable as the mean discharge during sampling was more than double the discharge in campaigns later in the year. It is interesting that the December sample has the second coarsest material, but such coarsening in winter samples is often seen in rivers.

Furthermore, the January samples, except the 65 and 80 m samples, are also more poorly sorted than other samples, whereas the 40 and 140 m samples from most other campaigns are usually the best sorted samples.

The bedload measurements that have been carried out at Krókur during the last two years give a very important evidence of bedload transport in Þjórsá. However, the limitations of such studies should not be discarded, as such studies will always be an adjustment between time/money spent on studies of the river and a reasonable error in the measurements, which is only lowered with more samples or continuous measurements. Our way to try to accommodate both views, i.e. relatively cheap bedload program with reasonable error, is to sample in each campaign >10 samples from seven stations, of which five are located where the greatest bedload transport has been found. The bedload transport for the other stretches, where bedload has been found to be minor, is instead interpolated based on only one station close to each river bank, with occasional samples in-between to validate the assumption that the transport is small.

In this report we do not give an error estimate of the bedload transport because even though it is possible to evaluate to some extent the precision of the individual measurements we are still hesitant to give the accuracy of the bedload calculations. The sampling efficiency of the Helley-Smith samplers has been discussed in numerous papers (e.g. Emmett 1980) which most show a great range for the effective retainment of sampling. Most of the results show efficiency less than 1 (1 representing full recovery of all bedload transport) and numbers close to 0.7 are often cited. Thus, the values published here for bedload transport should be used with some caution, keeping in mind that they most likely underrepresent the actual transport to a moderate extent.

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SUMMARY IN ICELANDIC

Í tilefni af fyrirhugaðri Urriðafossvirkjun í Þjórsá voru hafnar umfangsmiklar rannsóknir á heildaraurburði Neðri-Þjórsár sumarið 2001. Settur var upp nýr rafdrifinn kláfur við Krók en uppsetning hans var forsenda fyrir því að ítarleg aurburðarsýnataka gæti farið fram. Árið 2001 var farið í 10 sýnatökuferðir að Króki, auk þess sem svifaurssýni voru tekin við Urriðafoss í tengslum við efnavöktun í ám á Suðurlandi, en auk Vatnamælinga standa Landsvirkjun, Raunvísindastofnun háskólans, og Hollustuvernd, nú Umhverfisstofnun, að því verkefni.

Þessum ferðum var haldið áfram árið 2002 og voru sýni tekin af skriðaur og svifaur í sex ferðum að Króki og Urriðafossi það árið. Markmiðið með ferðunum var að afla góðrar vitneskju um heildarframburð Neðri-Þjórsár en slík þekking á aurburði á svæðinu er nauðsynleg fyrir umhverfismat og hönnun virkjunarinnar. Þetta átti að gera með því í fyrsta lagi að afla fleiri svifaurssýna úr neðri hluta Þjórsár og í öðru lagi að afla samanburðarpara af svifaur af Krókskláfnum og af hefðbundna sýnatökustaðnum kenndum við Urriðafoss undir brúnni við þjóðveg 1 annars vegar og hins vegar undir brúnni við þjóðveg 1 og með nýju vökvadrifnu spili af eldri kláfi um 500 m neðan við brúna. Þessi samanburðarsýnataka var gerð til þess að meta betur gæði sýnanna sem tekin hafa verið undir brúnni en talið hefur verið að þau vanmeti svifaur þar sem sýnatakinn sem notaður er nær ekki út í mesta strauminn þar sem svifaursstyrkur er talinn vera mestur. Í þriðja lagi átti að halda áfram skriðaurssýnatöku við Krók, en sýnin frá 2001 voru fyrstu skriðaurssýnin sem tekin hafa verið úr Þjórsá neðan við Sandártungu.

Alls voru tekin 12 svifaurssýni við Urriðafoss árið 2002, þar af þrjú þeirra með vökvadrifnu spili af kláfi. Kornastærð og svifaursstyrkur sýnanna var mjög mismunandi og reyndist styrkur sands (>0,2 mm) vera mestur yfir vetrarmánuðina en styrkur fínefna s.s. leirs (<0,002 mm) mestur yfir sumarmánuðina þegar jökulleysing var í gangi. Heildarstyrkur svifaurs breyttist ekki áberandi með rennsli eins og tilhneiging hafði verið til árið áður. Aðeins tvö sýnapör fengust á hefðbundnum stað undir brú og af kláfi við Urriðafoss en þau sýndu að brúarsýnin innihéldu aðeins 49% og 58% af heildarsvifaursstyrk kláfsýnisins og vanmátu þannig styrk svifaurs mikið.

Svifaurssýnin frá Króki voru tekin með punktsýnataka af rafdrifna kláfnum á 40, 50, 60, 65, 70 80 og 140 m frá húsi á vinstri (austari) bakka árinnar, en bakkinn er að meðaltali í um 18 m fjarlægð frá húsinu. Hver flaska var greind fyrir sig og síðan var reiknað út vegið styrkmeðaltal. Á þann hátt var bæði hægt að skoða breytileika svifaurs innan farvegarins og á milli sýnatökuferða. Niðurstöðurnar sýndu að grófasti svifaurinn barst yfirleitt fram á 50, 60 og 65 m en oftast voru sýnin frá 40 og 140 m fíngerðust þó að undantekningar væru á því. T.d. voru flóðasýni frá janúar af 140 m og ágústsýni af sömu breidd tiltölulega gróf og það sama má segja um 40 m sýni frá í desember. Þessi kornastærðarskipting milli stöðva sýnir að grófasti aurinn hefur haldið sig nær vinstri bakka árið 2002 en árið 2001 þegar grófasti svifaurinn var á ferðinni milli 60 og 80 m.

Samanburður milli heildarstyrks og kornastærðardreifingar Krókssýna og brúarsýna frá Urriðafossi sýna að heildarstyrkur Krókssýna var alltaf hærri en Urriðafosssýna og styrkur sands hærri í öllum Krókssýnum nema einu. Á móti kemur að styrkur leirs

(>0,002 mm), mélu (0,002–0,002 mm) og fínmós (0,02–0,06 mm) var meiri í öllum Urriðafosssýnum nema einu. Þetta eina sýni sem sker sig sérstaklega úr er Urriðafosssýni frá nóvember sem hefur afbrigðilega hátt sandhlutfall. Þessar niðurstöður staðfesta enn frekar að sýni tekin með handsýnataka undir brúnni við þjóðveg 1 vanmeta svifaur í Þjórsá. Samanburður Krókssýna við sýni af kláfi við Urriðafoss benda hins vegar til þess að Krókssýnin vanmeti jafnvel líka svifaursstyrk í Neðri-Þjórsá, en frekari sýnatöku þarf til þess að staðfesta þessar niðurstöður.

Engin áberandi fylgni var milli heildarsvifaursstyrks sýnategundanna þriggja (handsýni og kláfsýni frá Urriðafossi og kláfsýni frá Króki) og rennslis, eins og komið hafði fram í handsýnum frá Urriðafossi árið áður.

Tæplega 450 skriðaurssýni voru tekin á rafdrifna kláfnum við Krók í þeim sex sýnatökuferðum sem farnar voru. Sýnin voru tekin á sömu stöðum og svifaurssýnin auk þess sem einstaka aukasýni voru tekin milli 80 og 200 m til að staðfesta að hægt væri að nota 140 m stöðina sem viðmið fyrir þetta breiddarbil. Í hverri ferð var eitt sýni af hverri stöð þurrkað og kornastærðargreint á aurburðarstofu Vatnamælinga, alls 42 sýni.

Skriðaursframburður var yfirleitt mestur á 50 og 70 m stöðvunum, nokkuð minni á 60 og 65 m, og langminnstur á 40, 80 og 140 m. Framburðardreifing í miklu rigningarflóði dagana 10.–12. janúar skar sig þó mikið úr en þá var framburður langmestur á 40 og 50 m. Árið 2001 var framburður skriðaurs hins vegar mestur á 70 m en tiltölulega lítill á 50 m og virðist sem skriðaur hafi haldið sig meira í austari hluta farvegsins árið 2002 miðað við árið áður. Hugsanlegt er að hinn mikli framburður í janúarflóðinu á 40 og 50 m hafi breytt dreifingu framburðar innan farvegsins fram eftir árinu.

Heildarframburður skriðaurs var minnstur 1,3 kg/s en mestur 134 kg/s þann 10. janúar þegar rigningarflóðið í Þjórsá náði hámarki. Ef niðurstöðum mælinga í nóvember og desember, sem sýndu óvenju háan heildarskriðaursframburð miðað við rennsli, er sleppt, eykst framburður með veldisfalli við aukið rennsli og er fylgnin ágæt, eða R^2=0,87. Ef niðurstöður 2002 eru bornar saman við fyrra ár sést að heldur minni framburður mældist í ferðum 2002, en sama ár voru mælingarnar yfirleitt gerðar við hærra meðalrennsli en árið 2001. Ástæðan fyrir lægri heildarframburði seinna árið er óljós, en mögulegt er að flóðið í janúar hafi á einhvern á hátt breytt straumfræðilegum aðstæðum og setframboði á svæðinu.

Kornastærðarmælingar af skriðaur frá Króki sýndu að efnið sem er á ferðinni er að mestu leyti sandur með lítilsháttar möl. Fíngerðustu og best aðgreindu sýnin voru í helmingi sýnanna tekin á 40 og 140 m stöðvunum en grófustu sýnin voru í öllum nema einni ferðinni tekin á 70 m þar sem straumhraðinn og dýpið er meira. Sýnin sem tekin voru á 80 m stöðinni voru í flestum tilfellum fíngerð þó að einstaka sýni hafi verið grófari. Janúarsýnin voru skiljanlega yfirhöfuð grófust og verst aðgreind enda var straumhraði þá mun meiri en í öðrum ferðum.

Þegar niðurstöður skriðaursmælinganna eru túlkaðar þarf að hafa í huga að mikil óvissa fylgir slíkum mælingum og vanmeta þær botnskrið frekar en ofmeta. Sérstaklega vantar sýni við hærra rennsli en í sýnasöfnun sem þessari er reynt að fara meðalveg milli kostnaðar og samþykktrar óvissu í mælingunum.