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Total sediment transport in the lower reaches of river Þjórsá

Results from the year 2003

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Unnið fyrir Landsvirkjun

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Project no.: 7-546842

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Abstract:
This report introduces results from a comprehensive sediment sampling program in the lower reaches of river Þjórsá that was initiated in 2001. This year, suspended sediment samples were taken in five sampling campaigns from cableways at Krókur and Urriðafoss and from beneath the old bridge on Highway 1. In four of these campaigns bedload samples were also obtained at Krókur. The main objectives of the program is to get more suspended sediment samples from the lower reaches of Þjórsá, evaluate the older suspended samples taken at this site by taking comparison samples, and obtain some estimation of bedload transport in lower Þjórsá. The total concentration and grain size of suspended samples varies greatly between campaigns, but tend to increase with discharge, especially the bridge samples. Those and the Krókur samples appear to underestimate the concentration of total sediment and the coarsest size fraction (>0.2 mm) compared to samples taken at the Urriðafoss cableway. Bedload transport was highest at the 50 to 80 m stations and total transport was from 1.7 to 16.5 kg/ (values adjusted by extra sampling). The bedload material was mainly medium and coarse grained sand with pebbles smaller than -5.0 ϕ.

Key words:	**ISBN-number:**
Þjórsá, bedload, suspended sediment, grain size, bedload transport, discharge, cableway, Krókur, Urriðafoss, Þjórsártún (vhm 30)	
	Project manager's signature:
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1 INTRODUCTION

Þjórsá is one of the largest rivers in Iceland, with a watershed at Þjórsártún of 7380 km^2 (Fig. 1) and a mean annual flow for the period 1971–2002 (32 years) of 352 m^3/s. About 14% of the watershed (1032 km^2) is covered by glaciers; hence glacial meltwater 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 the 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 new 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 upstream of Urriðafoss 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 old 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 first two years of the total sediment program have been published in progress reports (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002; 2003), but in this analogous report we introduce the results from sediment measurements in 2003.

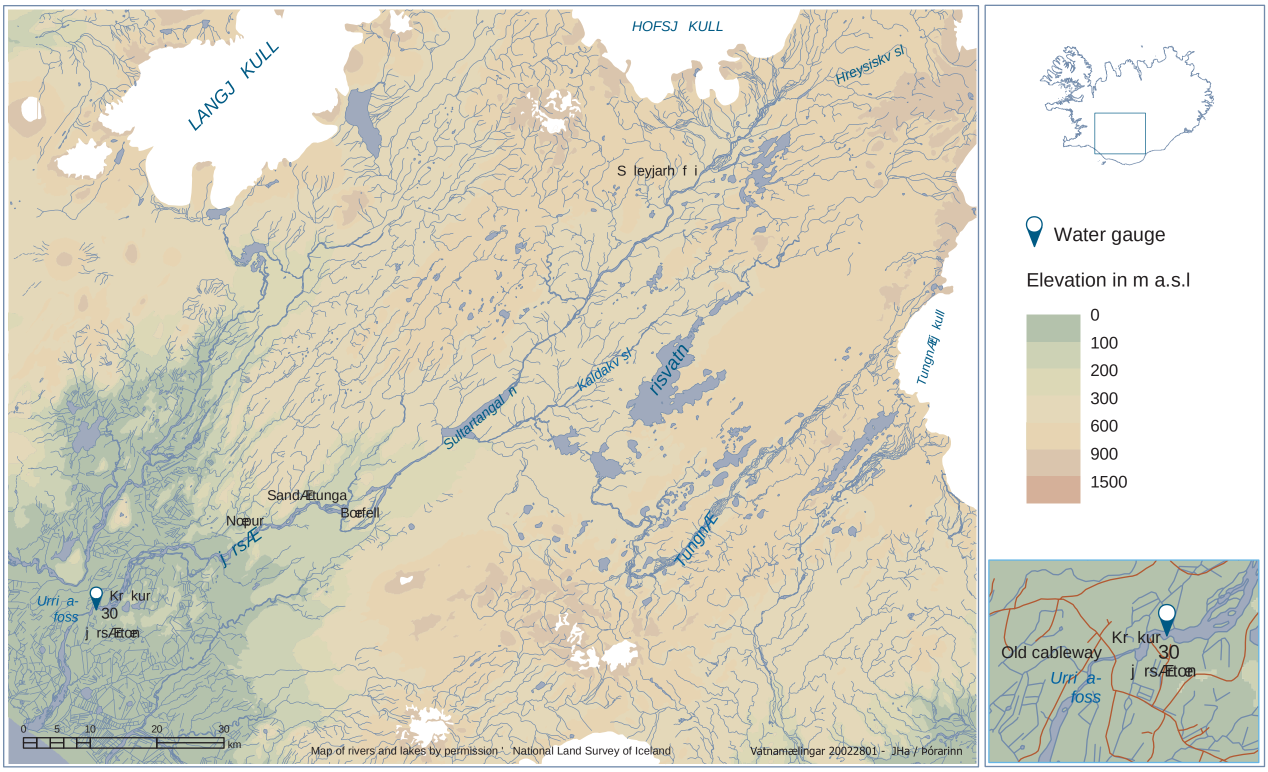


Figure 1: *Map of Þjórsá river basin, including main locations along the river.*

2 SAMPLING AND DATA ANALYSIS

In 2003, the sediment sampling in the lower reaches of Þjórsá was twofold like it has been during the previous two years. Firstly, nine suspended sediment samples were taken with a handheld DH48 sampler (so-called S3 samples) from the river bank beneath the old Highway 1 bridge. This sampling has been carried out in connection with a chemical analysis program in three rivers in South Iceland executed by the Science Institute of Iceland and the Hydrological Service, and funded by Landsvirkjun (National Power Company) and the Environment and Food Agency of Iceland, on behalf of the Ministry of Environment (Sigurður R. Gíslason *et al.* 2000, 2002, 2003, 2004). Secondly, five sediment sampling campaigns were carried out in 2003 as a continuation of an extensive sediment program that started in 2001.

In 2003, the extensive sampling campaigns were divided in two parts; four sampling campaigns during which both samples of suspended sediment and bedload were obtained, and one sampling campaign during which only suspended samples were taken. Table 1 shows the details of each sediment campaign carried out in 2003. All the bedload samples were taken from the motorized cableway at Krókur, which is located approximately 2 km upstream of the old Highway 1 bridge. The suspended samples were on the other hand taken from three locations in each campaign, i.e. one sample from the cableway at Krókur, another sample was taken from the cableway midway between the old and new Highway 1 bridges using a new hydraulic winch, and the third sample was taken from the river bank beneath the old Highway 1 bridge using a handheld sampler.

Table 1: *Number of sediment samples taken at Krókur and Urriðafoss in 2003.*

Date	Location	No. of suspended samples	No. of bedload samples	No. of bedload grain size analyses
2003-07-02–	Krókur cableway	1	74	7
2003-07-03	Urriðafoss cableway	1	–	–
	Urriðafoss bridge	1	–	–
2003-08-07–	Krókur cableway	1	84	9
2003-08-09	Urriðafoss cableway	1	–	–
	Urriðafoss bridge	1	–	–
2003-09-02–	Krókur cableway	1	78	7
2003-09-03	Urriðafoss cableway	1	–	–
	Urriðafoss bridge	1	–	–
2003-10-29 and	Krókur cableway	1	76	14
2003-11-13 and	Urriðafoss cableway	1	–	–
2003-11-19/20	Urriðafoss bridge	1	–	–
2003-12-16	Krókur cableway	1	–	–
	Urriðafoss cableway	1	–	–
	Urriðafoss bridge	1	–	–
Total sediment samples		**15**	**312**	**37**

Figure 2 shows the discharge at Þjórsártún water gauge (vhm 30; V320) (Fig. 1) and timing of the sediment sampling both in connection with chemical samples (red squares) and total sediment campaigns (diamonds).

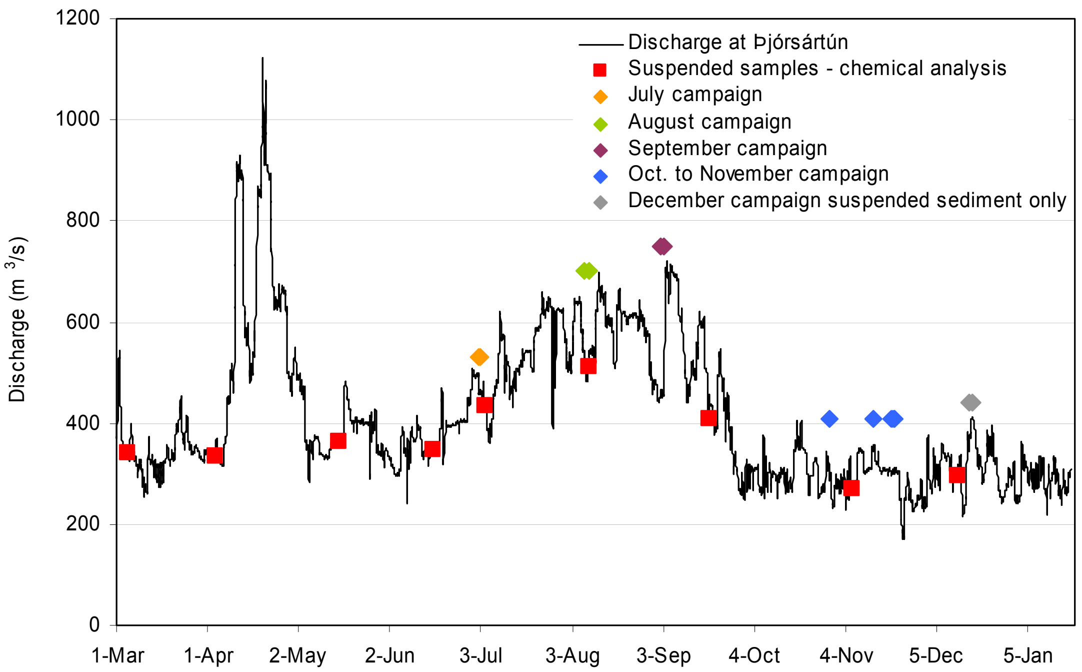


Figure 2: *Discharge at the Þjórsártún water gauge (vhm 30; V320) and the timing of sediment sampling in the lower reaches of Þjórsá in 2003.*

The discharge reached a maximum in April when spring floods occurred, but discharge was also relatively high during the summer as almost all the water was directed down the channel instead of being collected at reservoirs due to constructions at Þórisós.

The timing of sampling in association with chemical samples is well distributed throughout the year from March to December, although all such samples were taken at discharge less than 520 m^3/s. The first of the five sediment campaigns took place in July and the last one in December. These campaigns were carried out on a broad discharge spectrum from about 290 to 630 m^3/s (Fig. 2). The sampling campaign in late October was postponed because sampling was impossible as the water froze in the sampling bag. The campaign was finished in November instead.

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 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.

The samples collected from beneath the old Highway 1 bridge were always classified as S3 samples as they are taken with the handheld DH48. In contrast all samples collected from the cableways at Krókur and Urriðafoss are classified as S1 samples as they were taken from three or more locations across the channel. The samples at the Urriðafoss cableway were always taken with a S49 sediment sampler, but due to electrical difficulties at Krókur, only the samples taken in July and August were collected using the P61 sampler like in previous years, whereas the rest of the samples were taken with a S49 sampler. At Krókur the samples were taken at 40, 50, 60, 65, 70 80, 100, and 140 m. 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. 16 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. This year, the sampling bottles from the seven locations were combined prior to analysis instead of being analyzed separately before a weighted mean was calculated like in previous years (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002; 2003).

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 2). 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 2 for comparison.

Table 2: *Grain size classification used in this report for suspended sediment samples.*

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

Suspended 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.

Because the division into grain size classes is percentage based data, closed array problems are interlinked with such data handling. Hence, when percentage of one size class increases, the percentage of one or more classes must decrease. This must be kept in mind when the data are interpreted.

2.2 Bedload samples

2.2.1 Sampling procedure

The sampler used for retrieving bedload samples at the cableway at Krókur was of a Helley-Smith type, close to 48 kg, with a 7.6×7.6 cm opening, and a 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 usually remained for 120 seconds before it was pulled up again. The time differed, however, in the last campaign as the samples were taken over four different days. 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. The number of bedload samples collected in each campaign was between 74 and 84; however, no bedload samples were collected in December. In all campaigns when bedload sampling was carried out, one to two samples were collected from each station for grain size analysis at the Sedimentological Laboratory of the Hydrological Service (Table 1).

2.2.2 Bedload calculations

The bedload transport was calculated in the same way as for campaigns in 2001 and 2002 (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002; 2003). 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 15%, but could be higher for the smallest samples (up to 50%), 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 :

$$q_{b\,j} = \frac{1}{n_j} \sum_{i=1}^{n_j} \frac{M_i}{t_i d}$$

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). The size classes in phi and mm are shown in Table 3, which also includes the names of the size classes. Note that the names of the finer grain size classes is not equivalent to the names of the suspended grain size classes, where the bedload sand class is divided into *sandur* (>0.2 mm) and *grófmór* (0.06–0.2 mm).

Table 3: *Grain size classes used in bedload sieving.*

mm	ϕ	Size classes	mm	ϕ	Size classes
256	-8	Boulder	1,41	-0.5	Very coarse sand
64,0	-6	Cobble	1,00	0	
44,8	-5.5	Very coarse pebble	0,71	0.5	Coarse sand
32,0	-5		0.50	1	
22,4	-4.5	Coarse pebble	0,35	1.5	Medium sand
16,0	-4		0,25	2	
11,2	-3.5	Medium pebble	0,18	2.5	Fine sand
8,00	-3		0,125	3	
5,66	-2.5	Fine pebble	0,088	3.5	Very fine sand
4,00	-2		0,063	4	
2,83	-1.5	Very fine pebble/Granule	<0,063	>4	Silt and clay
2,00	-1				

Both the Udden-Wentworth scale and the linear Phi scale (ϕ) are shown in Table 3 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 using the Gradistat program procedure introduced by Blott and Pye (2001). Only the grain size >63µm was used in moment statistics calculations, but in all samples this fraction of the samples was negligible (<0.2%).

$$\text{Mean}: \qquad \bar{x}_\phi = \frac{\sum fm}{n}$$

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

$$\text{Skewness}: \qquad \overline{Sk}_\phi = \frac{\sum f\left(m - x_\phi\right)^3}{100\sigma_\phi{}^3}$$

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.

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

Although the sediment sampling in the lower reaches of Þjórsá was twofold, we have in the following chapters chosen to introduce the results by the location the samples were collected from instead of by the sampling program. Hence, in the following chapters the results from grain size analysis of the suspended sediment samples have been divided into three parts; S3 samples from beneath the old bridge above Urriðafoss, S1 samples from the Urriðafoss cableway, and S1 samples from Krókur.

3.1.1 Urriðafoss S3 samples

Altogether, 14 suspended sediment samples were taken in 2003 with the handheld DH48 rod sampler from the river bank below the old bridge on Highway 1. Nine of those were taken within the chemical sampling program funded by Landsvirkjun (National Power Company), and the Environmental and Food Agency of Iceland (see Sigurður R. Gíslason *et al.* 2004), but five samples were taken during sediment campaigns.

Table 4: *Grain size data on suspended S3 sediment samples from Þjórsá taken from beneath the old bridge on Highway 1 at Urriðafoss. Samples in other color than black represent samples from total sediment campaigns. The same color will be used throughout the report to distingish between campaigns.*

Date	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)	Largest part. (mm)
2003-03-04 14:15	340	26	58	33	29	9	22	7	0.8
2003-04-03 12:42	333	18	62	41	14	6	29	10	1.7
2003-05-15 11:45	363	24	53	37	18	7	34	4	1.0
2003-06-16 12:57	346	47	51	18	4	5	27	46	1.0
2003-07-03 18:28	466	152	45	29	3	4	22	42	2.2
2003-07-04 12:20	434	108	49	13	7	4	33	43	1.9
2003-08-07 22:30	484	123	39	1	21	3	15	60	0.1
2003-08-08 12:35	512	100	*52*	3	3	3	29	*62*	0.8
2003-09-03 23:20	699	294	41	31	9	8	32	20	1.8
2003-09-18 12:10	408	113	53	14	7	7	*32*	40	1.0
2003-11-06 12:20	269	53	55	39	8	8	16	29	2.1
2003-11-19 15:30	297	74	49	43	6	6	26	19	2.1
2003-12-12 11:10	296	25	57	45	11	6	17	21	1.2
2003-12-16 17:00	385	104	61	61	10	9	18	2	1.8

The results from all S3 suspended samples are shown in Table 4, whereas the division of the same samples into the five grain size classes (Table 2) is shown on Fig. 4. A distinct trend in grain size distribution is seen within the year with greatest percentage of the finer grain size classes, *méla* (0.002–0.02 mm) and *leir* (<0.002 mm), being observed during the months of June, July, August, and September. Except in the sample from September 3 the percentage of *leir* is 40% or higher in all these samples. During the winter months the percentage of *sandur* (>0.2 mm) is in contrast higher than in summer, or from over 30% to over 60% in the last sample from mid December (Fig. 4 upper). Such size distribution in S3 samples from Urriðafoss was also seen in 2001 and 2002 (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002; 2003) which is consistent with greater amount of fine fraction during the time of glacial melting.

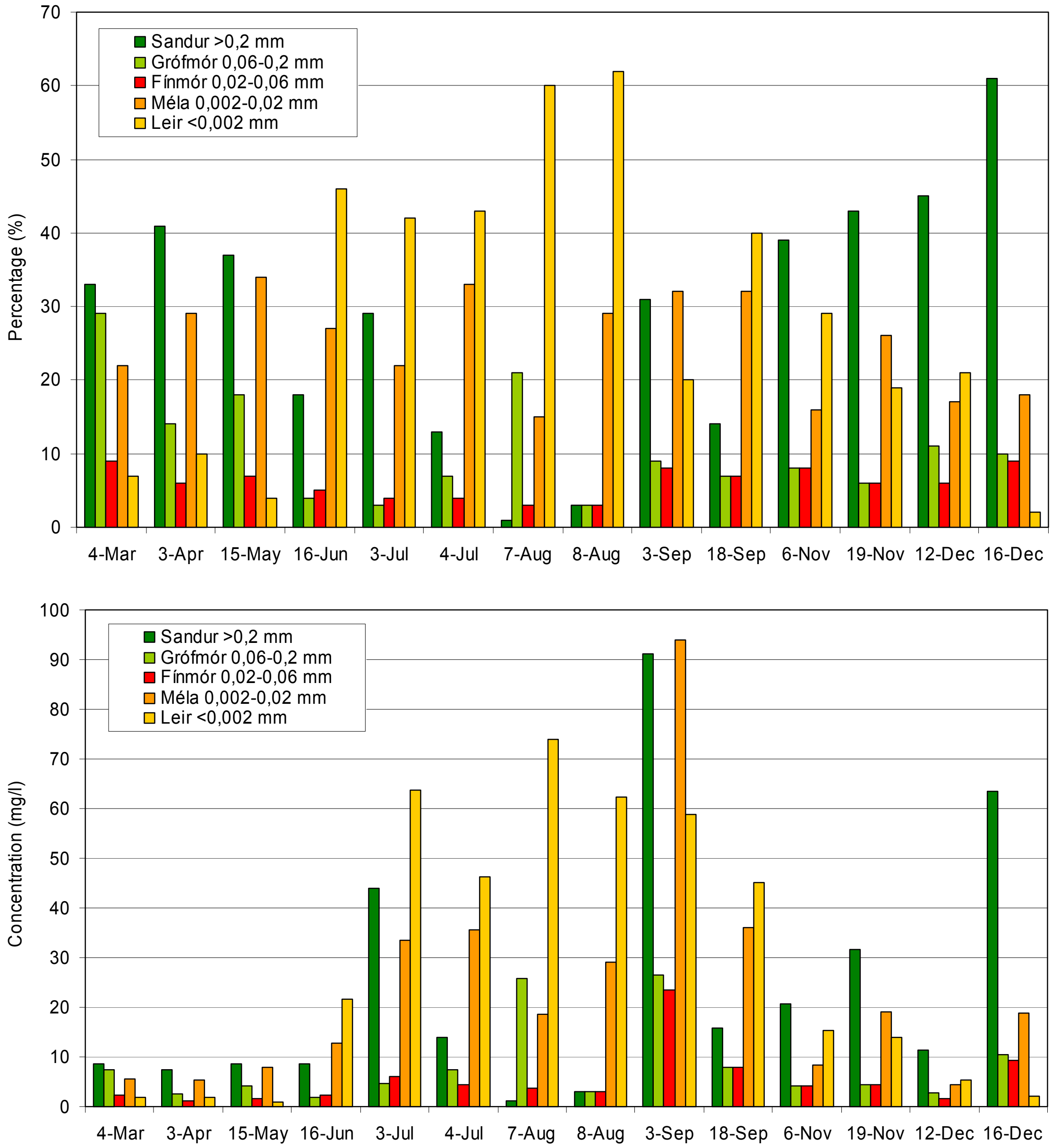


Figure 4: *Grain size distribution in S3 samples from Urriðafoss in 2003. Upper figure, percentage; Lower figure, concentration.*

The higher concentration of fine material during the summer months is even more pronounced when the concentration of individual grain size classes is observed (Fig. 4 lower).

3.1.2 Urriðafoss cableway samples

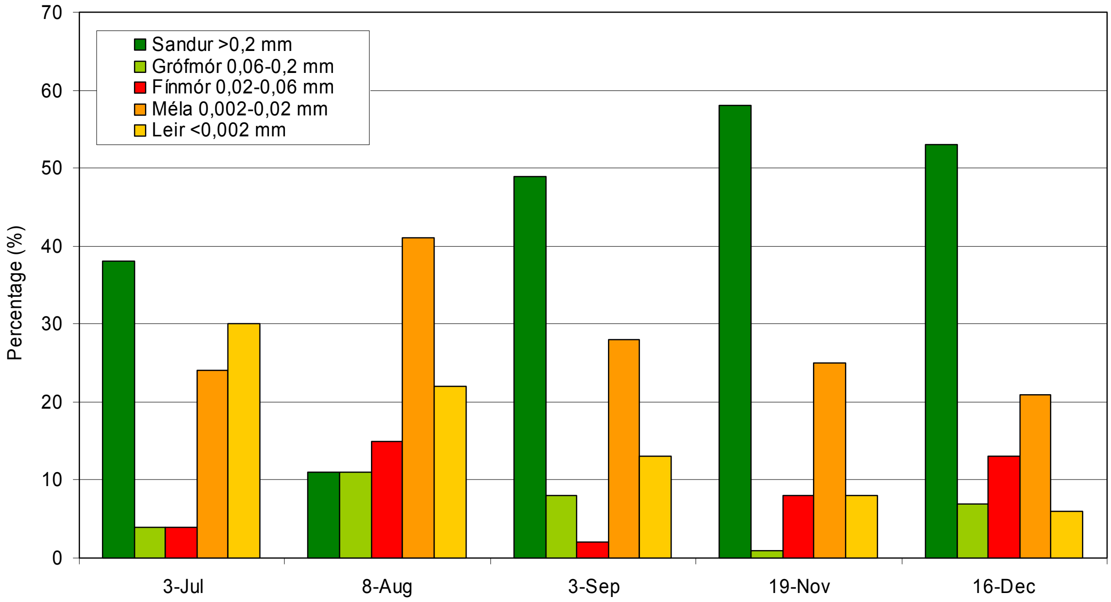
Five suspended samples were taken from the old cableway above Urriðafoss. These samples were all taken with the S49 sampler from three or more locations across the river channel and are thus classified as S1 samples. The results from the grain size analysis are shown in Table 5 and in Fig. 5. As with S3 samples from Urriðafoss, results are shown as both percentage and concentration.

Table 5: *Grain size data on suspended S1 sediment samples from Þjórsá taken from the old cableway above Urriðafoss. The color of the sample results corresponds to the sediment campaign they were obtained in.*

Date	Discharge (m^3/s)	Sediment (mg/l)	Dissolved (mg/l)	Sandur % (>0.2 mm)	Grófmór % (0.06–0.2 mm)	Fínmór % (0.02–0.06 mm)	Méla % (0.002–0.02 mm)	Leir % (<0.002 mm)	Largest part. (mm)
2003-07-03 21:07	480	188	56	38	4	4	24	30	1,5
2003-08-08 00:40	488	275	49	11	11	15	41	22	2,4
2003-09-03 21:49	702	498	40	49	8	2	28	13	1,6
2003-11-19 16:00	298	358	45	58	1	8	25	8	3,2
2003-12-16 17:30	387	184	56	53	7	13	21	6	2,7

The total sediment concentration varied from 184 mg/l in the December sample to 498 mg/l in the September sample, in which the discharge was highest of the sediment campaigns (Table 5).

The samples taken in November and December have the lowest fraction of fine sediment (*leir* (<0.,002 mm) and *méla* (0.002–0.02 mm)) both considering percentage and concentration data (Fig. 5). However, the difference between summer and winter samples is not as prominent as with S3 samples taken from the riverbank beneath the old Highway 1 bridge. The *leir* fraction is in all samples less than 30%, or 65 mg/l, whereas the *sandur* grain size class is the largest in four samples out of five, i.e. 38 to 58%, or from about 70 to 250 mg/l.



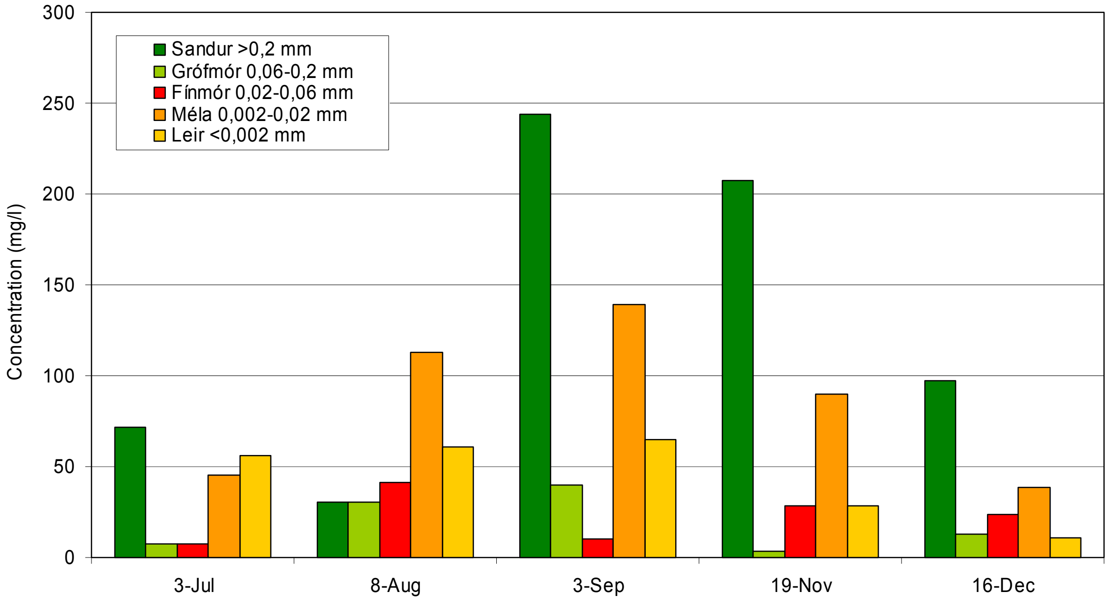


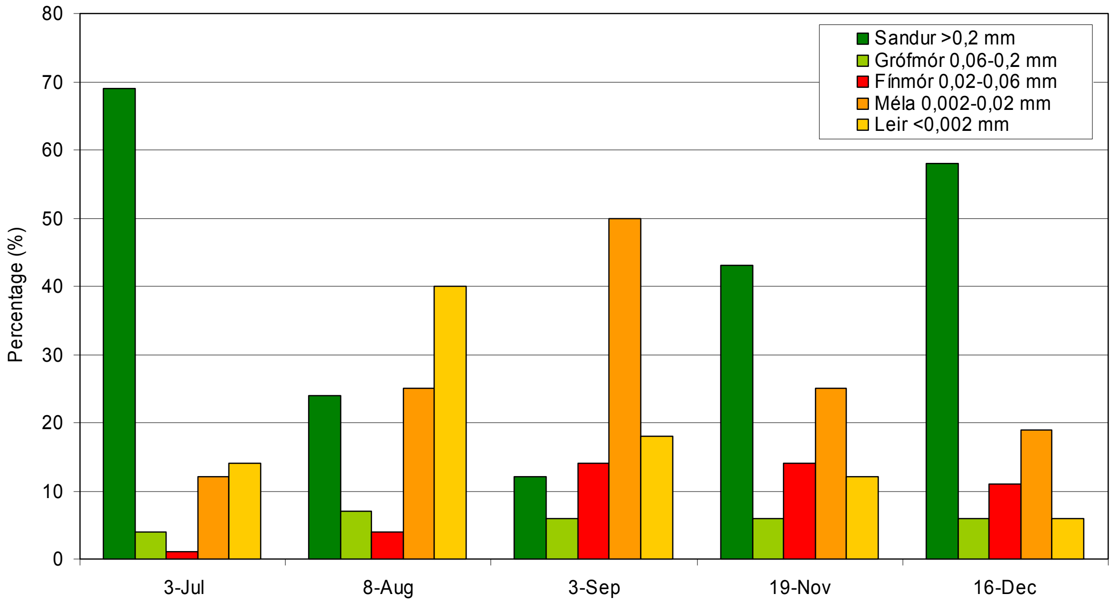
Figure 5: *Grain size distribution in S1 samples from Urriðafoss cableway in 2003. Upper figure, percentage; Lower figure, concentration.*

3.1.3 Krókur samples

Like in previous years, 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. However, in 2003 the samples from individual bottles were combined before analysis instead of being analyzed separately like in 2001 and 2002. The results from grain size analysis are shown in Table 6, and as for S1 and S3 samples from Urriðafoss the grain size classification is shown both percentage and concentration wise in Fig. 6.

Table 6: *Grain size data on suspended S1 sediment samples from Þjórsá taken from the motorized cableway at Krókur. The color of the sample results corresponds to the sediment campaign they were obtained in.*

Date	Discharge (m^3/s)	Sediment (mg/l)	Dissolved (mg/l)	Sandur % (>0.2 mm)	Grófmór % (0.06–0.2 mm)	Fínmór % (0.02–0.06 mm)	Méla % (0.002–0.02 mm)	Leir % (<0.002 mm)	Largest part. (mm)
2003-07-03 16:41	442	471	52	69	4	1	12	14	3,4
2003-08-07 17:15	510	166	46	24	7	4	25	40	1,2
2003-09-03 18:49	697	397	39	12	6	14	50	18	1,2
2003-11-19 13:45	297	144	48	43	6	14	25	12	1,4
2003-12-16 14:20	370	79	61	58	6	11	19	6	2,5



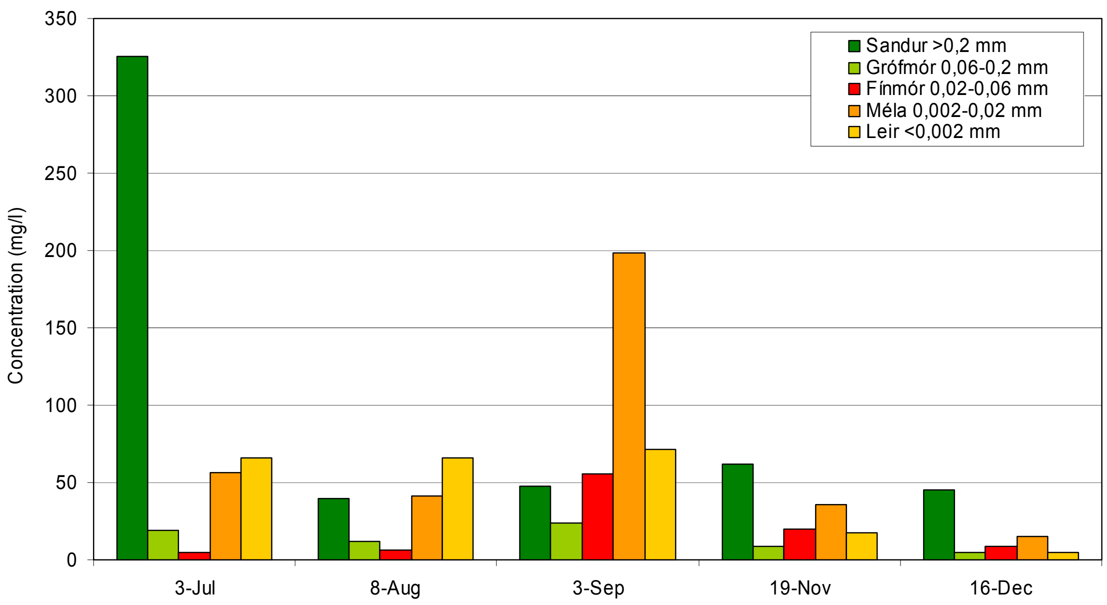


Figure 6: *Grain size distribution in S1 samples from Krókur in 2003. Upper figure, percentage; Lower figure, concentration.*

The total sediment concentration varied substantially among the five samples with highest concentration in samples taken in July and September (Fig. 6). The high concentration in the July sample is to a large extent caused by high concentration of *sandur* (>0.2 mm), >320 mg/l (69%), whereas the concentration of finer size classes (*leir* and *méla)* is more similar to the other summer samples from August and September. The highest concentration of all grain sizes except *sandur* is seen in the September sample, which was taken when discharge was close to 700 m^3/s, i.e. the highest during the five sampling campaigns. The total sediment concentration was lowest in the December sample, 79 mg/l, but in that sample the concentration of the fine grain size classes was especially low, 15 mg/l or less.

Because the sample bottles from each campaign were all analyzed together, it is not possible to evaluate the difference in grain size percentage or concentration across the channel like has been done in previous years. Instead more sample pairs from the three locations were analyzed.

3.1.4 Comparison between suspended samples from three locations

The three samples from each location were compared with each other to estimate better the difference between the sample types, and especially to better evaluate the error in sediment concentration of the S3 Urriðafoss samples.

Table 7: *Comparison of grain size results from suspended sediment samples from Krókur (K-S1) and the two types of Urriðafoss samples (U-S1 from the old cableway and U-S3 from beneath the old Highway 1 bridge).*

Time	Discharge (m^3/s)	Sediment (mg/l)	Dissolved (mg/l)	Sandur % (>0.2 mm)	Grófmór % (0.06–0.2 mm)	Fínmór % (0.02–0.06 mm)	Méla % (0.002–0.02 mm)	Leir % (<0.002 mm)	Larg. part. (mm)	Sample type
2003-07-03 16:41	442	471	52	69	4	1	12	14	3,4	K-S1
2003-07-03 18:28	466	152	45	29	3	4	22	42	2.2	U-S3
2003-07-03 21:07	480	188	56	38	4	4	24	30	1,5	U-S1
U. bridge/Krókur	*1.05*	*0.32*	*0.87*	*0.42*	*0.75*	*4.00*	*1.83*	*3.00*	*0.65*	
U. cableway/Krókur	*1.08*	*0.40*	*1.08*	*0.55*	*1.00*	*4.00*	*2.00*	*2.14*	*0.44*	
2003-08-07 17:15	510	166	46	24	7	4	25	40	1.2	K-S1
2003-08-07 22:30	484	123	39	1	21	3	15	60	0.1	U-S3
2003-08-08 00:40	488	275	49	11	11	15	41	22	2.4	U-S1
U. bridge/Krókur	*0.95*	*0.74*	*0.85*	*0.04*	*3.00*	*0.75*	*0.60*	*1.50*	*0.08*	
U. cableway/Krókur	*0.96*	*1.66*	*1.07*	*0.46*	*1.57*	*3.75*	*1.64*	*0.55*	*2.00*	
2003-09-03 18:49	697	397	39	12	6	14	50	18	1.2	K-S1
2003-09-03 23:20	699	294	41	31	9	8	32	20	1.8	U-S3
2003-09-03 21:49	702	498	40	49	8	2	28	13	1.6	U-S1
U. bridge/Krókur	*1.00*	*0.74*	*1.05*	*2.58*	*1.50*	*0.57*	*0.64*	*1.11*	*1.50*	
U. cableway/Krókur	*1.00*	*1.25*	*1.03*	*4.08*	*1.33*	*0.14*	*0.56*	*0.72*	*1.33*	
2003-11-19 13:45	297	144	48	43	6	14	25	12	1.4	K-S1
2003-11-19 15:30	297	74	49	43	6	6	26	19	2.1	U-S3
2003-11-19 16:00	298	358	45	58	1	8	25	8	3.2	U-S1
U. bridge/Krókur	*1.00*	*0.51*	*1.02*	*1.00*	*1.00*	*0.43*	*1.04*	*1.58*	*1.50*	
U. cableway/Krókur	*1.00*	*2.49*	*0.94*	*1.35*	*0.17*	*0.57*	*1.00*	*0.67*	*2.29*	
2003-12-16 14:20	370	79	61	58	6	11	19	6	2.5	K-S1
2003-12-16 17:00	385	104	61	61	10	9	18	2	1.8	U-S3
2003-12-16 17:30	387	184	56	53	7	13	21	6	2.7	U-S1
U. bridge/Krókur	*1.04*	*1.05*	*1.67*	*0.82*	*0.95*	*0.33*	*0.72*	*1.05*	*1.67*	
U. cableway/Krókur	*1.05*	*0.91*	*1.17*	*1.18*	*1.11*	*1.00*	*1.08*	*0.91*	*1.17*	

Table 7 shows the comparison of the three samples in each campaign and the calculated ratio of the Urriðafoss sample types vs. the Krókur samples (U-S1/K-S1 and U-S3/K-S1). The difference in discharge, total and dissolved sediment concentration, the different grain size percentages, and the largest particles is shown. The Krókur samples were always taken first, then the S3 Urriðafoss samples from underneath the old Highway bridge, and finally the S1 samples on the old cableway. When the suspended sediment samples were taken, the sampling was set up so that as little time as possible passed between the sample retrievals. The shortest time between the Krókur and the S1 sample from the Urriðafoss cableway was 2 hours and 15 minutes, but was over 7 hours when the longest time passed between the samplings.

The water level gauge is located at Þjórsá between Krókur and the Urriðafoss sampling sites; however, in this comparison the discharge was not corrected for the time it takes the river to flow between the sampling site and the gauge. This has to be taken into account when the differences in discharge at the time of sampling are compared. In July and December the discharge was 4 to 8% lower when the samples were taken at Krókur than at Urriðafoss in contrast to how it was in August when the discharge was 4–5% greater at Krókur than Urriðafoss. The difference was on the contrary less than 1% in September and November (Table 7).

To better visualize the results, the ratios for the Urriðafoss bridge/Krókur (U-S3/K-S1) and the Urriðafoss cableway/Krókur (U-S1/K-S1) samples are compared with discharge in Fig. 7. In four out of five sample pairs the total suspended sediment concentration in the S3 samples from Urriðafoss is less than in the Krókur samples, whereas the same number of S1 samples from Urriðafoss have greater concentration of suspended sediment than at Krókur. These results indicate that the S3 Urriðafoss samples underrepresent the sediment discharge compared to the Krókur samples, whereas the Krókur samples underrepresent the sediment discharge compared to the S1 Urriðafoss samples.

Figure 7 also shows how the individual grain size classes compare between the three locations. The *sandur* ratio is rather similar for the two Urriðafoss types from each campaign, where only the sample from September (taken at Q=702 m^3/s) has much higher *sandur* ratio in both Urriðafoss samples than the corresponding Krókur samples (Fig. 7). The percentage ratios of *fínmór* and *méla* of the two Urriðafoss sample types are also similar in all campaigns except the one taken around 500 m^3/s, in which the ratios for the two Urriðafoss types differ considerably. However, although the S1 and S3 ratios are similar for *fínmór* and *méla* in each of the four campaigns their values differ from one campaign to another.

In four campaigns out of five the S3 samples have higher or similar concentration of *grófmór* (0.06–0.2 mm) and *leir* (<0.002 mm) than the S1 samples from Krókur (U-S3/K-S1>1). The same is true in S1 samples for Urriðafoss for *grófmór,* but the opposite for the *leir* concentration which is lower in four of the S1 Urriðafoss samples than Krókur samples.

Compared with sample ratios from 2001 and 2002 the differences between coarse and fine grain size fractions are not as distinct in the 2003 samples. In previous years the S3 Urriðafoss samples showed more distinct difference between coarse and fine grain size fractions, with the percentage of coarser grain concentration being less than at Krókur and the concentration percentage of *fínmór*, *méla*, *leir* being greater at Urriðafoss (S3 samples) than at Krókur.

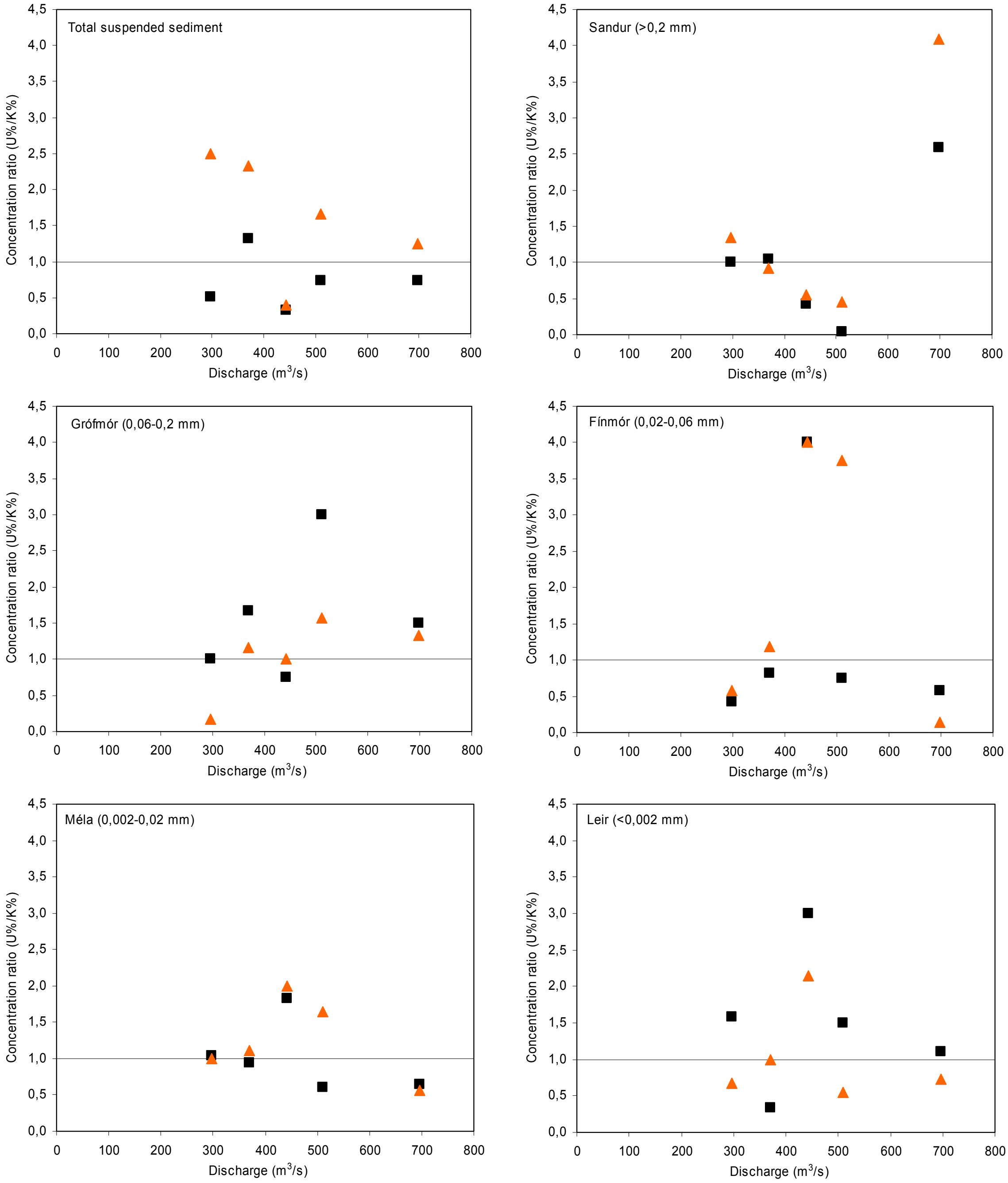


Figure 7: *Sediment ratio of total concentration and individual grain size classes (in %) between Krókur samples (K%) and the two different types of Urriðafoss samples (U%) (U-S1/K-S1 ratio is indicated with black squares and U-S3/K-S1 ratio is shown with orange triangles). The discharge value used is the one for the Krókur sample.*

Figure 8 shows the suspended sediment concentration and transport against discharge in the samples taken in 2003 at the three locations in lower Þjórsá. For comparison the same values for sediment samples taken in 2001 and 2002 are shown.

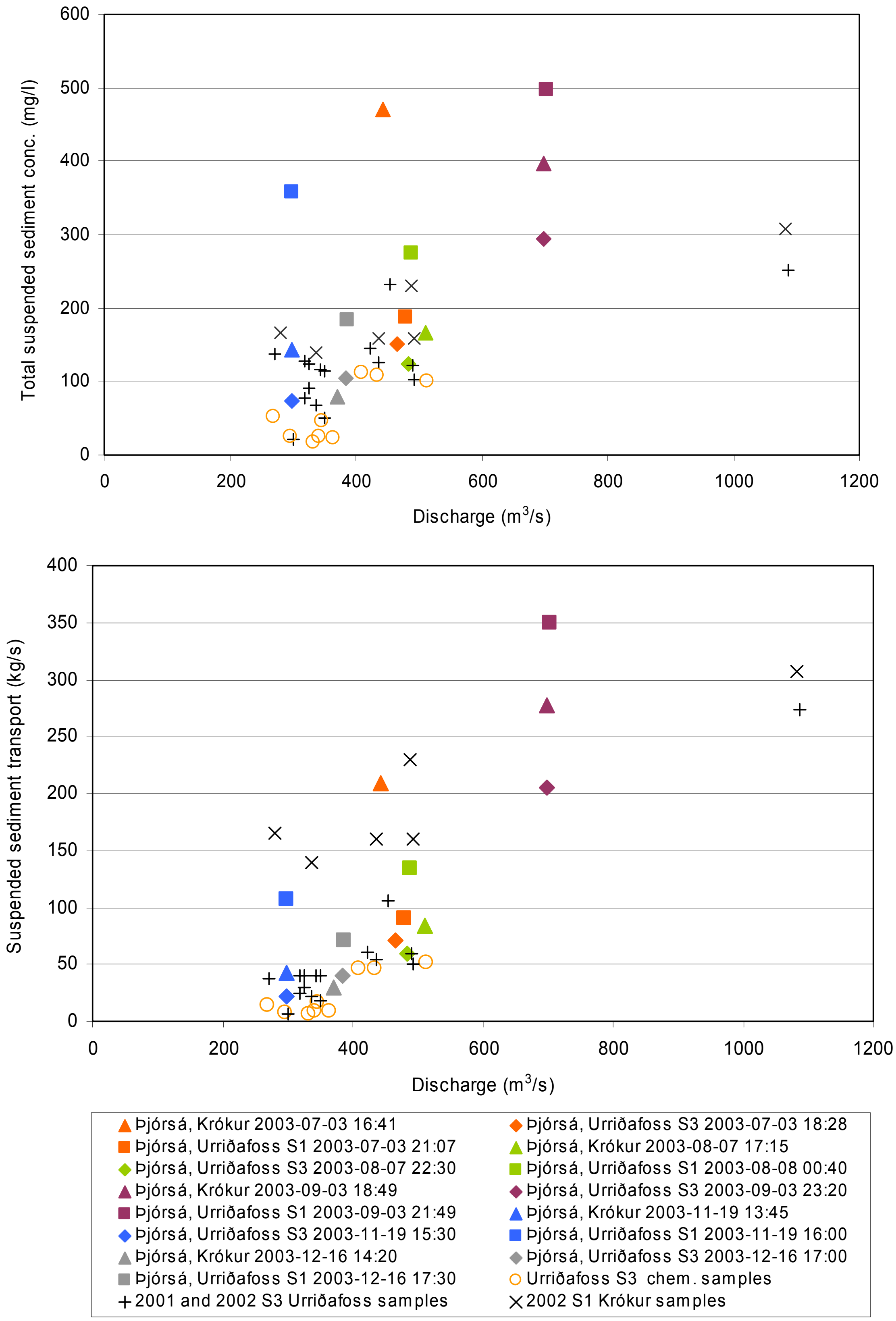


Figure 8: *Relationship between suspended sediment concentration (upper) and suspended sediment transport (lower) vs.discharge for samples taken at Krókur and Urriðafoss in 2003. Results from 2001 and 2002 are shown for comparison. The samples are color-coded according to each campaign to ease comparison of sample types in each sediment campaign.*

Of the samples taken in the five sediment campaigns, only the S3 samples from Urriðafoss show a good correlation of increasing sediment concentration and transport with increasing discharge (R2=0.94). The correlation value for the other sample types is around 0.3.

Figure 8 shows, as well as Fig. 7, how the concentration and transport is highest at the Urriðafoss cableway in four sample campaigns out of five. Similarly, the S3 samples from Urriðafoss have lower sediment concentration and transport values than the other sample types in four out of five sediment campaigns.

3.2 Bedload samples

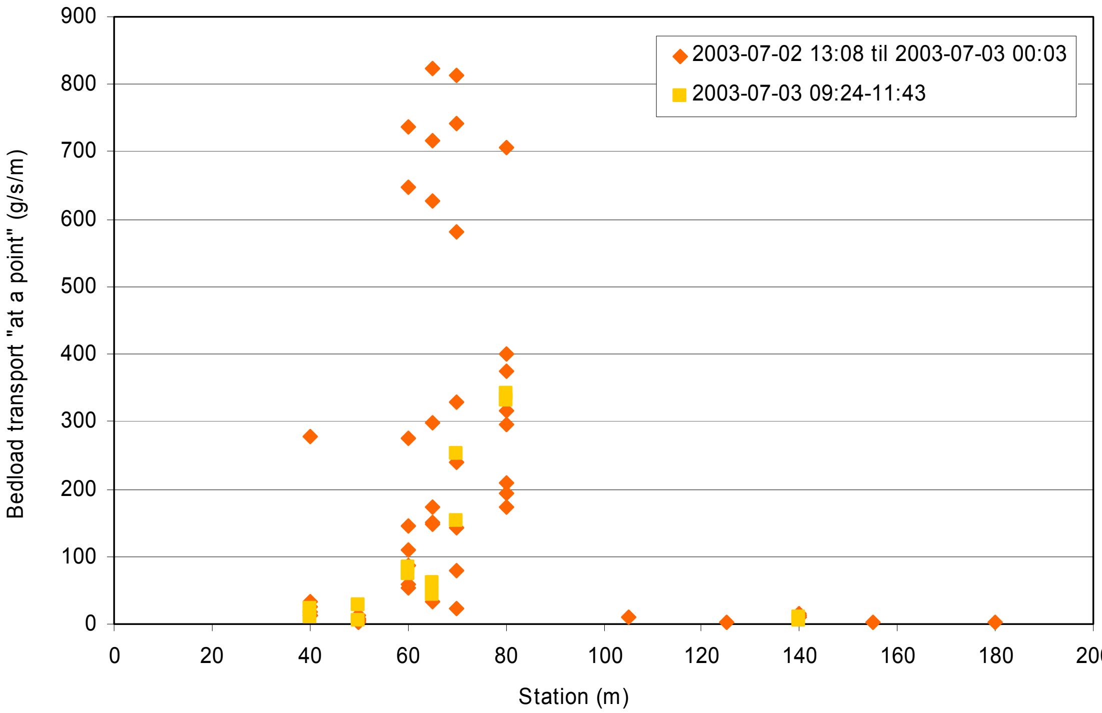
3.2.1 Bedload transport

In 2003, 312 bedload samples were collected from the cableway at Krókur in four of the five total sediment campaigns (Table 1). The samples were taken at 40, 50, 60, 65, 70, 80, and 140 m in all campaigns, but in addition 2 to 4 samples were taken between 80 and 200 m; most often at 105, 125, 155, and 180 m. These extra samples were used to better evaluate the bedload transport in the ca. 120-m-wide section from 80 m to the right bank. Those samples were not used in calculations, but are instead used to confirm bedload transport at around 140 m.

In the first three campaigns the bedload samples were taken over two days whereas the samples were taken over a period of four alternate days in the last campaign. This last campaign had to be postponed twice due to malfunction in the motorized cableway and poor weather conditions where the water froze in the sampling bags and hindered sediment sampling. Furthermore, the discharge varied somewhat during each campaign; hence the results were divided into smaller data sets for each discharge range and according to sampling days. The discharge range was smaller than 14 m^3/s in all data sets except on September 3rd when discharge varied over 41 and 90 m^3/s respectively during the two subsets.

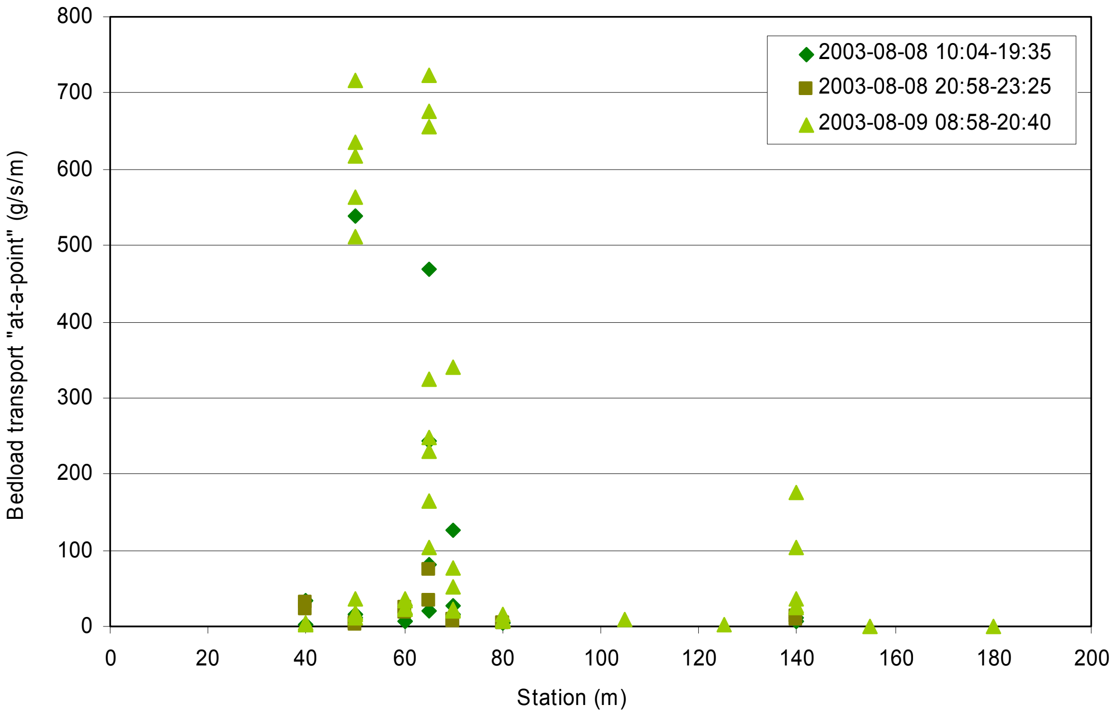
On Figs. 9 to 12 the results from each campaign are shown with a graph of sample transport in g/s/m and a table that portrays the transport data at each station, between station midpoints, total transport, as well as the mean discharge and its range. As in earlier reports bedload transport is calculated for the channel between 16 and 200 m which is the mean moving stretch of the river according to discharge measurements.

To summarize the information shown on Figs. 9 to 12 the mean transport at each station and between station midpoints is shown on Fig. 13. To try to distinguish between the many data subsets the color of the lines corresponds to the color scheme for each campaign shown on Figs. 9 to 12.



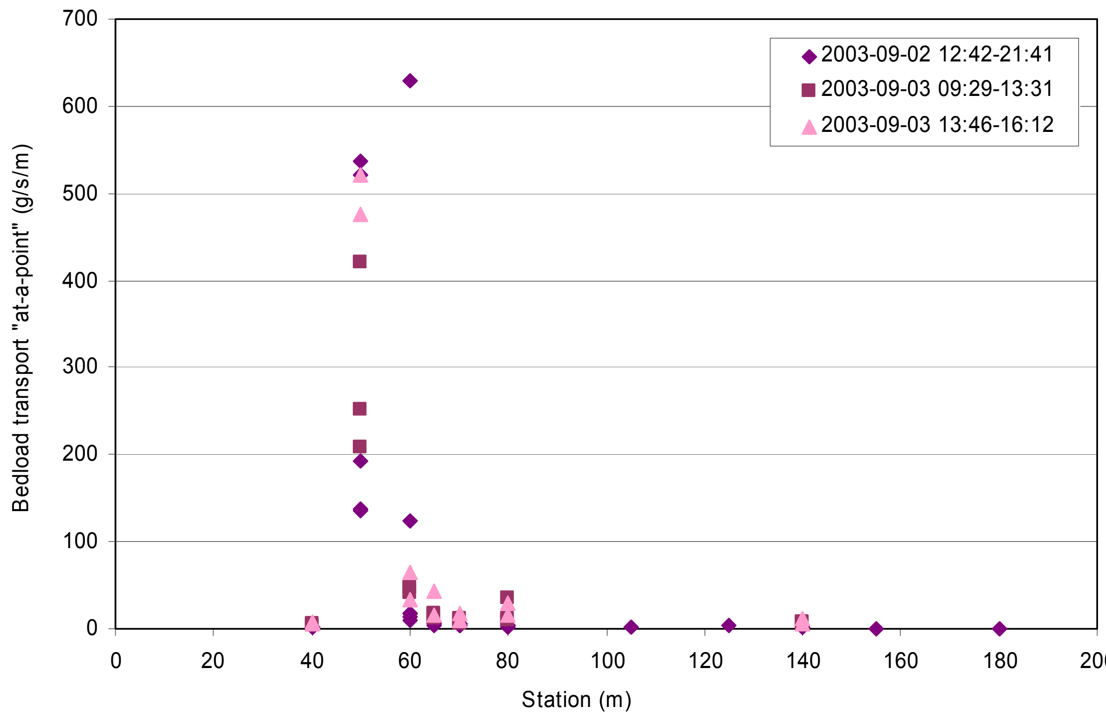
2003-07-02 13:08 to 2003-07-03 00:03	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=462 m^3/s
Mean bedload transport at each station (g/s/m)	50	6	264	371	368	334	11	Range Q=5.5 m^3/s
Total transport btw. station midpoints (g/s)	804	64	1981	1854	2763	11691	686	**Total transport 19.8 kg/s**
2003-07-03 09:24-11:43	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=444 m^3/s
Mean bedload transport at each station (g/s/m)	16	16	79	52	202	337	7	Range Q=3.8 m^3/s
Total transport btw. station midpoints (g/s)	259	160	592	258	1516	11778	440	**Total transport 15.0 kg/s**

Figure 9: *Results from bedload measurements during 2–3 July 2003.*



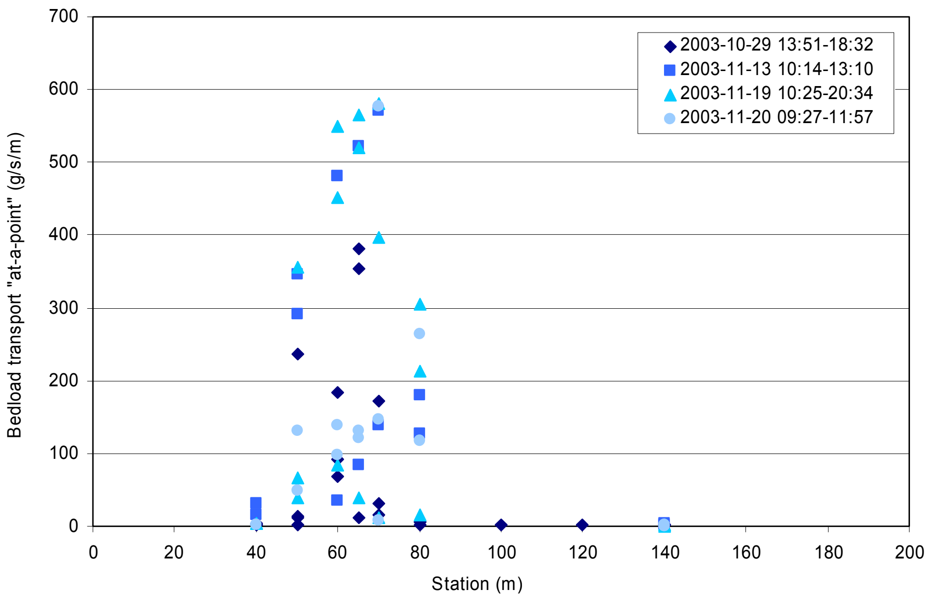
2003-08-08 10:04-19:35	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=513 m^3/s
Mean bedload transport at each station (g/s/m)	13	146	10	203	56	4	8	Range Q=10.3 m^3/s
Total transport btw. station midpoints (g/s)	204	1457	76	1017	422	149	472	**Total transport 3.8 kg/s**
2003-08-08 10:04-19:35	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=534 m^3/s
Mean bedload transport at each station (g/s/m)	27	3	21	55	8	4	11	Range Q=13.9 m^3/s
Total transport btw. station midpoints (g/s)	430	33	160	275	59	149	643	**Total transport 1.8 kg/s**
2003-08-09 08:58-20:40	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=542 m^3/s
Mean bedload transport at each station (g/s/m)	3	348	28	391	102	10	73	Range Q=10.2 m^3/s
Total transport btw. station midpoints (g/s)	48	3476	214	1954	765	366	4391	**Total transport 11.2 kg/s**

Figure 10: *Results from bedload measurements during 8–9 August 2003.*



2003-09-02 12:42-21:41	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=455 m^3/s
Mean bedload transport at each station (g/s/m)	2	305	135	7	5	4	2	Range Q=7.8 m^3/s
Total transport btw. station midpoints (g/s)	34	3046	1015	35	37	136	121	**Total transport 4.5 kg/s**
2003-09-03 09:29-13:31	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=551 m^3/s
Mean bedload transport at each station (g/s/m)	5	294	45	15	9	19	7	Range Q=90 m^3/s
Total transport btw. station midpoints (g/s)	72	2937	341	76	68	663	416	**Total transport 4.6 kg/s**
2003-09-03 13:46-16:12	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=630 m^3/s
Mean bedload transport at each station (g/s/m)	7	498	49	30	14	22	9	Range Q=41 m^3/s
Total transport btw. station midpoints (g/s)	110	4983	371	149	107	781	531	**Total transport 7.0 kg/s**

Figure 11: *Results from bedload measurements during 2–3 September 2003.*



2003-10-29 13:51-18:32	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=291 m^3/s
Mean bedload transport at each station (g/s/m)	3	66	114	249	73	5	2	Range Q=10 m^3/s
Total transport btw. station midpoints (g/s)	47	657	858	1246	545	164	94	**Total transport 3.6 kg/s**
2003-11-13 10:14-13:10	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=546 m^3/s
Mean bedload transport at each station (g/s/m)	23	319	259	303	354	154	3	Range Q=1.9 m^3/s
Total transport btw. station midpoints (g/s)	367	3187	1941	1515	2657	5397	201	**Total transport 15.3 kg/s**
2003-11-19 10:25-20:34	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=302 m^3/s
Mean bedload transport at each station (g/s/m)	3	154	362	375	330	177	1	Range Q=4.8 m^3/s
Total transport btw. station midpoints (g/s)	51	1538	2711	1874	2475	6209	79	**Total transport 14.9 kg/s**
2003-11-20 09:27-11:57	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7.5	5	7.5	35	60	Mean Q=302 m^3/s
Mean bedload transport at each station (g/s/m)	2	91	119	126	76	191	1	Range Q=2.5 m^3/s
Total transport btw. station midpoints (g/s)	36	906	892	632	574	6673	61	**Total transport 9.8 kg/s**

Figure 12: *Results from bedload measurements in October and November 2003.*

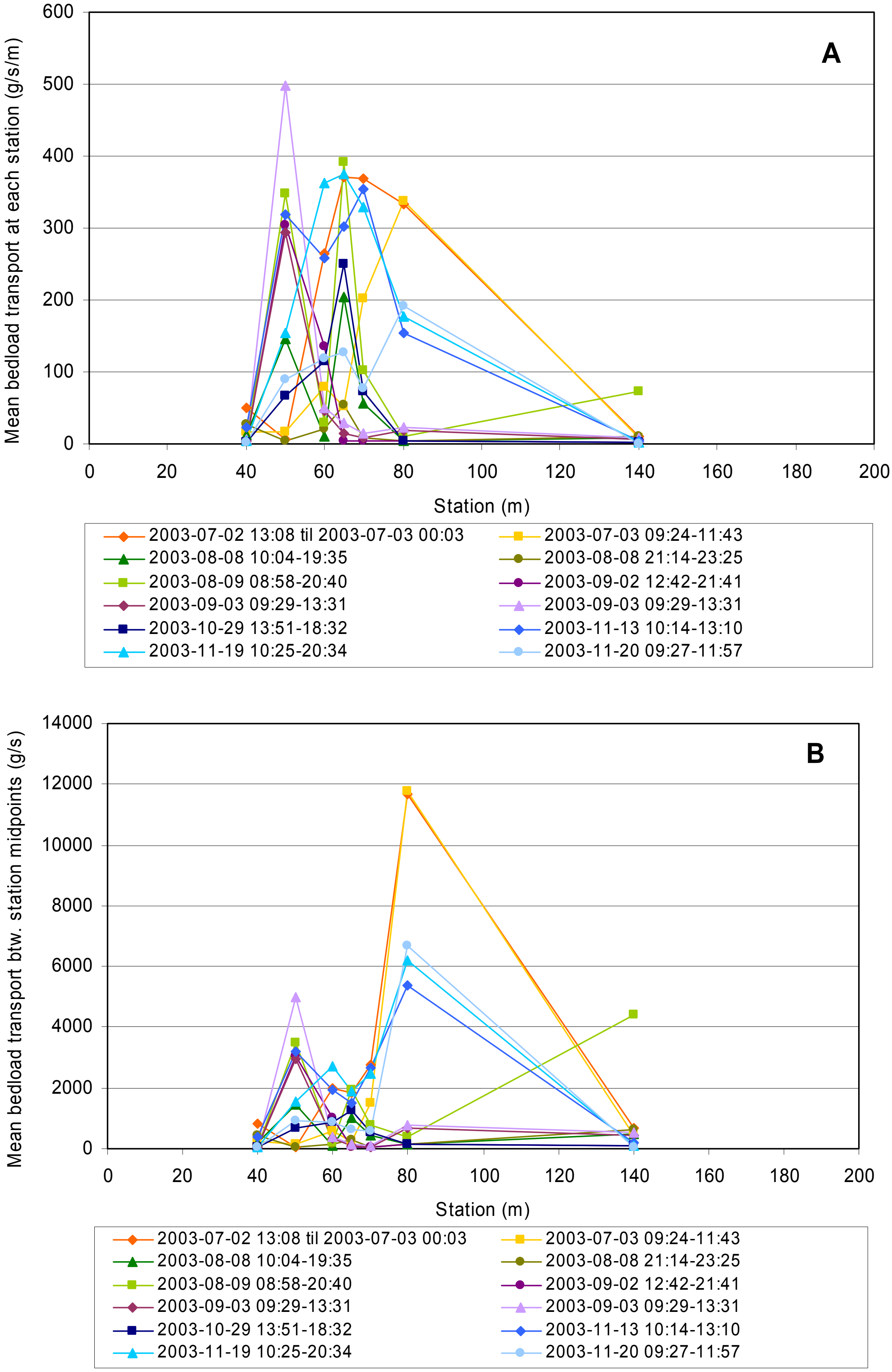


Figure 13: *A. Mean bedload transport at each station at Krókur 2003. B. Total bedload transport between station midpoints at Krókur 2003.*

The mean bedload transport at each station is very variable from one data set to another as well as from one station to another (Fig. 13A). However, most of the bedload was transported between 50 and 70 m in all bedload data sets except the two July campaign sets (orange/yellow) and in the November data sets (blue). In those data sets the amount of bedload observed at 80 m was much higher (150–330 g/s/m) than in all other sets (<35 g/s/m). The bedload transport over the long stretch of the channel from 80 to 200 m appears to have been small except on August 9 when it reached a mean value of 73 g/s/m. The supplementary samples taken at 105, 125, 155, and 180 m within each campaign support this result.

Due to the variable channel width the bedload data is calculated for, the values for bedload transport between station midpoints at the 80 m station are relatively higher than values for other station (Fig. 13B). Hence, the integrated bedload transport at 80 m in July and November is up to more than triple the transport at other stations between 50 and 70 m. As we do not have data to confirm this high bedload transport between 75 and 110 m, over which width the bedload between station midpoints is calculated (no samples were taken at 105 m during these days), we use these high values shown on Fig. 13B with caution. Similarly, the high value of bedload transport between station midpoints for the 140 m station on August 9 will probably also cause an overestimation of the total bedload across the channel.

The total bedload transport for each bedload data set is shown in Table 8. The results shown here are the values calculated using the formulas in chapter 2.2.2; however, the number in parenthesis indicates the recalculated total bedload for the 80 and 140 m stations. For the July and November data sets we integrated the 80-m-values for 25 m around the station instead of 35 m, and instead we used the 140-m-values for 10 m greater width. This reevaluation decreased the total bedload transport by over 3 kg/s in July and up to 1,9 kg/s in November (Table 8), but these values can shift even more if other widths are chosen. Although there are good indications that the 140-m-values on August 8 cause overestimation of the total bedload transport it is not easy to estimate the magnitude of such overestimation. In Table 8 we suggest a minimum number of about 8 kg/s for the total transport on August 8.

Table 8: *Results from bedload measurements at Krókur in 2003. Numbers in parenthesis show reevaluated values for total bedload as indicated in text.*

Campaign date	Mean discharge (m^3/s)	Range (m^3/s)	Total integrated bedload transport (kg/s)
2003-07-02 13:08-00:03	462	5.5	19.8 (16.5)
2003-07-03 09:24-11:43	444	3.8	15.0 (11.7)
2003-08-08 10:04-19:35	513	10.3	3.8
2003-08-08 21:14-23:25	534	13.9	1.7
2003-08-09 08:58-20:40	542	10.2	11.2 (~8)
2003-09-02 12:42-21:41	455	7.8	4.4
2003-09-03 09:29-13:31	551	90.2	4.6
2003-09-03 13:46-16:12	630	40.8	7,0
2003-10-29 13:51-18:32	291	10.0	3.6
2003-11-13 10:14-13:10	346	1.9	15.3 (13.8)
2003-11-19 10:25-20:34	302	4.8	14.9 (13.2)
2003-11-20 09:27-11:57	302	2.5	9.8 (7.9)

Figure 14 shows the relationship between total bedload and mean discharge during sampling. Both the values before and after reevaluation of the total bedload transport are shown for comparison for six of the data sets. The total bedload transport varied from about 1.7 kg/s to 19.8 kg/s, or 16.5 kg/s if the evaluated results are used. No correlation is seen between the total transport and discharge in these data unlike what was seen in 2002 when total transport increased significantly with discharge, if two values at discharge <300 m^3/s are excluded (Fig. 14).

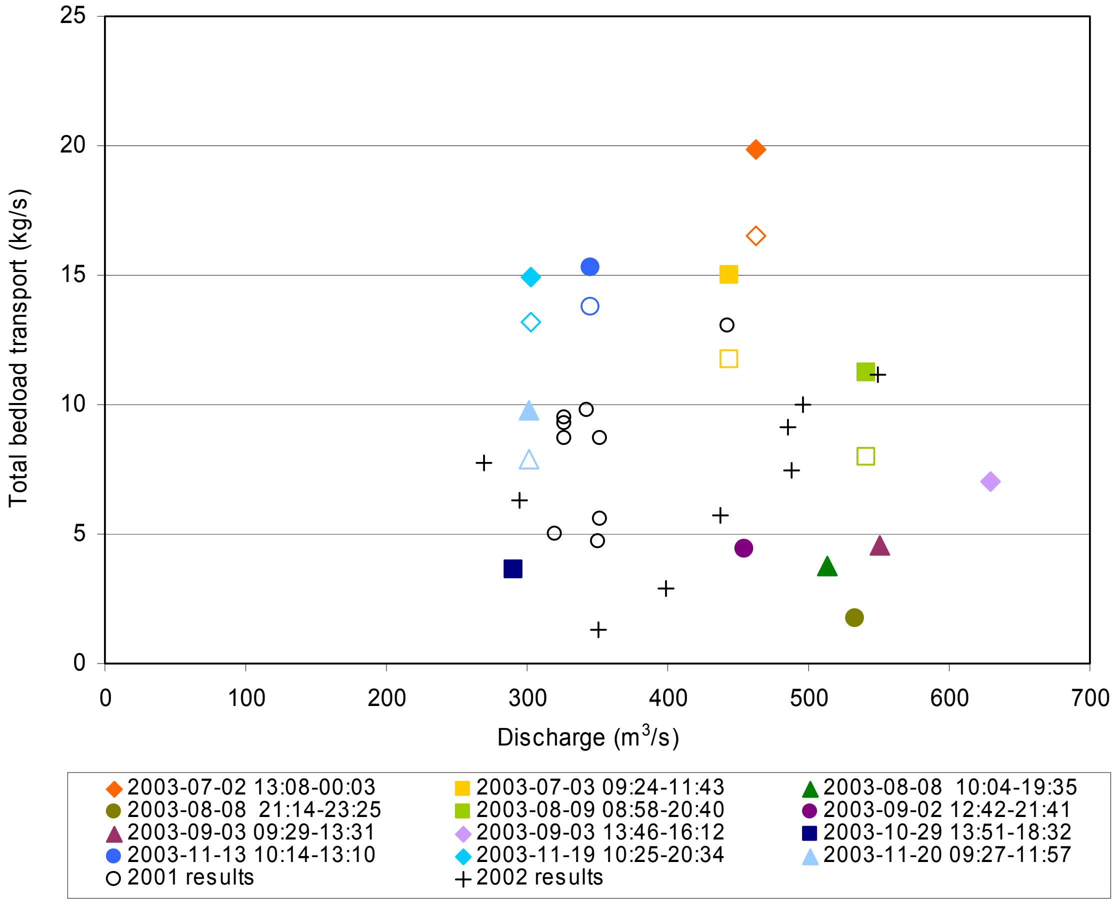


Figure 14: *Total bedload transport vs. mean discharge in the 2003 sediment campaigns. The reevaluated values discussed in the text are indicated with unfilled signs of the same color. Values from 2001 and 2002 (Q<550 m^3/s) are shown for comparison.*

3.2.2 Grain size of bedload samples

In all bedload campaigns sediment samples were taken from each of the seven stations, 40, 50, 60, 65, 70, 80, and 140 m for grain size analysis. Two extra samples were taken at 50 and 65 m in the August campaign, and in the October/November campaign an extra set of samples was taken at all stations as the sampling was spread over a long period. All 37 samples were analyzed for grain size analysis at the Sedimentology Laboratory of the Hydrological Service, as described in chapter 2.1.2.

The cumulative frequency graphs for each set of samples are shown on Figs. 15 to 19. The same colors are used in all five graphs for easier comparison. The grain size differed greatly between stations within each set of samples, but the grain size of the samples from each station varied also substantially. However, in the last three data sets the samples from 40 and 140 m included the finest material. The coarsest samples were in three data sets taken at 80 m, but up to 80% of the material in these samples is >-1.0 ϕ (2 mm) and classified as pebbles of variable size (Table 3).

In August two samples were taken during the same day at 50 and 65 m. The difference in grain size between these sample pairs (Fig. 16) display well the variability in the transported bedload material.

The variability in grain size between samples from different stations and between the different data sets is better displayed on Figs. 20 to 22 which show the results from moment statistics. The three coarse samples from 80 m are evident as well as the relatively fine-grained samples from 140 m. Considerable variability is seen between samples from each station in the middle of the channel from 50 to 70 m; this is where most of the bedload material was transported. It is also observed that the samples taken in the September campaign are usually one of the most fine-grained samples taken at each station (Figs. 17 and 20), even though they were taken at discharge around 450 m^3/s which is in the mean range of discharge (Fig. 14).

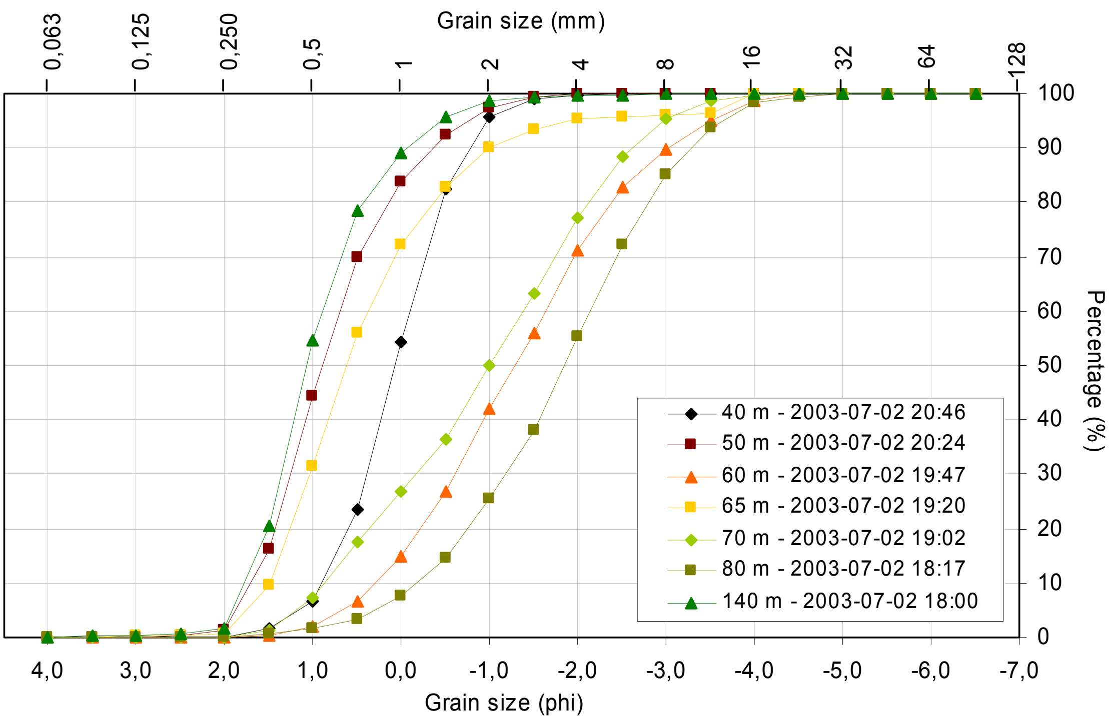


Figure 15: *Cumulative grain size curve for Krókur bedload samples collected July 2 2003.*

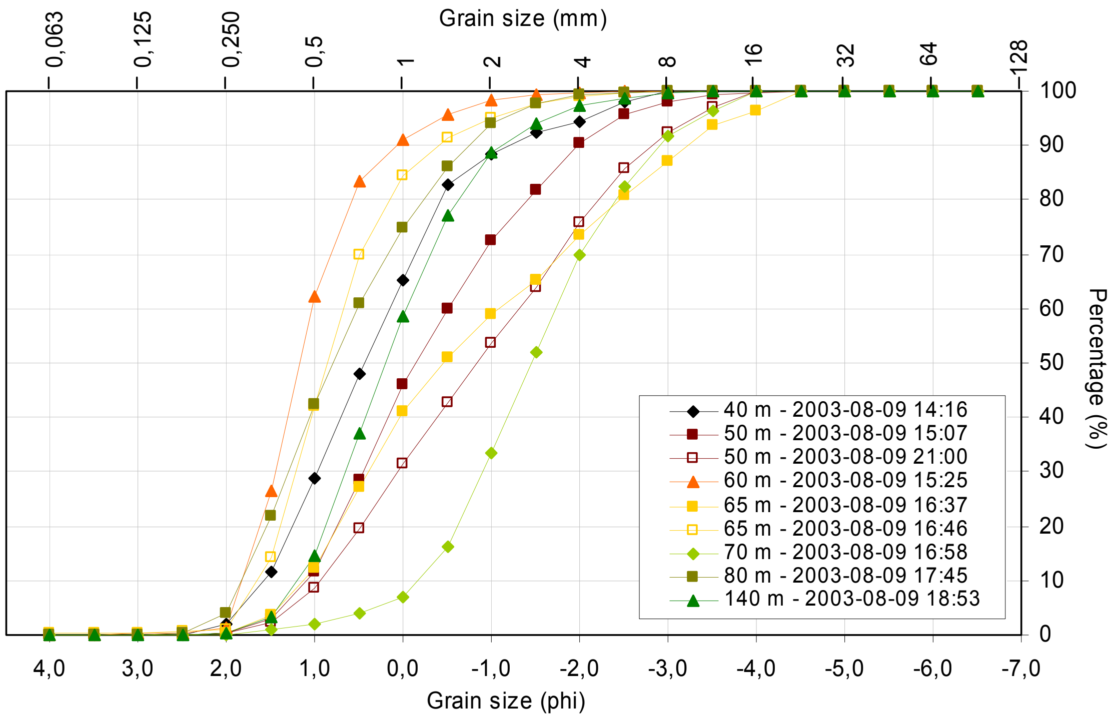


Figure 16: *Cumulative grain size curve for Krókur bedload samples collected August 9 2003.*

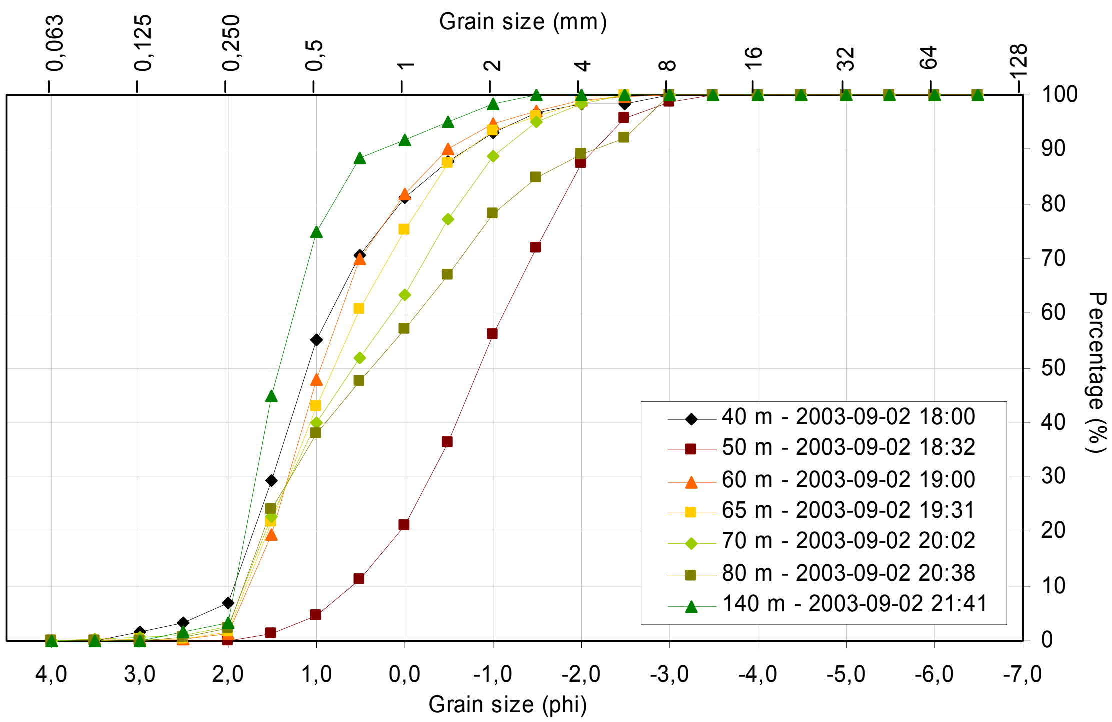


Figure 17: *Cumulative grain size curves for Krókur bedload samples collected September 2 2003.*

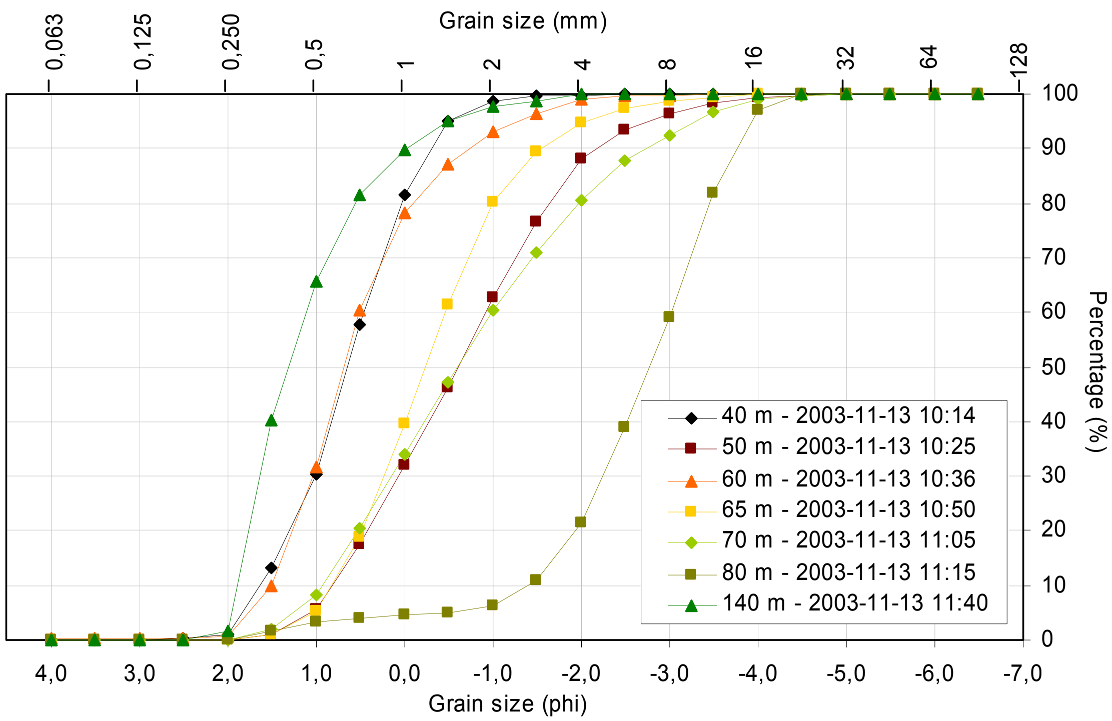


Figure 18: *Cumulative grain size curves for Krókur bedload samples collected November 13 2003.*

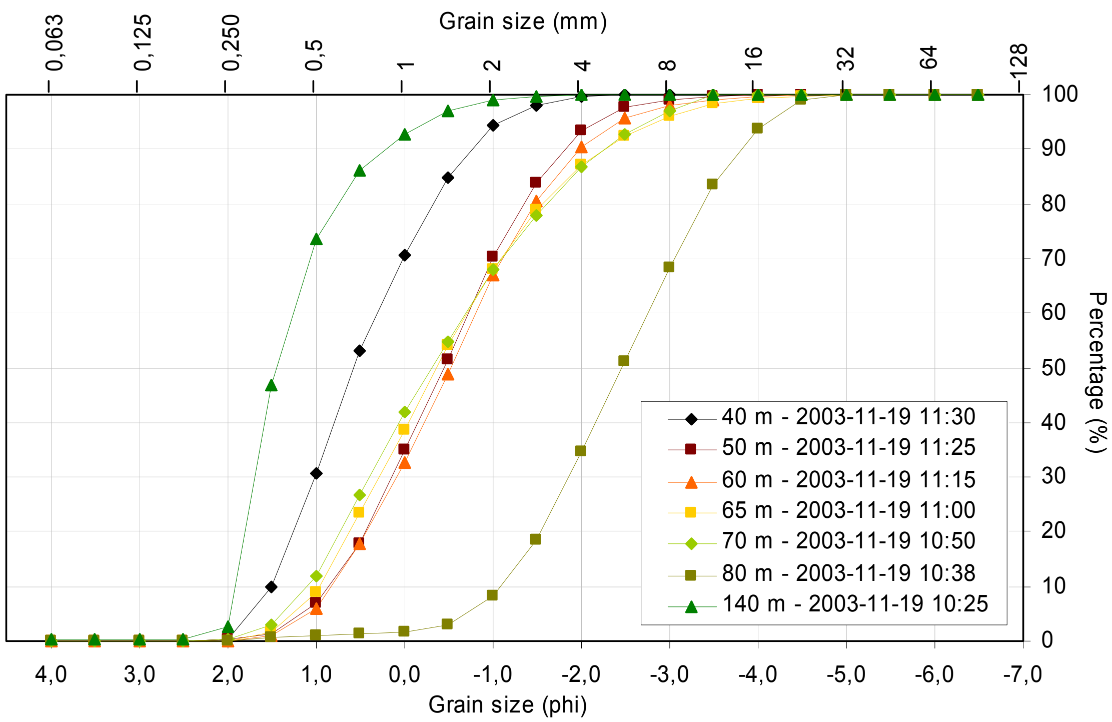


Figure 19: *Cumulative grain size curves for Krókur bedload samples collected November 19 2003.*

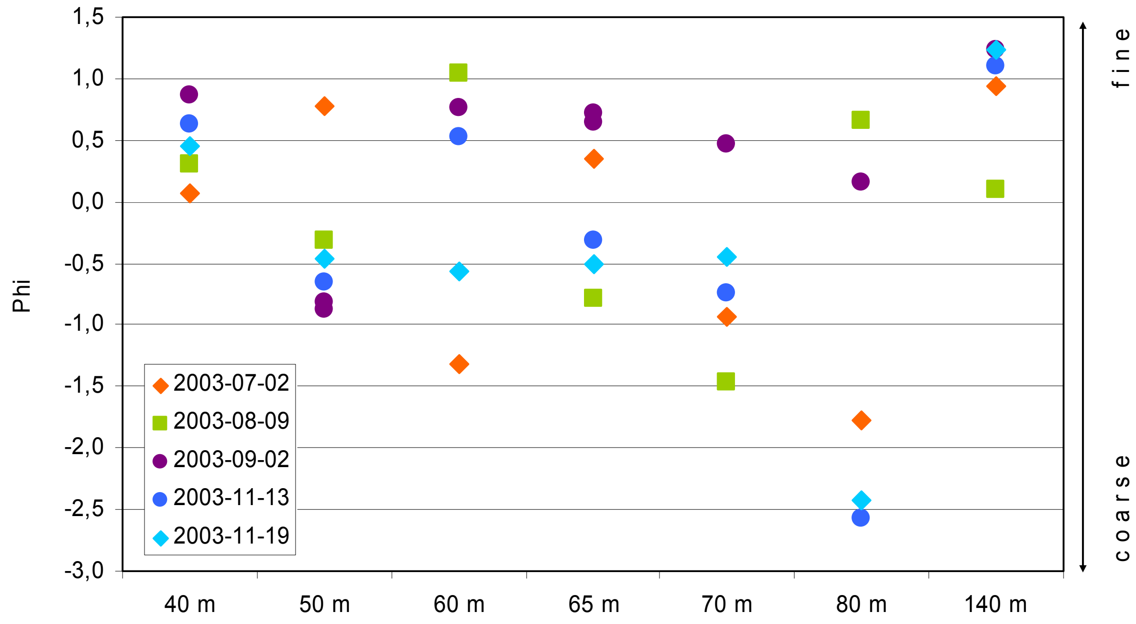


Figure 20: *Mean grain size (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2003.*

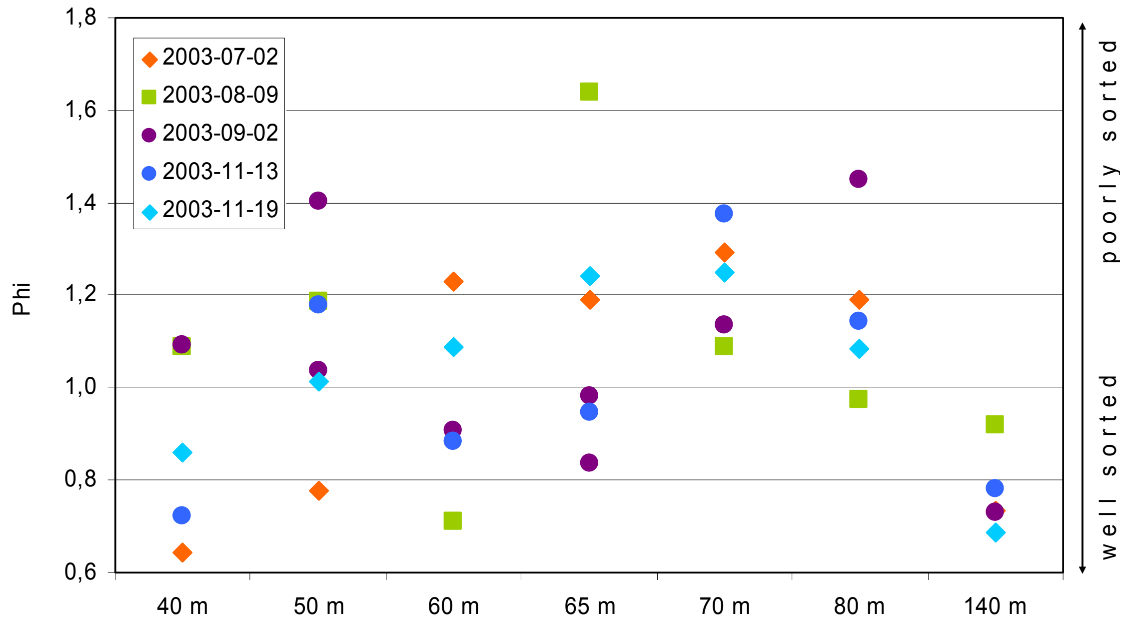


Figure 21: *Sorting values (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2003.*

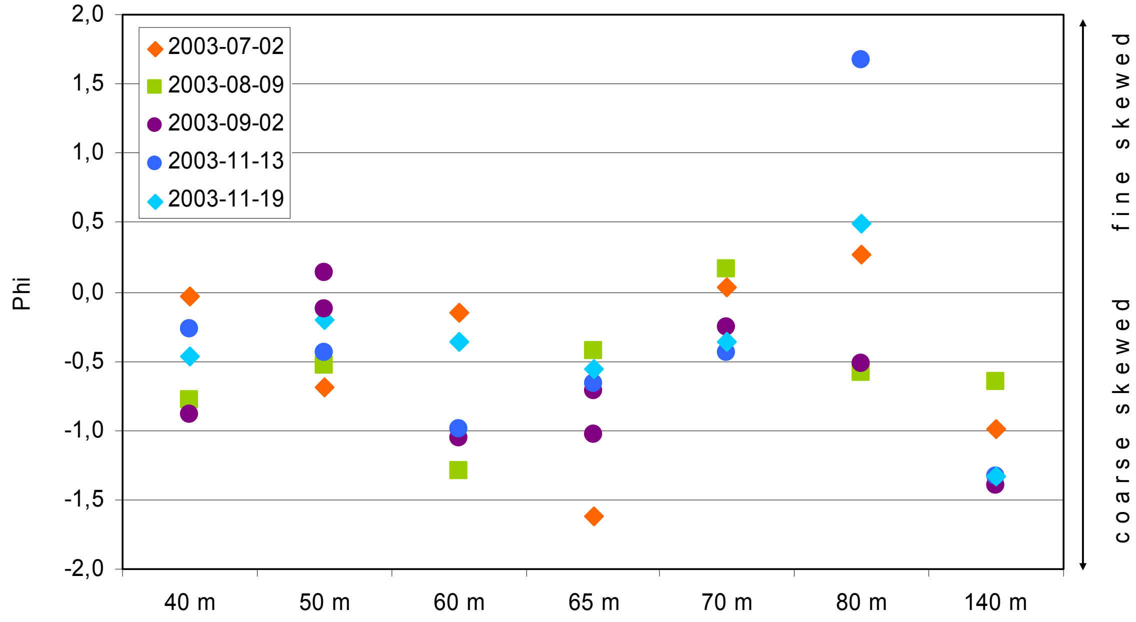


Figure 22: *Skewness values (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2003.*

The sorting values vary much between data sets especially at the station from 40 to 65 m (Fig. 21). Less variability is seen in sorting values at 70, 80, and 140 m, with relatively high values at 70 and 80 m and low values, i.e. relatively better sorted at 140 m. Skewness is shown on Fig. 22 where it is prominent that most of the samples have negative skewness values and are most symmetrical or coarsely skewed. Three of the samples from 80 m are though finer skewed than others.

For samples finer than -1.0 ϕ (2 mm) there is a reasonable correlation between smaller mean grain size and better sorting with a R^2=0.53 (Fig. 23A), although this correlation is not observed for coarser samples. Even better correlation is seen between grain size and skewness, where finer grained samples are more coarsely skewed than coarse samples (R^2=0.73)(Fig. 23B). Conversely, the relationship between sorting and skewness is much worse as is seen on Fig. 23C.

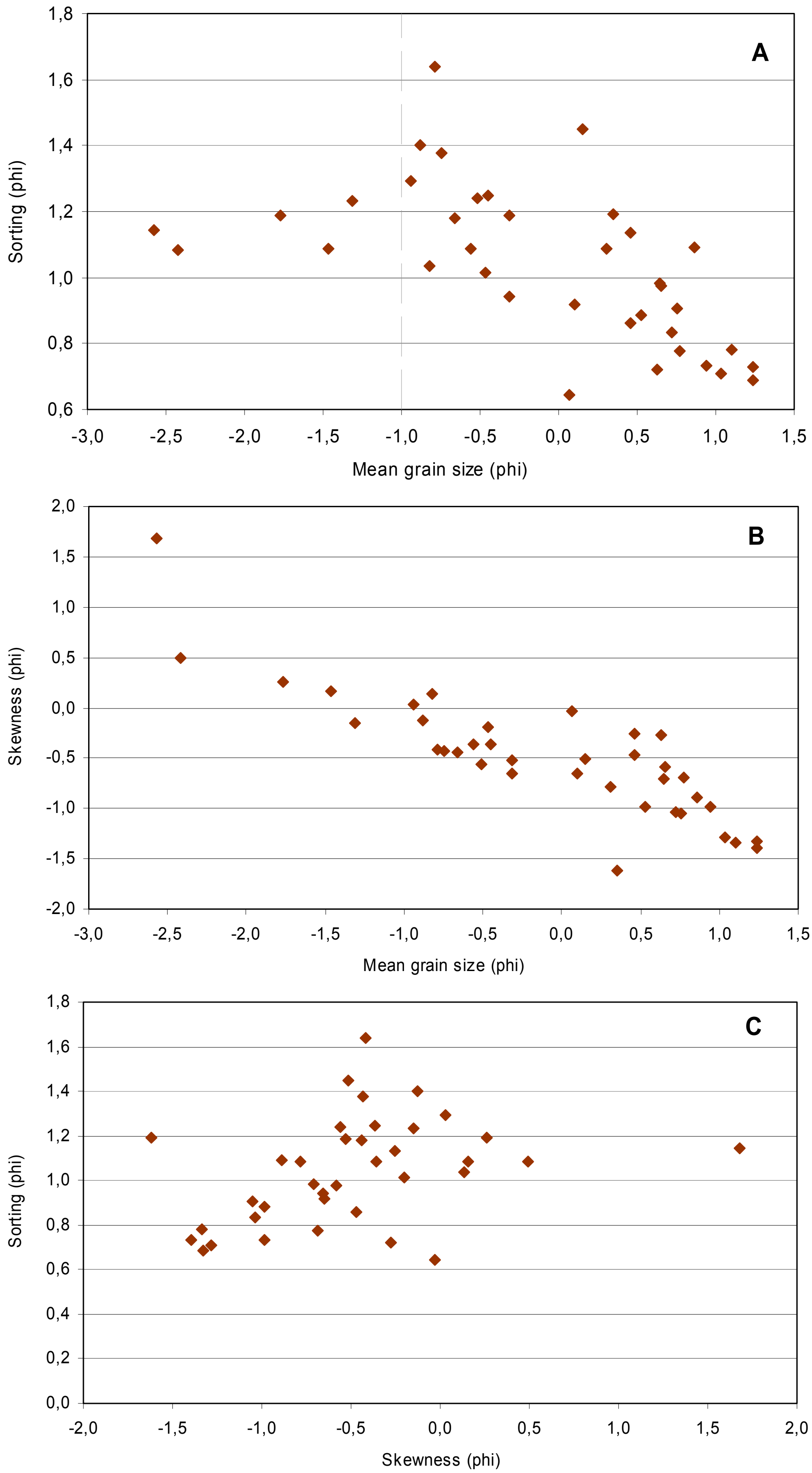


Figure 23: *Comparison of moment statistics values in 2003. A. Sorting vs. mean grain size; line represents a shift in correlation for grain size values above and below -1.0 ϕ. B. Skewness vs. mean grain size. C. Sorting vs. skewness.*

4 CONCLUSIONS

This report describes the results gathered during the third year of the extensive sediment sampling program initiated in 2001 at Krókur and Urriðafoss in the lower reaches of Þjórsá. The main objective of the program was threefold: 1) to obtain additional suspended samples at variable discharge values in Þjórsá; 2) to compare suspended samples from Krókur and Urriðafoss; and 3) continue the bedload sampling at Krókur to estimate the bedload transport in Lower Þjórsá.

Five sampling campaigns were carried out at Krókur and Urriðafoss in 2003 which were distributed over the year from July to December. In each campaign three suspended sediment samples were taken, one from the motorized cableway at Krókur, one from the Urriðafoss cableway, and one sample was taken with a handheld sediment sampler from the river bank beneath the old Highway 1 bridge. Bedload samples were additionally taken at Krókur in all campaigns except in December.

Moreover, nine suspended sediment samples were taken from beneath the old Highway 1 bridge as a part of another integrated study on chemical transport in rivers in South Iceland (Sigurður R. Gíslason *et al*. 2004) and those results are also shown here.

In the following chapters the main results from each part of these studies are summarized.

4.1 Suspended samples from Urriðafoss

Two types of samples were taken at Urriðafoss in 2003; fourteen samples were taken with a handheld rod-sampler from the river bank beneath the bridge on Highway 1 (S3 samples) and five samples (S1) were taken with the normal suspended sediment sampler (S49) from the cableway downstream of the bridge with a newly developed hydraulic winch.

Very distinct seasonal changes were seen in the S3 samples that were taken from the river bank with the handheld rod-sampler (Table 4; Fig. 4). The concentration of the finer grain size groups *méla* (0.002–0.02 mm) and *leir* (<0.002 mm) was significantly higher in the samples taken during the glacial melting time in June to September than in the winter samples. The winter samples had much higher percentage of *sandur* (>0.2 mm) than the summer samples, but the winter samples can be divided in two parts based on their concentration; i.e. samples taken in March to May had lower total sediment concentration than three out of four samples taken in November and December.

The S3 samples are highly susceptible to the sampling procedure as the grain size and concentration depends greatly on how far and deep into the main current the handheld rod-sampler reaches. It is possible that during the sampling of the coarser winter samples the rod was inserted deeper and closer to the river bed where the coarser material is transported as discharge was lower when these samples were obtained.

For these samples, as with other suspended sediment samples, it must though be emphasized that due to the closed array nature of percentage data which is the basis of the grain size classification shown here, one grain size group is bound to increase when another decreases.

The results from the five S1 samples which were taken from the Urriðafoss cableway are shown in Table 5 and on Fig. 5. Total sediment concentration of these samples ranges from 184 to 498 mg/l with the greatest concentration found in the sample taken at highest discharge. Seasonal changes are not obvious in these samples although *leir* (<0.002 mm) concentration is somewhat higher in the summer samples (>50 mg/l) that in the two winter samples (<30 mg/l). In four samples out of five is *sandur* the main grain size group; only in the August sample is the *sandur* percentage lowest of the grain size ratios.

4.2 Suspended samples from Krókur

Like in 2002 the five 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, but this year all the bottles were analyzed together as one sample instead of being analyzed individually.

The total suspended sediment concentration of the Krókur samples ranges from 79 to 471 mg/l with highest concentration in the July sample, which includes very high concentration of *sandur* (about 325 mg/l) that greatly increases the total concentration. Although inconclusive it is possible that the sediment sampler collected coarse material from the riverbed when this sample was obtained. The concentration of fine sediment (*leir* <0.002 mm and *méla* 0.002–0.02 mm) was higher in the summer samples (about 50 to 200 mg/l) than in the samples from November and December (9–36 mg/l), with the September sample with highest concentrations. This high concentration corresponds well with high discharge which was close to 700 m^3/s at the time of sampling.

4.3 Comparison of suspended sediment samples from Urriðafoss and Krókur

The three sample types were compared to try to evaluate the difference between them in total sediment concentration and grain size. When more sample pairs have been gathered these samples may also be used for comparison with older samples taken at the Urriðafoss cableway. Earlier studies of sample pairs from Krókur and S3 samples from Urriðafoss have shown that the Urriðafoss samples underrepresent sediment concentration and the *sandur* concentration in the latter is lower (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002, 2003). The results are shown in Table 7 and Fig. 7 shows the ratio of Krókur S1 samples and Urriðafoss S3 samples (U-S3/K-S1) and the ratio of Krókur S1 samples and Urriðafoss S1 samples (U-S1/K-S1) for the samples taken in 2003.

Like in the sample pairs from previous years the Urriðafoss S3 samples underestimate the total sediment concentration compared to the Krókur samples in four out of five samples, whereas four out of five S1 samples from the Urriðafoss cableway have higher sediment concentration than the Krókur samples. Although the U/K ratio for the total sediment concentration behaves dissimilarly for the two sample types, the *sandur* ratios are similar for the S1 and S3 samples from Urriðafoss, with higher sandur percentage in the majority of the Krókur samples than in both the Urriðafoss sample types. The U-S3/K-S1 ratio differs from one grain size class to another with four out of five S3 samples having higher or similar percentage of *grófmór* (0.06–0.2 mm) and *leir* (<0.002 mm) than the Krókur samples, but lower or similar percentage of *fínmór* (0.02–0.06 mm) and *méla* (0.002–0.02 mm). Greater difference is observed in the U-S1/K-S1 ratio between grain size groups although four out of five S1 samples from Urriðafoss have higher percentage of *grófmór* and lower of *leir* than their Krókur sample pair.

This substantial difference between the Krókur and the Urriðafoss sample types with both regard to grain size percentages and total suspended sediment concentration was also observed in 2001 and 2002. However, in 2003 the variability is not as consistent within each grain size group as it was in earlier years where the coarser grain sizes were underestimated in the Urriðafoss S3 samples, whereas the finer grain sizes were overestimated.

It is possible that this interannual difference may to some extent be caused by difference in the sediment samplers used at Krókur in 2003. The P61 sampler, which was used in 2001 and 2002, was only used in July and August 2003, whereas the S49 sampler was used in the remaining campaigns. The latter sampler will, if anything, result in higher percentage of fine material as it integrates the sample from the river surface, to the river bottom and to the surface again. The lower percentage of *sandur* in the S3 samples from Urriðafoss is understandable as it is impossible to lower the handheld rod-sampler deep into the current beneath the Highway 1 bridge where the concentration of *sandur* is greatest. The higher total sediment concentration in the S1 samples from Urriðafoss cableway compared to the Krókur samples may suggest that sediment is better distributed within the watercolumn at Urriðafoss than Krókur; possibly because of greater current speed.

Figure 8 shows a slight trend between sediment concentration and discharge for the Urriðafoss and Krókur samples; with a correlation (R^2) around 0.3 for the S1 samples from Urriðafoss and Krókur and slightly higher correlation (R^2=0.54) for the S3 Urriðafoss samples. The same Figure shows even better the variability between suspended sediment concentration/transport and discharge.

4.4 Bedload studies

First bedload studies in Þjórsá were performed in the 1980's (Haukur Tómasson *et al.* 1996, Svanur Pálsson 2000), but measurements of bedload transport in the lower reaches of Þjórsá downstream of Sandártunga have only been carried out in 2001 and 2002 (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002, 2003). The results shown here are based on the measurements in four total sediment campaigns at Krókur in July, August, September, and October/November 2003. During these campaigns, samples were taken at seven locations from the 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. Moreover, several samples were taken at 105, 125, 155, and 180 m for comparison with samples taken at 140 m.

The results from each campaign were divided into smaller data sets based on the date samples were taken and changes in discharge during the sampling period. When these data sets are compared a vast difference is seen in bedload transport from one station to another with high transport on average between 50 and 80 m and less bedload transport at 40, 100, and 140 m. However, great variability is seen from one set to another where exactly the bedload is transported (Fig. 13). In July, all bedload was transported between 60 and 80 m (Fig. 9), but in August most of the bedload was transported at 50 and 65 m, with minor transport at 70 and 140 m (Fig. 10). The bedload transport was even confined to a narrower stretch in September when almost all the bedload was transported at 50 m with minor transport at 60 m (Fig. 11). The sampling in the last campaign was distributed over four days in October and November with some bedload being transported between 50 and 70 m all days; however, in November relatively great amount of bedload was transported at 80 m as well (Fig. 12).

Total bedload transport differed substantially between the twelve data sets from the four campaigns, from 1.7 to 19.8 kg/s (Fig. 14). The results were subsequently reevaluated for the data sets with relatively high bedload transport at 80 and 140 m, and this lowered total values for half of the data sets (see Table 8 and Fig. 14 where both the initial and the reevaluated numbers are shown). No real correlation is seen between total bedload transport and discharge in 2003, different from what was observed in 2002. In 2002 samples were also obtained over much wider discharge range as is seen in Fig. 24, which shows all total bedload evaluations performed at Krókur in 2001, 2002, and 2003.

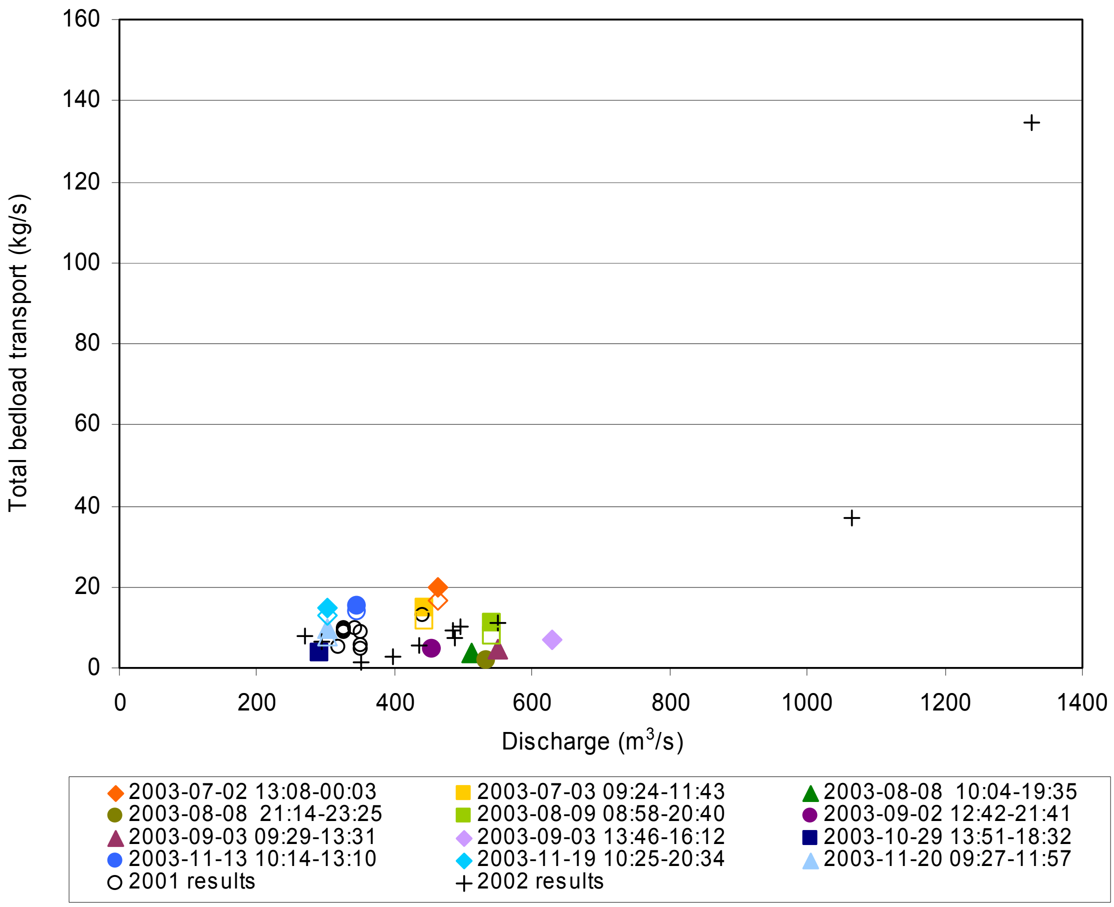
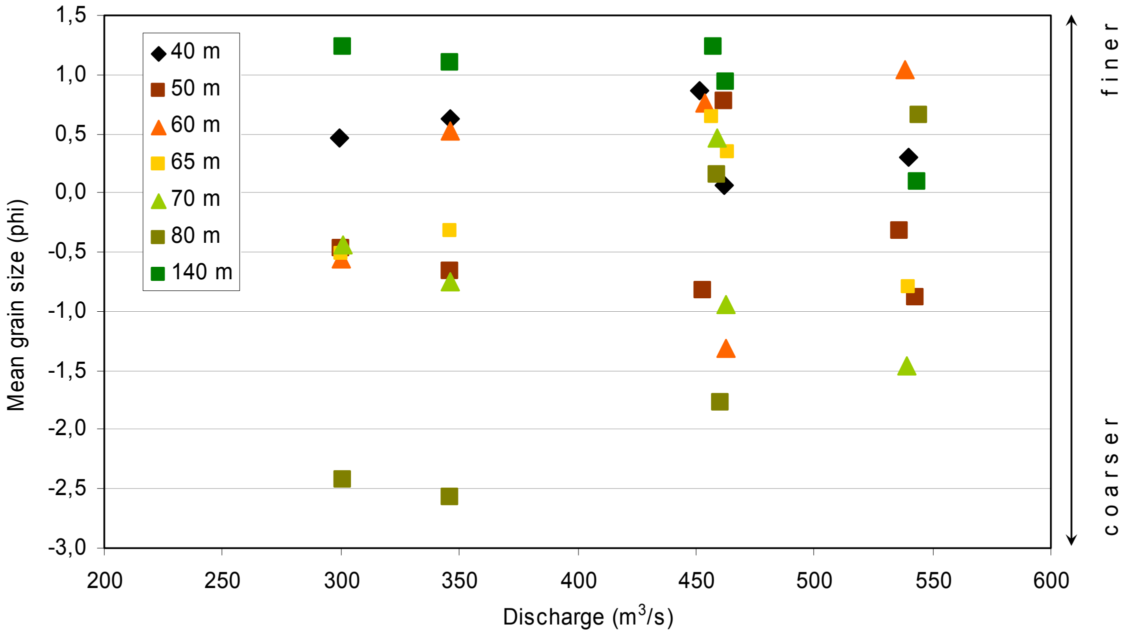


Figure 24: *Total bedload transport in all campaigns at Krókur in 2001 to 2003. Both initial (filled signs) and reevaluated (unfilled signs) values are shown for data from 2003.*

The total bedload transport in 2003 appears to have been somewhat lower than in 2002 when the samples from August and September are concerned, but slightly above looking at the transport in July and November. The relatively higher bedload during the winter months is, however, similar to what was observed in 2002.
Grain size was measured in 37 bedload samples; i.e. one or two samples from each station during each campaign. The grain size distribution in each sample differed somewhat between campaigns with coarser samples taken in July and August, although two samples taken at 80 m in November included particularly coarse material. More than 50% (wt.) of all except five samples was material finer than -1.0 ϕ (sand, <2 mm), with the rest of the material being pebbles of various size fractions less than -5.0 ϕ (3.2 mm) (Figs. 15–19).



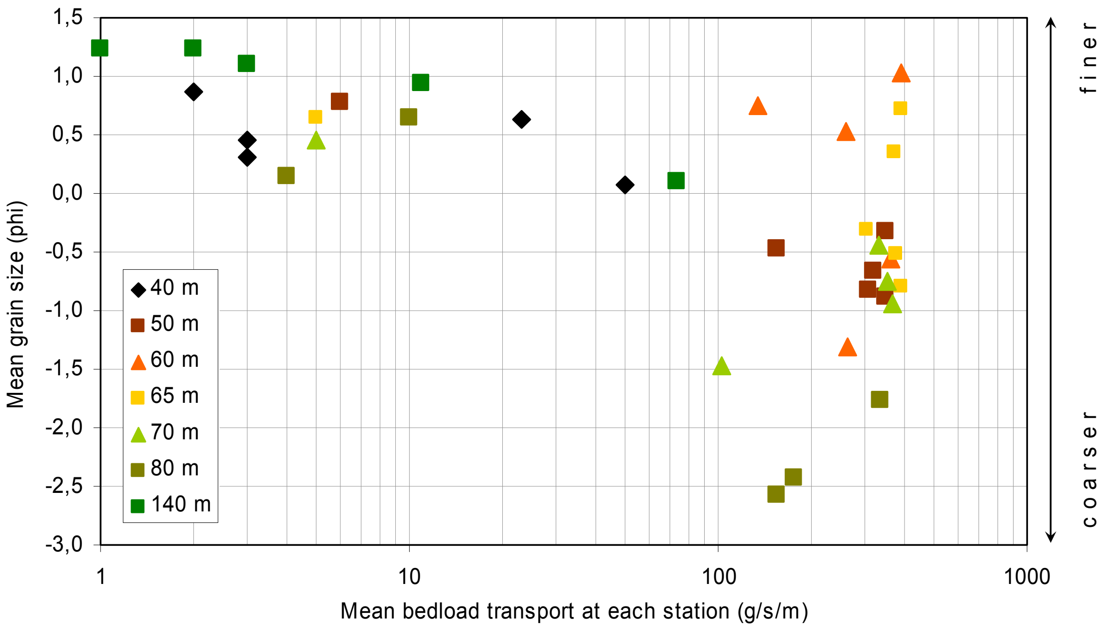


Figure 25: *Mean grain size in bedload samples vs. discharge (upper) and mean bedload transport at each station (lower) in 2003.*

For most stations no real trend is seen in mean size with discharge although the samples taken at 70 and 140 m get somewhat coarser with increasing discharge (Fig. 25 upper), especially if the samples taken around 450 m^3/s in July are excluded. The lower part of Fig. 25 shows how the mean grain size of the samples varies with mean bedload transport at each station. Only the samples from 140 m tend to get significantly coarser with increasing bedload transport. Conversely, many samples from the other stations tend to have either similar grain size (50 m) and/or similar mean bedload transport (65 m).

Figure 25 also shows the difference in grain size from one station to another with many samples from 40, 60, and 140 m being somewhat finer grained than other samples. The samples taken closest to either river bank, i.e. 40 and 140 m, also tend be better sorted than samples within the main channel, which is consistent to what has been observed in previous years.

Decent correlation is seen with mean grain size and sorting for grain size finer than -1.0 ϕ (2 mm) (R^2=0.53), and even better correlation for mean grain size vs. skewness (R^2=0.73) for the whole data set (Fig. 23). The finer grained samples thus tend to be better sorted and more negatively skewed, i.e. with a tail of excess coarse material, than coarser grained 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 they will always be a compromise 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.

As in previous reports 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. Not only is there error included in the measurements themselves, but the results also rely significantly on the division of the data set into discharge ranges and how additional information transport in wide channel stretches such as around 140 m is handled. In this study additional information on bedload transport over the stretch from 80 to 140 m tended to lower the bedload transport.

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SUMMARY IN ICELANDIC

Eftir að hugmyndir um Urriðafossvirkjun í neðri hluta Þjórsár voru endurvaktar hafa sjónir manna beinst að setflutningi í ánni á þessu svæði. Af þessu tilefni setti Landsvirkjun árið 2001 af stað umfangsmiklar rannsóknir á heildaraurburði í neðri hluta Þjórsár, en uppsetning rafdrifins kláfs við Krók var forsenda þess að hægt væri að afla betri svifaurssýna og fyrstu skriðaurssýnanna. Árið 2001 voru farnar 10 aurburðarferðir á svæðið, árið 2002 voru ferðirnar sex og í þessari skýrslu eru settar fram niðurstöður fjögurra slíkra ferða á neðra Þjórsársvæðið. Á sama tíma hefur verið í gangi rannsóknarverkefni um efnavöktun í ám á Suðurlandi, en auk Vatnamælinga standa Landsvirkjun, Raunvísindastofnun háskólans, og Hollustuvernd, nú Umhverfisstofnun, að því verkefni.

Meginmarkmið stóru aurburðarferðanna á neðri hluta Þjórsársvæðisins er að afla góðrar vitneskju um heildarframburð Neðri-Þjórsár en slík þekking er nauðsynleg allri úttekt á virkjunarkostum, bæði hvað viðkemur hönnun og umhverfismati virkjunar. Þessu takmarki er náð með því að afla betri svifaurssýna en áður hefur verið gert, með því að taka í notkun rafdrifna kláfinn við Krók. Með því að taka svifaurssýnasett af honum og með handsýnataka undir gömlu brúnni á þjóðvegi 1 þar sem mörg fyrri sýni hafa verið tekin er einnig reynt að meta hvernig eldri sýni vanmeta svifaursstyrk í Þjórsá þar sem sýnatakinn nær ekki að safna sýni úr þeim hluta árinnar þar sem hæstur styrkur ætti að mælast, þ.e. nálægt botni í mesta strengnum. Árið 2002 var einnig byrjað að taka sýni með vökvadrifnu kláfspili á eldri strengjabraut um 500 m neðan við gömlu brúna á þjóðvegi 1 til að meta enn betur gæði sýnanna sem tekin hafa verið með handsýnatakanum og tengja niðurstöður frá Króki og við gömlu brúna við eldri niðurstöður frá gömlu strengjabrautinni. Öll þessi sýni nýtast einnig til að meta heildarsvifaur í ánni. Annað meginmarkmið ítarlega aurburðarverkefnisins hefur verið að afla upplýsinga um skriðaursflutning í Neðri-Þjórsá en áður en þetta verkefni byrjaði höfðu skriðaurssýni eingöngu verið tekin úr efri hluta árinnar (Haukur Tómasson o.fl. 1996; Svanur Pálsson 2000).

Sýnataka ársins 2003 gekk vel og var farið í fjórar hefðbundnar svifaurs- og skriðaursferðir og eina svifaurssýnaferð. Í öllum ferðum voru svifaurssýni tekin á fyrrnefndum þremur stöðum, þ.e. við Krók, undir brú ofan Urriðafoss og á Urriðafosskláfnum, og í heildaraurburðarferðunum voru einnig tekin á bilinu 74 til 84 skriðaurssýni af kláfnum við Krók. Til viðbótar við þau svifaurssýni sem tekin voru í þessum ferðum voru níu sýni tekin með handsýnataka undir eldri brúnni á þjóðvegi 1 í efnavöktunarferðum á Suðurland.

Í svokölluðum S3 sýnum sem tekin voru undir brúnni ofan Urriðafoss var kornastærð og svifaursstyrkur nokkuð mismunandi innan ársins. Hlutfall sands (>0,2 mm) var töluvert hærra yfir vetrarmánuðina, en á móti var hlutfall fínefna s.s. leirs mun hærra innan sumarmánuðina þegar reikna má með leysingu á jökli. Heildarsvifaursstyrkur var einnig mestur á sama tíma ef frá er talið sýni frá 16. desember sem innihélt hlutfallslega mikinn sand miðað við önnur vetrarsýni. Styrkur kornastærðarflokkanna í mg/l var einnig þegar á heildina er litið minni yfir vetrartímann en yfir sumarið.

Ef borin eru saman Urriðafosssýnin, sem tekin voru með handsýnataka annars vegar, og af kláfnum hins vegar, kemur í ljós að handsýnin vanmeta heildarstyrk svifaurs um allt frá 19 til 79%.
Svifaurssýnin frá Króki voru tekin með sýnataka 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 16 m fjarlægð frá húsinu. Þetta árið var innihaldi allra sýnaflaskna blandað saman áður en sýnið var kornastærðargreint og fengust því ekki upplýsingar um dreifingu kornastærðar innan farvegarins eins og síðastliðin ár. Í Krókssýnunum frá 2003 var ekki jafn áberandi mismunur í styrk kornastærðarflokka innan ársins eins og í handsýnum frá Urriðafossi en þó var styrkur fínefna í vetrarsýnunum heldur minni en í sumarsýnunum. Styrkur sands í júlísýni frá Króki er hins vegar mjög hár miðað við í öðrum sýnum svo að mögulegt er að sýnatakinn hafi safnað í sig sandi af botni í sýnatökunni.

Heildarstyrkur og kornastærðardreifing sýnanna frá Króki annars vegar og beggja Urriðafoss sýnategundanna hins vegar var borin saman. Í ljós kom að S3 brúarsýnin frá Urriðafossi höfðu í fjórum sýnum af fimm lægri heildarstyrk og lægra hlutfall sands en Krókssýnin og er sú niðurstaða sambærileg við samanburð sýnategundanna tveggja frá Urriðafossi. Á hinn bóginn höfðu fjögur af fimm S1 sýnum af Urriðafosskláfnum hærri heildarstyrk en Krókssýnin og er það eins og í samanburðarsýnum sem tekin voru á þessum stöðum 2002. Sýnin frá Króki virðast því heldur vanmeta svifaursstyrk ef miðað er við sýnin frá kláfinum við Urriðafoss enda virðist straumur vera heldur meiri á síðarnefnda staðnum og því hugsanlegt að efni sé betur blandað í vatnsbolnum. Ekki var eins afgerandi mismunur milli sýnategunda í fíngerðari kornastærðarflokkum ef undanskilinn er leirflokkurinn (<0,002 mm) þar sem fjögur af fimm S3 brúarsýnum frá Urriðafossi höfðu hærra styrkhlutfall en Krókssýnin, en jafnmörg S1 kláfsýni frá Urriðafossi höfðu lægra styrkhlutfall en sýnin frá Króki. Hafa þarf þó í huga að við mat á kornastærðarhlutfalli að um er að ræða hundraðshlutagögn þannig að ef hlutfall eins kornastærðarflokks hækkar verður hlutfall eins eða fleiri flokka að lækka.

Jákvæð fylgni sést milli heildarstyrks hverrar sýnagerðar og rennslis og er fylgnin góð fyrir S3 sýnin frá Urriðafossi (R^2=0,93) en mun minni fyrir kláfsýnin frá Króki og Urriðafossi (í kringum 0,3). Fylgnin fyrir kláfsýnin eykst hins vegar til muna þegar skoðaður er skriðaursflutningur með rennsli (R^2=0,66–0,75).

Alls voru tekin 312 skriðaurssýni af rafdrifna kláfnum við Krók árið 2003 í fjórum heildaraurburðarferðum í júlí, ágúst, september og október/nóvember. 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 einu til tveimur sýnum safnað til kornastærðargreiningar á aurburðarstofu Vatnamælinga, alls 37 sýnum.

Nokkuð var misjafnt á milli ferða á hvaða stöð skriðaursframburður var mestur en yfirleitt var hann mikill á stöðvum frá 50 til 70 m. Í júlí og nóvember mældist hann þó einnig mikill á 80 m. Meðalframburður á milli stöðva sem og heildarframburður skriðaurs var reiknaður bæði með og án þess að taka tillit til aukasýna á milli 80 og 200 m. Nokkur munur var á milli þessara útreikninga, sér í lagi fyrir meðalframburð í kringum 80 og 140 m stöðvarnar þar sem skriðaursflutningur var heildaður yfir breitt bil, en aukasýni gáfu til kynna að framburður væri hugsanlega ekki jafnmikill yfir allt breiddarbilið. Mestur mældist heildarskriðaursframburður í júlí (11,7 og 16,5 kg/s) og nóvember (7,9–13,8 kg/s), en einnig var hann hár 9. ágúst (um 8 kg/s) (hér er miðað við leiðréttan skriðaursflutning með tilliti til aukasýna).

Mestur hluti skriðaurssýnanna frá Króki var sandur og fínmöl og voru fíngerðustu og best aðgreindu sýnin yfirleitt tekin á 40 og 140 m. Hluti sýna af 60 m var einnig tiltölulega fíngerð en þrjú sýni af 80 m skáru sig úr hvað varðar grófleika. Sýnin sem tekin voru á 70 og 140 m urðu heldur grófari við hækkandi rennsli en minni munur sást með rennsli í sýnum frá öðrum stöðvum.

Eins og áður sagði gekk aurburðarsýnataka í Neðri Þjórsá vel árið 2003 og bætast fjölmörg sýni við gagnagrunn svifaur- og skriðaursmælinga á svæðinu. Hafa ber í huga að töluverð óvissa er fyrir hendi í slíkum mælingum sem erfitt getur verið að meta, þá sér í lagi í skriðaursmælingum.