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Total sediment transport in the lower reaches of river Þjórsá

Results from the year 2004

Jórunn Harðardóttir
Svava Björk Þorláksdóttir

Prepared for Landsvirkjun

OS-2005/010

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Abstract:
This report presents data on suspended and bedload sediment samples taken in the lower reaches of the Þjórsá river in 2004. Five sediment campaigns were carried out in 2004, in four of them both suspended and bedload samples were obtained. In addition, bedload transport was also estimated at Sandártunga in one campaign. The main objectives with the study are to obtain samples for better understanding of the total sediment transport in the area, to gain a better idea of the quality of different suspended sediment samples, and gather information for later comparison with older suspended sediment samples. Suspended sediment concentration varied substantially between sampling sites and between campaigns. The suspended sediment was relatively coarser during winter than in summer/fall samples, and coarsest in samples taken from the old Urriðafoss cableway. Bedload transport at Krókur was highest between 50 and 70 m, with total transport lowest, 1.4 kg/s, in August. Total bedload transport reached a maximum of 66.5 kg/s during one sampling set in a winter flood in March, but was lower by an order of a magnitude at Sandártunga.

Keywords:	**ISBN:**
Þjórsá, bedload, suspended sediment, grain size, bedload transport, discharge, cableway, Krókur, Urriðafoss, Þjórsártún (vhm 30) , Sandártunga	
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1 INTRODUCTION

Þjórsá is one of the largest rivers in Iceland, with a watershed at Þjórsártún (V320) of 7380 km^2 (Fig. 1), of which roughly 1100 km^2 is covered by glaciers (Helgi Björnsson 1988). The mean annual flow for the period 1971–2004 (34 years) is 354 m^3/s. A large part of the summer discharge is affected by glacier melting at the Hofsjökull and Vatnajökull glaciers, but due to the several major hydroelectric power plants on the upper reaches of Þjórsá, the seasonal variation in discharge has stabilized by reservoir retention, so that the discharge has decreased during summer and increased in winter, although the annual discharge is similar as before the main power constructions. Moreover, minor floods have been dampened whereas larger floods have remained more or less unaffected.

Hydroelectric power plant construction has in contrast greatly modified the sediment transport downstream of the large reservoirs (Haukur Tómasson 1982). Most of the coarse material is deposited in the reservoirs and only the fine material is transported downstream where it is combined with sediment from smaller streams and sediment from the river channel itself.

In recent years, almost a century old ideas of hydroelectric power plant construction on the lower reaches of Þjórsá have been renewed. The present options will use the current facilities on the upper reaches of the river to mitigate water, but include smaller reservoirs at Núpur and Urriðafoss where the location of the two or three power plants have been proposed in alternative designs.

Relatively good information is available on discharge in the lower reaches of Þjórsá where a discharge gauge has been operated for more than 50 years at Krókur (vhm 30: V30) and later at nearby Þjórsártún (vhm30; V320) (Fig. 1). Knowledge on sediment transport in the lower reaches of the river is more irregular, although a comprehensive understanding of sediment transport is essential for all studies concerning 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). Since then occasional samples have been 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 (the older S3 bank samples are thought to under-represent the sediment load because they are not taken from the main current where the load is greatest), 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. Since 1996 the S3 samples have been taken 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). However, to extend the knowledge on sediment transport in the lower reaches of Þjórsá, the National Power Company (Landsvirkjun) initiated in 2001 an extensive sediment monitoring program, which has been carried out by the Vatnamælingar (Hydrological Service (VM)) of Orkustofnun (National Energy Authority). The main objectives of the study are: 1) to obtain additional suspended samples from the lower reaches of Þjórsá to evaluate with a greater certainty the suspended sediment transport in the Urriðafoss area; and 2) to evaluate the bedload transport in the same area.

Reports on data obtained in earlier years have been published in three progress reports (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002; 2003; 2004), but in this analogous report we introduce results from sediment campaigns in 2004.

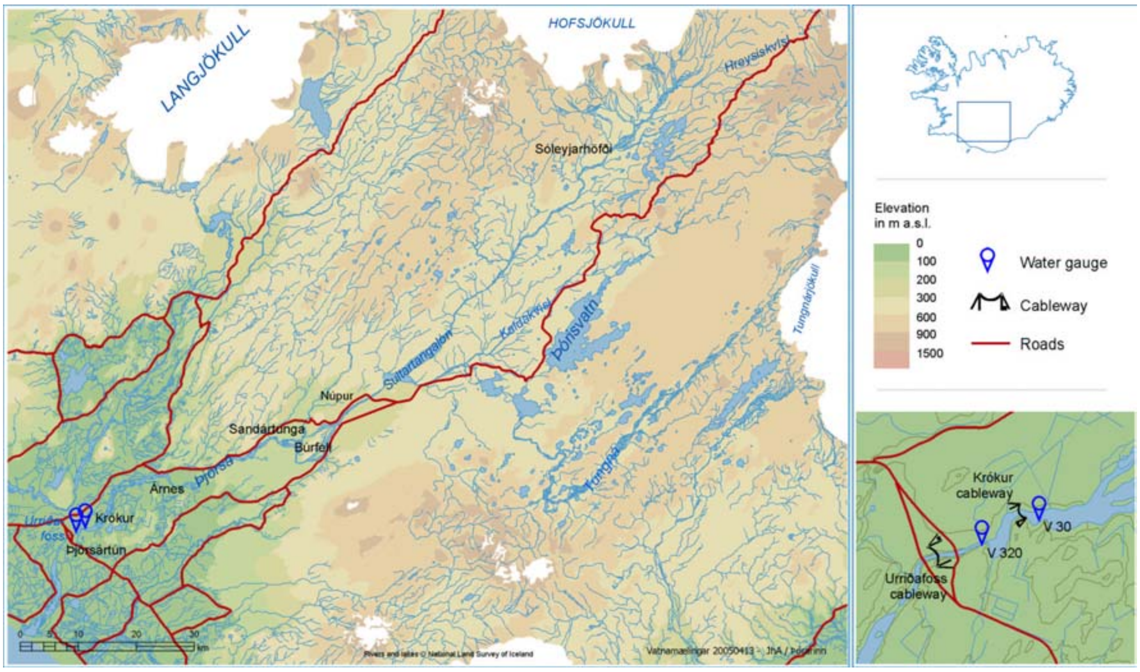


Figure 1: *Map of the Þjórsá river basin, including main locations along the river. The sampling sites at the two cableways are shown on the insert in lower righthand corner. Krókur cableway is located between water gauges V30 and V320, and the Urriðafoss cableway is located midway between the old (upstream) and the new Highway 1. The third sampling location is beneath the old Highway 1 bridge.*

2 SAMPLING AND DATA ANALYSIS

In 2004, the sediment sampling in the lower reaches of Þjórsá was threefold instead of twofold like in previous years. Firstly, suspended samples were taken with a handheld DH48 sampler (so-called S3 samples) from the river bank beneath the old Highway 1 bridge as a part of the chemical analysis program mentioned in the previous chapter. Secondly, as in earlier years five sediment campaigns were carried out as a part of the extensive sediment program that was initiated in 2001. Thirdly, as an addition to that same program bedload samples were taken at Sandártunga upstream of the proposed Núpsvirkjun, at a possible cableway location.

Table 1 shows the details of the five sediment campaigns carried out in 2004. In four campaigns both suspended sediment samples and bedload samples were taken, but only suspended samples were obtained in the December campaign. The bedload samples were normally taken from the motorized cableway at Krókur, which is located approximately 2 km upstream of the old Highway 1 bridge. In the September campaign several samples were additionally taken from a specially equipped boat at Sandártunga. The suspended samples were taken from three locations in each campaign except in March, 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 hydraulic winch, and the third sample was taken from the river bank beneath the old Highway 1 bridge using a handheld sampler. In March it was impossible to transport the hydraulic winch to the cableway at Urriðafoss as rain had made the trail impassable.

Table 1: *Number of sediment samples taken at Krókur, Urriðafoss and Sandártunga in 2004.*

Date	Location	No. of suspended samples	No. of bedload samples	No. of bedload grain size analyses
2004-03-10 to	Krókur cableway	1	89	8
2004-03-12	Urriðafoss cableway	0	–	–
	Urriðafoss bridge	1	–	–
2004-08-03 to	Krókur cableway	1	74	7
2004-08-05	Urriðafoss cableway	1	–	–
	Urriðafoss bridge	1	–	
2004-09-20 to	Krókur cableway	1	79	7
2004-09-23	Urriðafoss cableway	1	–	–
	Urriðafoss bridge	1	–	–
	Sandártunga	0	22	7
2004-10-11 to	Krókur cableway	1	75	7
2004-10-12	Urriðafoss cableway	1	–	–
	Urriðafoss bridge	1	–	–
2004-12-14	Krókur cableway	1	0	0
	Urriðafoss cableway	1	–	–
	Urriðafoss bridge	1	–	–
Total sediment samples		**14**	**339**	**36**

Figure 2 shows the discharge at Þjórsártún water gauge (vhm 30; V320) (Fig. 1) using newly established rating curve no. 4 and timing of the sediment sampling both in connection with chemical samples (red squares) and total sediment campaigns (different colored diamonds).

The spiky appearance of the hydrograph due to the harnessed nature of the river is compelling. The first sediment campaign was carried out in March during one of the highest discharge peaks observed, which was caused by an intense winter rain flood. The other four sediment campaigns were completed during the latter part of the year from early August to mid-December. In contrast, suspended samples collected in relation to chemical samples were better distributed over the whole year, although they were in some instances taken at similar time as when the intensive sediment campaigns were carried out. All except the March samples were taken at discharges less than 500 m^3/s.

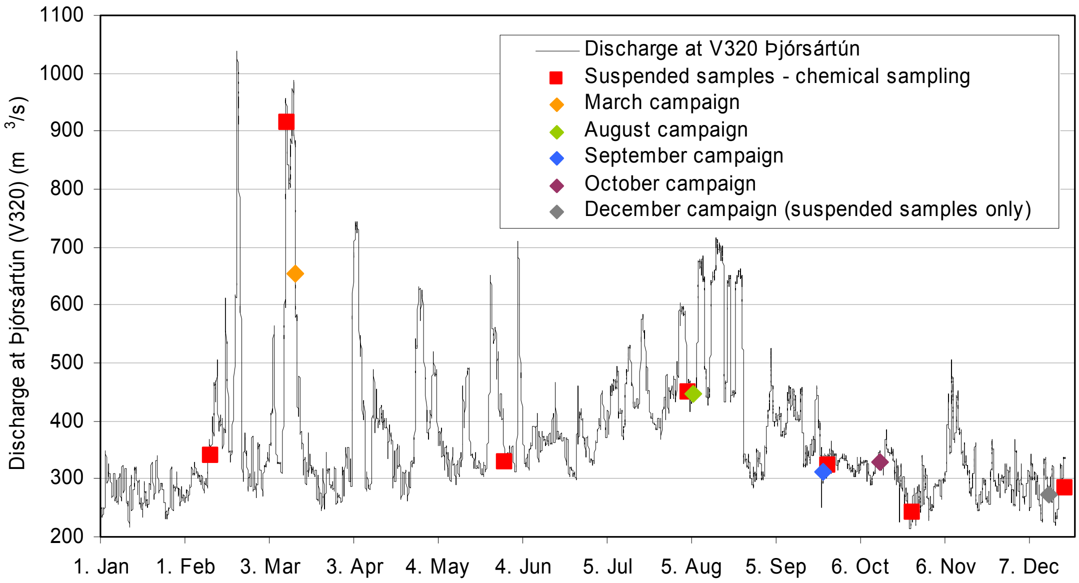


Figure 2: *Discharge at the Þjórsártún water gauge (vhm 30; V320) and the timing of sediment sampling in the lower reaches of Þjórsá in 2004.*

2.1 Suspended sediment samples

2.1.1 Sample types

The suspended sediment samples that were collected from the lower reaches of Þjórsá in 2004 were classified into two 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. The quality of the S3 samples is usually poor as in most instances it is not possible to reach with the sampler where the sediment concentration is greatest, i.e. close to the bottom in the main current.

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.

Both 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. All the samples taken from beneath the old Highway 1 bridge were classified as S3 samples as they are taken with the handheld DH48. At Krókur the samples were taken at 40, 50, 60, 65, 70 80, 100, and 140 m. In the following text, all references 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. The samples obtained on the Urriðafoss cableway were on the contrary taken at three to six locations across the channel, but the individual widths differed from one campaign to another. Hence, 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. No samples were taken this year with the point integrated sampler (P61) that has been used in previous years. This sampler has an electronic opening which can be opened with a remote control, but the intake valve on the P61 sampler is in contrast to the other samplers first opened when the sampler is lifted up from the river bed, which results in an integrated sample from the bottom to the surface. By not using the P61 sampler in 2004 we eliminated possible bias due to different sampling techniques at the Krókur and Urriðafoss cableways.

2.1.2 Grain size analysis

As in previous studies of suspended sediment samples from Þjórsá, all the 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. As in 2003, the sampling bottles from each of 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; 2004).

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 nearest 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 and from the boat at Sandártunga 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 at Krókur, 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, as well as at 105 m in the March campaign. 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. At Sandártunga the samples were taken at 15, 25, 35, 45, 55, 65, 76, 85, 95, 105, and 115 m, with the river banks located at 5 and 119 m.

Figure 3: *Top: Bedload sampling at the cableway at Krókur, Þjórsá (Photo: Arndís Ólafsdóttir). Bottom left: The location of bedload sampling at Sandártunga, Þjórsá (Photo: Jórunn Harðardóttir). Bottom right: The specially equipped boat used for bedload sampling at Sandártunga, Þjórsá, here used at Sóleyjarhöfði, Þjórsá (Photo: Steen Henriksen).*

At each station the Helley-Smith sampler was lowered to the riverbed where it usually remained for 60 to 300 seconds before it was pulled up again. 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 (top), this bag is being fastened to the opening of the bedload sampler.

At Krókur, 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 89; however, no bedload samples were collected in December (Table 1). In all campaigns at Krókur 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).

On the contrary, at some stations in Sandártunga the sampling bag came up empty as no bedload was being transported. Samples from all the other stations were brought back to the laboratory where they were weighed immediately upon arrival, and set aside for subsequent grain size analysis.

2.2.2 Bedload calculations

The bedload transport was calculated in the same way as for campaigns in 2001 to 2003 (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002; 2003; 2004). 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 (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 :

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

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

The samples were initially dried at 60°C before they were analyzed for grain size. The sieve stack that was used ranged from 64 to 0.063 mm, with sieve aperture interval of 0.5 ϕ (phi). Table 3 shows the size classes used in both ϕ and mm, as well as the corresponding names according to Wentworth size classes (Boggs 1995). 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 but one sample this fraction of the samples was negligible (<0.4%) (2,9% in a sample from 40 m taken 2004-09-20 at 10:46.

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

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

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

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.

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

As in previous data reports the results from grain size analysis of the suspended sediment samples has been divided into three parts based on the sampling location instead of introducing data from the two sampling programs separately. These are: 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

Twelve suspended sediment samples were taken in 2004 with the handheld DH48 rod sampler from the river bank below the old bridge on Highway 1. Seven 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.

The sample from October 25th has much higher total concentration than the other samples which is mainly caused by abnormal *sandur* (>0.2 mm) percentage, 90% or 1207 mg/l (off the scale on Fig. 4.). Nothing was unusual with the collecting procedure of the sample although the people who took the sample noticed its high concentration when the sample was taken. One explanation could be that the low discharge (243 m^3/s) during the time of sampling may have caused the rod sampler to have reached closer to the bottom where the *sandur* fraction should be highest.

The main observed seasonal change is an increase in the *leir* (<0.002 mm) fraction during the latter part of the year to 30–55%, first seen in the sample from early August. In contrast, the cumulative *sandur* and *grófmór* (0.06–0.2 mm) percentage is higher in most of the samples taken during the winter season. Finer sediment during the summer and autumn seasons corresponds well with greater abundances of fine material during the glacier melting period. However, the high *sandur* percentages in winter time are partly caused by the closed array problem of percentage data, so that the *sandur* percentage must decrease when the fine fraction increases. Hence, it is useful to study the percentage and concentration graphs together for better understanding of the behaviour of the grain size changes. These seasonal changes are similar to what has been observed in S3 samples from Urriðafoss in recent years (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2002; 2003; 2004).

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 distinguish 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)
2004-02-10 11:40	339	71	68	36	17	10	31	6	1,5
2004-03-09 12:15	914	137	50	15	23	12	41	9	1,2
2004-03-12 16:30	654	56	40	17	27	4	47	5	1
2004-05-28 12:05	330	25	61	28	4	3	47	18	1
2004-08-03 17:05	448	114	37	7	5	11	33	44	1,1
2004-08-05 11:50	446	90	65	26	2	2	25	45	2,6
2004-09-22 10:15	313	67	58	9	3	4	35	49	0,9
2004-09-24 11:45	323	74	58	6	1	4	35	54	1,2
2004-10-13 12:15	329	66	46	39	2	1	25	33	2,6
2004-10-25 12:35	243	1341	72	90	5	2	2	1	2,7
2004-12-14 15:53	273	30	72	24	8	1	30	37	1,1
2004-12-20 13:14	283	29	83	65	5	9	14	7	1,7

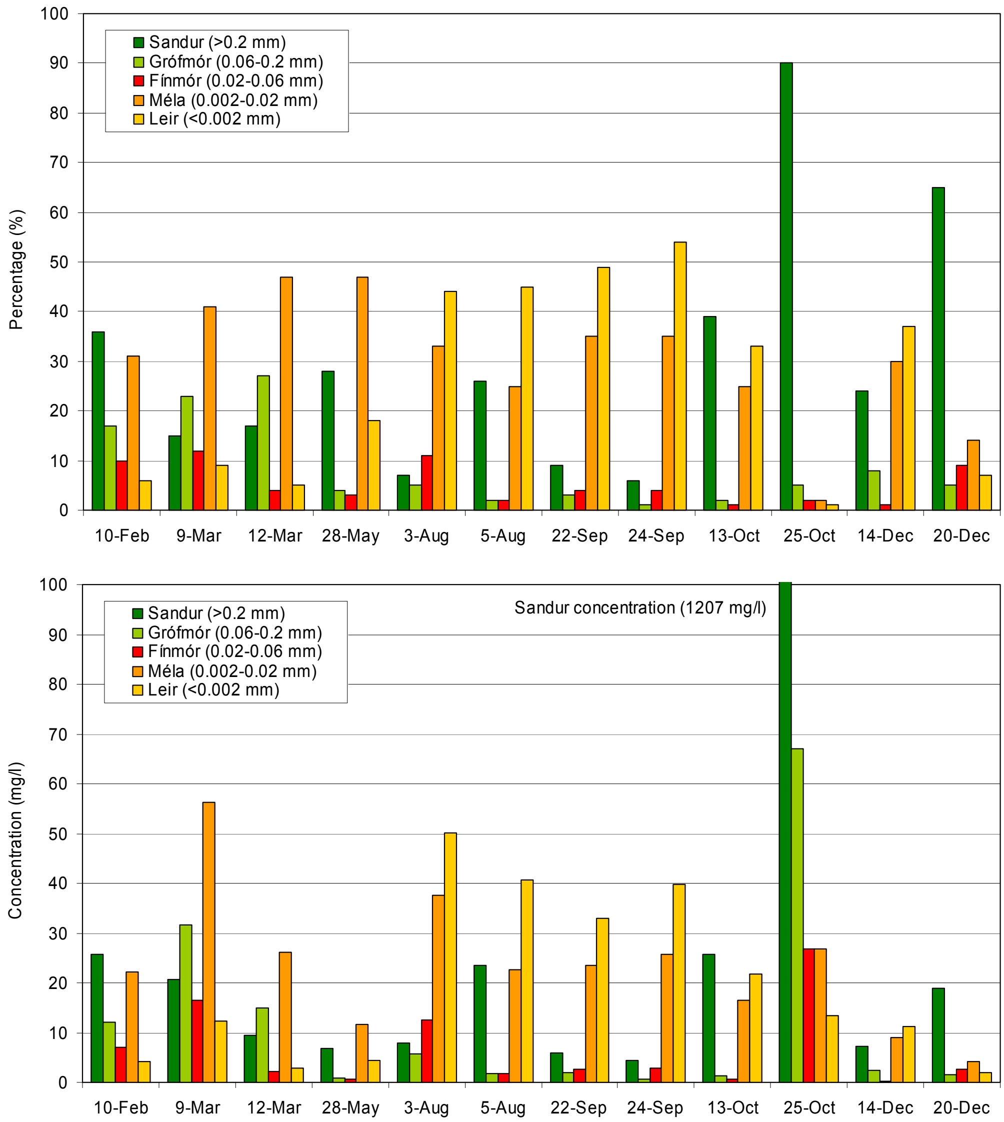


Figure 4: *Grain size distribution in S3 samples from Urriðafoss in 2004. Upper figure, percentage; Lower figure, concentration. Note that sandur concentration for sample taken on October 25 is off the scale.*

3.1.2 Urriðafoss cableway samples

Only four suspended samples were taken from the old cableway above Urriðafoss as it was not possible to reach the cableway with the sampling equipment during the March flood. 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.

The total sediment concentration was highest in the October sample, 423 mg/l, but lowest in the December sample, or only 65 mg/l. The low concentration is consistent with the lowest discharge, but unusually high sandur percentage (92%) in the October sample increases the total sediment concentration greatly in that sample so that concentration is higher that expected at the discharge of 321 m^3/s.

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)
2004-08-05 13:35	439	187	58	31	4	12	30	23	2,4
2004-09-22 11:15	304	121	65	43	2	3	20	32	3
2004-10-13 14:10	321	423	75	92	2	2	2	2	2
2004-12-14 17:10	277	65	78	69	2	3	19	7	2,2

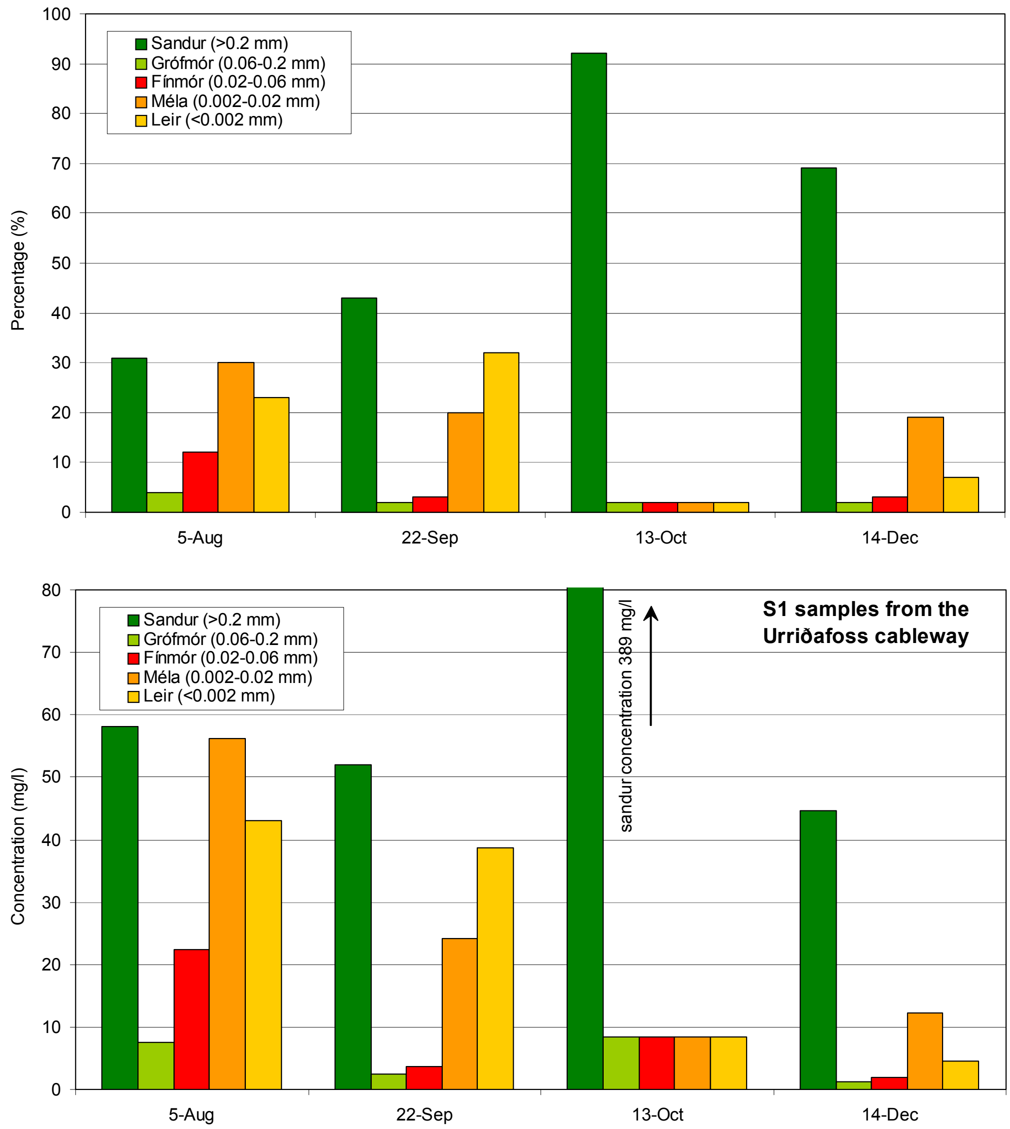


Figure 5: *Grain size distribution in S1 samples from the Urriðafoss cableway in 2004. Upper figure, percentage; Lower figure, concentration. Note that sandur fraction for the sample taken on October 13 is off the scale.*

The seasonal variations in grain size appear to be similar as in the S3 samples from beneath the bridge on Highway 1; i.e. higher percentage/concentration of the fine material in the summer summer samples (20–32%; 24–56 mg/l) than the October and December samples (2–19%; <12 mg/l). The *sandur* percentage is thus higher in the winter samples (69–92%) than in the summer samples (31–43%), but this effect is partly caused by the nature of the percentage data as is seen when the concentration data is studied where the sandur concentration of the December sample is lower than in the other samples.

3.1.3 Krókur samples

All the suspended sediment samples taken from the electric cableway at Krókur were taken in seven sample bottles at 40, 50, 60, 65, 70, 80, and 140 m distance from the house. The contents of the individual bottles were combined into one sample before grain size analysis, in contrast to what was done in 2001 and 2002 when each sample bottle was analyzed separately. The results are shown in Table 6 and the same results are shown both as percentage and concentration 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)
2004-03-12 15:15	659	92	39	18	20	7	46	9	1,3
2004-08-05 09:35	455	158	61	28	3	11	31	27	1,9
2004-09-22 08:46	330	120	55	43	2	2	22	31	2,5
2004-10-13 10:30	338	116	46	51	3	4	19	23	1,5
2004-12-14 14:00	275	57	78	60	4	2	24	10	2,2

The total sediment concentration varied from 57 mg/l in the December sample when the discharge was only 275 m^3/s to 158 mg/l in the August sample, which was taken when discharge was 455 m^3/s. Unexpectedly, the total sediment concentration in the sample taken in the March flood (659 m^3/s) was relatively low, or only 92 mg/l.

Grain size in the individual size classes changed somewhat from one sample to another. The percentage of *sandur* increased from 18% in the first sample to 60% in the December sample, whereas the *leir* percentage was highest in the samples taken in August, September and October, i.e. 23–31% (Table 6; Fig. 6). Similar results are seen in the concentration data (Fig. 6) although the *sandur* concentration in the December sample does not increase as substantially as the percentage data suggests.

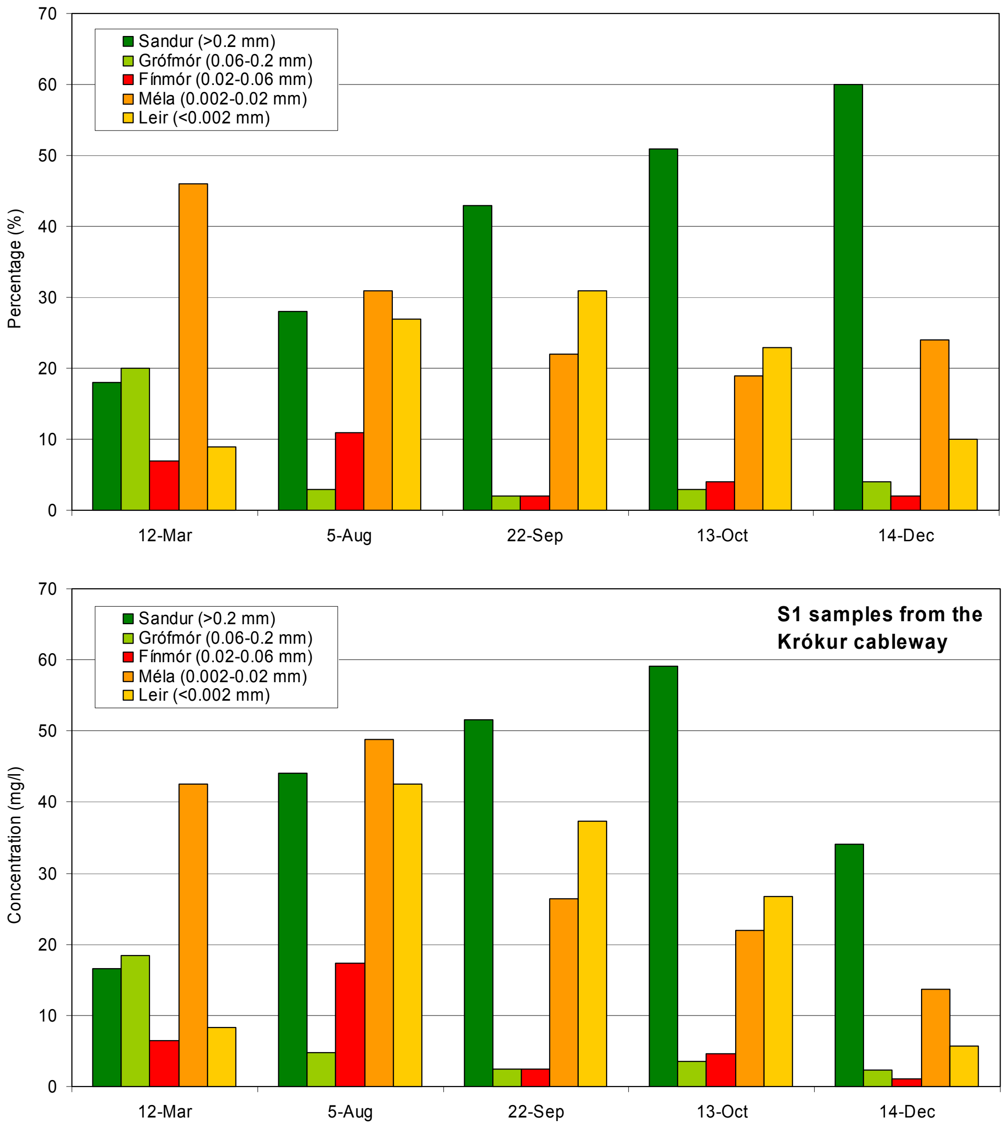


Figure 6: *Grain size distribution in S1 samples from Krókur in 2004. Upper figure, percentage; Lower figure, concentration.*

3.2 Bedload samples

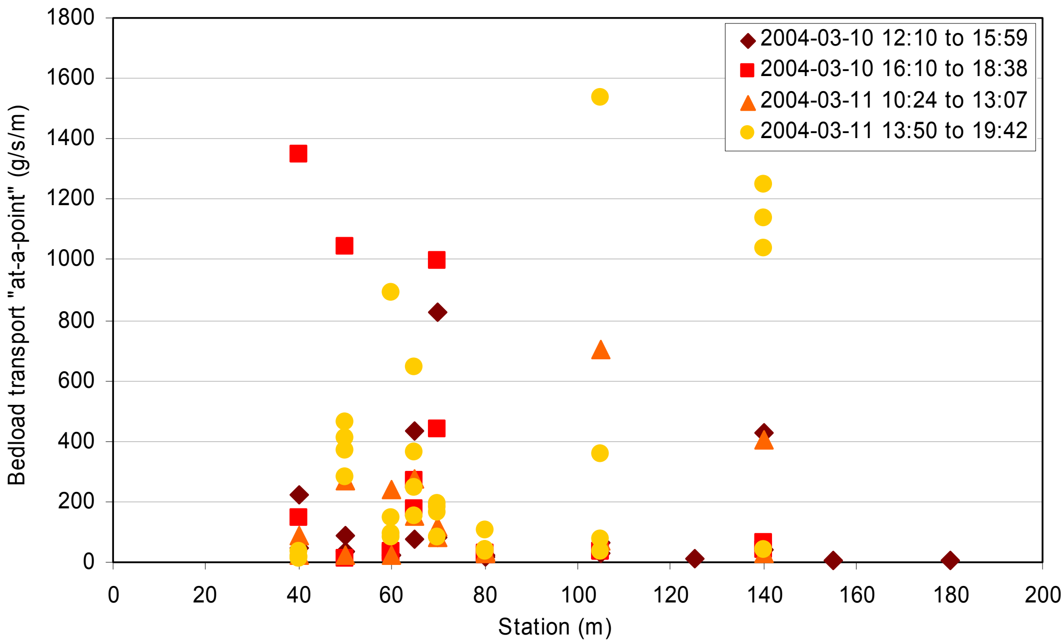
3.2.1 Bedload transport at Krókur

Bedload samples were obtained at two locations in lower Þjórsá in 2004. In four of the five total sediment campaigns (Table 1), 317 samples were collected from the Krókur cableway. In all campaigns, samples were taken at 40, 50, 60, 65, 70, 80, and 140 m with supplementary samples taken at 105, 125, and 155 m to better evaluate the bedload transport in the ca. 120-m-wide section from 80 m to the right bank at 200 m. Moreover, the 105 m station was a regular sampling site in the March campaign, and was included in calculation of bedload transport; however, the other sites were only used to confirm the transport at around 140 m and not used in calculations. Of those, one sample from the standard sampling sites in each campaign (seven or eight samples) were used for grain size analysis.

In the Krókur campaigns, the samples were taken within two to three days in each campaign, during which period discharge changed substantially in some instances. Hence, bedload calculations were performed after each campaign data set had been divided into smaller data sets according to discharge range and sampling days.

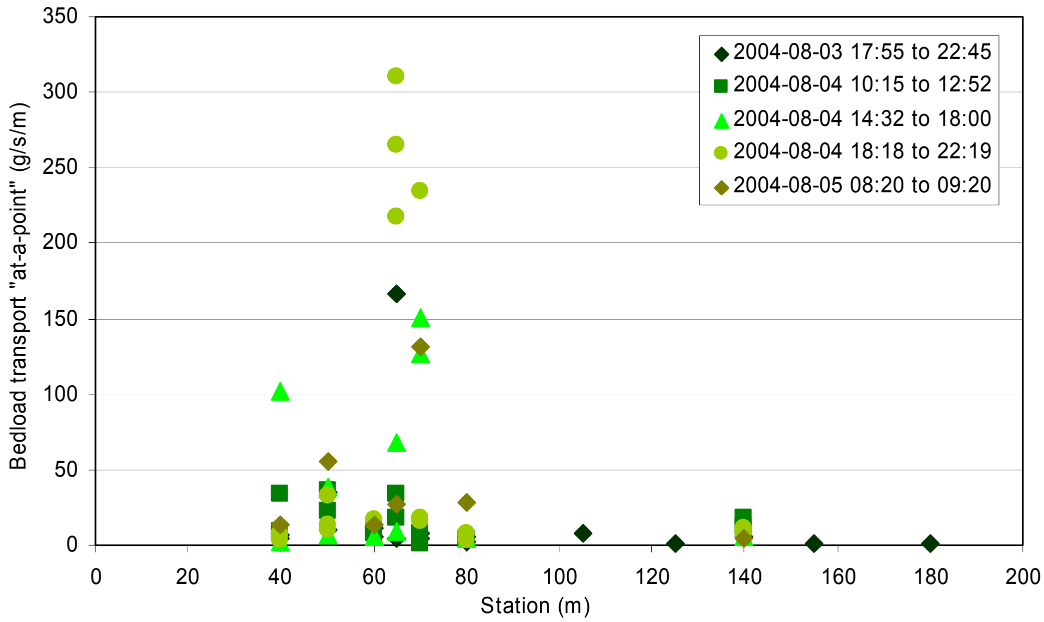
As in previous data reports, the results from each campaign are shown as a graph of sample transport in g/s/m and in a table that portrays the transport data at each station, between station midpoints, total transport, as well as the mean discharge and its range (Figs. 7 to 10). Bedload transport is calculated for the channel between 16 and 200 m which is the mean moving stretch of the river according to discharge measurements. The mean bedload transport at each station is summarized on Fig. 11 and mean transport between station midpoints is shown on Fig. 12. For easier separation between the many data subsets, each data set has been divided into two figures and a color corresponding to the color scheme used within each campaign used (see on Figs. 7 to 10).

The mean bedload transport differed substantially from one station to another, within each campaign, as well as between the campaigns. The greatest mean bedload was usually transported between 50 and 70 m, with only minor bedload transported at 40, 80, and 140 m (most often <15 g/s/m). However, the bedload transport in the March flood campaign differed greatly as much more bedload was transported closer to the banks at 40, 105, and 140 m than in other campaigns, with mean bedload transport at 140 m reaching 865 g/s/m on the afternoon of March 11th. When the bedload transport is integrated for the stretch between the stations, the great bedload transport at 140 m within three of the four March data sets, and the high mean transport at 40 m in the fourth data set (Fig. 12) increase substantially due to the longer stretch of the channel they are integrated for (see section 2.2.2 for methods of calculations). Although the data clearly shows that at the high discharge (787–956 m^3/s) occurring during the March flood bedload was transported closer to the river banks, we do not have data to confirm whether this was true for the whole channel stretch the data is integrated over. Hence, we suggest that the high total bedload transport between station midpoints at 40 and 140 m (10000–45000 g/s) in March (Fig. 12) should be used with caution.



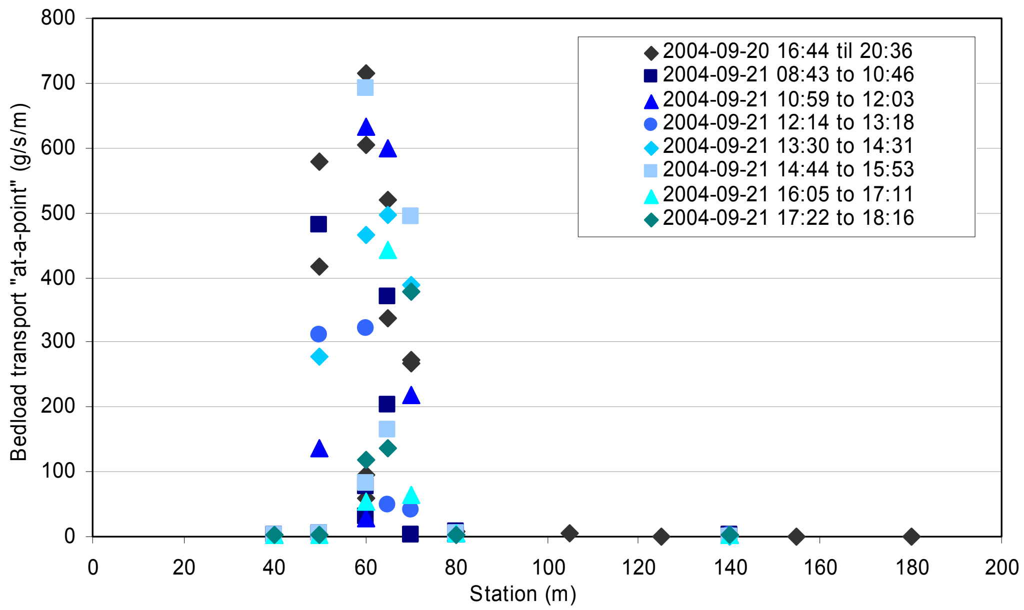
2004-03-10 12:10 to 15:59	40 m	50 m	60 m	65 m	70 m	80 m	105 m	140 m	
Width btw. station midpoints	16	10	7,5	5	7,5	17,5	30	47,5	Mean Q=787 m^3/s
Mean bedload transport at each station (g/s/m)	134	62	24	257	453	19	47	234	Range Q=9 m^3/s
Total transport btw. station midpoints (g/s)	2145	620	179	1283	3397	333	1424	11127	**Total transport 20.5 kg/s**
2004-03-10 16:10 to 18:38	40 m	50 m	60 m	65 m	70 m	80 m	105 m	140 m	
Width btw. station midpoints	16	10	7,5	5	7,5	17,5	30	47,5	Mean Q=799 m^3/s
Mean bedload transport at each station (g/s/m)	747	528	30	224	718	26	38	53	Range Q=9 m^3/s
Total transport btw. station midpoints (g/s)	11951	5278	221	1118	5387	448	1135	2535	**Total transport 28.1 kg/s**
2004-03-11 10:24 to 13:07	40 m	50 m	60 m	65 m	70 m	80 m	105 m	140 m	
Width btw. station midpoints	16	10	7,5	5	7,5	17,5	30	47,5	Mean Q=910 m^3/s
Mean bedload transport at each station (g/s/m)	55	145	133	215	99	34	387	218	Range Q=28 m^3/s
Total transport btw. station midpoints (g/s)	882	1448	997	1073	745	593	11608	10337	**Total transport 27.7 kg/s**
2004-03-11 13:50 to 19:42	40 m	50 m	60 m	65 m	70 m	80 m	105 m	140 m	
Width btw. station midpoints	16	10	7,5	5	7,5	17,5	30	47,5	Mean Q=956 m^3/s
Mean bedload transport at each station (g/s/m)	20	380	305	353	157	55	502	865	Range Q=41 m^3/s
Total transport btw. station midpoints (g/s)	323	3804	2285	1764	1175	966	15046	41111	**Total transport 66.5kg/s**

Figure 7: *Results from bedload measurements during 10–11 March 2004.*



2004-08-03 17:55 to 22:45	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=459 m^3/s
Mean bedload transport at each station (g/s/m)	6	23	9	86	6	4	6	Range Q=7 m^3/s
Total transport btw. station midpoints (g/s)	89	230	66	429	48	153	346	**Total transport 1.4 kg/s**
2004-08-04 10:15 to 12:52	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=461 m^3/s
Mean bedload transport at each station (g/s/m)	21	30	8	26	5	4	15	Range Q=15 m^3/s
Total transport btw. station midpoints (g/s)	339	296	60	131	37	140	923	**Total transport 1.9 kg/s**
2004-08-04 14:32 to 18:00	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=434 m^3/s
Mean bedload transport at each station (g/s/m)	52	22	6	39	139	5	6	Range Q=11 m^3/s
Total transport btw. station midpoints (g/s)	836	224	43	193	1040	162	353	**Total transport 2.9 kg/s**
2004-08-04 18:18 to 22:19	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=447 m^3/s
Mean bedload transport at each station (g/s/m)	6	19	16	264	89	6	8	Range Q=5 m^3/s
Total transport btw. station midpoints (g/s)	96	187	116	1322	669	209	507	**Total transport 3.1 kg/s**
2004-08-05 08:20 to 09:20	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=464 m^3/s
Mean bedload transport at each station (g/s/m)	13	56	14	27	131	28	5	Range Q=3 m^3/s
Total transport btw. station midpoints (g/s)	215	560	104	135	983	995	284	**Total transport 3.3 kg/s**

Figure 8: *Results from bedload measurements during 3–5 August 2004.*

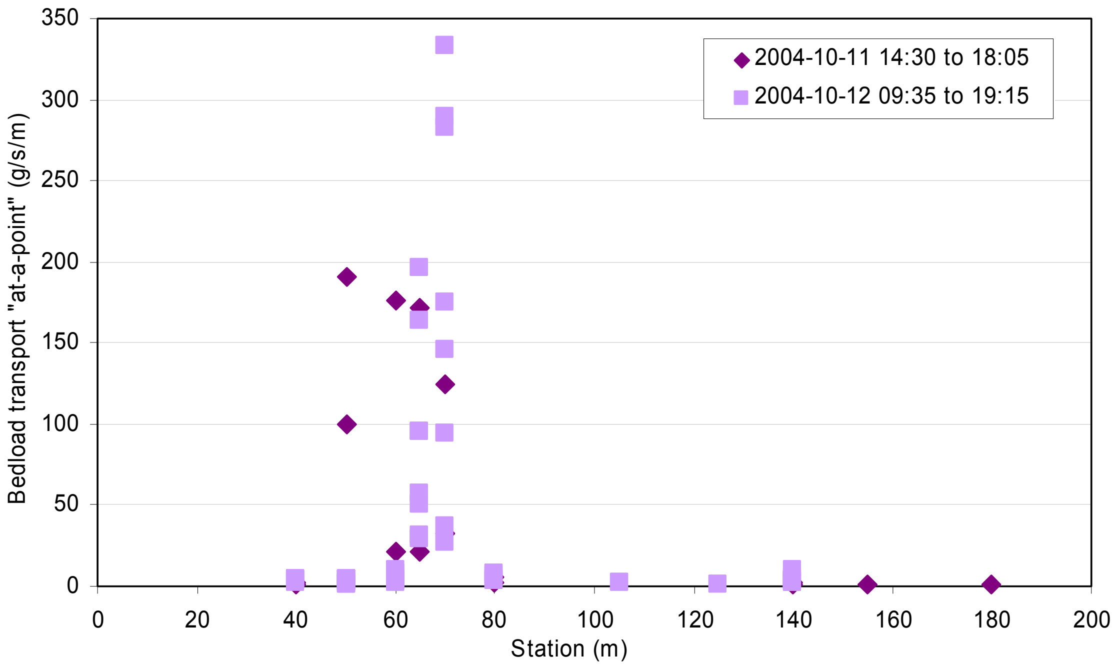


2004-09-20 16:44 to 20:36	40 m	50 m	60 m	65 m	70 m	80 m	140 m	
Width btw. station midpoints	16	10	7,5	5	7,5	35	60	Mean Q=408 m^3/s
Mean bedload transport at each station (g/s/m)	3	497	369	428	270	7	3	Range Q=8 m^3/s
Total transport btw. station midpoints (g/s)	16	4975	2766	2138	2026	256	164	**Total transport 12.4 kg/s**
2004-09-21 08:43 to 10:46	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=391 m^3/s
Mean bedload transport at each station (g/s/m)	2	244	54	286	2	5	2	Range Q=12 m^3/s
Total transport btw. station midpoints (g/s)	38	2437	406	1432	14	176	144	**Total transport 4.6 kg/s**
2004-09-21 10:59 to 12:03	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=379 m^3/s
Mean bedload transport at each station (g/s/m)	2	137	330	599	219	5	3	Range Q=10 m^3/s
Total transport btw. station midpoints (g/s)	31	1371	2478	2995	1639	191	157	**Total transport 8.9 kg/s**
2004-09-21 12:14 to 13:18	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=369 m^3/s
Mean bedload transport at each station (g/s/m)	2	310	321	48	40	6	2	Range Q=7 m^3/s
Total transport btw. station midpoints (g/s)	28	3101	2410	238	302	214	105	**Total transport 6.4 kg/s**

Figure 9: *Results from bedload measurements during 20–21 September 2004.*

2004-09-21 13:30 to 14:31	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=362 m^3/s
Mean bedload transport at each station (g/s/m)	2	279	464	498	388	2	1	Range Q=7 m^3/s
Total transport btw. station midpoints (g/s)	31	2787	3483	2488	2913	77	66	**Total transport 11.8 kg/s**
2004-09-21 14:44 to 15:53	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=350 m^3/s
Mean bedload transport at each station (g/s/m)	2	4	388	164	495	4	1	Range Q=11 m^3/s
Total transport btw. station midpoints (g/s)	28	42	2908	820	3709	145	66	**Total transport 7.7 kg/s**
2004-09-21 16:05 to 17:11	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=330 m^3/s
Mean bedload transport at each station (g/s/m)	2	2	53	442	64	5	2	Range Q=20 m^3/s
Total transport btw. station midpoints (g/s)	31	20	397	2209	479	168	92	**Total transport 3.4 kg/s**
2004-09-21 17:22 to 18:16	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=303 m^3/s
Mean bedload transport at each station (g/s/m)	2	3	118	137	378	3	2	Range Q=23 m^3/s
Total transport btw. station midpoints (g/s)	24	35	887	684	2831	107	92	**Total transport 4.7 kg/s**

Figure 9 cont.: *Results from bedload measurements during 20–21 September 2004.*



2004-10-11 14:30 to 18:05	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=327 m^3/s
Mean bedload transport at each station (g/s/m)	2	145	99	96	78	3	2	Range Q=12 m^3/s
Total transport btw. station midpoints (g/s)	26	1453	741	482	588	122	98	**Total transport 3.5 kg/s**
2004-10-12 09:35 to 19:15	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=337 m^3/s
Mean bedload transport at each station (g/s/m)	4	3	5	90	173	6	4	Range Q=10 m^3/s
Total transport btw. station midpoints (g/s)	59	30	38	450	1298	194	259	**Total transport 2.7 kg/s**

Figure 10: *Results from bedload measurements during 11–12 October 2004.*

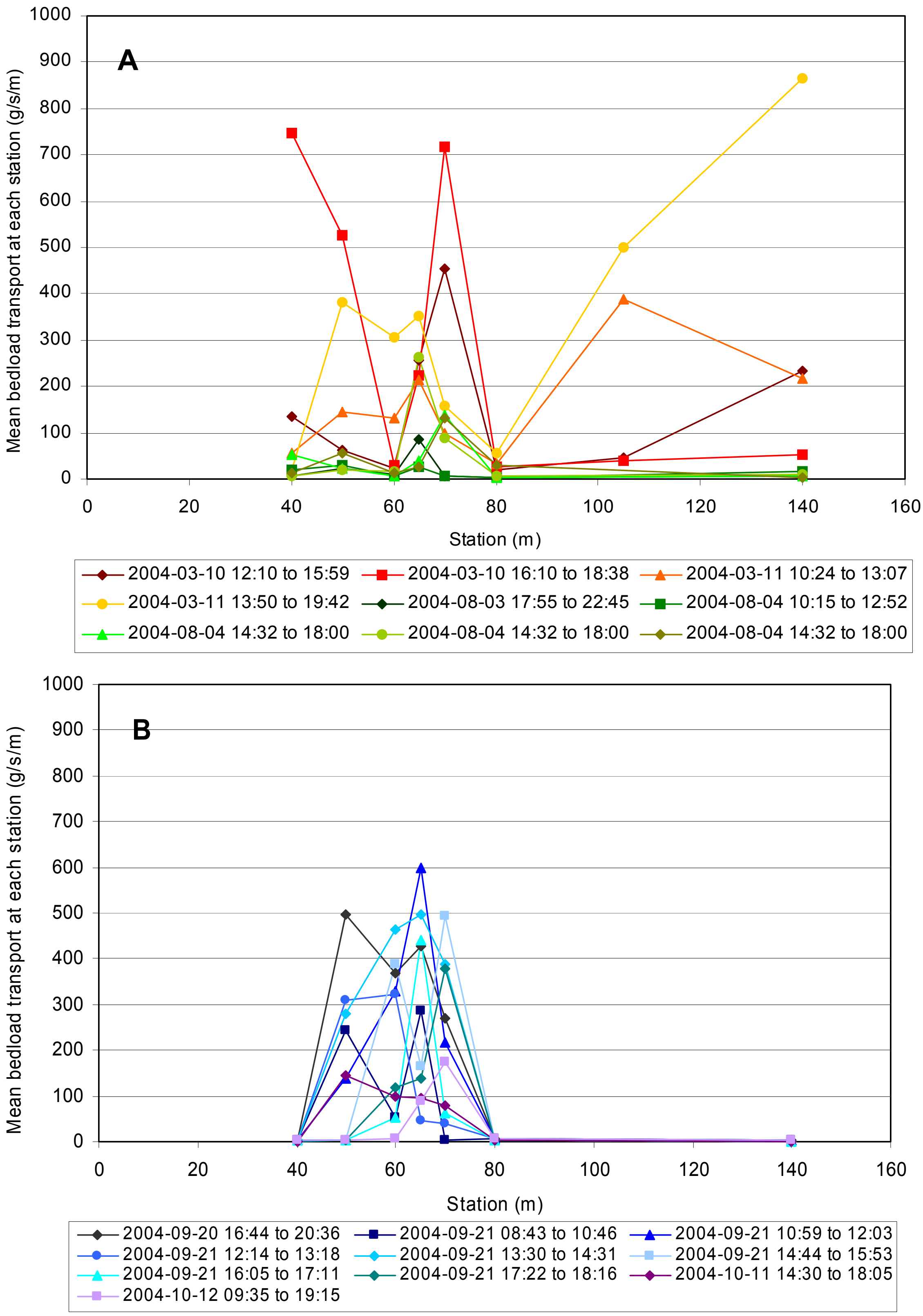


Figure 11: *Mean bedload transport at each station at Krókur in 2004. A. March and August campaigns. B. September and October campaigns. River banks are located at approx. 16 and 200 m. The same scale is used for both parts for easier comparison.*

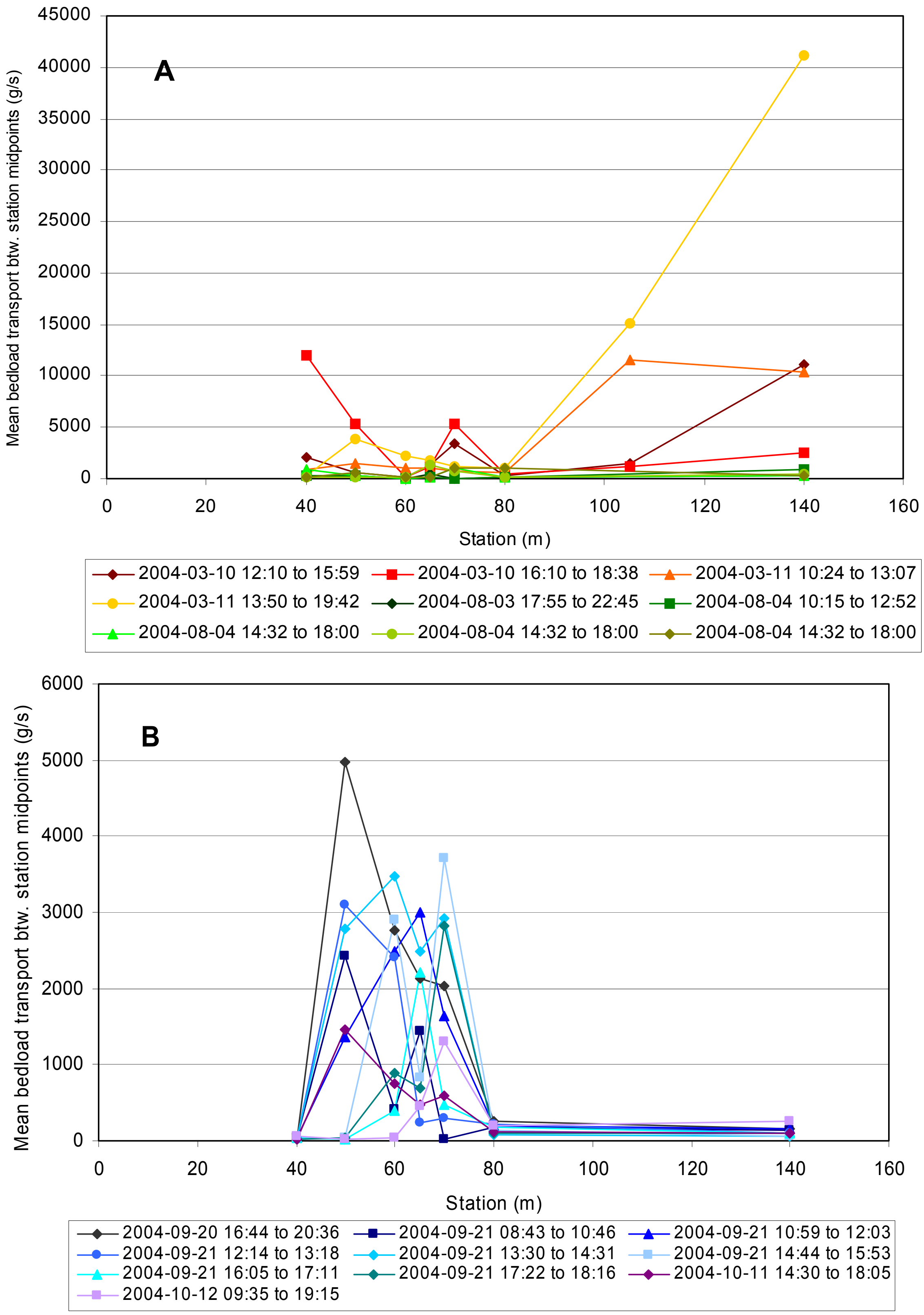


Figure 12: *Total bedload transport between station midpoints at Krókur in 2004. A. March and August campaigns. B. September and October campaigns. River banks are located at approx. 16 and 200 m.*

Figures 11 and 12 show the great difference in bedload campaigns, where the mean bedload at each station and between station midpoints is by far lowest during the August campaign and second lowest in the October campaign. The mean bedload transport in September was closer to that of the March flood for the stations in the middle of the channel, and even higher in most instances.

Table 7 and Fig. 13 show the total bedload transport for each bedload data set. The transport is by far highest in the March campaign (20.5–66.5 kg/s); however, the high transport close to the banks may cause an overestimate in the total bedload values, especially in the last bedload data set (66.5 kg/s, yellow). As with the mean bedload transport the total transport was the second highest in the September data sets, 3.4–12.4 kg/s (blue colors) and lowest in August (1.4–2.9 kg/s, green colors). The difference between the total bedload in March and September is to a large extent caused by the high transport closer to the river banks in the March flood.

Table 7: *Results from bedload measurements at Krókur in 2004.*

Campaign date	Mean discharge (m^3/s)	Range (m^3/s)	Total integrated bedload transport (kg/s)
2004-03-10 12:10 to 15:59	787	9	20.5
2004-03-10 16:10 to 18:38	799	9	28.1
2004-03-11 10:24 to 13:07	910	28	27.7
2004-03-11 13:50 to 19:42	956	41	66.5
2004-08-03 17:55 to 22:45	459	7	1.4
2004-08-04 10:15 to 12:52	461	15	1.9
2004-08-04 14:32 to 18:00	434	11	2.9
2004-08-04 18:18 to 22:19	447	5	3.1
2004-08-05 08:20 to 09:20	464	3	3.3
2004-09-20 16:44 to 20:36	408	8	12.4
2004-09-21 08:43 to 10:46	391	12	4.6
2004-09-21 10:59 to 12:03	379	10	8.9
2004-09-21 12:14 to 13:18	369	7	6.4
2004-09-21 13:30 to 14:31	362	7	11.8
2004-09-21 14:44 to 15:53	350	11	7.7
2004-09-21 16:05 to 17:11	330	20	3.4
2004-09-21 17:22 to 18:16	303	23	4.7
2004-10-11 14:30 to 18:05	327	12	3.,5
2004-10-12 09:35 to 19:15	337	10	2.3

Figure 13 shows well the large difference in total bedload transport among the data sets. The August transport is unusually low compared to the relatively high mean discharge at the time the samples were obtained (434–461 m^3/s). The reason for the low transport in August compared to in other campaigns is unknown, although it may be partly caused by a short-lived discharge peak that occurred a couple of days earlier when discharge reached close to 600 m^3/s. This event may have flushed the channel at Krókur clean of bedload causing less bedload to be sampled a couple of days later. Nevertheless, this is only speculative.

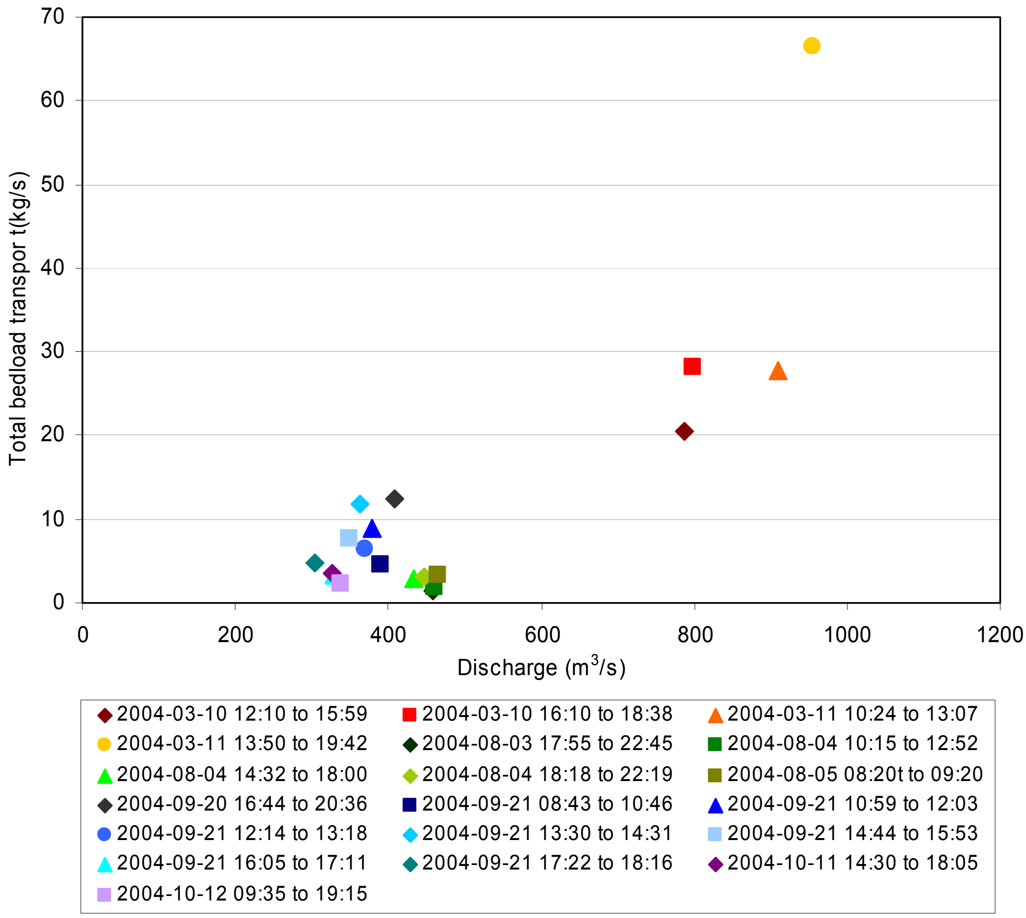


Figure 13: *Total bedload transport vs. mean discharge in the 2004 sediment campaigns.*

3.2.2 Bedload transport at Sandártunga

Using a specially equipped boat, 22 samples were retrieved from Sandártunga in two separate series on September 22, 2005 (Figs. 1 and 3). The samples were taken at 15, 25, 35, 45, 55, 65, 76, 85, 95, 105, and 115 m, with the river banks located at 5 and 119 m. It only took about a hour to obtain all samples in each series; however, the logistics with setting up the boat cable took several hours. All samples larger than 10 g were collected and used for grain size analysis; altogther seven samples.

The current conditions at Sandártunga make bedload sampling from a boat favorable, at least at the discharge values (about 350 m^3/s) prevailing during the September sampling. The discharge during sampling is, however, not well defined as there is no direct measurement at the site. Instead the discharge at Þjórsártún (vhm 30; V320) 50 km downstream is used with a 14 hours delay.

During both sampling series, the channel depth was measured. The measurements agree well with each other (Fig. 14) and show that the channel is deepest about 4.4 m close to the left (south) bank of the river. Based on the sentiment of the sampling team, the current was also greatest in this part of the river, but discharge was not measured directly.

The bedload transport at each station in both sampling series is also shown on Fig. 14 and the underlying data are portrayed in Table 8. It is evident that the bedload transport was concentrated in a narrow stretch on the right slope of the channel, from 55 to 75 m. There was, however, a large difference between samples taken at these three sites during each sampling series. The bedload transport was from 10 to 13 g/s/m at sites 55–75m in the first series, but reached over 30 g/s/m in the second series, when it was concentrated at 55 and 65 m (Fig. 14; Table 8). Very little transport was measured at the other sites, with the bag being empty at many stations.

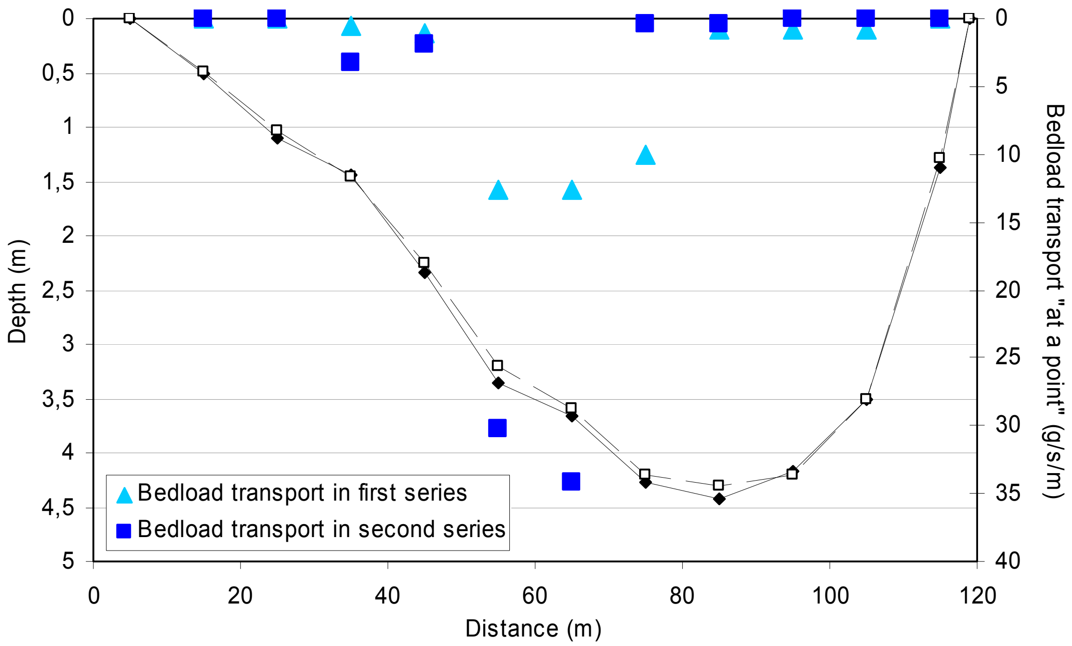


Figure 14: *The measured channel depth in the two sampling series at Sandártunga (black lines) and bedload transport "at-a-point" in same sampling series.*

Table 8: *Results from bedload measurements at Sandártunga on September 22, 2004.*

2004-09-22 18:06-19:03	**15**	**25**	**35**	**45**	**55**	**65**	**75**	**85**	**95**	**105**	**115**	(m)
Width btw. station midpoints	10	10	10	10	10	10	10	10	10	10	7	Mean Q= ~350 m^3/s
Mean bedload transport at each station (g/s/m)	0	0	0,5	1,1	12,6	12,6	10,1	0,9	0,9	0,9	0	
Total transport btw. station midpoints (g/s)	0	0	5	11	126	126	101	9	9	9	0	**Total transport 0.4 kg/s**
2004-09-22 19:03-20:06	**15**	**25**	**35**	**45**	**55**	**65**	**75**	**85**	**95**	**105**	**115**	(m)
Width btw. station midpoints	10	10	10	10	10	10	10	10	10	10	7	Mean Q= ~350 m^3/s
Mean bedload transport at each station (g/s/m)	0	0	3,2	1,9	30,2	34,2	0,4	0,4	0	0	0	
Total transport btw. station midpoints (g/s)	0	0	32	19	302	342	4	4	0	0	0	**Total transport 0.7 kg/s**

Using the same methods for transport calculations as for Krókur (chapter 2.2.2), the total bedload transport was 0.4 kg/s in the first series and 0.7 kg/s in the second series. This is over an order of magnitude less transport than was measured at Krókur two days earlier (3.4–12.4 kg/s).

3.2.3 Grain size of bedload samples

3.2.3.1 Krókur samples

One sample from each station at Krókur, i.e. 40, 50, 60, 65, 70, 80, and 140 m, were collected for grain size analysis in each of the four bedload campaigns, as well as an extra sample from 105 m in March, altogether 29 samples. All samples were analyzed at the Sedimentology Laboratory of the Hydrological Service, as described in chapter 2.2.3. The cumulative frequency graphs are shown on Figs. 15 to 18 and the same colors are used for each station in all graphs for easier comparison. The results from moment statistics are shown in Table 9 where the type of sample and the sediment name is also shown.

Great variability is seen from one station to another within each campaign as well as between the same stations in different campaigns. Despite the difference, some general indications can be made. The finest material was usually taken from 80 and 140 m, with the sample from 60 m being similarly fine in three out of four campaigns. In contrast, the coarsest material in each campaign was most often taken at 50, 65, and 70 m. The frequency curves (Figs. 15–18) show that most samples taken in March and August are coarser than the ones taken in September and October, although this is better portrayed on Fig. 19, which shows the mean grain size of each sample. The coarsest samples were taken in March when three samples had mean grain size coarser than -1.0 ϕ, or 2 mm. In contrast, all September samples but one had mean grain size finer than 0.5 ϕ, i.e. 0.71 mm or coarse sand.

It should be noted from the start that care should be taken when the statistical results from the method of moments calculations are interpreted. Strictly, such analysis should only be valid when performed on closed-end, unimodal size distributions, which these data are often not. Table 9 lists the shape of the distributions, i.e. whether they are uni-, bi-, tri-, or polymodal.

The coarse March samples and the coarse 50 m sample from October were less sorted (>1.3 ϕ) than the rest of the samples which were relatively similar, with sorting between 0.7 and 1.2 ϕ (Fig. 19). Figure 19C shows the skewness calculated by moment statistics, which differed greatly from one station to another, but also within each station. Using the definition in moment statistics for logarithmic calculations of -0.43 as the upper limit for coarse skewed distributions (Blott and Pye 2001), all the samples from 60 and 140 m are negatively (coarse) skewed, as well as half of the samples from 40, 70, and 80 m. This indicates that these samples have an excess tail of coarse material. Most of the remaining samples have symmetrical distribution (skewness between -0.43 and 0.43).

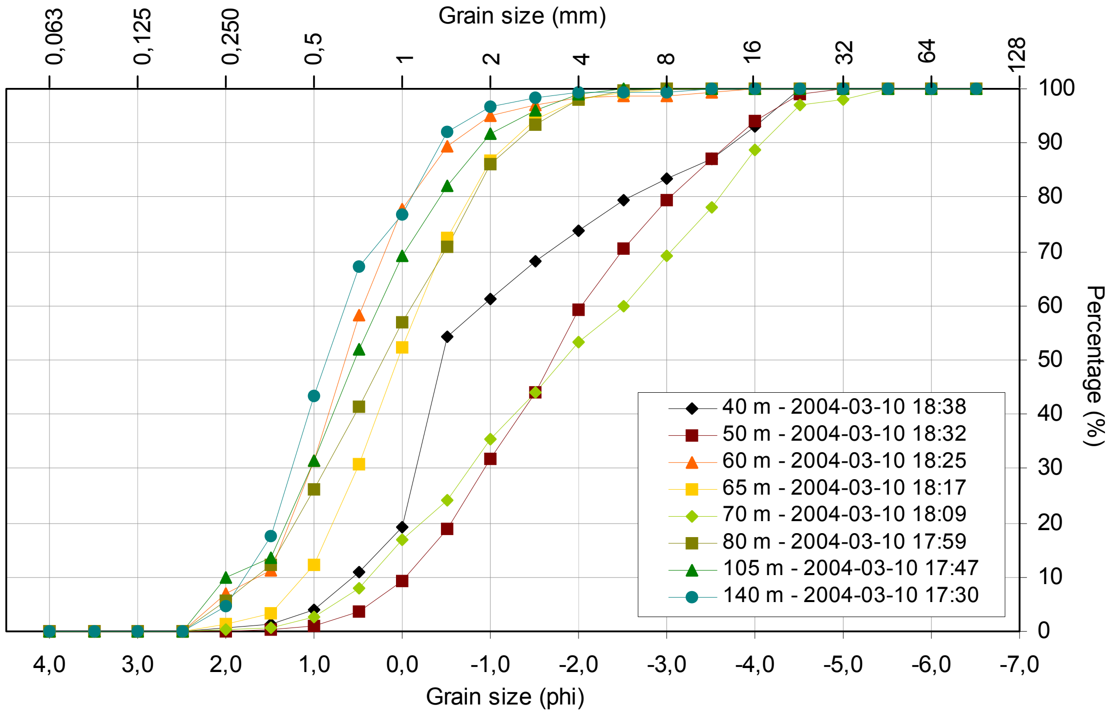


Figure 15: *Cumulative grain size curve for Krókur bedload samples collected on March 10, 2004.*

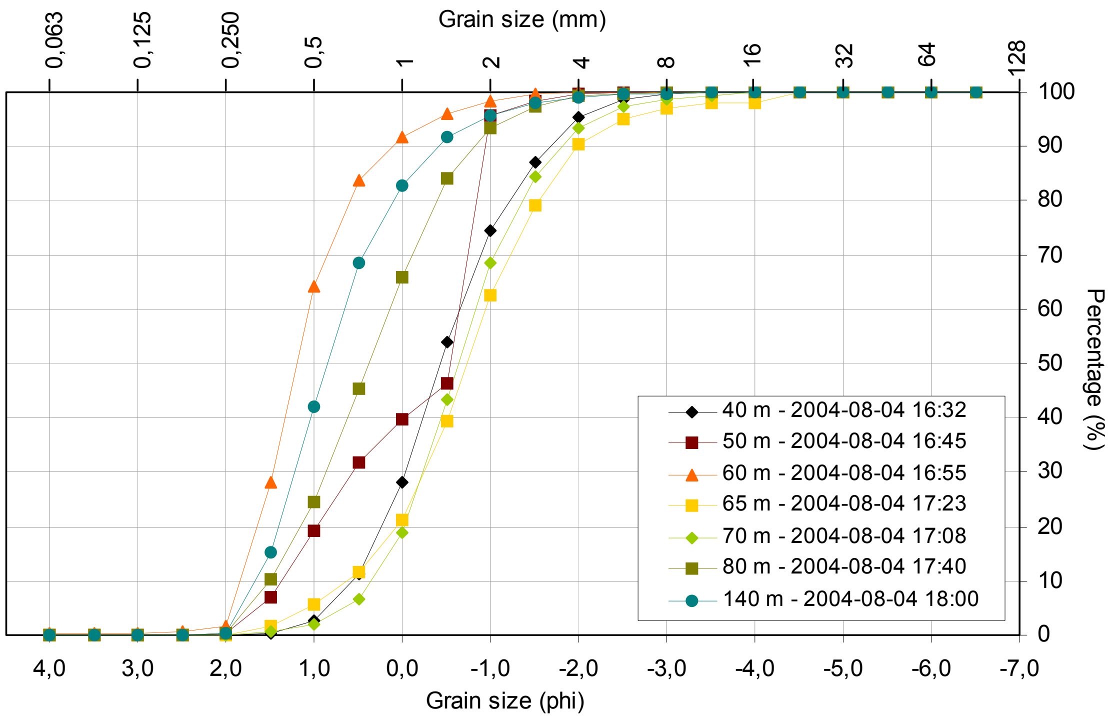


Figure 16: *Cumulative grain size curve for Krókur bedload samples collected on August 4, 2004.*

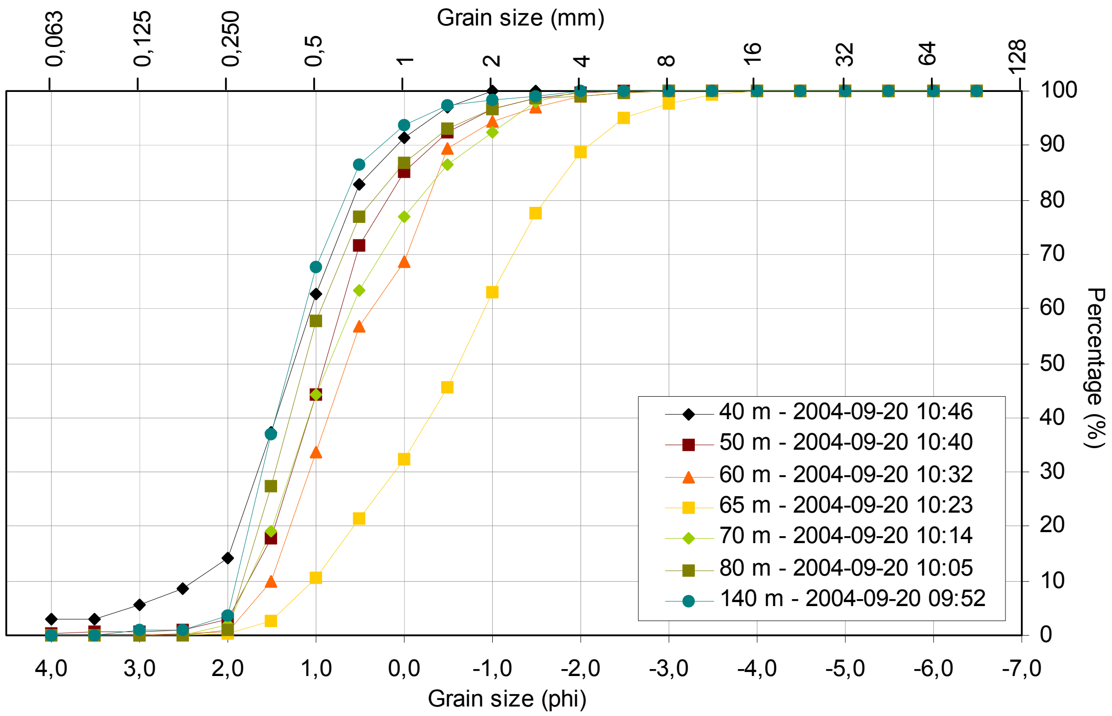


Figure 17: *Cumulative grain size curves for Krókur bedload samples collected on September 20, 2004.*

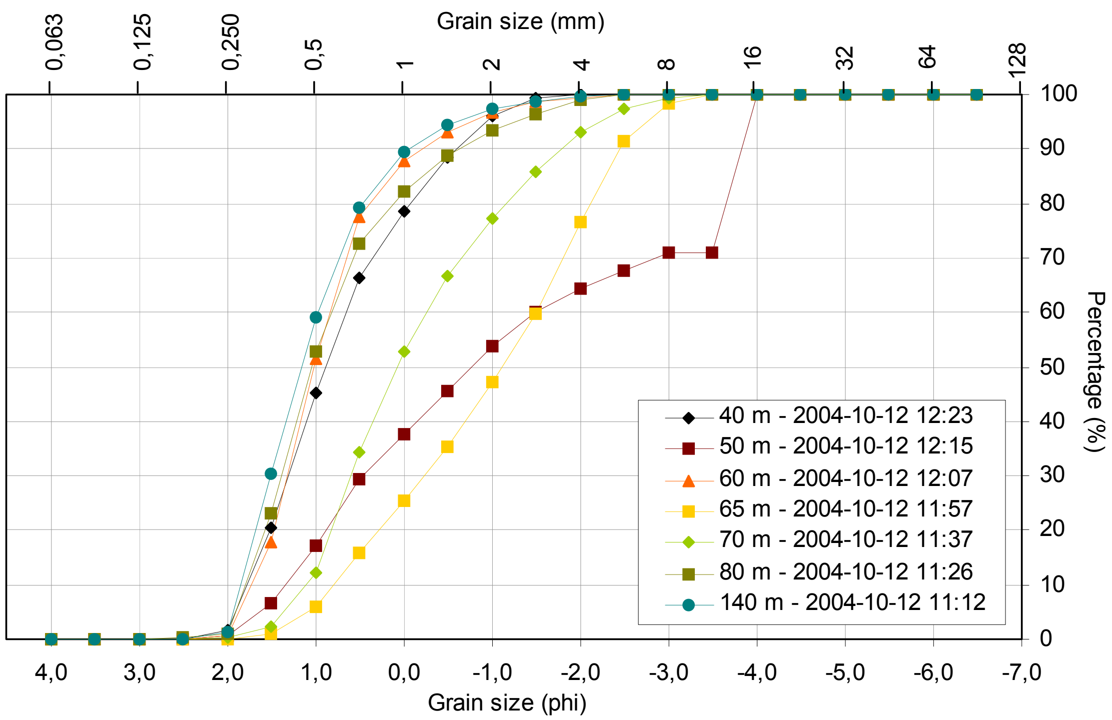


Figure 18: *Cumulative grain size curves for Krókur bedload samples collected on October 12, 2005.*

Table 9: *Results of statistical analysis of the grain size distribution (logarithmic method of moments), shape of the grain size curve, and sediment name of all samples taken at Krókur (K) and Sandártunga (S) in 2004.*

Sample name	Shape of grain size distribution	Sediment name*	Mean grain size (ϕ)	Sorting (ϕ)	Skewness (ϕ)
K-40 m - 2004-03-10 18:38	Polymodal	Sandy Very Fine Gravel	-1,06	1,55	-0,69
K-50 m - 2004-03-10 18:32	Unimodal	Sandy Very Fine Gravel	-1,75	1,35	-0,10
K-60 m - 2004-03-10 18:25	Bimodal,	Very Fine Gravelly Coarse Sand	0,56	0,96	-1,05
K-65 m - 2004-03-10 18:17	Unimodal	Very Fine Gravelly Coarse Sand	0,01	0,91	-0,23
K-70 m - 2004-03-10 18:09	Polymodal	Sandy Medium Gravel	-1,86	1,68	0,03
K-80 m - 2004-03-10 17:59	Bimodal	Very Fine Gravelly Coarse Sand	0,20	1,10	-0,10
K-105 m - 2004-03-10 17:47	Bimodal	Very Fine Gravelly Coarse Sand	0,47	1,03	-0,27
K-140 m - 2004-03-10 17:30	Bimodal	Slightly Very Fine Gravelly Medium Sand	0,72	0,89	-0,82
K-40 m - 2004-08-04 16:32	Unimodal	Very Fine Gravelly Very Coarse Sand	-0,49	0,85	-0,29
K-50 m - 2004-08-04 16:45	Bimodal	Slightly Very Fine Gravelly Very Coarse Sand	-0,06	0,92	0,58
K-60 m - 2004-08-04 16:55	Unimodal	Slightly Very Fine Gravelly Medium Sand	1,06	0,69	-1,25
K-65 m - 2004-08-04 17:23	Unimodal	Sandy Very Fine Gravel	-0,75	1,08	-0,40
K-70 m - 2004-08-04 17:08	Unimodal	Sandy Very Fine Gravel	-0,68	0,87	-0,42
K-80 m - 2004-08-04 17:40	Unimodal	Very Fine Gravelly Coarse Sand	0,35	0,89	-0,39
K-140 m - 2004-08-04 18:00	Unimodal	Slightly Very Fine Gravelly Medium Sand	0,71	0,83	-1,16
K-40 m - 2004-09-21 10:46	Unimodal	Moderately Sorted Medium Sand	1,19	0,83	-0,01
K-50 m - 2004-09-21 10:40	Unimodal	Slightly Very Fine Gravelly Medium Sand	0,80	0,81	-0,66
K-60 m - 2004-09-21 10:32	Bimodal	Very Fine Gravelly Coarse Sand	0,49	0,88	-0,68
K-65 m - 2004-09-21 10:23	Unimodal	Sandy Very Fine Gravel	-0,58	1,18	-0,11
K-70 m - 2004-09-21 10:14	Bimodal	Very Fine Gravelly Medium Sand	0,66	0,94	-0,69
K-80 m - 2004-09-21 10:05	Unimodal	Slightly Very Fine Gravelly Medium Sand	0,93	0,83	-1,34
K-140 m - 2004-09-21 09:52	Unimodal	Slightly Very Fine Gravelly Medium Sand	1,17	0,71	-1,12
K-40 m - 2004-10-12 12:23	Unimodal	Slightly Very Fine Gravelly Medium Sand	0,73	0,87	-0,64
K-50 m - 2004-10-12 12:15	Trimodal	Sandy Medium Gravel	-1,12	1,99	-0,17
K-60 m - 2004-10-12 12:07	Unimodal	Slightly Very Fine Gravelly Medium Sand	0,86	0,77	-1,30
K-65 m - 2004-10-12 11:57	Bimodal,	Sandy Very Fine Gravel	-0,96	1,21	0,26
K-70 m - 2004-10-12 11:37	Unimodal	Very Fine Gravelly Coarse Sand	-0,14	1,09	-0,59
K-80 m - 2004-10-12 11:26	Unimodal	Very Fine Gravelly Medium Sand	0,80	0,93	-1,15
K-140 m - 2004-10-12 11:12	Unimodal	Slightly Very Fine Gravelly Medium Sand	0,99	0,79	-1,29
S-35 m - 2004-09-22 19:54	Unimodal,	Slightly Very Fine Gravelly Medium Sand	0,90	0,64	-0,94
S-45 m - 2004-09-22 19:49	Bimodal	Sandy Very Fine Gravel	-0,62	1,07	0,25
S-55 m - 2004-09-22 18:32	Bimodal	Sandy Medium Gravel	-2,44	1,93	0,87
S-55 m - 2004-09-22 19:42	Trimodal	Sandy Medium Gravel	-1,09	1,85	-0,13
S-65 m - 2004-09-22 18:39	Unimodal	Very Fine Gravel	-1,90	0,76	0,35
S-65 m - 2004-09-22 19:35	Unimodal	Very Fine Gravel	-1,64	0,64	-0,07
S-75 m - 2004-09-22 18:43	Bimodal	Very Coarse Gravel	-3,77	1,95	1,04

* Sediment name is given by the GRADISTAT program (Blott and Pye 2001), but is based on the work of Folk (1954).

The correlation between the different moment statistics are shown on Fig. 20. Obvious correlation is seen between mean grain size and sorting although the correlation coefficient (R^2) is only medium high (0.64). The coefficient is though significantly higher for the individual sampling campaigns, i.e. 0.74–0.90, if the August campaign is excluded (0.54). Hence, samples with smaller grain size (larger ϕ) tend to be better sorted (lower ϕ). Good correlation is only seen for the September campaign if skewness vs. mean grain size are compared. Still there appears to be a tendency for finer samples to be more negatively skewed (Fig. 20B). No correlation is on the other hand seen between sorting and skewness (Fig. 20C).

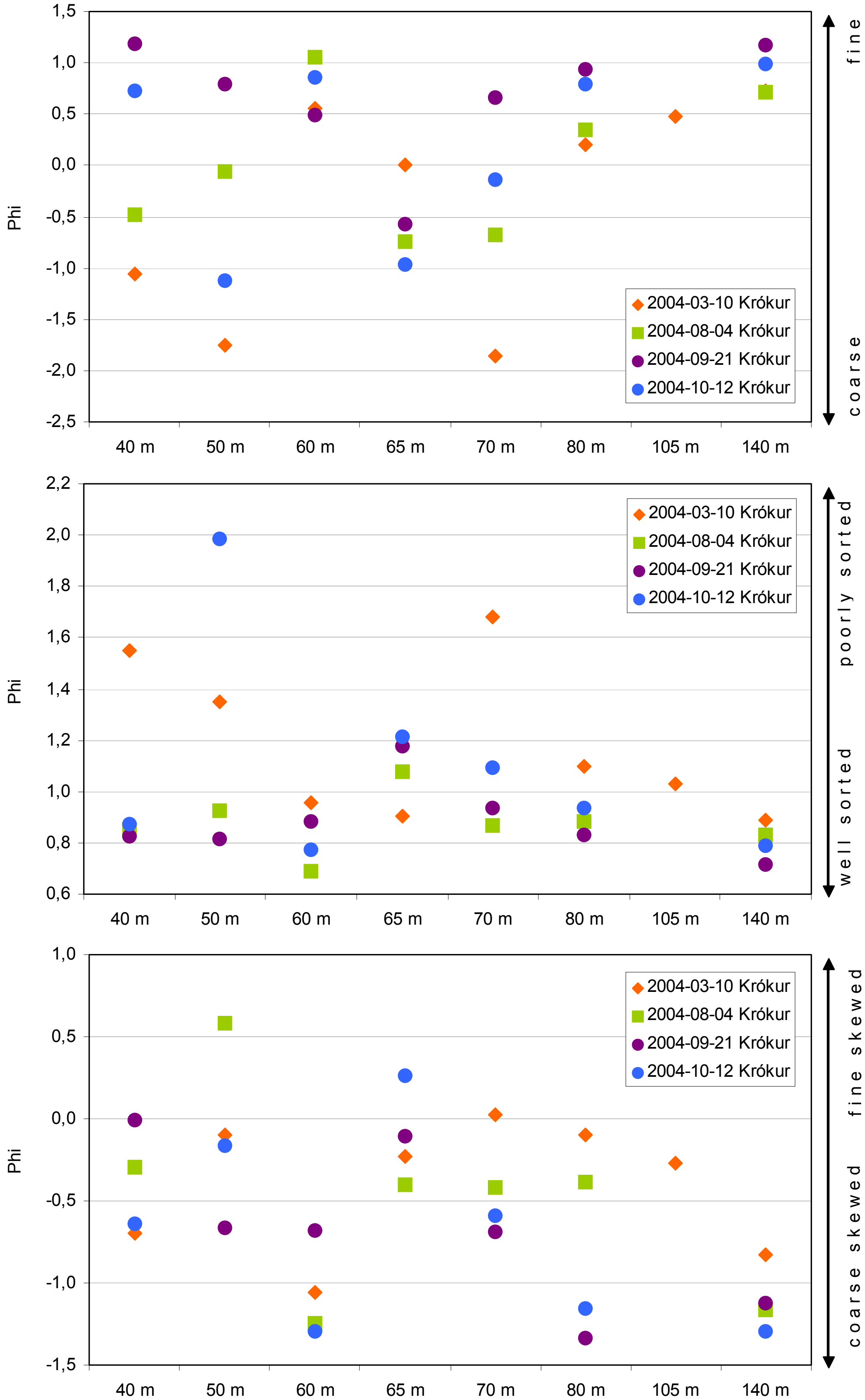


Figure 19: *Mean grain size (A), sorting (B), and skewness (C) (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2004.*

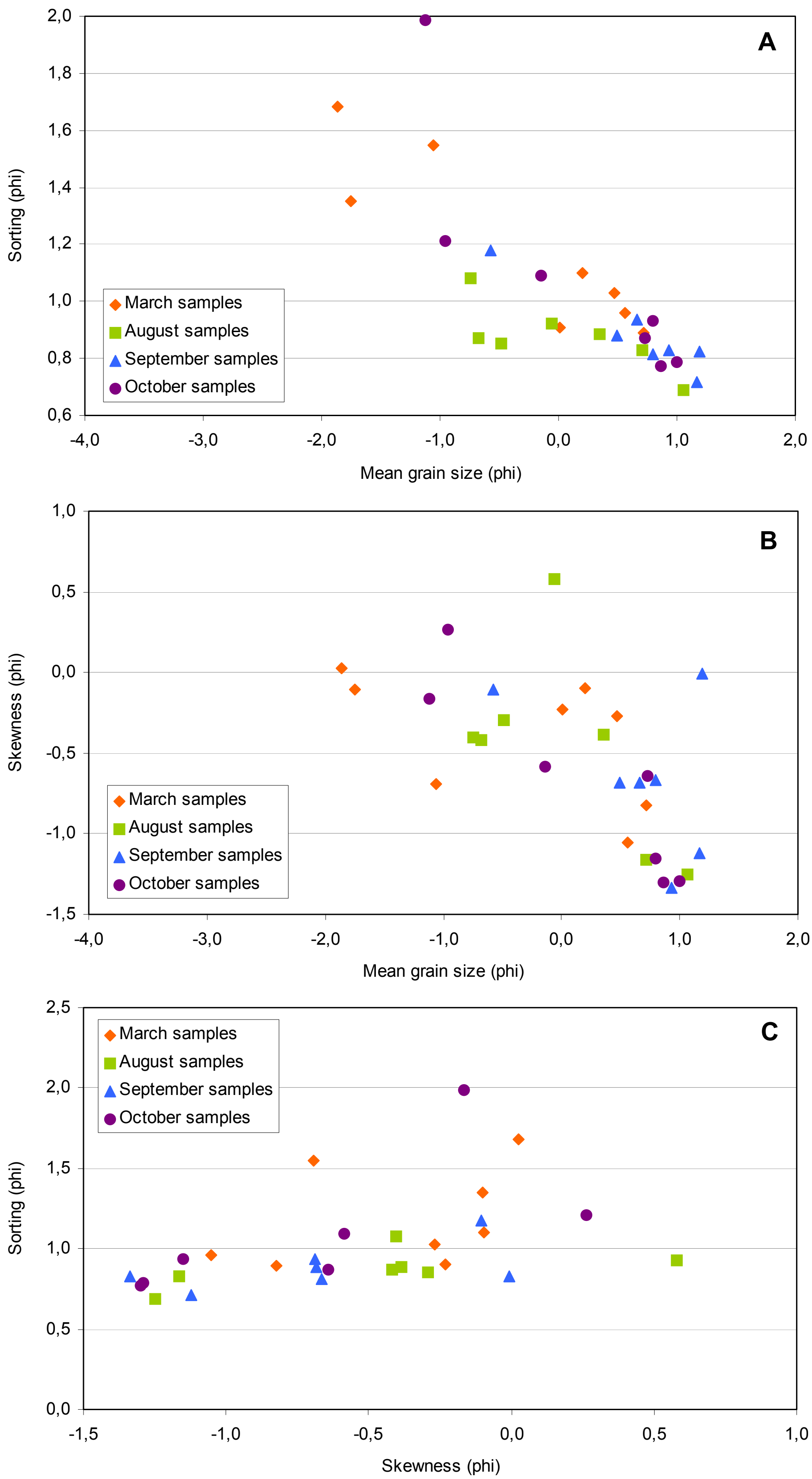


Figure 20: *Comparison of moment statistics values in 2004. A. Sorting vs. mean grain size. B. Skewness vs. mean grain size. C. Sorting vs. skewness.*

3.2.3.2 Sandártunga samples

The cumulative frequency curves of the seven samples taken at Sandártunga on September 22 are represented on Fig. 21, whereas the results from moment statistics were shown in Table 9 and are illustrated on Fig. 22.

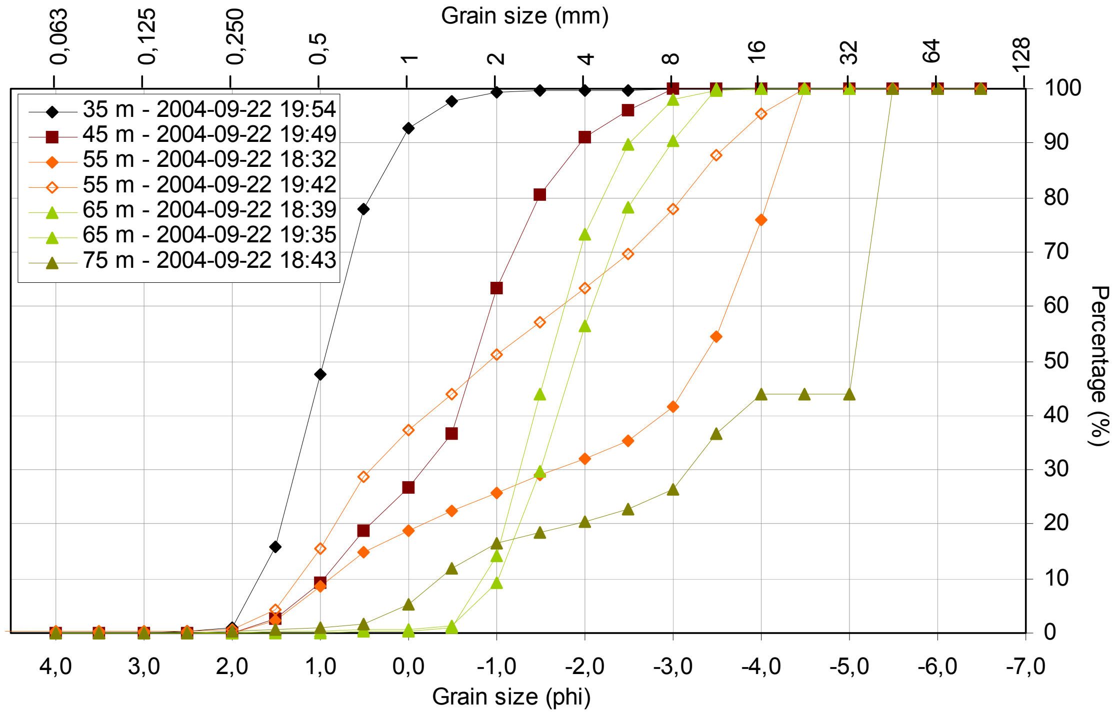


Figure 21: *Cumulative grain size curves for Sandártunga bedload samples collected on September 22, 2004.*

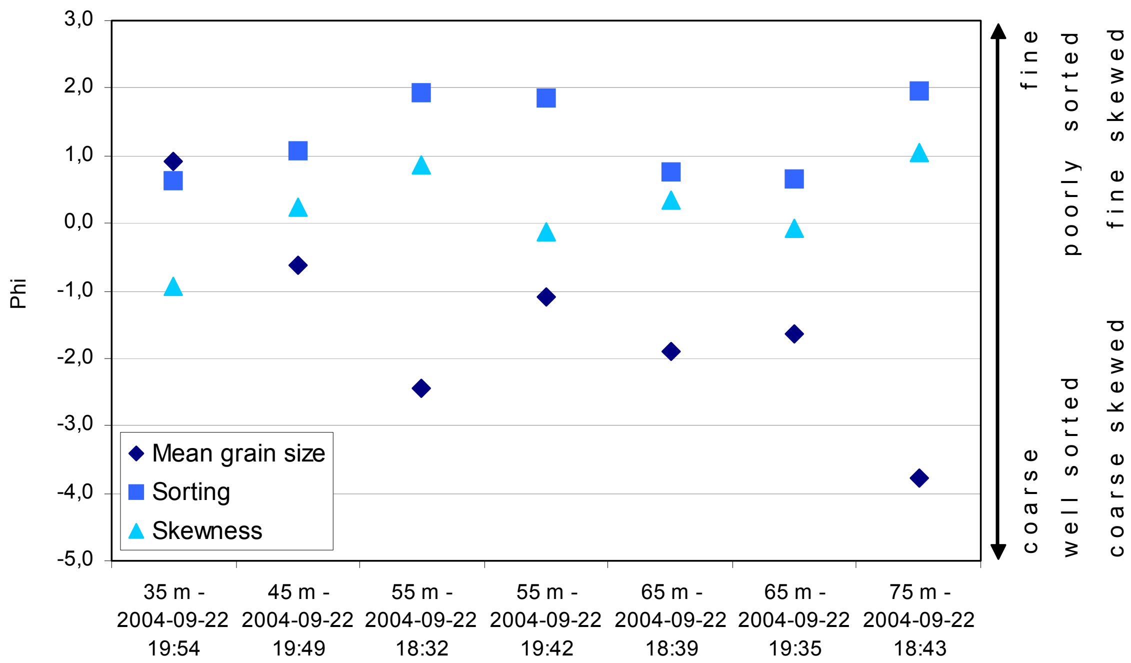


Figure 22: *Mean grain size (diamonds), sorting (squares), and skewness (triangles) (according to moment statistics) of all sieved samples obtained at Sandártunga on September 22, 2004.*

Great difference is seen in the grain size among the seven samples that were taken at five widths, 35, 45, 55 (2 samples), 65 (2 samples), and 75 m. This is both seen on the frequency graphs on Fig. 21, which are very dissimilar except for the two 65 m samples, and on Fig. 22 which shows the mean grain size. The coarsest samples were taken at 75 m, but the finest material was collected at 35 m. In all samples but the ones from 35 and 45 m is about half of the sample or more coarser than -1 ϕ (2 mm), which classifies as gravel (mean grain size >-1 ϕ).

Large difference is also seen in the sorting values of the samples, which range from -1.0 ϕ to 2.0 ϕ. Sorting is least in the two samples from 55 m and the coarse sample from 75 m. Skewness is symmetrical (-0.43–0.43) in four samples, but is positively (fine) skewed in the poorly sorted samples from 55 and 75 m and negatively (coarse) skewed in the fine sample from 35 m.

3.3 Comparison of suspended and bedload transport

The bedload and suspended sediment samples were only obtained during the same day in August; a day passed between the sampling in the other three campaigns. However, the discharge did not change substantially between the sampling days in September and October so bedload and suspended transport was compared for samples/sampling sets in August, September, and October. The difference in discharge was too great between sampling days in March to justify such comparison. Figure 23 shows the percentage of bedload/suspended transport of the total sediment transport. However, these results show only a momentary idea of the sediment distribution given the error within both measurements and the fact that the sample types were taken during separate days. Based on these three sample pairs the bedload transport at Krókur was from 4 to 8% of the total sediment transport.

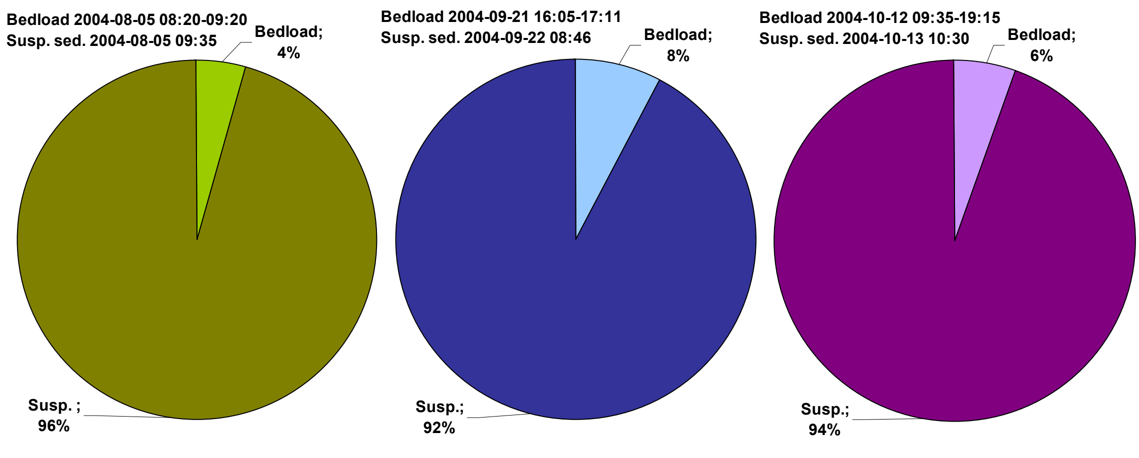


Figure 23: *Comparison of suspended sediment tranport with bedload transport in three campaigns at Þjórsá, Krókur in 2004.*

4 CONCLUSIONS

This report describes the results gathered during the fourth year of the extensive sediment sampling program initiated in 2001 at Krókur and Urriðafoss in the lower reaches of Þjórsá, as well as results from grain size analysis of samples taken as a part of chemical sampling campaign at Urriðafoss.

The execution of the campaigns in 2004 was similar as in 2003, including five sediment campaigns where suspended sediment samples were taken at three locations: 1) the motorized cableway at Krókur; 2) from the Urriðafoss cableway; and 3) with a handheld sediment sampler from the river bank beneath the old Highway 1 bridge. Bedload samples were taken at Krókur in all but the December campaign. An addition to the program carried out in earlier years bedload sampling was performed in September at Sandártunga.

The main objectives of the sediment program in the lower reaches of Þjórsá can be classified into two main categories. Firstly, the campaigns were carried out to obtain additional suspended sediment samples in the lower Þjórsá region at variable discharge and to compare suspended samples from Urriðafoss and Krókur. Secondly, the project is also carried out to evaluate the bedload transport in lower Þjórsá, and in this year to also compare the difference in bedload transport between Krókur and Sandártunga. In the following chapters the main results from the analysis of suspended and bedload sediment samples are summarized.

4.1 Suspended samples from lower Þjórsá

Twelve suspended samples were taken with a handheld rod-sampler from the river bank beneath the bridge on Highway 1 (Urriðafoss S3 samples), four samples (Urriðafoss S1 samples) were taken with the normal suspended sediment sampler (S49) from the cableway downstream of the bridge with a hydraulic winch, and five suspended sediment samples were obtained with a S49 sampler from the Krókur electric cableway (Krókur S1 samples).

The discharge during the time of suspended sediment sampling ranged greatly, or from about 240 to over 900 m^3/s, with the reatest difference observed between the Urriðafoss S3 samples. In this report the discharge at the Þjórsártún gauge (vhm 30/V320) is used unmodified for samples taken at all three locations although the three sampling locations are located at different distances away from the Þjórsártún gauge.

4.1.1 Urriðafoss S3 samples

The total sediment concentration in the Urriðafoss S3 samples varied from 25 to 1341 mg/l; however, the high concentration in the late October sample is significantly higher than the second-highest concentration of 137 mg/l in a sample taken in the March flood at 914 m^3/s. The high total concentration is mainly caused by abnormally high *sandur* (>0.2 mm) percentage (90%). This high sandur percentage may possibly be explained by the low discharge during the time of sampling (243 m^3/s) causing the handheld rod-sampler to reach closer to the river bottom than normal (Fig. 4; Table 4).

Some seasonal changes are seen in the grain size distribution of the S3 samples with increased percentage of the *leir* (<0.002 mm) grain size (44–54%) in the August and September samples coinciding to the glacier melting season. In contrast, the percentage of the *sandur* and *grófmór* (0.06–0.2 mm) grain size classes are highest in the winter samples as has been evident in recent years. As with other suspended 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.

4.1.2 Urriðafoss S1 samples

Only four samples were obtained from the old Urriðafoss cableway as the trail to the site was not passable during the March flood. The total sediment concentration ranged from 65 to 423 mg/l in the samples, of which the *sandur* grain size has the greatest concentration, about 45 to 389 mg/l (Fig. 5; Table 5). The October sample does though include abnormally high sandur percentage (92%) which causes the total sediment concentration to be relatively high compared to samples taken at similar or higher discharge. The fraction of fine material in these S1 Urriðafoss samples is, as with the S3 samples, higher in the August and September samples than the winter samples.

4.1.3 Krókur S1 samples

Suspended sediment samples were obtained from the Krókur cableway in all five sediment campaign. The individual sample bottles were taken at 40, 50, 60, 65, 70, 80, and 140 m and combined before analysis. The total sediment concentration of these five samples ranged from 57 mg/l during the December campaign (Q=275 m^3/s) to 158 mg/l in the August campaign (Q=455 m^3/s) (Fig. 6; Table 6). As in samples from the other two locations, the concentration of the fine material *leir* and *méla* (0.002–0.02 mm) is highest in the August and September samples; however, the seasonal difference is not as pronounced as at Urriðafoss.

4.1.4 Comparison between suspended samples from three locations

Similar comparison was carried out for the three individual sample types as in 2003 (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2004) to better evaluate the difference between the sample types. The comparison was done both for the percentage and the concentration results; however, in contrast to what was done for the 2003 samples, in this report we show the concentration results instead of percentage results.

Table 10 shows the comparison of the sediment concentration in each campaign for the discharge, total and dissolved sediment, the five individual grain size classes, and the size comparison of the largest particle in each sample. In each campaign, the samples were taken in the order of flow direction (Fig. 1), i.e. first the sample was taken at Krókur (K-S1), then beneath the old bridge on Highway 1 (U-S3), and last at the cableway at Urriðafoss (U-S1). Even though the sampling equipment was put up at each location prior to sampling (except in the March campaign when it was not possible to reach the lowermost location), it usually took three to four hours to get the three samples.

The discharge at Þjórsártún is used for each sample although the water level gauge is located between the Krókur and Urriðafoss sites. No correction is made for the time it takes the river to flow between the sampling site and the gauge. The greatest difference in discharge between the three samples in each campaign was in September when the discharge at the Krókur sampling was 8% higher than when the S1 sample from the Urriðafoss cableway was taken. In all other samples the difference was 5% or less, with the Krókur discharge being highest in all instances but one.

Table 10: *Comparison of grain size results (concentration in mg/l) 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).*

Sample name Time	Discharge (m^3/s)	Sediment (mg/l)	Dissolved (mg/l)	Sandur mg/l (>0.2 mm)	Grófmór mg/l (0.06–0.2 mm)	Fínmór mg/l (0.02–0.06 mm)	Méla mg/l (0.002–0.02 mm)	Leir mg/l (<0.002 mm)	Larg. part. (mm)	Sample type
K-S1 2004-03-12 15:15	659	92	39	17	18	6	42	8	17	K-S1
U-S1 2004-03-12 16:30	654	56	40	9	15	2	26	3	9	U-S3
U. bridge/Krókur	*0.99*	*0.60*	*1.04*	*0.94*	*1.35*	*0.57*	*1.02*	*0.56*	*0.77*	
K-S1 2004-08-05 09:35	455	158	61	44	5	17	49	43	44	K-S1
U-S3 2004-08-05 11:50	446	90	65	23	2	2	23	41	23	U-S3
U-S1 2004-08-05 13:35	439	187	58	58	7	22	56	43	58	U-S1
U. bridge/Krókur	*0.98*	*0.57*	*1.07*	*0.93*	*0.67*	*0.18*	*0.81*	*1.67*	*1.37*	
U. cableway/Krókur	*0.96*	*1.19*	*0.94*	*1.11*	*1.33*	*1.09*	*0.97*	*0.85*	*1.26*	
K-S1 2004-09-22 08:46	330	120	55	52	2	2	26	37	52	K-S1
U-S3 2004-09-22 10:15	313	67	58	6	2	3	23	33	6	U-S3
U-S1 2004-09-22 11:15	304	121	65	52	2	4	24	39	52	U-S1
U. bridge/Krókur	*0.95*	*0.56*	*1.05*	*0.21*	*1.50*	*2.00*	*1.59*	*1.58*	*0.36*	
U. cableway/Krókur	*0.92*	*1.01*	*1.18*	*1.00*	*1.00*	*1.50*	*0.91*	*1.03*	*1.20*	
K-S1 2004-10-13 10:30	338	116	46	59	3	5	22	27	59	K-S1
U-S3 2004-10-13 12:15	329	66	46	26	1	1	17	22	26	U-S3
U-S1 2004-10-13 14:10	321	423	75	389	8	8	8	8	389	U-S1
U. bridge/Krókur	*0.97*	*0.57*	*1.00*	*0.76*	*0.67*	*0.25*	*1.32*	*1.43*	*1.73*	
U. cableway/Krókur	*0.95*	*3.65*	*1.63*	*1.80*	*0.67*	*0.50*	*0.11*	*0.09*	*1.33*	
K-S1 2004-12-14 14:00	275	57	78	34	2	1	14	6	34	K-S1
U-S3 2004-12-14 15:53	273	30	72	7	2	0	9	11	7	U-S3
U-S1 2004-12-14 17:10	277	65	78	45	1	2	12	5	45	U-S1
U. bridge/Krókur	*0.99*	*0.53*	*0.92*	*0.40*	*2.00*	*0.50*	*1.25*	*3.70*	*0.50*	
U. cableway/Krókur	*1.01*	*1.14*	*1.00*	*1.15*	*0.50*	*1.50*	*0.79*	*0.70*	*1.00*	

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. 24. All the S3 samples from Urriðafoss (U-S3) have lower concentration of total suspended sediment, *sandur* (>0.2 mm), and *méla* (0.002–0.02 mm), as well as lower concentration in four out of five samples in the *grófmór* (0.06–0.2 mm), *fínmór* (0.02–0.06 mm), and *leir* (<0.002 mm) grain size classes. In contrast, the samples taken from the Urriðafoss cableway (U-S1) have higher concentration than the Krókur samples of total sediment, *sandur*, and *fínmór* in all four sample pairs, whereas in three pairs the U-S1 samples had lower concentration of *méla* and *leir* (Fig. 24).

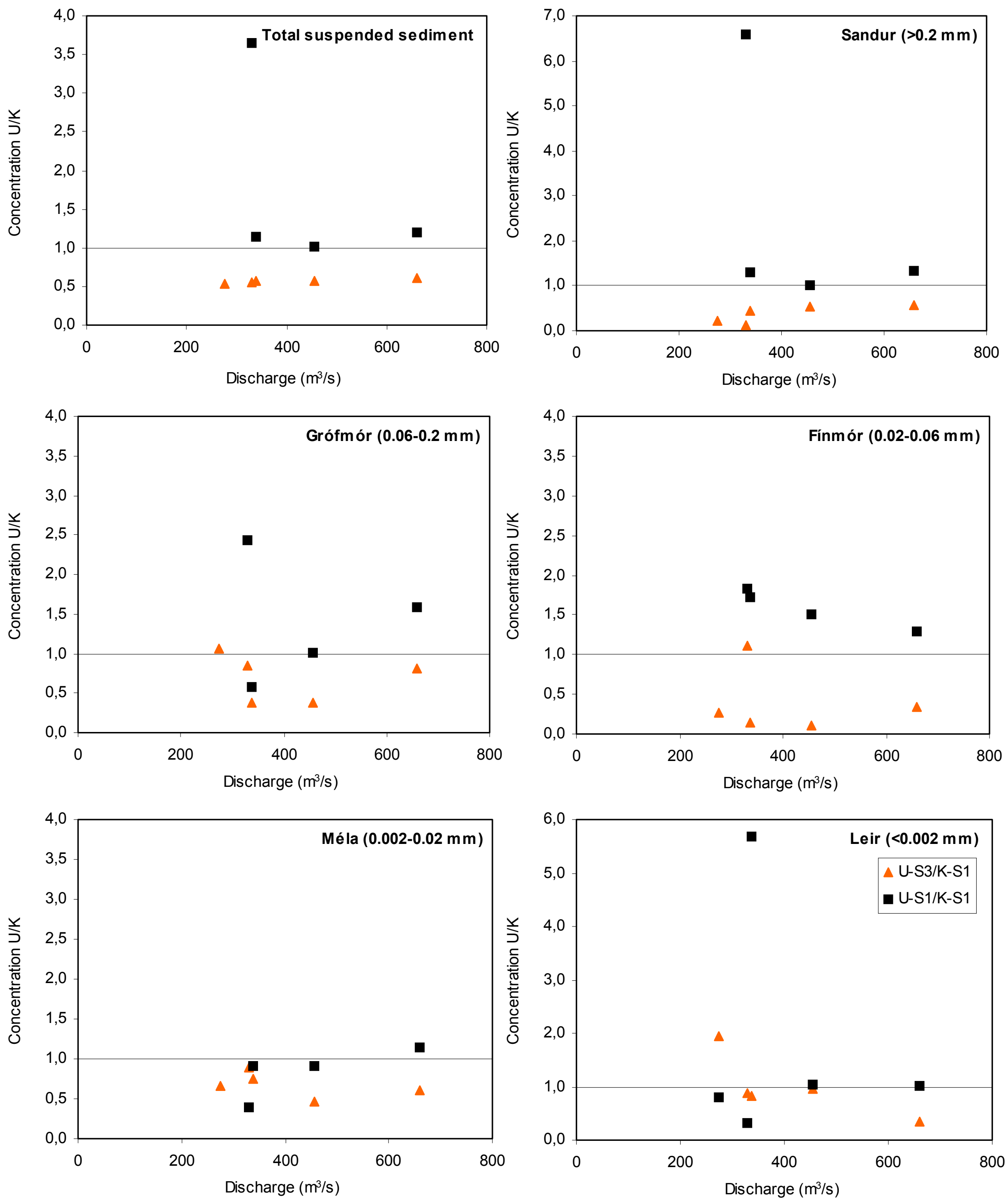


Figure 24: *Sediment ratio of total concentration and individual grain size classes (in mg/l) between Krókur samples (K-S1) and the two different types of Urriðafoss samples (U-S1 and U-S3). The U-S1/K-S1 ratio is indicated with black squares and U-S3/K-S1 ratio is shown with orange triangles. The discharge value used is the one for the Krókur sample.*

These results are similar to what was observed in 2003 with similar sediment pairs (Jórunn Harðardóttir og Svava Björk Þorláksdóttir 2004) and indicate that the S3 Urriðafoss samples under-represent the sediment discharge compared to the Krókur samples, whereas the Krókur samples under-represent the sediment discharge compared to the S1 Urriðafoss samples.

The reason for the low concentration in the Urriðafoss S3 samples is mainly due to the different sampling technique as it is not possible to reach the main current where most of the sediment is transported with the handheld DH48 rod sampler that is used to collect the S3 samples from below the bridge on Highway 1.

The higher concentration of coarse material in the Urriðafoss S1 samples than in the Krókur samples (K-S1) has more to do with the local current conditions than the sampling technique, as there is no fundamental difference is between sampling from the electric cableway at Krókur and the Urriðafoss cableway with the hydraulic winch. No direct comparison is available of the current conditions below the two cableways; however, the current speed is visually greater at Urriðafoss, so larger grains may be transported higher in the water column where the S49 suspended sediment sampler can collect them.

Figure 25 shows the suspended sediment concentration and transport against discharge in the samples taken in 2004 at the three locations in lower Þjórsá. For comparison the same values for S3 Urriðafoss samples taken in 2001 to 2003 are shown as well as the S1 samples from Urriðafoss and Krókur from 2003.

The concentration of the samples taken in the winterflood in March is much lower than expected given the high discharge of about 650 m^3/s; however, the lack of sediment-laden glacial meltwater in that season is probably liable for the low concentration. The reason for the high concentration in the S1 Urriðafoss sample from October is unclear, but that and the low concentration March samples weaken the correlation between the concentration/sediment transport and discharge for the individual sample types.

Figure 25 shows like the data in Table 10 and Fig. 24 how the S1 samples from Urriðafoss have the highest concentration and thus the highest sediment transport of the three sample types in each campaign, while the S3 Urriðafoss have the lowest concentration.

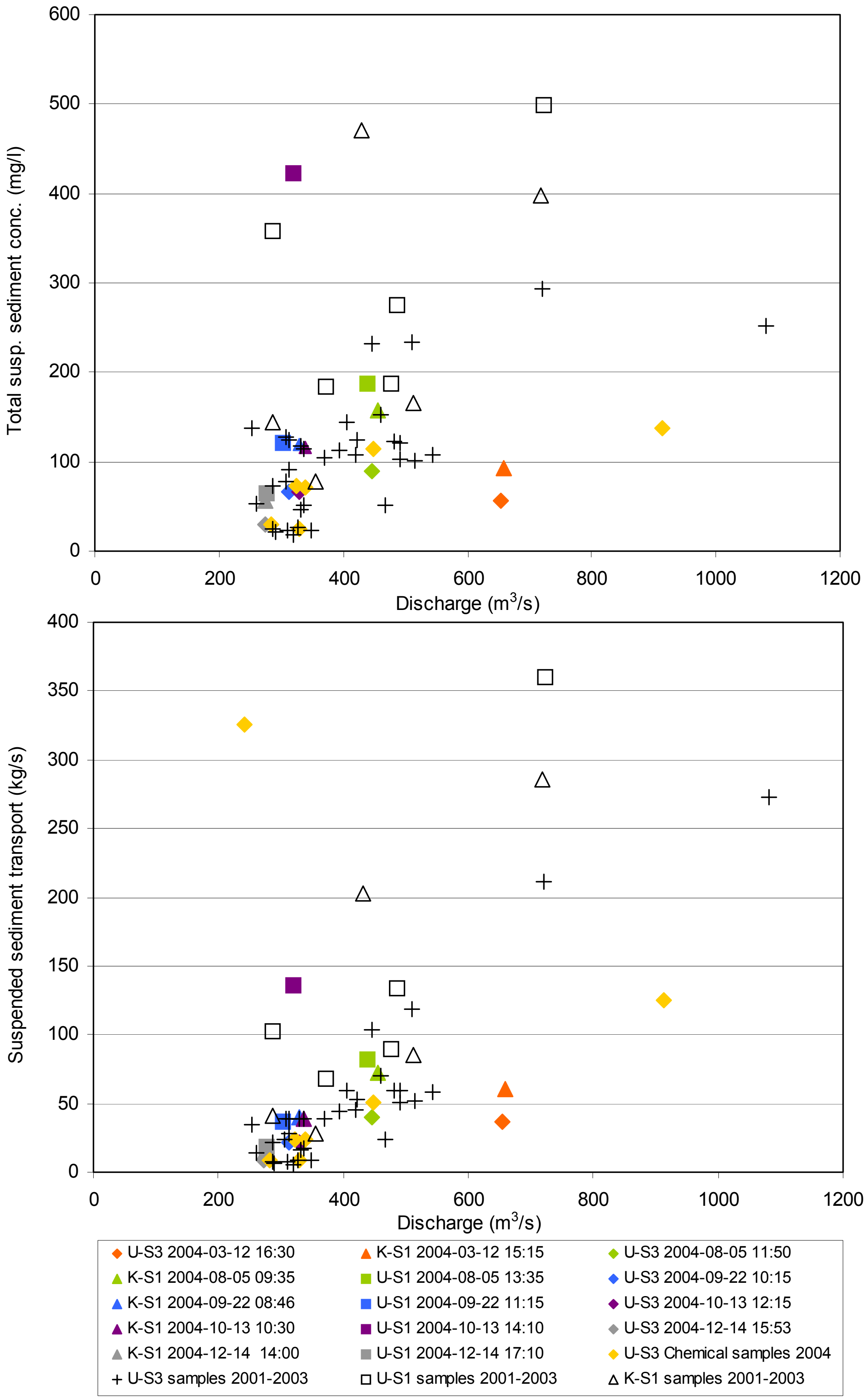


Figure 25: *Relationship between suspended sediment concentration (upper) and suspended sediment transport (lower) vs. discharge for samples taken at Krókur and Urriðafoss in 2004. Results from 2001–2003 are shown for comparison. One S3 sample from 2004 is excluded on the upper panel. The samples are color-coded according to each campaign to ease comparison of sample types in each sediment campaign.*

4.2 Bedload studies

The bedload sampling within the detailed sediment study initiated in 2001 of the lower reaches of Þjórsá are the first such studies since several bedload sampling series were carried out at Hreysiskvísl, Sóleyjarhöfði, and Sandártunga (Fig. 1) in the 1980's (Haukur Tómasson *et al.* 1996, Svanur Pálsson 2000). Only the Sandártunga site is located downstream of the main hydropower developments on the river and is approximately the same site as was sampled in 2004.

In this report we show results from bedload sampling at two sites, i.e. from the electric cableway at Krókur and from Sandártunga (Figs. 1 and 3) using a specially equipped boat. The latter site is similar in location as the sampling that was carried out in 1982. In 2004, the bedload campaigns were carried out at Krókur in March, August, September, and October, whereas samples were only taken from Sandártunga in September. During the Krókur campaigns samples were taken at seven locations 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. At Sandártunga, samples were taken at 11 locations across the river channel, but only two series were sampled.

In 2004, the results from each campaign were divided into smaller data sets (up to eight sets) based on the day the samples were taken and discharge changes during the sampling period. Bedload transport differs greatly between stations although it is different from one data set to another at which station most of bedload is transported. On average most of the bedload at Krókur is transported between 50 and 70 m (Fig. 26); however, bedload distribution differs somewhat during the March flood campaign where more bedload is transported closer to the river banks at 40 and 140 m than in other campaigns.

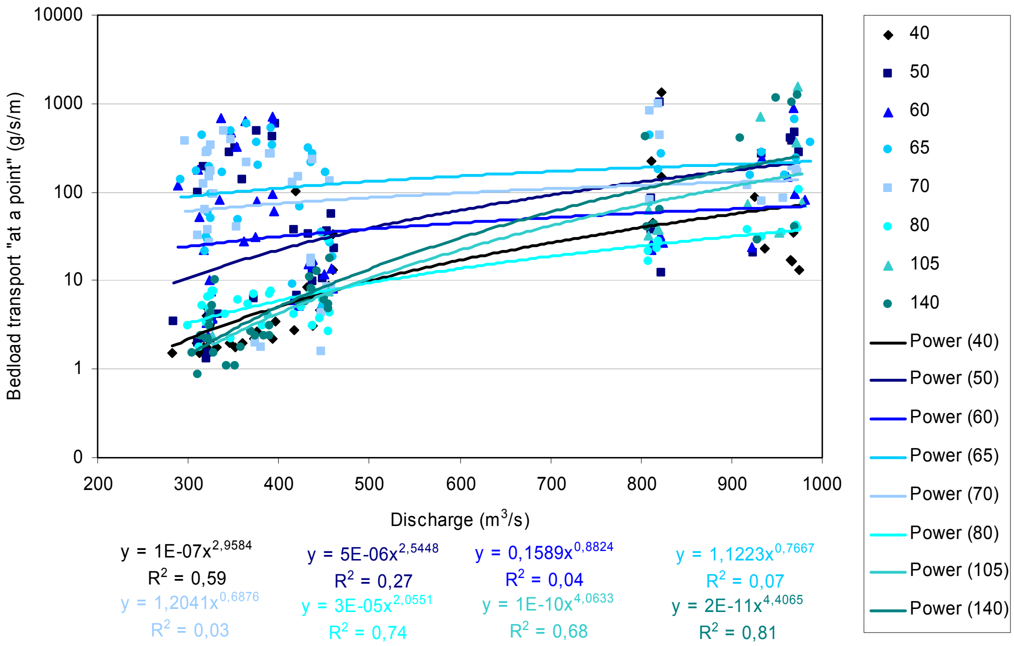


Figure 26: *Comparison of bedload transport "at-a-point" with discharge in all samples taken at Krókur in 2004. Samples from same stations have the same color code. Power trend lines for samples at each station and their correlation coefficient (R^2) are also shown.*

The increased bedload transport closer to the river banks at Krókur in the March flood (mean Q from 787 to 956 m^3/s) is manifested by a relatively high correlation coefficient (R^2=0.59 to 0.81) for the 40, 80, 105, and 140 m stations compared to transport at the stations within the center of the channel, which show no correlation with discharge. The absent correlation of bedload transport with discharge in the center channel also illustrates the great transport variability at the 50 to 70 m stations, of which most bedload is transported at 65 and 70 m.

The bedload transport at Sandártunga was concentrated at 55, 65, and 75 m on the gentler margin of the river channel, just right (north) off the deepest part of the river (Fig. 14). Hardly any bedload was transported at other stations during the sampling which was carried out at discharge around 350 m^3/s, based on data from Þjórsártún with 14 hour lag-time.

Total bedload transport was calculated for 19 data sets for the Krókur results and differed substantially among the sets, from 1.4 to 66.5 kg/s (Fig. 13). By far the greatest transport was calculated for the last data set on 2004-03-11, 66.5 kg/s, which is over double the transport observed within the data sets earlier the same day. Although it is likely that bedload was highest within this last data set when discharge reached over 950 m^3/s, the calculations may overestimate the total bedload. This is because of exceptionally high transport at 140 m, which is then integrated for a large part of the river channel where no data is available to either confirm or refute such high bedload transport.

Total bedload transport was lowest in Krókur data sets from August (1.4–3.3 kg/s) and October (2.2–3.5 kg/s) although the discharge during the August campaign was much higher (408–461 m^3/s) than in October (327–337 m^3/s). Such seasonal difference in bedload has been observed in previous years where bedload transport appears to be higher during the winter months than in the midst of summer when suspended sediment transport is greater.

At Sandártunga, the total bedload transport was only 0.4 and 0.7 kg/s which was more than an order of magnitude less than at Krókur in the September campaign (3.4 to 12.4 kg/s). These numbers are low compared to the earlier studies of bedload transport at Sandártunga in September 1982 when bedload transport was 6.4 kg/s at 140 m^3/s. The conditions during the 1982 measurement were, however, poor, which was thought to affect the accuracy of the measurement. The difference in bedload transport measured twenty-two years apart is probably due to long-term channel adjustments, causing more stable channel in the source area of the bedload sediment below Búrfell.

The large difference between roughly coinciding measurements at Sandártunga and Krókur supports the common idea that bedload in the lower reaches of Þjórsá is today predominately derived from the braided sandur channel system downstream of the Árnes island. However, more information on bedload transport is needed before the difference between Krókur and Sandártunga is assessed in detail, or the origin of the bedload asserted. More data on bedload transport at Sandártunga during normal and high discharge with comparison with results from Krókur is especially needed.

Bedload samples were collected for grain size analysis from both Krókur (seven or eight samples in each campaign) and Sandártunga (total seven samples). Figure 27 shows how the mean grain size of the Krókur samples from each station varies with discharge and mean bedload transport at each station. No distinct correlation was observed between mean grain size and discharge although the same Fig. shows that the finest samples were usually taken at 140 m, and the samples from 60 m were often relatively fine grained (>0.5 ϕ; i.e. >0.71 mm or coarse sand). The mean grain size of most of the 65 and 70 m samples was rather coarse (Fig. 27), and two of the 50-m-samples had mean grain size coarser than -1.0 ϕ (2 mm or granules).

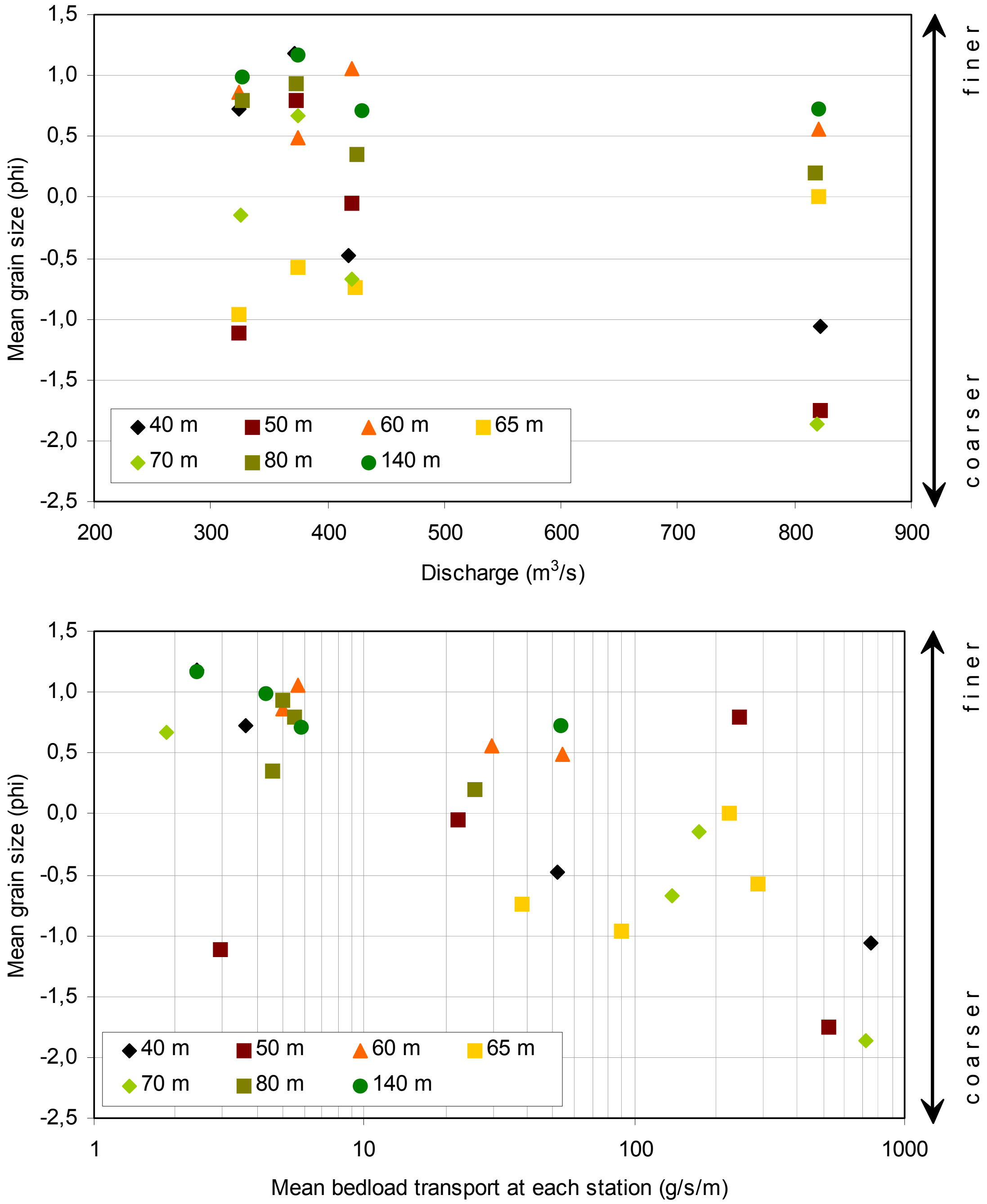


Figure 27: *Mean grain size in bedload samples from Krókur vs. discharge (upper) and mean bedload transport at each station (lower) in 2004.*

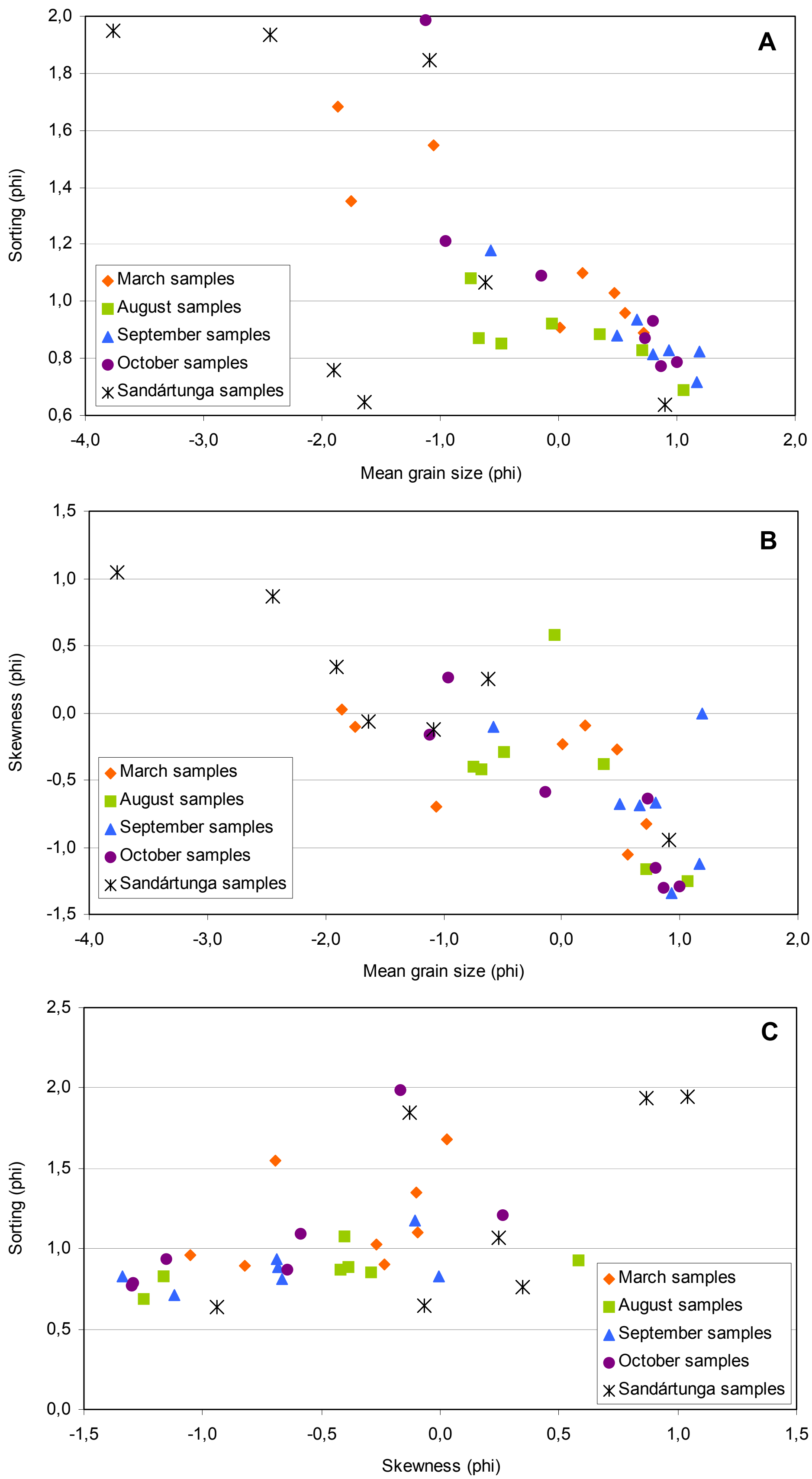


Figure 28: *Comparison of moment statistics values in samples taken from Krókur and Sandártunga in 2004. A. Sorting vs. mean grain size. B. Skewness vs. mean grain size. C. Sorting vs. skewness.*

For the analyzed samples from all stations there appears to be a trend towards coarser samples with greater bedload transport at each station (Fig. 27 lower). However, the same trend is not as distinct for the individual stations. Nevertheless, samples from 40, 60, 70, and 140 m seem to be coarser within the data sets with greater mean transport, although occasional samples do not conform with the rest of the samples.

Figure 28 shows the same information as Fig. 20 with the results from Sandártunga added. The mean grain size of most of the Sandártunga samples is greater than most part of the Krókur samples, with five of seven samples coarser than -1.0 ϕ, i.e. >2mm. More detailed textural classification of the samples is given in Table 9.

The coarsest Sandártunga samples are also the least sorted samples, but all but two Sandártunga samples follow the main trend of finer samples being better sorted (Fig. 28A). Similarly, the coarse Sandártunga samples have relatively positive (fine) skewness, indicating that they have a tail of excess fine particles, or have close to symmetrical distribution (skewness between 0.43–-0.43). As with the sorting parameter, the Sandártunga samples extend the earlier recognized trend of finer sampler having more negatively (coarse) skewed distribution. Hence, a decent correlation is observed for the whole data set from Krókur and Sandártunga between mean grain size and sorting (R^2=0.52) and mean grain size and skewness (R^2=0.62) as in 2003 (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2004). Finer grained samples tend thus to be better sorted and more negatively (coarser) skewed than coarser samples.

As discussed in the previous report on sediment results from lower reaches of Þjórsá (Jórunn Harðardóttir and Svava Björk Þorláksdóttir 2004), bedload studies of this type will always inherit some limitations. Such point studies will always be a compromise between time/money spent on studies of the river and the accepted error in the measurements. Error in bedload studies can be lowered by increasing the number of samples, or to make continuous recording of bedload transport, e.g. by collecting bedload in sediment trenches (impossible at this site), or sound recording, which then needs to be calibrated inheriting the same problems as within the point sampling. To accommodate both cost efficiency and reasonable error in the measurements, we have designed the sampling program so that most of the samples are taken from the channel where most of the bedload is transported with fewer sampling stations closer to the right (west) bank (80–200 m). These are the stations where least bedload is transported in most cases, most time consuming in sampling, and are thus most expensive per sample. Occasional samples are then collected on this wide stretch 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 on transport in wide channel stretches such as around 140 m is handled.

5 FUTURE WORK

This report presents the results from the fourth year of detailed sediment sampling in the lower reaches of Þjórsá. The initiative was originally designed as a five year program, with greatest number of campaigns during the first year, but reduced campaign number in subsequent years. During these years, much better information has become available on the suspended sediment transport in the lowermost reaches of Þjórsá, as well as the distribution of the suspended sediment within the channel. These studies have also concentrated on the difference between sample types, which will be informative for evaluation of the older suspended samples taken at this location. Furthermore, bedload samples have been obtained in these total sediment campaigns, which together with the numerous suspended samples have added substantially to our knowledge of sediment transport in the region. These data will mostly benefit the National Power Company as information for possible future construction of the Urriðafoss hydropower facility, in addition to be fundamental information on the environmental conditions of the lower reaches of Þjórsá.

The main change between the setup in 2004 and the year before was the extra sampling at Sandártunga in 2004, where bedload samples had been taken once before in 1982 (Haukur Tómasson et al. 1996; Svanur Pálsson 2000). The information on bedload transport at Sandártunga will benefit the assessment of environmental as well as constructional questions that may appear during evaluation of the upper hydropower designs that have been suggested at Núpur, Hagi, and Skarðsfjall. A better understanding of the amount of bedload transport at different discharge levels, as well as the source of such material, is important for future references. The ideal sampling design would include sampling campaigns at both the upper location at Sandártunga and the lower region at Krókur, and to also get an idea of the difference between the sites, which to some extent can indicate the main source areas for bedload material.

A new discharge rating curve was established in early 2005 for V320 at Þjórsártún so the discharge used for the 2004 data has been updated accordingly, as well as the discharge for older suspended samples represented in this report. The discharge for the lowermost part of Þjórsá is thus well documented. No other water level gauge is located between Sandafell (vhm97; V297) and the gauge at Þjórsártún, although discharge through the Búrfell hydropower plant is estimated. Construction of a water gauge below Búrfell but above the proposed hydroelectric facilities would increase the accuracy of discharge estimates in this critical location, as well as being a basis for concurrent discharge approximation for sediment samples from Sandártunga.

Furthermore, it is soon time to collectively summarize in one report the main results from the sediment program initiated in 2001. Such a report would make ensure that all data is updated with newest information on discharge, and if any, additional information on the best division of the data series. Moreover, it would be useful to include the results from all older samples taken at Urriðafoss and compare the sediment transport based on the newer samples with the samples taken 30 years ago.

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SUMMARY IN ICELANDIC

Í tengslum við endurvaktar hugmyndir um byggingu vatnsaflsvirkjana á neðri hluta Þjórsársvæðisins setti Landsvirkjun af stað umfangsmiklar rannsóknir á heildaraurburði á svæðinu og hafa Vatnamælingar Orkustofnunar séð um framkvæmd þeirra. Forsenda verkefnisins var uppsetning rafdrifins kláfs sem settur var upp við Krók árið 2001. Á fyrsta árinu var farið í 10 aurburðarferðir á svæðið að Króki og Urriðafossi, ári síðar voru ferðirnar sex, árið 2003 var farið í fimm ferðir og í þessari skýrslu er fjallað um niðurstöður fimm aurburðarferða sem farið var í árið 2004. Á sama tíma hefur verið í gangi rannsóknarverkefni um efnavöktun í ám á Suðurlandi, en auk Vatnamælinga standa Landsvirkjun, Jarðvísindastofnun Háskólans (áður Raunvísindastofnun háskólans), og Hollustuvernd, nú Umhverfisstofnun, að því verkefni. Niðurstöður þess verkefnis sem snúa að aurburðarmælingum í neðri hluta Þjórsá eru einnig settar fram í þessari skýrslu.

Meginmarkmið ítarlegu 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 virkjana á svæðinu. Annars vegar er um að ræða að afla betri vitneskju um framburð svifaurs, en til þess hefur þurft að safna syrpu af betri svifaurssýnum en tekin hafa verið á síðustu árum og er það gert með því að taka sýnin af rafdrifna kláfnum við Krók. Nauðsynlegt er þó að bera þau sýni saman við eldri sýni og er þeim upplýsingum safnað með því að taka einnig sýni með handsýnataka undir gömlu brúnni á þjóðvegi 1 og með vökvadrifnu kláfspili á eldri strengjabraut um 500 m neðan við gömlu brúna. Þannig er hægt að meta betur gæði gömlu handsýnanna sem og sýna sem tekin voru frá gömlu strengjabrautinni. Með rannsóknum á svifaurssýnum hefur einnig verið reynt að meta hversu framburður svifaurs er breytilegur innan sjálfs farvegarins. Hins vegar hafa rannsóknir verið gerðar til að afla vitneskju um skriðaursflutning í Neðri-Þjórsá, en aðeins var til ein sýnatökusyrpa úr ánni neðan við Búrfell áður en byrjað var að taka skriðaurssýni við Krók (Haukur Tómasson o.fl. 1996; Svanur Pálsson 2000).

Árið 2004 var farið í fjórar hefðbundnar svif- og skriðaursferðir að Þjórsá og eina svifaurssýnaferð. Í öllum ferðum sem mögulegt var voru svifaurssýni tekin við Krók, undir brú á gamla þjóðvegi 1 og á gömlu strengjabrautinni ofan við Urriðafoss, og í hefðbundnu heildarferðunum voru einnig tekin skriðaurssýni af kláfnum við Krók. Það sem var nýtt þetta árið miðað við fyrri ár var að einnig voru tekin skriðaurssýni við Sandártungu í landi Ásólfsstaða til að skoða betur flutning skriðaurs inn í lón sem búið verður til ef af byggingu Núpsvirkjunar (og/eða Haga-/Skarðsvirkjunar) verður. Til viðbótar var sjö svifaurssýnum safnað í tengslum við efnavöktun á Suðurlandi. Í skýrslunni eru settar fram niðurstöður svifaurs- og skriðaursmælinga frá hverjum stað fyrir sig áður en svifaursmælingar eru bornar saman á milli staða, og á milli aurburðartegunda (svifaur–skriðaur).

Eins og fyrri ár sást árstíðamunur í kornastærð og svifaursstyrk í svokölluðum S3-sýnum sem tekin voru með handsýnataka undir gömlu brúnni við þjóðveg 1. Þannig var hlutfall grófu svifaursflokkanna hærra um vetartímann en hlutfall fíngerða svifaursins hærra yfir sumarið. Þetta aukna hlutfall fínefna yfir sumartímann tengist jökulleysingu yfir aðalsumarmánuðina og fram á haust. Hafa þarf þó í huga að kornastærðargögnin eru hundraðshlutagögn þannig að ef hlutfall eins kornastærðarflokks eykst lækkar hlutfall annars. Því er nauðsynlegt að skoða saman bæði styrk hvers flokks og hundraðshluta hans.

Styrkur fínefna var einnig mestur í sýnum sem tekin voru í ágúst og september með vökvadrifnu spili af gamla kláfnum neðan við gamla þjóðveg 1. Væntanlega er jökulleysing einnig ástæðan fyrir þessum hærri styrk fínefna í þessum haustsýnum. Hins vegar var styrkur sands (>0,2 mm) óeðlilega hár í sýni sem tekið var í október, en engin einhlýt skýring er augljós fyrir þessum háa styrk.

Þriðja svifaurssýnategundin var tekin af rafdrifna kláfnum við Krók í 40, 50, 60, 65, 70 80 og 140 m frá húsi á vinstri (austari) bakka árinnar. Einnig þar má sjá árstíðabundinn mun í kornastærð þó að hann sé ekki jafn áberandi og í hinum sýnagerðunum.

Áhugaverðast er að bera saman heildarstyrk og styrk einstakra sýnategunda milli þessara þriggja sýnagerða í svifaurspörunum sem tekin voru. Greinilegur munur er á sýnategundunum og sýna niðurstöðurnar frá árinu 2004 að S3 handsýnin sem tekin eru undir gömlu brúnni vanmeta svifaursstyrk S1-sýnanna sem tekin eru af kláfunum tveimur, bæði hvað varðar heildarsvifaur og styrk einstakra kornastærða. Lægri styrkur í handsýnunum er að mestu leyti til kominn vegna aðstæðna við sýnatökuna, en með handsýnatakanum er ekki hægt að ná niður niður undir botn í mesta straumi þar sem mestur framburður svifaurs er eins og gert er þegar hin sýnin eru tekin. Heildarstyrkur sýnanna sem tekin voru með vökvadrifnu spili af gamla kláfnum við Urriðafoss er hins vegar heldur hærri en Krókssýnanna, sem og styrkur grófari kornastærðarflokkanna (fínmór, grófmór og sandur (kornastærð >0,02 mm)). Þessi munur stafar að öllum líkindum af mismunandi straumaðstæðum á sýnatökustöðunum en straumur virðist vera töluvert meiri undir gamla Urriðafosskláfnum en nýja Krókskláfnum þó að hann hafi ekki verið borinn saman með beinum mælingum. Þannig geta fleiri og stærri setkorn flust hærra í vatnsbolnum við Urriðafoss en við Krók sem passar ágætlega við mismunandi styrk svifaurs milli staðanna. Enn er ekki búið að endurmeta eldri sýni miðað við þessar niðurstöður enda hefur hingað til verið talið nauðsynlegt að afla fyrst frekari gagna til slíkrar endurskoðunar. Lagt hefur verið til að slík endurskoðun verði gerð í samantektarskýrslu um mælingar síðustu ára.

Fylgni svifaursstyrks og svifaursframburðar við rennsli er ekki áberandi í sýnum ársins 2004. Aðalástæðan er að öllum líkindum sú að sýnasyrpunar fimm voru teknar við mjög mismunandi aðstæður, t.d. hvað varðar tímasetningu innan ársins. Þannig voru tekin vetrarsýni í mars, október og desember, en af þeim voru marssýnin tekin í miklum rigningarflóðum sem ekki virðast hafa skilað miklum aurburði út í ána þó að rennslið hafi aukist mikið. Hins vegar minnkar fylgnin verulega vegna einstakra sýna sem hafa hlutfallslega mun hærri sandstyrk en sambærileg sýni, og má þar nefna S1 sýni frá Urriðafossi sem tekið var 13. október og S3 handsýni sem tekið var í tengslum við efnasýnatöku tæpum tveimur vikum síðar.

Árið 2004 voru 317 skriðaurssýni tekin af rafdrifna kláfnum við Krók og voru sýnin tekin á sömu stöðum og svifaurssýnin. Til viðbótar voru tekin aukasýni milli 80 og 200 m til að meta hversu dæmigerð sýnin frá 140 m stöðinni voru fyrir þann hluta farvegarins. Í hverri ferð var sýnum safnað af flestum stöðvum til kornastærðargreiningar á aurburðarstofu Vatnamælinga, alls 29 sýnum.

Skriðaursframburður við Krók var reiknaður út fyrir einstök rennslisbil í hverri ferð fyrir sig og var hann yfirleitt mestur á bilinu 50 til 70 m, og mun minni á 40, 80 og 140 m, ef frá eru talin nokkur rennslisbil innan marsflóðsins þegar skriðaursframburður barst fram mun nær bökkum árinnar en í öðrum ferðum. Þessi aukni framburður á stöðvum nær bökkunum við hátt rennsli veldur mun hærri fylgni skriðaursflutnings fyrir þær stöðvar (R^2=0,59–0,81) en stöðvarnar í miðjum farveginum (50–70 m) þar sem fylgni skriðaursframburðar einstakra sýna við rennsli var lítil eða engin (R^2=0,03–0,27).

Heildarframburður skriðaurs var reiknaður út fyrir 19 rennslisbil og var hann mjög misjafn, eða frá 1,4 til 66,5 kg/s. Þar var langmestur framburður í sýnatökusyrpunni sem tekin var síðla dags þann 11. mars, þegar meðalrennsli innan sýnatökunnar náði um 950 m^3/s. Innan þessa rennslisbils barst sérstaklega mikill skriðaur fram á 140 m en við útreikninga á heildarsvifaur voru þær tölur framreiknaðar fyrir stóran hluta farvegarins. Þar sem ekki voru tekin sýnis samtímis til að staðfesta þennan mikla framburð skriðaurs innan alls breiddarbilsins í kringum 140 m er talið rétt að telja 66,5 kg/s algera hámarkstölu fyrir skriðaursflutning innan rennslisbilsins. Áberandi er að heildarframburður skriðaurs var minnstur í byrjun ágústs (1,4–3,3 kg/s) þrátt fyrir að rennsli hafi verið næsthæst í þeirri ferð, eða í kringum 450 m^3/s. Mögulegt er að skriðaur hafi náð að skolast út úr farveginum í stuttum flóðtoppi sem náði hámarki nokkrum dögum áður en sýnin voru tekin, og því hafi framburður skriðaurs mælst minni en í ferðum í september og október þegar rennsli var milli rúmlega 300 og 400 m^3/s.

Mikil munur sést í kornastærð skriðaurssýnanna sem tekin voru við Krók, bæði milli stöðva í hverri ferð fyrir sig og milli sömu stöðva í mismunandi ferðum. Þó má sjá ákveðna sameiginlega þætti, t.d. að sýnin sem tekin voru af 80 og 140 m voru oftast fíngerðust á meðan grófustu sýnin í hverri ferð voru yfirleitt tekin á 50, 65 eða 70 m. Sýnin sem tekin voru í september voru áberandi fíngerðust og var meðalstærð allra sýnanna nema eins innan við 0,5 ϕ, eða <0,71 mm (grófur sandur). Sýnin sem tekin voru í mars og ágúst voru hins vegar grófust, en meðalstærð þriggja marssýna var >-1,0 ϕ, eða >2 mm.

Grófleiki sýnanna jókst ekki áberandi mikið með auknu rennsli þó að sýnin sem tekin voru í marsflóðinu hafi verið heldur grófari en sýni sem tekin voru við minna rennsli. Sömuleiðis sést ekki áberandi fylgni fyrir sýni af hverri stöð fyrir sig með meðalframburði skriðaurs á hverri stöð. Hins vegar jókst kornastærð greinilega með meðalframburði skriðaurs á hverri stöð ef öll sýnin voru skoðuð saman.

Þegar aðrir afleiddir kornastærðareiginleikar s.s. aðgreining og skakki eru bornir saman sést að fíngerðari sýni eru heldur betur aðgreind en grófari sýnin og að skakki fíngerðu sýnanna er neikvæðari en grófu sýnanna.

Við Sandártungu voru 22 skriðaurssýni tekin af sérútbúnum báti í september og þar af voru sjö sýni kornastærðargreind. Heildarframburður skriðaurs var reiknaður fyrir hvora sýnatökusyrpu fyrir sig og reiknaðist hann vera 0,4 og 0,7 kg/s sem er meira en stærðargráðu minni en framburður við Krók. Hægt er að bera framburð við Sandártungu saman við mælingar sem gerðar voru við 140 m^3/s rennsli árið 1982, en þá reiknaðist heildarframburður skriðaurs vera 6,4 kg/s. Sú mæling var hins vegar gerð við mjög erfiðar aðstæður og var talið að skekkjumörk hennar væru sérstaklega víð. Reikna má þó með því að skriðaursframburður hafi verið heldur meiri þá en nú enda líklegt að farvegurinn neðan við Búrfellsvirkjun hafi náð mun betra jafnvægi nú en fyrir 22 árum.

Fleiri mælingar þarf hins vegar að gera við Sandártungu til að meta framburð skriðaurs nákvæmar.

Sýnin frá Sandártungu eru flest grófari en sýnin sem tekin voru við Krók og er meðalstærð flestra þeirra >-1,0 ϕ, eða >2 mm. Grófustu sýnin frá Sandártungu eru einnig verst aðgreindu sýnin og hafa jákvæðastan skakka.

Að lokum var hlutfall svifaurs- og skriðaursflutnings í þremur sýnapörum frá Króki borið saman til að meta hlutfall hvorrar setgerðar af heildaraurburði. Eingöngu er um stakar mælingar að ræða og þar að auki voru sýnapörin aðeins tekin samtímis í einu pari þó að rennsli hafi verið svipað í þeim þremur pörum sem voru skoðuð. Ef miðað er við þessi þrjú pör var skriðaursframburður um 4 til 8% af heildaraurburði við Krók.

Þegar á heildina er litið gekk aurburðarsýnataka í Neðri Þjórsá vel árið 2004 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.

Eftir aurburðarrannsóknir ársins 2004 á Neðra Þjórsársvæðinu hefur verið sett fram kostnaðaráætlun um framhaldsmælingar á svæðinu þar sem lagt er til að aurburðarmælingar verði framkvæmdar bæði við Krók og Sandártungu. Þannig fengist bæði samanburður milli svæðanna sem og upplýsingar um aurburð inn í efri lónin sem fyrirhuguð eru í hönnun Núps-/Skarðs-/Hagavirkjana. Einnig er talið tímabært eftir mælingar ársins 2005, að setja fram í einni skýrslu þær upplýsingar sem safnast hafa um aurburð á Neðra-Þjórsársvæðinu í þessu ítarlega aurburðarverkefni sem byrjaði árið 2001. Í þeirri skýrslu væri einnig tímabært að bera saman gögn síðustu ára við eldri svifaurssýnagögn frá Urriðafossi.