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Total sediment transport in the lower reaches of Þjórsá at Krókur

Results for the year 2001

Jórunn Harðardóttir
Svava Björk Þorláksdóttir

Prepared for Landsvirkjun

2002

OS-2002/020

ORKUSTOFNUN
Hydrological Service

Report
Project no.: 7-546842

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ISBN 9979-68-097-0

ORKUSTOFNUN – HYDROLOGICAL SERVICE

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Key page

Report no.:	**Date:**	**Distribution**
OS-2002/020	May 2002	☒ Open ☐ Closed

Report name / Main and subheadings:	**Number of copies:**
Total sediment transport in the lower reaches of Þjórsá at Krókur – Results from the year 2001	25
	Number of pages:
	50
Authors:	**Project manager:**
Jórunn Harðardóttir and Svava Björk Þorláksdóttir	Jórunn Harðardóttir Kristinn Einarsson
Classification of report:	**Project no.:**
Sediment load studies, bedload measurements	7-546842

Prepared for:

Landsvirkjun

Co-operators:

Abstract:

Extensive sediment sampling progam was initiated in the lower reaches of Þjórsá in 2001. The main objectives of the study were to evaluate sediment concentration in previous Urriðafoss samples with comparison with samples taken at a new cableway at Krókur, obtain addtional suspended samples from Krókur and Urriðafoss, and carry out the first bedload measurements in Þjórsá downstream of Sandártunga. The results show that grain size of suspended samples from Urriðafoss and Krókur varies greatly among sediment campaigns as well as among sampling sites on the Krókur cross-section, where the coarsest material is transported in a gully at the 60–80 m stations. Comparison between the two sampling sites indicate that the Urriðafoss samples largely underestimate sediment concentration of the coarsest fraction. Total bedload transport ranged from ca. 4700–13000 g/s. Bedload has the highest concentration and is coarsest at the 50–70 m stations.

Key words:	**ISBN-number:**
Þjórsá, bedload, suspended sediment, grain size, discharge, Krókur, Urriðafoss,	9979-68-097-0
	Project manager's signature:
	Reviewed by: KE, PI, ASn

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1 INTRODUCTION

Þjórsá is one of the largest rivers in Iceland, with a watershed of 7380 km^2 at Þjórsártún, whereof 1032 km^2 are covered by glaciers. Major hydroelectric power plants have been constructed on the upper reaches of the river during the last 30 years, which have modified the sediment transport greatly; however, mean discharge has changed minorly. Today, the annual mean discharge at Þjórsártún (Fig. 1) is about 355 m^3/s, similar to what it was before dam constructions on the upper reaches of the river. The dams have though stabilized the seasonal discharge distribution slightly by increasing the winter discharge and decreasing summer discharge. Furthermore, whereas larger floods have been unaffected, minor floods appear to have been dampened to some extent in recent years due to larger reservoirs.

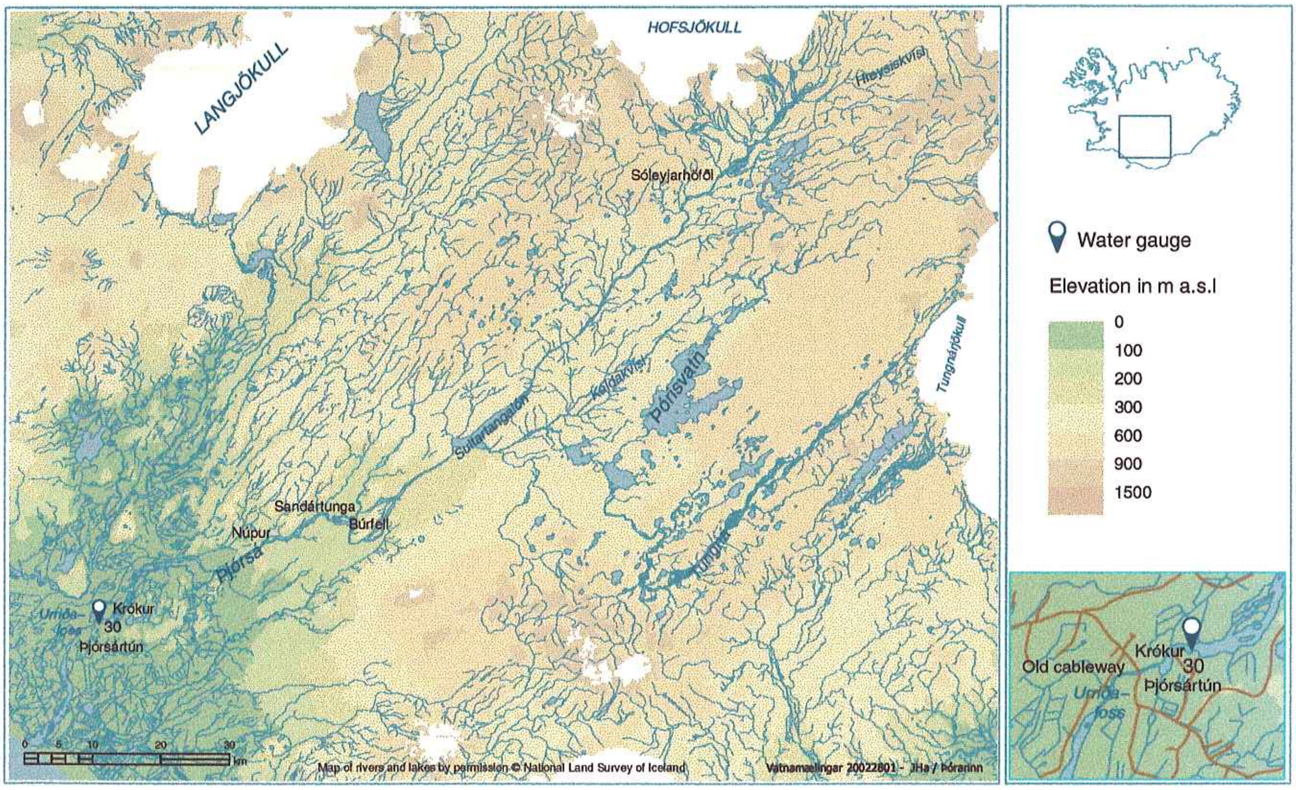


Figure 1. *Map of Þjórsá river basin, including main locations along the river.*

Sediment transport in river Þjórsá has decreased significantly in the lower part of the river after the large reservoirs were constructed in the Upper Þjórsá region, as most of the sand and gravel is deposited in the reservoirs (Haukur Tómasson 1982). Suspended sediment samples have been taken irregularly at Urriðafoss since 1962, and these indicate that after 1970, when the first power plant was constructed at Búrfell, sediment transport decreased substantially (Fig. 2). Figure 2 shows, however, that large gaps exist within the sample series after 1970, which complicates statistical analysis of the data.

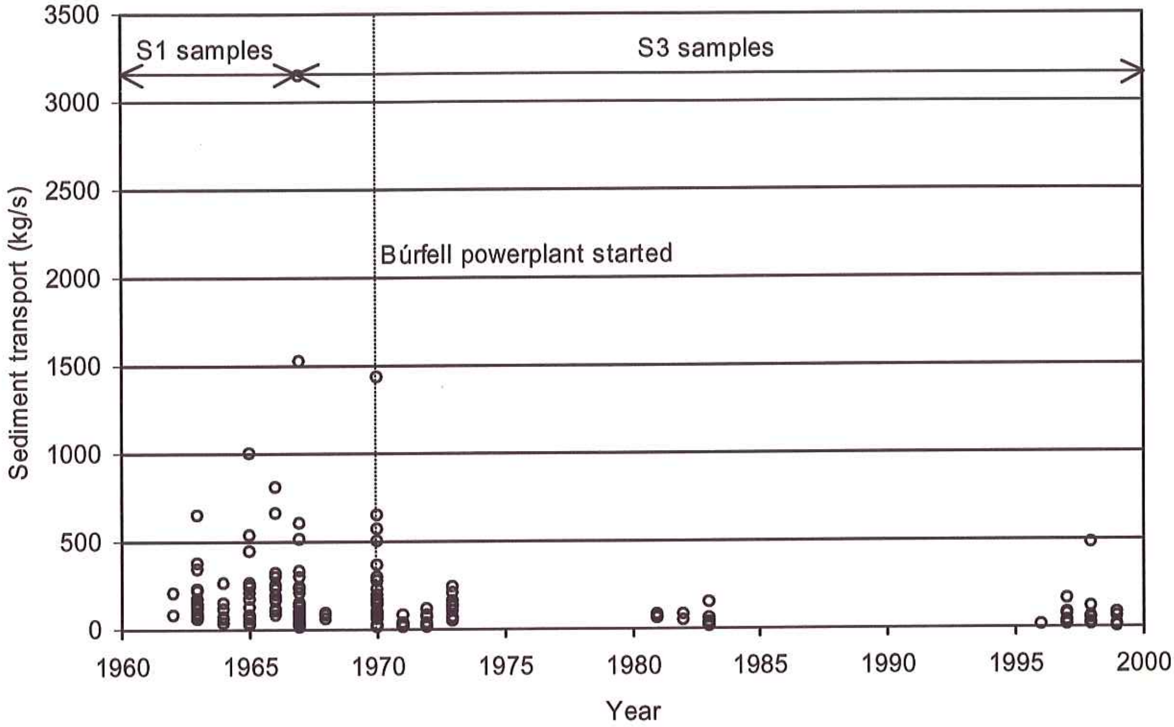


Figure 2. *Suspended sediment transport according to samples taken at Urriðafoss, Þjórsá. Each circle represents a sample. S1 samples were taken with sediment sampler S49 from several locations on the cableway below the bridge on Highway 1; S3 samples were taken with handsampler DH48 from one side of the river bank close to the same bridge.*

Hydropower plant construction on the lower reaches of Þjórsá was first proposed at the beginning of last century, but these optimistic plans fell short. In recent years these ideas have been revived and two possible reservoir locations are presently being investigated, i.e. at Núpur and Urriðafoss (Fig. 1). One of the main concerns for both the ongoing environmental impact assessment and the design of the hydropower plants is river sediment transport and the fill-in time of the reservoirs. For this reason a detailed study on total sediment transport was initiated in the Urriðafoss area during the year 2001. The study was completed by the Hydrological Service of Orkustofnun (National Energy Authority).

The suspended samples that have been taken at the sampling site below the bridge on Highway 1in recent years (hereafter called Urriðafoss samples) are an integral part of a larger research project that involves detailed chemical analysis of Þjórsá and three other rivers in the southern lowlands of Iceland. The Þjórsá sediment samples are, however, imperfect as they are taken with a handheld sediment sampler (DH48), which does not reach the middle nor the bottom of the river where the sediment concentration is the greatest and the suspended sediment grains the largest. Thus, sediment concentration in the Urriðafoss samples is thought to be underestimated. Because of this problem, a motorized cableway was built across the river at Krókur, approximately 2 km upstream of the Highway 1 bridge, for the sediment sampling program that was initiated in 2001. The construction of the cableway also permits bedload sampling, but previous bedload samples from Þjórsá had only been collected from its upper reaches at Sandártunga, Sóleyjarhöfði, and above Hreysiskvísl (Fig. 1) (Haukur Tómasson *et al.* 1996; Svanur Pálsson 2000). The data introduced in this report includes results from suspended sediment samples at Urriðafoss and Krókur and bedload samples at Krókur, all taken in 2001.

2 SAMPLING AND DATA ANALYSIS

The sediment sampling at Krókur and Urriðafoss was twofold in the year 2001. Firstly, six suspended sediment samples were taken at Urriðafoss in connection with a chemical analysis program in southern Iceland. Secondly, nine sediment sampling campaigns were completed at Krókur/Urriðafoss in 2001. During each campaign, a set of bedload samples and an integrated suspended sediment sample was taken from the cableway at Krókur, as well as a suspended sediment sample at the ordinary sampling location below the Highway 1 bridge above Urriðafoss for comparison. In addition to the full sediment campaigns, one extra comparison set of suspended samples at Krókur and Urriðafoss was taken. Figure 3 shows the discharge at Þjórsártún during the latter part of 2001 and the timing of the sampling campaigns (circles). The discharge data is taken directly from the computerized Þjórsártún water gauge (vhm 30; V320).

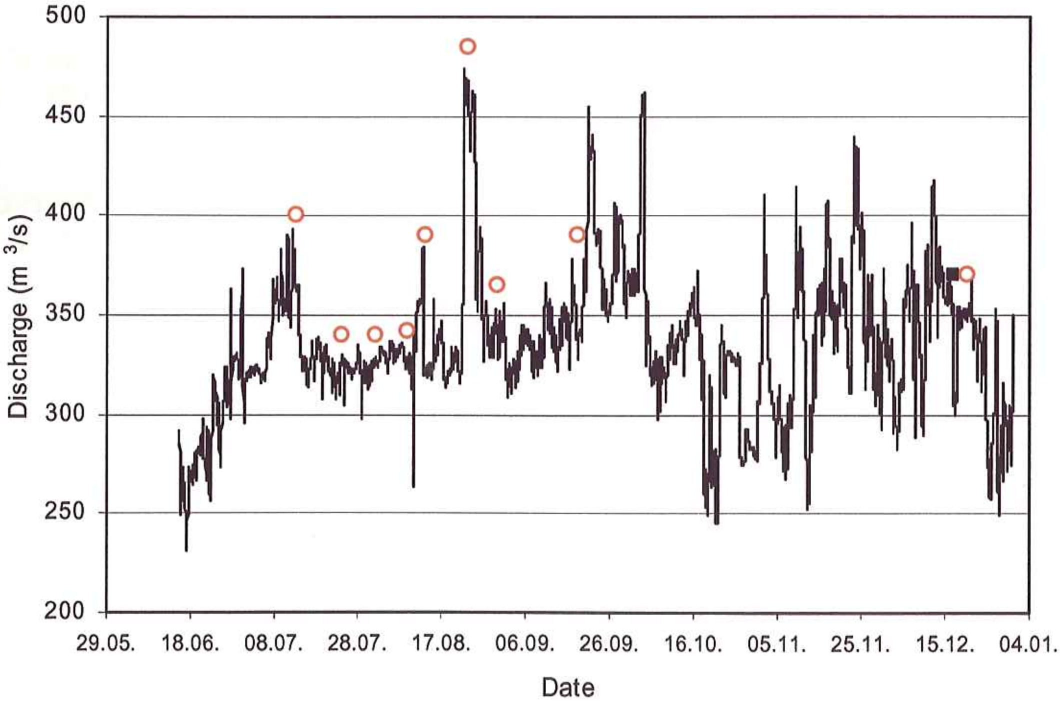


Figure 3. *Discharge at Þjórsártún during the summer of 2001. Timing of the bedload campaigns is shown as open circles and the comparison sample campaign with a solid square.*

The discharge was relatively uniform during the summer, with some peak flows in between, whereas it fluctuated much more during the latter part of the year. In addition to samples collected at medium high discharge, samples were taken during the peak discharge in mid July and late August. The discharge values during each campaign are shown in Table 1. The discharge fluctuated by as much as 59 m^3/s during the first campaign, but less than 10 m^3/s in campaigns 3, 4, and 9.

Table 1. *Discharge at Þjórsártún during the sample campaigns in 2001.*

Campaign date	Campaign no.	Mean discharge (m^3/s)	Minimum discharge (m^3/s)	Maximum discharge (m^3/s)	Range
11–14 July 2001	1	351	322	381	59
23–25 July 2001	2	320	306	329	23
31 July–1 August 2001	3	326	324	328	4
8–9 August 2001	4	327	323	331	7
13–14 August 2001	5	326	318	351	33
23–24 August 2001	6	442	432	461	29
29–30 August 2001	7	342	328	353	25
18–19 September 2001	8	352	331	372	42
19–20 December 2001	9	352	351	356	5
17 December 2001 suspended samples only		311	308	316	8

2.1 Suspended sediment samples

2.1.1 Sample types

Suspended sediment samples that are taken within the river sampling program of the Hydrological Service are classified into two main groups, F and S samples. The classification depends on the sampling procedures used in the field.

F-samples are sampled directly in bottles without the use of a sampler. All but two F-samples from Urriðafoss were taken before 1966 and are thus not of concern in this study.

S-samples are sampled into 1 pint (0.47 l) bottles using a specific water sampler. Three types of samplers are used: 1) The handsampler (DH48), which is fastened to a rod that is lowered by hand into the river; 2) the S49 sampler, which is attached to a winch; and 3) the P61 sampler, which is also attached to a winch, but is heavier than the S49 sampler and has an electronic opening that is possible to open with a remote control. All these samplers allow the water to flow into the flask through a valve, while the air in the flask is sucked out through another valve on the side. As the valve in the DH48 and the S49 samplers is always open, these samplers take an integrated river sample from the river surface, to the riverbed, and to the river surface again when the samplers are lowered into the river and lifted up again at a constant rate. When the P61 sampler is used, the sampler is lowered to the riverbed where the valve is opened and then lifted up again. This procedure results in an integrated sample from the bottom to the surface.

The S-samples are further divided into three categories, S1, S2, and S3.

S1 samples are taken from several locations (usually 3–5) on the river transect using the S49 and P61 samplers. These samples are considered to be the best quality samples.

S2 samples are taken from 1–2 locations on the river transect. They are taken with the S49 sampler and are usually equal to S1 samples in quality, especially when taken in high discharge rivers where turbulent flow occurs.

S3 samples are always taken with the handsampler, DH48, and are taken from either riverbank in the greatest current if possible. These samples are of less quality than S1 and S2 samples as they do usually not reach the bottom where the greatest sediment concentration is. S3 samples are thought to represent the finer sediment fraction reasonably, but underrepresent the coarser sediment load.

Most samples that were taken from the old cableway between the Highway 1 bridge and Urriðafoss before 1968 were of S1 type, although several F, S2, and S3 samples exist from this time. Excluding two F-samples, only S3 samples have been taken at this location since 1968.

The suspended samples taken during the sediment campaigns in 2001 were of two categories: 1) S1 samples taken with a P61 sampler from the cableway at Krókur and 2) S3 samples taken with a DH48 sampler from either bank at the Highway 1 bridge above Urriðafoss.

The samples during the first two sediment campaigns were taken at ten locations on the river transect, but the number of locations was decreased to seven in campaigns 3–9 (Table 2). However, samples were only collected at six locations during the suspended sampling campaign on December 17th. In the following text, all references to stations are in meters from house, which is located ca. 18 m from the left (eastern) bank of the river.

Table 2. *Station locations on the river transect during sample campaigns at Krókur in 2001.*

Campaign date	Campaign no.	Station locations m from house
11–14 July, 2000	1	40,50,60,70,80,90,100,130,160,180
23–25 July, 2001	2	40,50,55,60,65,70,80,100,140,180
31 July–1 August, 2001	3	40,50,60,65,70,80,140
8–9 August, 2001	4	—
13–14 August, 2001	5	—
23–24 August ,2001	6	—
29–30 August, 2001	7	—
18–19 September, 2001	8	—
19–20 December, 2001	9	—
17 December, 2001	susp. only	40,50,60,70,100,140

2.1.2 Grain size analysis

The S3 samples of last year from Urriðafoss included in most cases six bottles that were combined into one sample and analyzed for grain size, using a combination of sedimentation method (<63μm) and sieving (≥63μm). Suspended sediment concentration (mg/l), total dissolved sediment concentration (TDS in mg/l), and grain size distribution were measured on all samples. S1 samples from Krókur consisted of either 6 or 10 sample bottles taken at a specific distance from the river bank. Each bottle was analyzed separately for grain size using the same methods as the S3 samples. The result from each bottle was then weighted with the volume of each flask to compare the samples with Urriðafoss samples, using the following formula:

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

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

This study reports the results in five grain size classes based on a modified Atterberg grain size scale. Table 3 shows the size classes and the Icelandic and Swedish terms used for those categories. Due to problems translating the Icelandic terms for size classes into English without confusing them with other grain size scales, such as the widely used Udden-Wentworth scale, the Icelandic names are hereafter used in this report. The near applicable grain size terms according to Udden-Wentworth are, however, also included in Table 3 for comparison.

Table 3. *Grain size classification used in this report.*

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

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

2.2 Bedload samples

2.2.1 Sampling procedure

Bedload samples were retrieved from the cableway at Krókur with a Helley-Smith bedload sampler. The sampler that was used is 105 lbs (47.7 kg) and has an opening of 3×3 inches (ca. 7,6×7,6 cm), and 3.22 expansion ratio (Fig. 4).

The bedload stations were the same as the suspended sediment stations shown in Table 2, but the exact location of the bedload station may differ by as much as 1–2 m due to variable slack of the main cable. This is especially true for distance measurements during campaign no. 1 when the cableway was new.

At each station the bedload sampler was lowered to the riverbed where it sat for a certain time before it was pulled up again. This time ranged from 30–300 seconds, depending on the bedload transport at the station. While the sampler was situated at the river bed, the bedload was collected in a woven sample bag behind the opening, which has a mesh size of 250 μm; thus allowing the finest suspended material to filter through. Each sample was weighted in the sample bag on a scale with ±1 g precision after which the weight of the bag was subtracted. The largest pebble, if any, in each sample was also measured with a ruler. When the samples had been weighted they were thrown away, excluding one sample from each station during each campaign, which was analyzed with sieving for grain size at the sedimentology laboratory at the Hydrological Service.

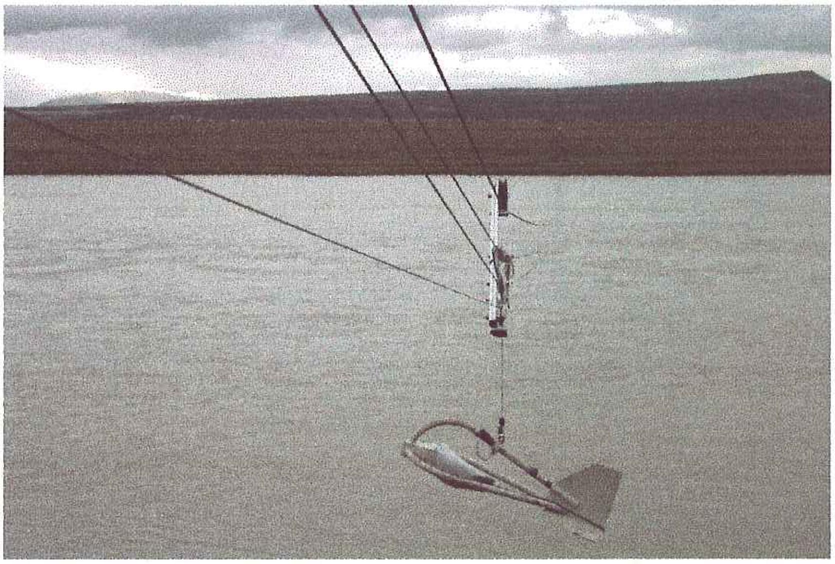


Figure 4. *Bedload sampling at the cableway at Krókur, Þjórsá.*

During each campaign, approximately 10 samples were retrieved from each station. The bedload transport was very variable so the sample bag overfilled occasionally; hence extra samples were taken at such incidents. All samples were, however, used in calculations of bedload transport. For those calculations, the wet weight of samples was used which can be considerately greater than dry weight, i.e. for samples >50 g their wet weight was usually <30% greater than their dry weight, but even greater difference was seen in the smallest samples collected at 40 and 140 m.

2.2.2 Bedload calculations

The total bedload was calculated in several steps. 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 : $$Q_b = \frac{q_{b1}}{2} x_1 + \frac{q_{b1} + q_{b2}}{2} x_2 + ... + \frac{q_{bn-1} + q_{bn}}{2} x_n + \frac{q_{bn}}{2} x_{n+1}$$

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 collected bedload samples were dried at 60 °C and then analyzed by dry sieving into grain size classes. The largest sieve size that was used was 64 mm and the smallest 0.063 mm, but the sieve stack included sieves with aperture at every half-phi (Table 4).

Table 4. *Grain size classes used in bedload sieving.*

mm	phi (ϕ)
128	-7
90.5	-6.5
64	-6
44.8	-5.5
32	-5
22.4	-4.5
16	-4
11.2	-3.5
8	-3
5.6	-2.5
4	-2
2.83	-1.5
2	-1
1.41	-0.5
1	0
0.71	0.5
0.5	1
0.35	1.5
0.250	2
0.177	2.5
0.125	3
0.088	3.5
0.063	4
<0.063	pan

Table 4 shows both the metric Udden Wentworth scale and the linear Phi scale (ϕ), which is used in the following sections, as it simplifies statistical analysis of the data. To change from Udden Wentworth values the following equation is used:

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

where d is grain diameter in mm.

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

The moment statistics were calculated in the following manner:

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

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

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

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

The mean value in moment statistics indicates a simple arithmetic mean, whereas sorting represents the standard deviation of the data. The sorting value represents the slope of the cumulative graph; as the sorting value decreases, the sample is better sorted. Folk (1974) divided the sorting values into seven groups for better verbal expression of the data and those are shown in Table 5.

Table 5. *Description of sorting values.*

Sorting value	Description
<0.35 ϕ	very well sorted
0.35–0,50 ϕ	well sorted
0.50–0,70 ϕ	moderately well sorted
0.71–1,00 ϕ	moderately sorted
1.00–2,00 ϕ	poorly sorted
2.00–4,00 ϕ	very poorly sorted
>4.00 ϕ	extremely poorly sorted

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

3 RESULTS

3.1 Suspended sediment samples

3.1.1 Urriðafoss samples

Sixteen suspended sediment samples were taken from either river bank below the bridge on Highway 1 in the year 2001. At this location, Urriðafoss, the samples were taken with a handheld rod sampler (DH48). Even though the samples are taken where the current is greatest and sediment is well mixed within the water column, the sampler probably underestimates the coarser fraction because the handsampler does not reach close to the river bed where the coarsest material travels.

The results from all 16 samples are shown in Table 6. The samples indicated in bold were taken during an integrated chemical, discharge, and sediment study of four rivers in southern Iceland in cooperation between scientists from the Science Institute and Hydrological Service of Orkustofnun. The study is funded by Orkustofnun, Landsvirkjun (National Power Company), and the Environmental and Food Agency of Iceland (on behalf of the Ministry of Environment) (Sigurður R. Gíslason *et al.* 2000).

Table 6. *Grain size data on suspended sediment samples from Þjórsá at Urriðafoss*

Date	Time	Discharge (m^3/s)	Sediment (mg/l)	Dissolved (mg/l)	Sand % (>0.2 mm)	Grófmór % (0.2–0.06 mm)	Fínmór % (0.06–0.02 mm)	Méla % (0.02–0.002 mm)	Clay % (<0.,002 mm)	Largest part. (mm)
2001.03.13.	**12:00**	**(323)**	**76**	**48**	**37**	**16**	**8**	**26**	**13**	**1.6**
2001.05.02.	**12:00**	**328.7**	**31**	**62**	**38**	**7**	**7**	**34**	**14**	**1.2**
2001.06.15.	**10:40**	**273.9**	**51**	**72**	**5**	**4**	**4**	**69**	**18**	**0.5**
2001.07.13.	19:35	350.2	114	45	1	1	5	34	59	0.3
2001.07.25.	14:50	324.3	91	68	25	3	1	32	39	1.8
2001.08.01.	21:00	325.4	124	4*	22	2	5	22	49	1.8
2001.08.08.	**10:35**	**326.5**	**108**	**66**	**2**	**1**	**1**	**38**	**58**	**0.5**
2001.08.10.	00:00	318.8	78	57	10	2	4	28	56	0,8
2001.08.13.	20:00	319.6	127	51	16	2	2	27	53	2
2001.08.24.	21:25	422.0	145	51	7	4	4	22	63	0.6
2001.08.30.	17:45	343.7	117	50	12	3	3	27	55	1.1
2001.09.20.	16:45	454.9	232	63	14	6	6	43	31	1.5
2001.09.24.	**10:36**	**360.2**	**125**	**62**	**6**	**1**	**1**	**33**	**59**	**1.1**
2001.11.15.	**11:50**	**351.1**	**57**	**69**	**16**	**14**	**8**	**38**	**24**	**0.8**
2001.12.17.	11:05	300.8	21	78	29	20	7	26	18	2
2001.12.20.	12:55	351.1	51	63	25	5	2	35	33	2.5

Samples in bold were taken during a different sediment research program; see text. * represent a TDS value that is most likely erroneous; however, the reason for such low value is unknown.

The other Urriðafoss samples were taken during nine bedload campaigns and one suspended campaign (see Tables 1 and 2), roughly simultaneous to a sample at the cableway at Krókur.

Figure 5 shows the relationship between suspended sediment concentration and discharge in the Urriðafoss samples from the year 2001. Generally, the sediment concentration increases with discharge as is seen with correlation coefficient (r^2) of 0.57, and is highest when the discharge is more than 450 m^3/s in late September. However, samples taken during the winter season (October–June) show the lowest sediment concentration even though some of their corresponding discharge values are relatively high (see samples within the rectangle on Fig. 5). The low total sediment concentration in the winter samples is probably due to lack of sediment derived from glacial summer melting, and higher and less variable discharges due to regulation for hydropower production.

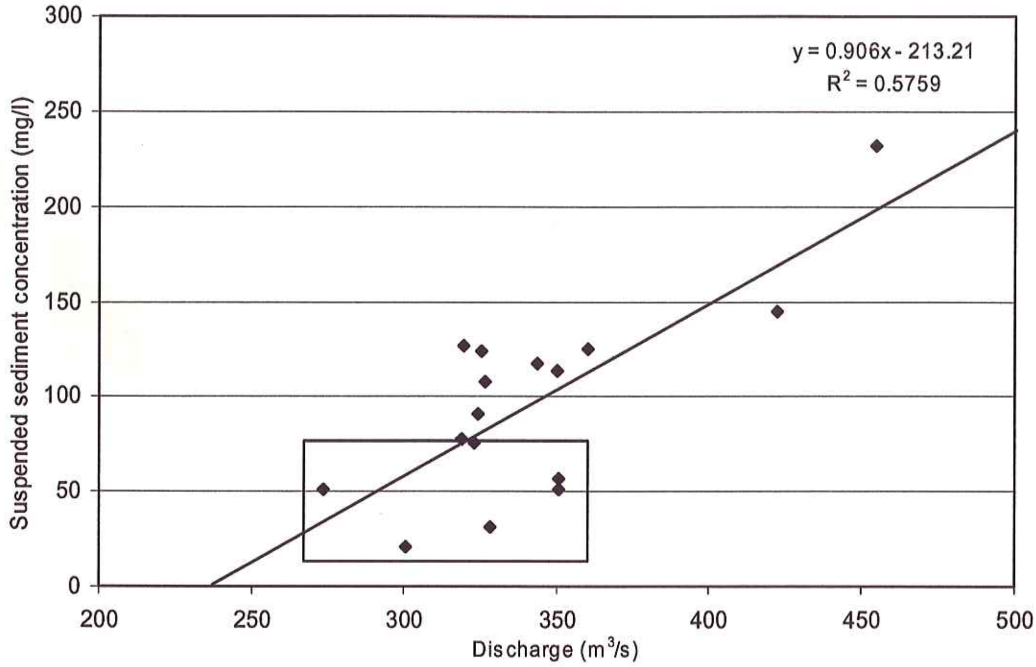


Figure 5. *Relationship between suspended sediment concentration and discharge in Urriðafoss samples from 2001.*

The distribution of the Urriðafoss samples into grain size groups is shown on Fig. 6. The distribution varies greatly between samples, although it is evident that that *leir* (<0.002 mm) concentration is greater during the summer months than winter months, i.e. from October to June. This distribution supports the variability seen in the total concentration values (Fig. 5), and confirms that the lower sediment concentration during winter months is to a large extent related to lack of fine-grained glacial sediment outside the glacial melting season.

Conversely, the percentage of *sandur* is higher during the winter months, which is partly due to the closed array problems of such percentage data (when one value decreases, other values increase), but to some extent due to the fact that coarser material is transported down the river channel during the winter season. At this time the discharge is higher than it would be if not regulated for hydropower production. Furthermore, the water is colder and its viscosity greater, which causes larger grains to stay in suspension than they would at higher temperatures.

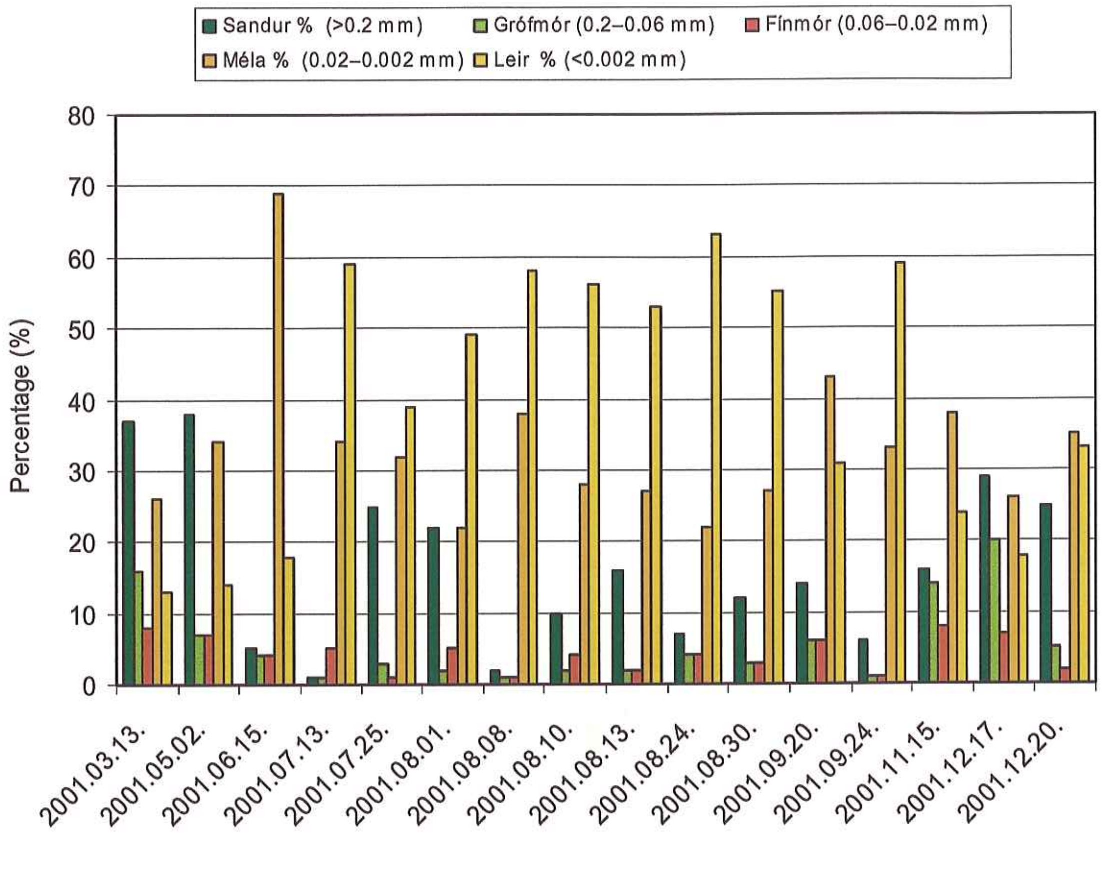


Figure 6. *Grain size distribution in S3 samples from Urriðafoss in 2001.*

3.1.2 Krókur samples

Each suspended sediment sample from Krókur consists of 6 to 10 sample bottles taken from the cableway at equal number of locations on the cross section (Table 2). Water volume was usually very small in the bottles closest to the river banks at 40 and 140 m. This results in a larger error in grain size calculations for these bottles, especially for the finer fractions and the TDS, which should be born in mind when the results are interpreted.

Figure 7 shows the grain size distribution of the individual bottles before the weighted mean distribution was calculated for each sample. Grain size distribution was very variable among the bottles taken at 10 different occasions from July 13 to December 20, 2001. In almost all bottles the concentration of *grófmór* (0.2–0.06 mm) and *fínmór* (0.06–0.02 mm) is less than 5 %, whereas percentage of *méla* (0.02–0.002 mm) and *leir* (<0.002 mm) varies between 0 and 70 %. *Sandur* (>0.2 mm) concentration varies, however, the most, and is greatest, or over 90 %, in a 70 m bottle from December 20, 2001. The coarsest material appears to travel at 60–80 m distance from the house (located 18 m from the left river bank), and is especially concentrated at 70 m (Fig. 7). The highly variable *sandur* percentage is readily explained by the stochastic nature of the coarse material being transported in pulses close to the bottom, except when the current it great enough to lift the material into suspension. Minor current changes can thus determine whether *sandur* is transported in suspension and collected with a suspension sampler, or as bedload and consequently overlooked by the same sampler.

Hence, the variable grain size seen in bottles from different stations can be explained by different hydraulic conditions at each location, but as with the Urriðafoss samples, the closed array problem of percentage values can not be ignored.

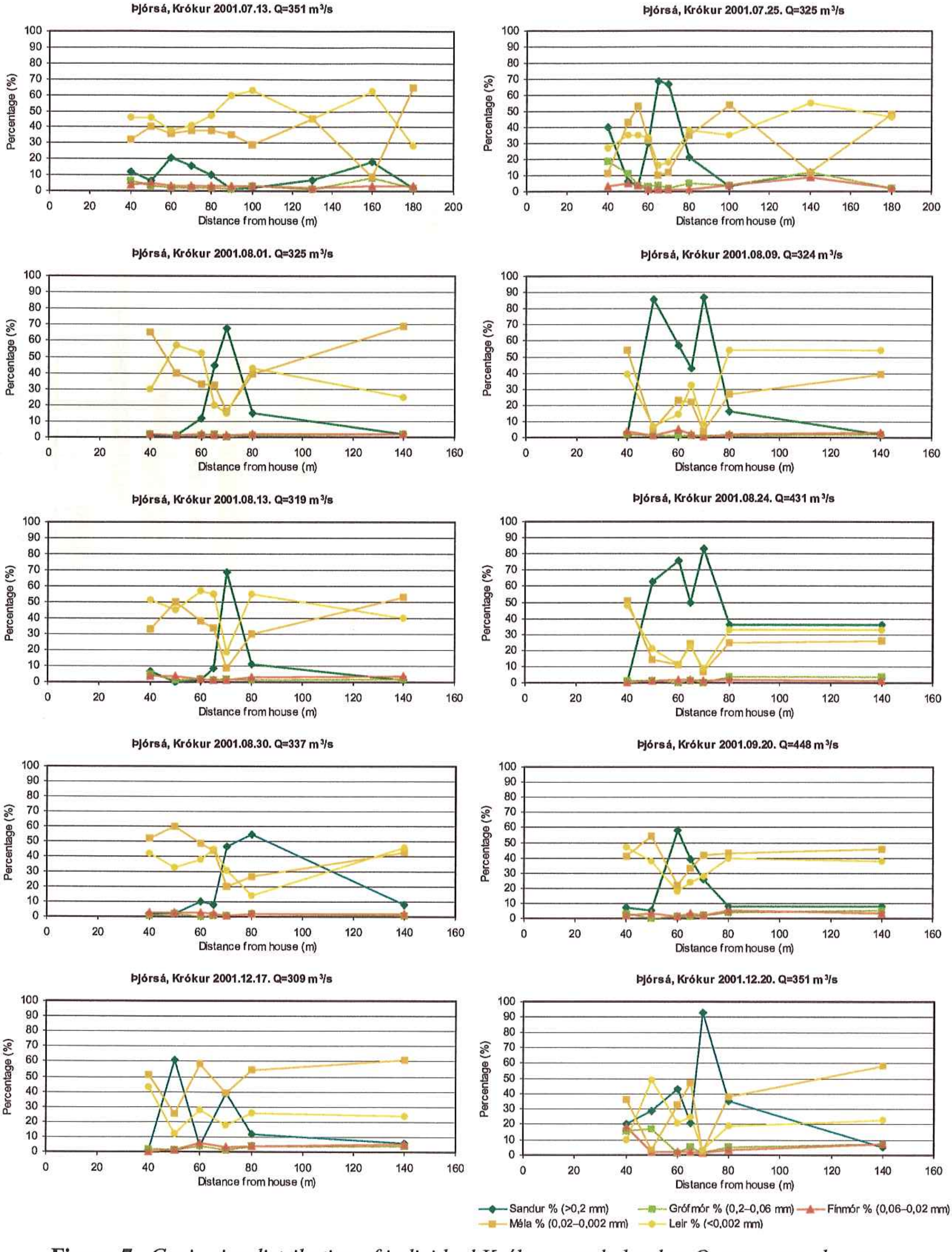


Figure 7. *Grain size distribution of individual Krókur sample bottles. Q represents the mean discharge at Þjórsártún during the suspended sampling interval.*

Figure 8 shows the grain size distribution of the integrated Krókur samples. As was seen on Fig. 7, *sandur* fraction varies greatly in the samples, or from 9 to 79%. Contrastingly, *grófmór* and *finmór* is less than 5 % in all integrated Krókur samples.

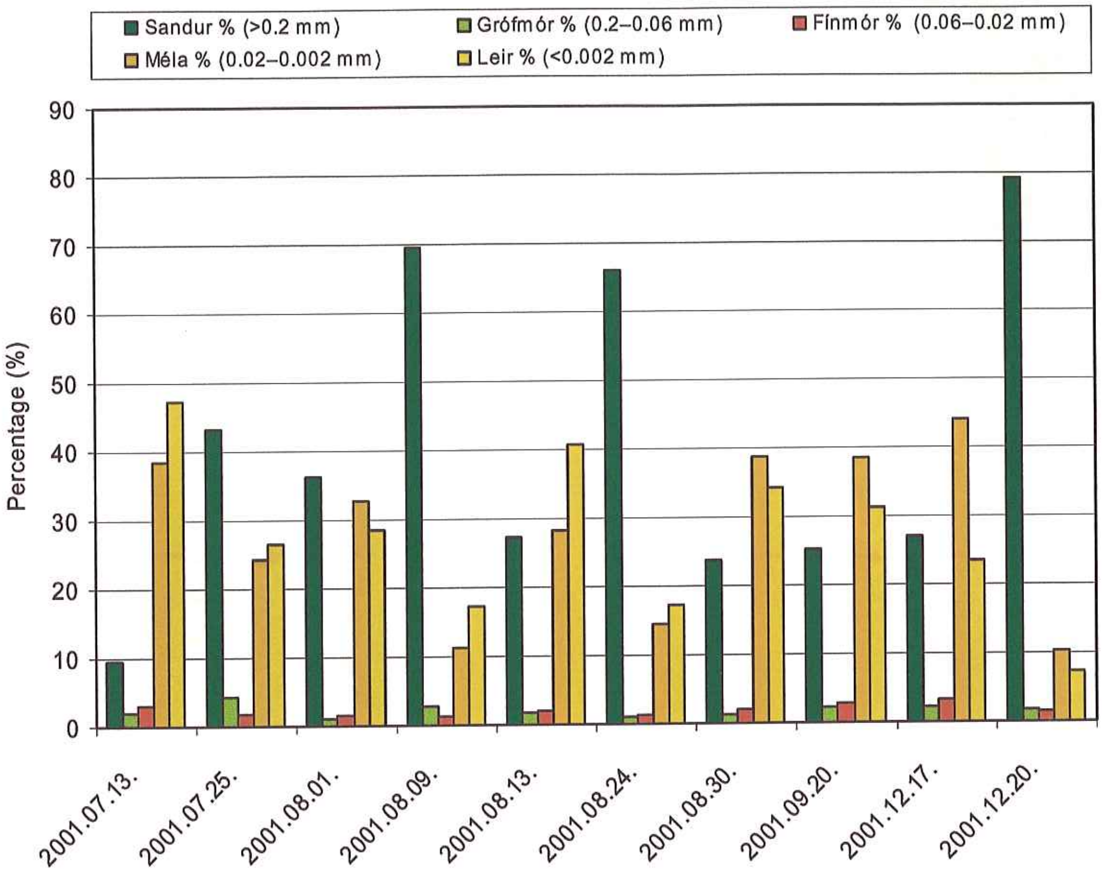


Figure 8. *Grain size distribution in S1 samples from Krókur in 2001.*

Examination of the depth profile beneath the cableway at Krókur can help in explaining the variable grain size distribution in the suspended sediment samples. Figure 9 shows depth profiles measured with the suspended sediment sampler during six sediment campaigns; however, the depths are not adjusted for different water levels because such measurements are not performed at the cableway. For comparison, the water stage at Þjórsártún farther downstream is shown. Minor changes (173-179 cm) are seen between all measurements but one, when the water stage was over 20 cm higher than during other measurements (211 cm) (Fig. 9). The profile from 13–14 August (orange squares) was measured at more frequent intervals and shows well the gully within the river channel between ca. 60 and 80 m distance from the house. This is where the highest current speed is and where the greatest concentration of coarse material is measured in the suspended sediment samples.

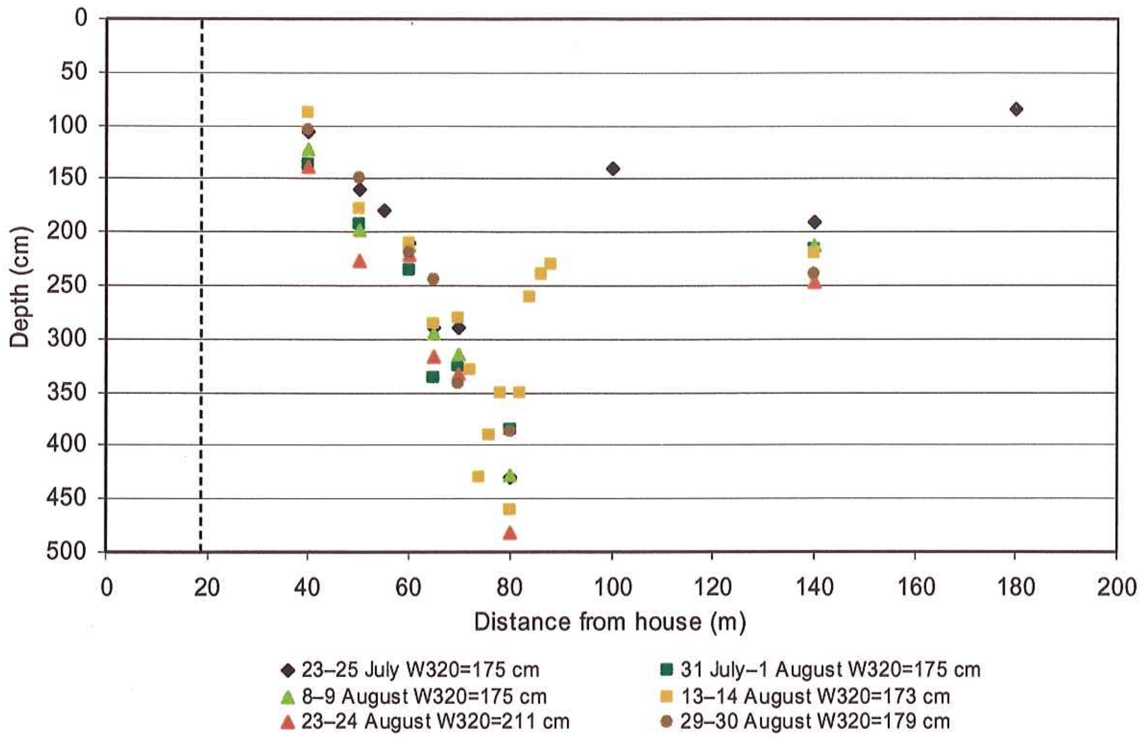


Figure 9. *Depth profiles beneath the Krókur cableway measured with the suspended sediment sampler. Vertical line indicates the left bank at ca. 18 m, whereas the right bank is located at ca. 200 m. No measurements of water stage are available at the cableway location, thus it is not possible to correct the depth values for water level changes. For comparison, the water stage at Þjórsártún (W320) is shown for each depth profile.*

Using the suspended sediment sampler to measure depth is not as accurate as using a normal depth measuring weight, and this uncertainty results in part of the depth variability of up to 1 m seen at each station. The water stage difference and errors in the measurement of station distance from house have added to the variability, but some of it must be attributed to the fluctuating bedload transported at the river bed. Such channel changes have e.g. been recorded in Jökulsá á Dal at Hjarðarhagi in eastern Iceland (Ásgeir Gunnarsson *et al.* 2001).

3.1.3 Comparison between Urriðafoss and Krókur samples

Ten sample pairs were taken at Urriðafoss and Krókur in 2001. The results from their grain size analyses are shown in Table 7 and on Fig. 10 where U indicates Urriðafoss samples and K represents Krókur samples.

The Krókur samples were always, but once, taken before the Urriðafoss samples. Although the samples were taken up to 3.5 hours apart, the discharge as evaluated at Þjórsártún (Fig. 1) never differs by more than 3 % between the sample retrievals. Note however that the time shown in Table 7 for the Krókur samples indicates the time when sampling started and the difference is thus maximum time interval between the samples.

Table 7. *Grain size results from suspended sediment samples from Krókur (K-) and Urriðafoss (U-).*

Location and date	Time	Discharge (m^3/s)	Sediment (mg/l)	Dissolved (mg/l)	Sandur % (>0.2 mm)	Grófmór % (0.2–0.06 mm)	Fínmór % (0.06–0.02 mm)	Méla % (0.02–0.002 mm)	Leir % (<0.002 mm)	Largest part. (mm)	Sample type
U-20010713	19:35	350	114	45	1	1	5	34	59	0,3	S3
K-20010713	17:05	351	185	102	10	2	3	38	47	1,1	S1
Ratio U/K		*1,00*	*0,62*	*0,44*	*0,11*	*0,48*	*1,65*	*0,89*	*1,25*	*0,27*	
U-20010725	14:50	324	91	68	25	3	1	32	39	1,8	S3
K-20010725	12:45	325	116	64	43	4	2	24	27	2,0	S1
Ratio U/K		*1,00*	*0,78*	*1,06*	*0,58*	*0,72*	*0,54*	*1,32*	*1,47*	*0,90*	
U-20010801	21:00	325	124	(4)	22	2	5	22	49	1,8	S3
K-20010801	18:32	325	235	78	36	1	1	33	29	2,2	S1
Ratio U/K		*1,00*	*0,53*	*0,05*	*0,60*	*2,17*	*3,59*	*0,67*	*1,72*	*0,82*	
U-20010810	00:00	319	78	57	10	2	4	28	56	0,8	S3
K-20010809	20:35	324	335	103	70	3	1	11	17	2,5	S1
Ratio U/K		*0,98*	*0,23*	*0,55*	*0,14*	*0,75*	*3,48*	*2,48*	*3,26*	*0,32*	
U-20010813	20:00	320	127	51	16	2	2	27	53	2,0	S3
K-20010813	17:34	319	171	71	27	2	2	28	41	2,3	S1
Ratio U/K		*1,00*	*0,74*	*0,72*	*0,59*	*1,22*	*0,94*	*0,96*	*1,30*	*0,87*	
U-20010824	21:25	422	145	51	7	4	4	22	63	0,6	S3
K-20010824	18:40	431	686	54	66	1	1	14	17	3,7	S1
Ratio U/K		*0,98*	*0,21*	*0,94*	*0,11*	*4,53*	*3,04*	*1,52*	*3,65*	*0,16*	
U-20010830	17:45	344	117	50	12	3	3	27	55	1,1	S3
K-20010830	16:00	337	215	86	24	1	2	39	34	1,8	S1
Ratio U/K		*1,02*	*0,54*	*0,58*	*0,50*	*2,64*	*1,42*	*0,70*	*1,61*	*0,61*	
U-20010920	16:45	455	232	63	14	6	6	43	31	1,5	S3
K-20010920	14:40	448	337	78	25	2	3	38	31	3,0	S1
Ratio U/K		*1,02*	*0,69*	*0,81*	*0,55*	*2,70*	*2,23*	*1,12*	*0,99*	*0,50*	
U-20011217	11:05	301	21	78	29	20	7	26	18	2	S3
K-20011217	14:30	309	181	83	27	2	3	44	23	2,1	S1
Ratio U/K		*0,97*	*0,12*	*0,94*	*1,07*	*8,53*	*2,23*	*0,59*	*0,77*	*0,95*	
U-20011220	12:55	351	51	63	25	5	2	35	33	2,5	S3
K-20011220	10:48	351	337	79	79	2	2	10	7	3,0	S1
Ratio U/K		*1,00*	*0,15*	*0,80*	*0,32*	*2,70*	*1,33*	*3,43*	*4,52*	*0,83*	

Large difference is seen in all grain size classes between the Urriðafoss and Krókur samples. Total sediment concentration is in all sample pairs lower at Urriðafoss than at Krókur, whereas *sandur* % is lower in all, but one, Urriðafoss sample (Table 7 and Fig. 10). Similarly, all the Krókur samples include grains with larger mean diameter than Urriðafoss samples. One possibility for the large difference in *sandur* % between the samples at Urriðafoss and Krókur is incorporation of bedload grains in the Krókur samples, as the largest grains are up to 3.7 mm in mean diameter. When the sampler touches the bottom the opening of the suspended sediment sampler is located 10 cm above the river bed so there is a chance that occasional bedload grains are sampled. Two samples are suspect concerning this possibility, i.e. Krókur samples taken 2001.08.09. and 2001.12.20. These samples have very high sand concentration (≥70 %) and largest particles >2.5 mm.

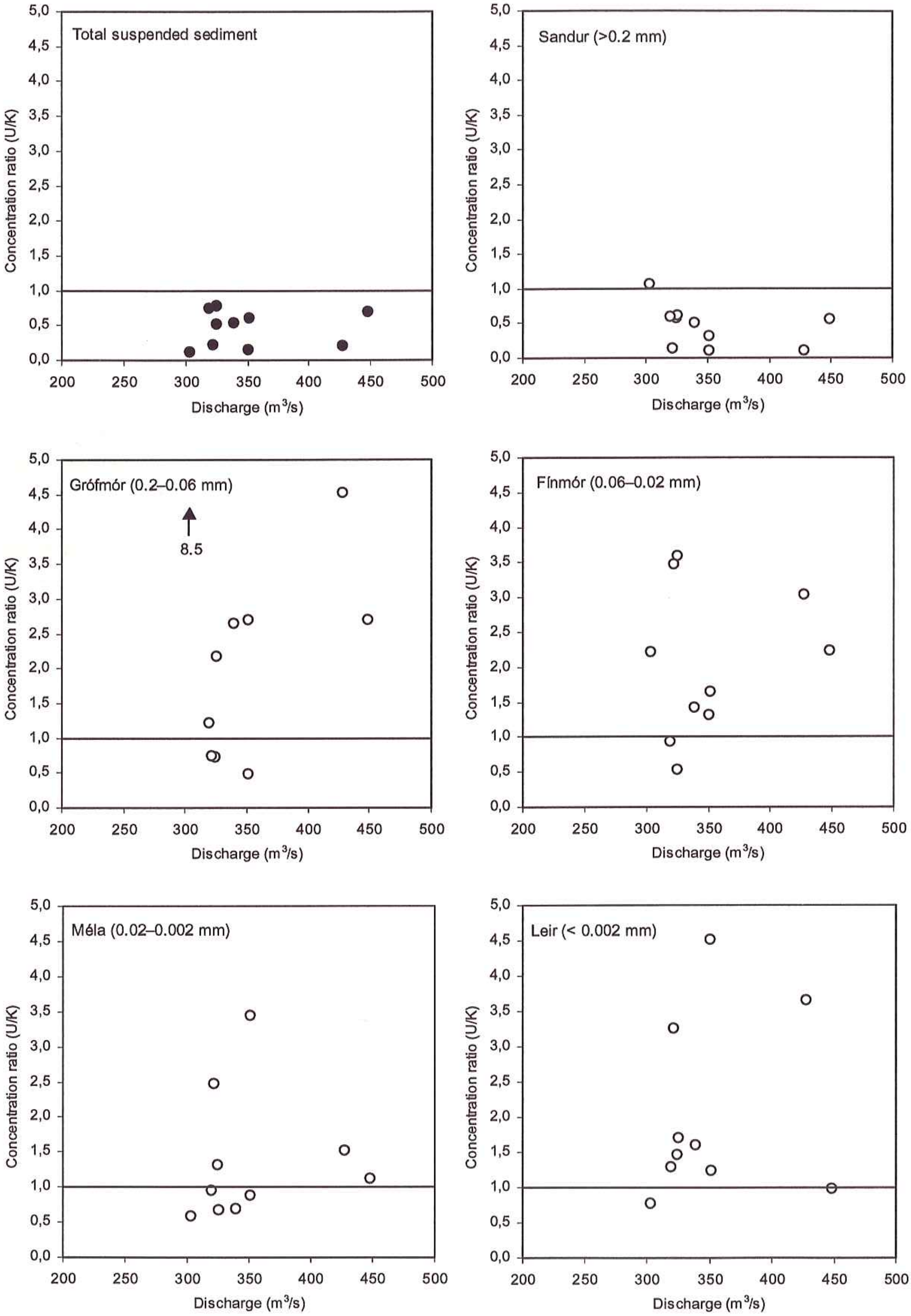


Figure 10. *Sediment ratio of total concentration and individual grain size classes between Urriðafoss samples (U) and Krókur samples (K).*

On the contrary, *finmór* and *leir* % is higher in all but two Urriðafoss samples (although not the same samples) and *grófmór* % is greater in 7 of 10 Urriðafoss samples (Table 7); however, the values for both *grófmór* and *finmór* are very low for almost all samples and comparison thus inaccurate. The lower concentration of the finer sediment fraction in many of the Krókur samples is partly due to the close array problem of grain size percentage data—the high sand fraction in many of the Krókur samples will decrease percentage of finer fractions as well as increase the U/K ratio of the same fractions.

The large difference of the finer fraction of the sediment between the two locations raises some questions on the accuracy and precision of the grain size measurements of the smaller-volume Krókur samples. It is known that results from those bottles, which have very small water volume, have large errors in the grain size calculations (often the 40 and 140 m bottles). However, when the total and size class concentration is calculated for the total Krókur sample, this error is minimized as the results are weigted for volume. This error might though add to the difference between the sample locations. One approach to check for this is to collect two samples at Krókur each time. For one sample, the volume of all the sample bottles would be added together before measurement, whereas in the other sample each bottle would be measured separately similar to what has been done with the samples introduced in this report.

It is, however, clear that the Urriðafoss samples underestimate the total sediment concentration and especially lack the coarsest *sandur* fraction (>0.2 mm). Still, many more sample pairs need to be analyzed before the relationship can be established.

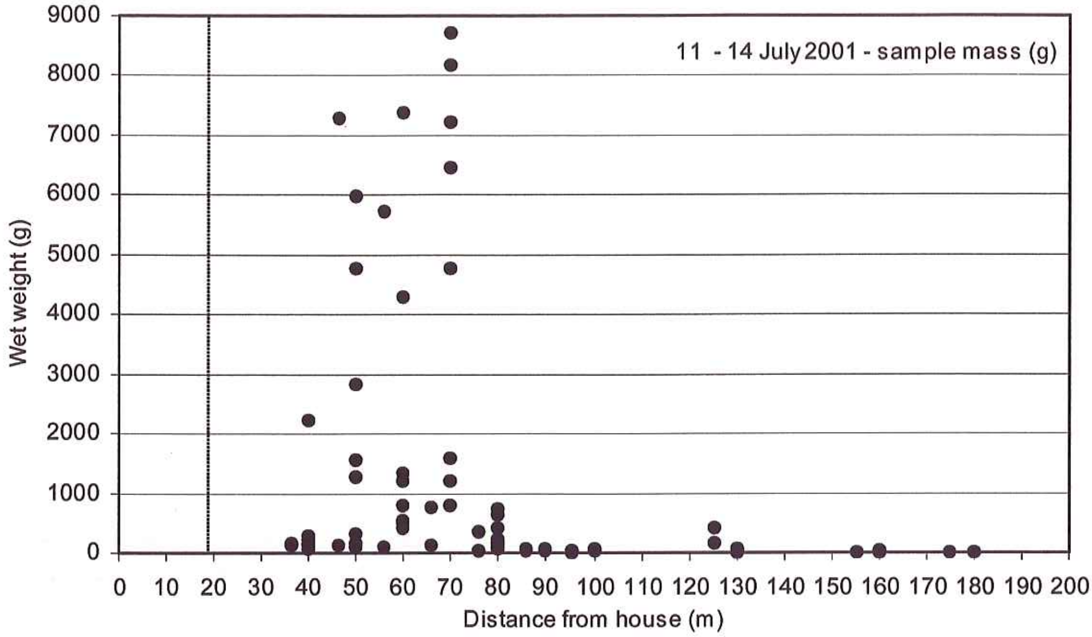
3.2 Bedload samples

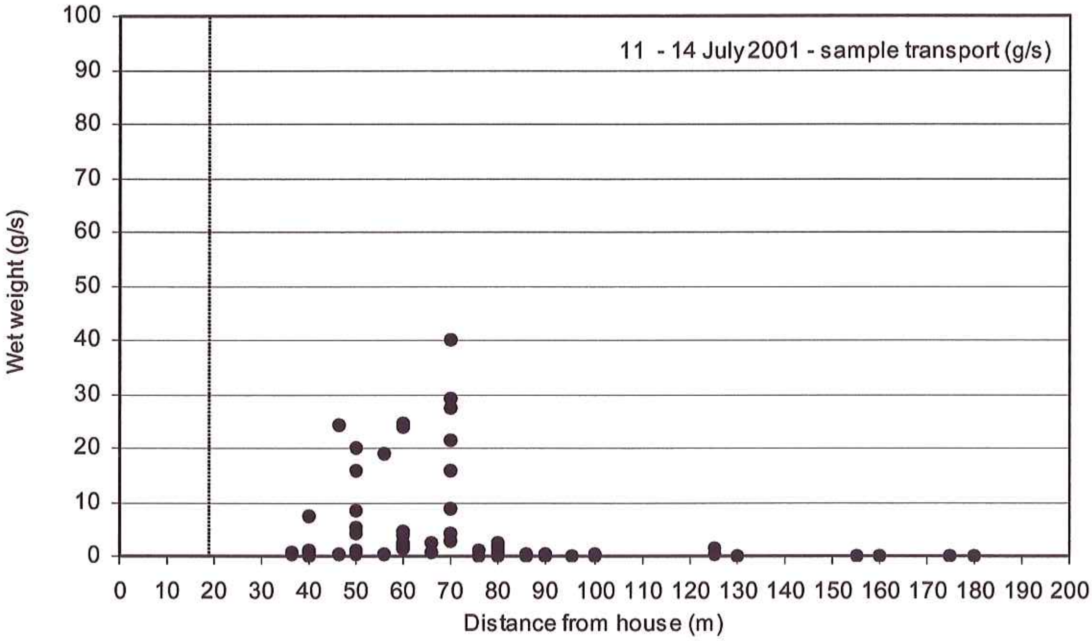
3.2.1 Bedload transport

During each of the 9 bedload campaigns, roughly 10 samples were collected at each station on the river transect. Hence, about 700 samples were obtained from the cableway at Krókur in the year 2001, which are reported on in this report. In the following section, results are shown in two graphs and a table (Figs. 11–19) for each of the bedload campaign. Vertical line on the graphs indicates location of the left bank as before. The same scale is used for the graphs to improve comparison among the campaigns. Results are calculated for each sample representing per unit width (0.0762 m) and are shown both as mass (g) and mass per second (g/s) as the sampling time varied between samples (30–300 seconds).

Ten main sampling stations were used in campaigns 1 and 2 and seven stations in campaigns 3 to 9. However, due to initial adjustment of the cableway during the first campaign, two of the ten samples at each station were shifted 4 meters, i.e. samples at 40 m were taken at 36 m, samples at 50 m at 46 m, etc. This shift is disregarded in calculations and bedload at both the shifted and original stations included in the cumulative transport for the main stations.

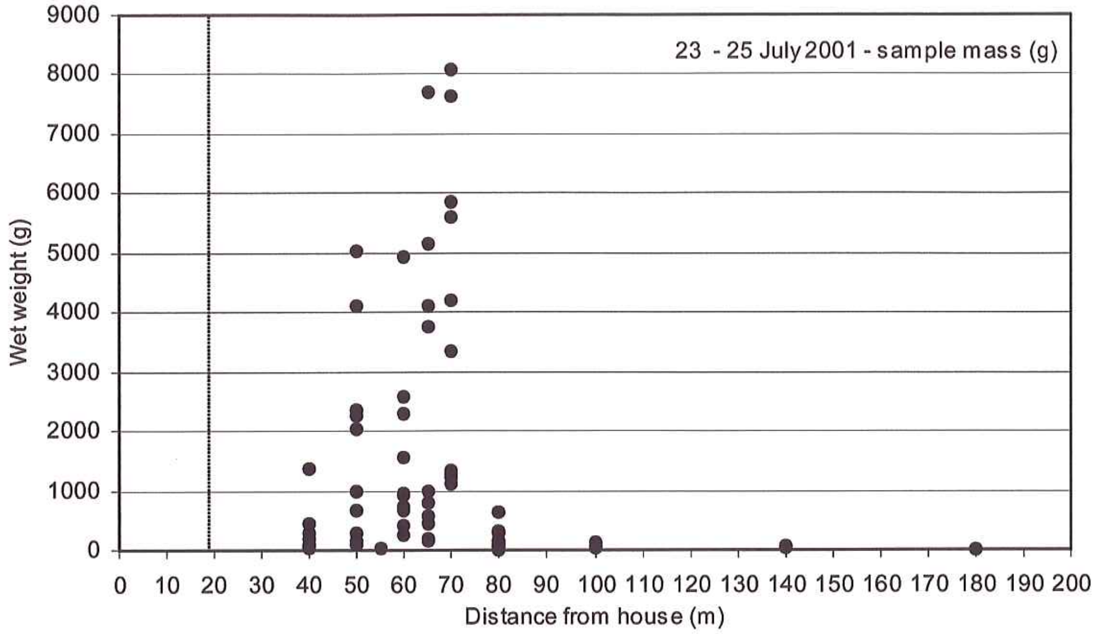
Figures 11 to 19 show that the mass of each sample varies greatly at each station and the main bedload is transported at the 50, 60, 65, and 70 m stations. Only a minor fraction is transported at other stations. To ease comparison of results from the individual bedload campaigns Fig. 20 and Table 8 summarize the results shown on Figs. 11–19.

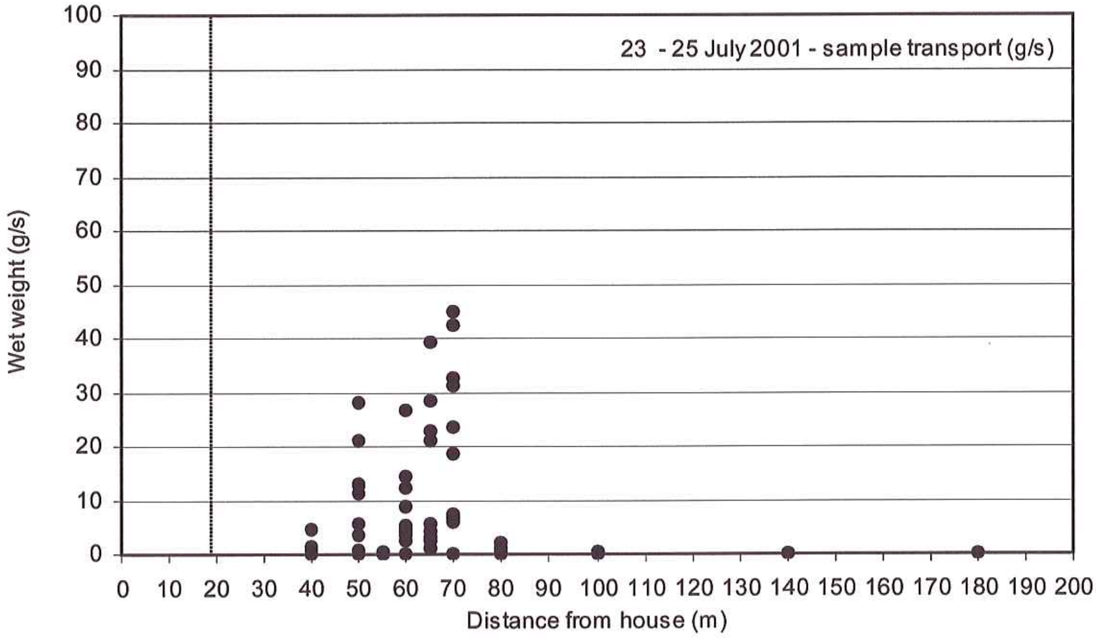




11–14 July 2001	40 m	50 m	60 m	70 m	80 m	90 m	100 m	130 m	160 m	180 m	Total transport
Width btw. station midpoints	16	10	10	10	10	10	20	30	25	30	Q=351 m^3/s
Mean bedload transport at each station (g/s/m)	16	105	110	200	12	2	2	4	0,4	0,2	
Total transport btw. station midpoints (g/s)	251	1054	1100	2001	121	21	31	110	10	6	**4705 g/s**

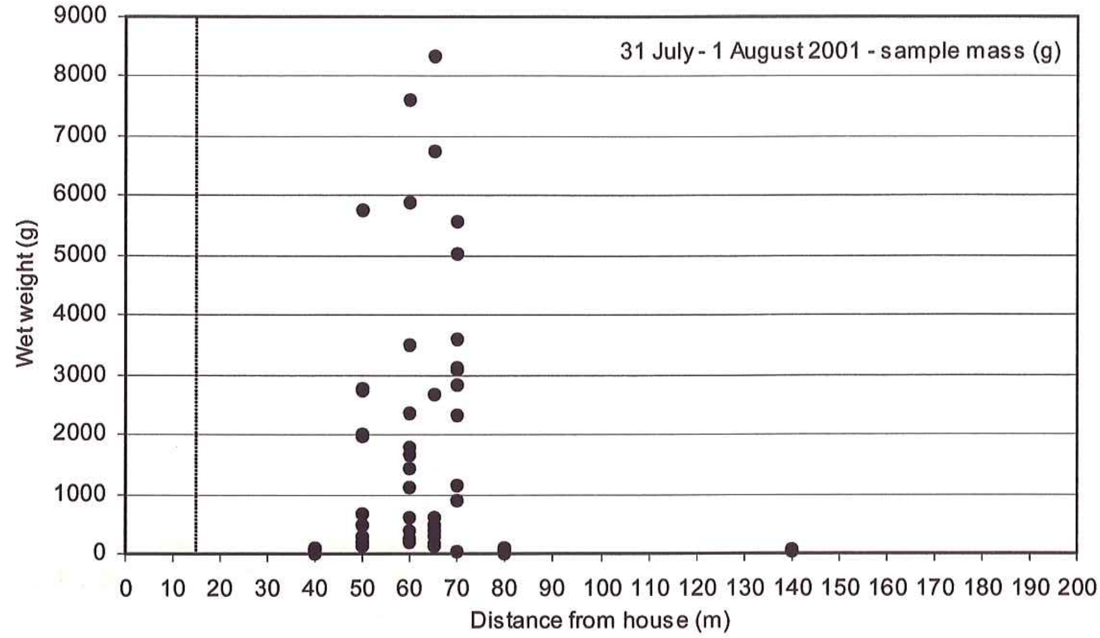
Figure 11. *Results from bedload measurement during 11–14 July, 2001.*

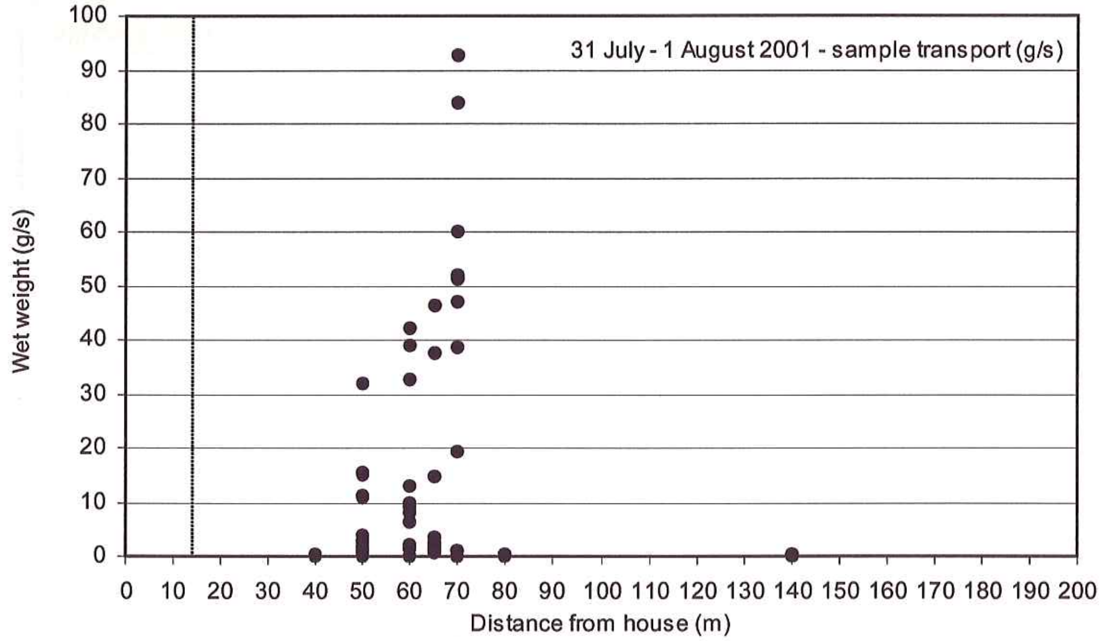




23–25 July 2001	40 m	50 m	55 m	60 m	65 m	70 m	80 m	100 m	140 m	180 m	Total transport
Width btw. station midpoints	16	7,5	5	5	5	7,5	15	30	40	30	Q=320 m^3/s
Mean bedload transport at each station (g/s/m)	12	127	2	111	170	289	8	2	2	0,4	
Total transport btw. station midpoints (g/s)	190	954	8	554	848	2170	118	68	70	12	**4992 g/s**

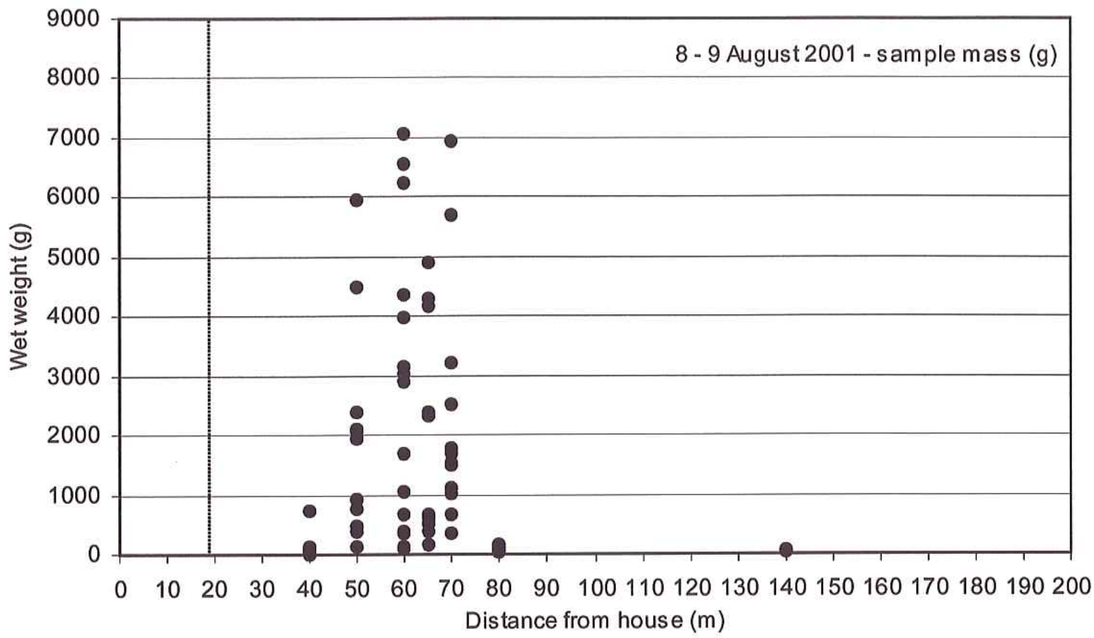
Figure 12. *Results from bedload measurement during 23–25 July, 2001.*

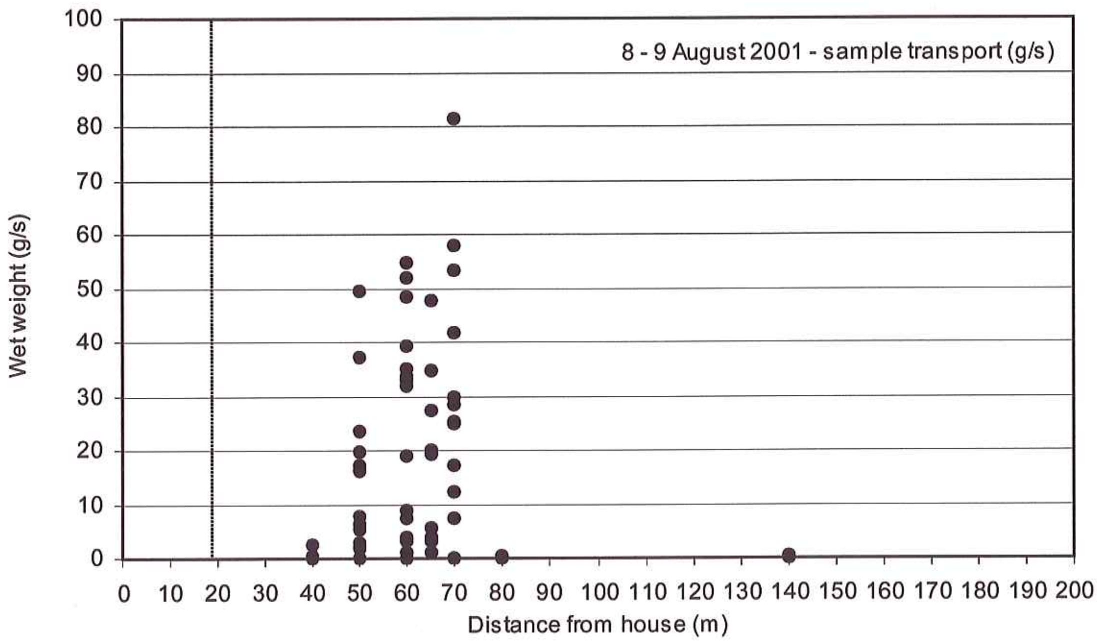




31 July–1 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	7,5	5	7,5	35	60	Q=326 m^3/s
Mean bedload transport at each station (g/s/m)	2	124	215	146	653	2	2	
Total transport btw. station midpoints (g/s)	38	1237	1610	732	4898	75	127	**8716 g/s**

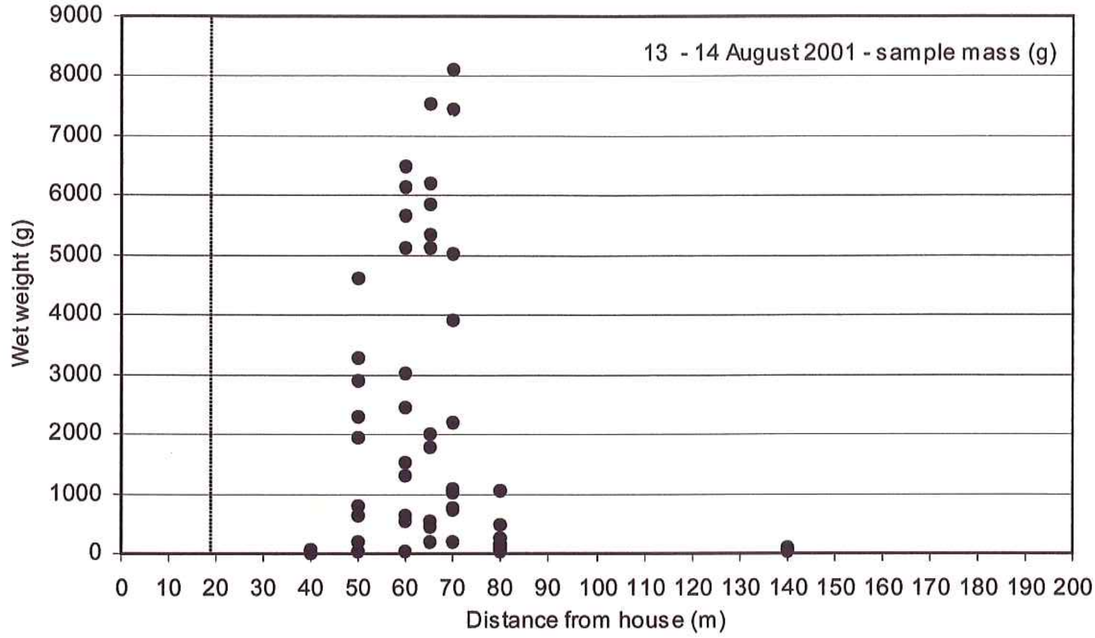
Figure 13. *Results from bedload measurements during 31 July–1 August, 2001.*

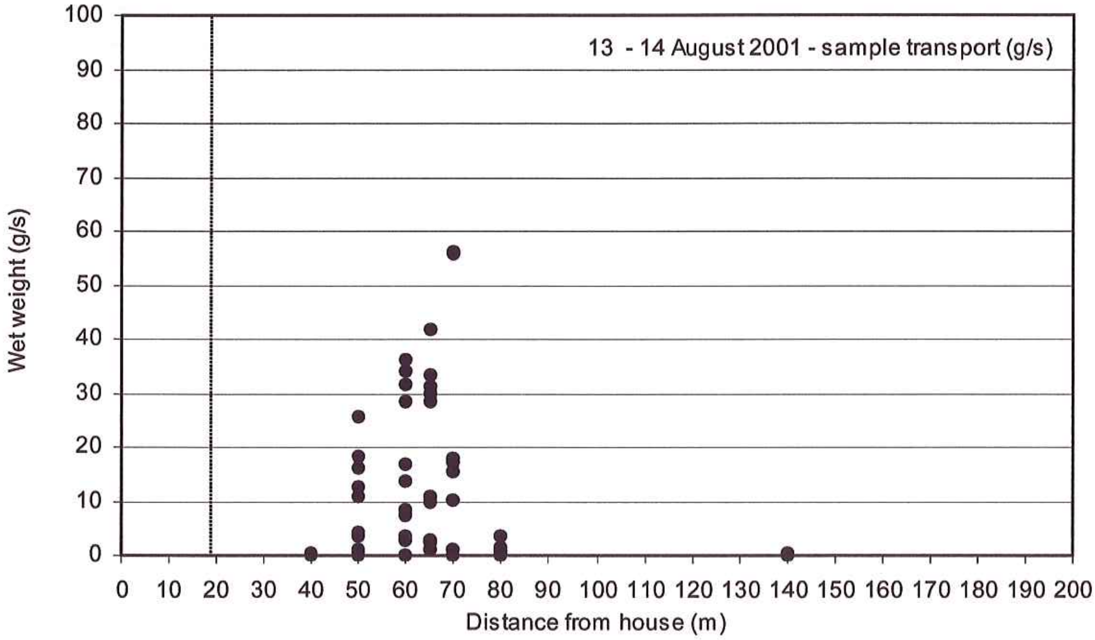




8–9 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	7,5	5	7,5	35	60	Q=327 m^3/s
Mean bedload transport at each station (g/s/m)	5	207	348	217	453	4	2	
Total transport btw. station midpoints (g/s)	86	2069	2608	1086	3396	137	141	**9523 g/s**

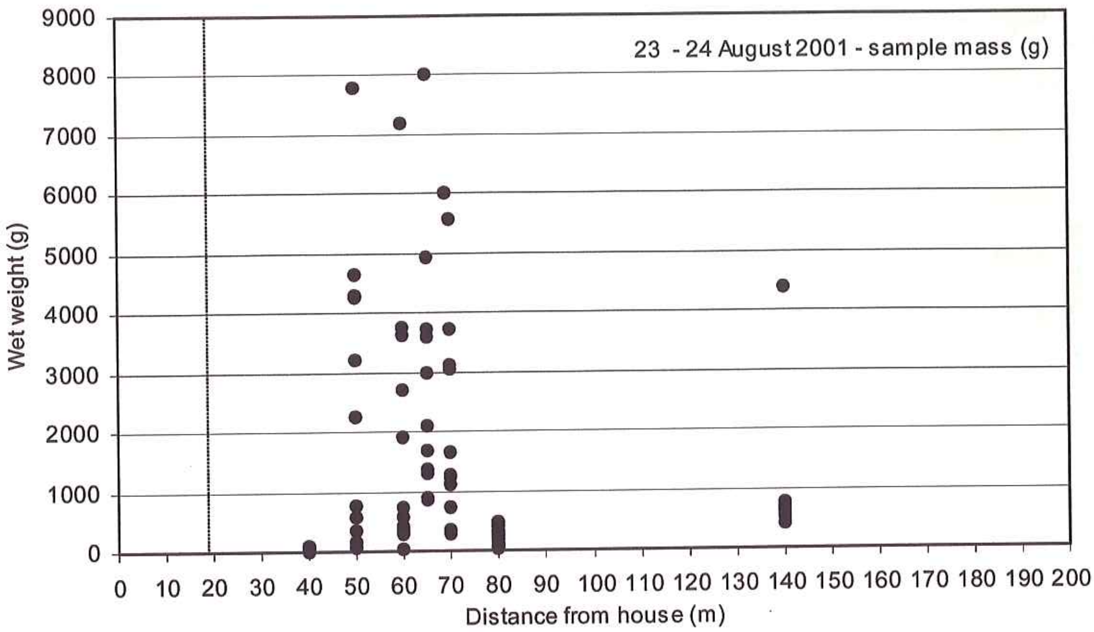
Figure 14. *Results from bedload measurements 8–9 August, 2001.*

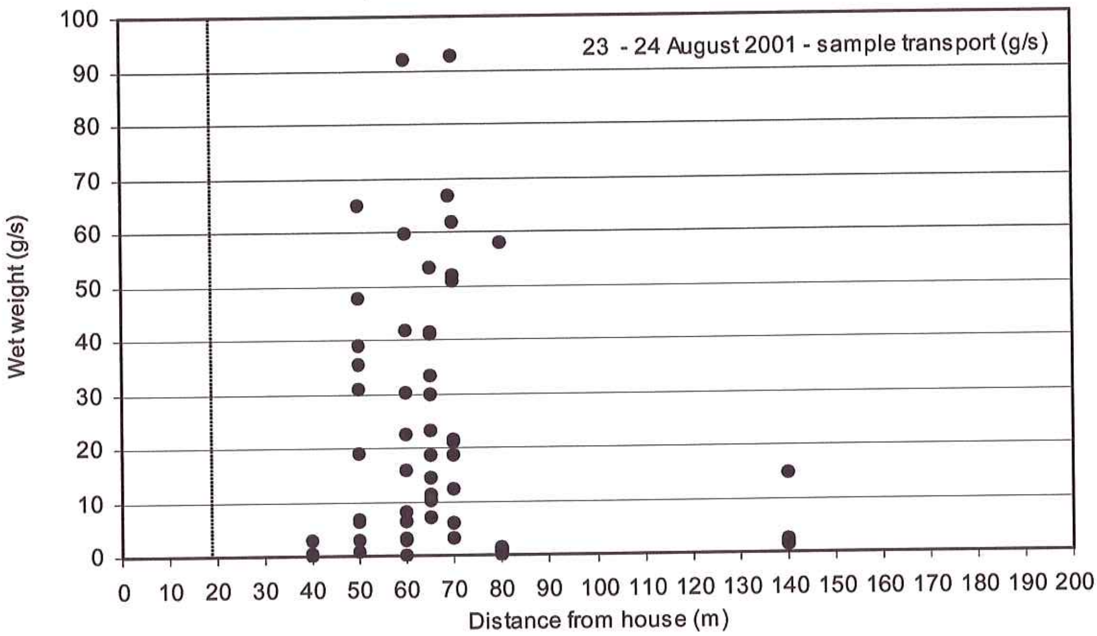




13–14 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	7,5	5	7,5	35	60	Q=326 m^3/s
Mean bedload transport at each station (g/s/m)	1	135	240	252	578	10	3	
Total transport btw. station midpoints (g/s)	18	1352	1798	1259	4331	356	168	**9281 g/s**

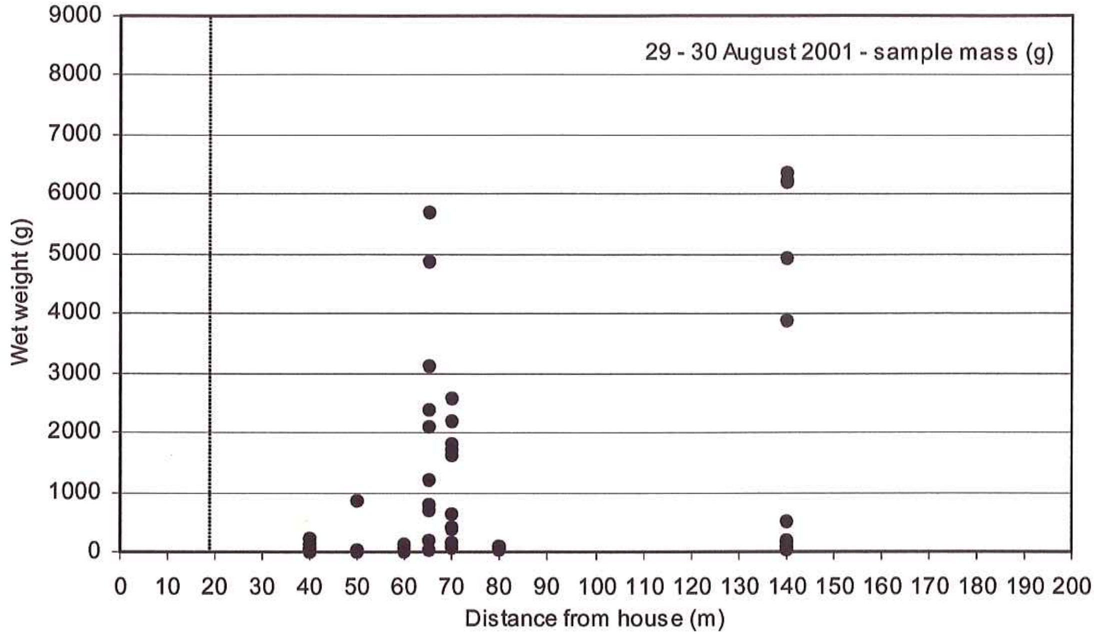
Figure 15. *Results from bedload measurements 13–14 August, 2001.*

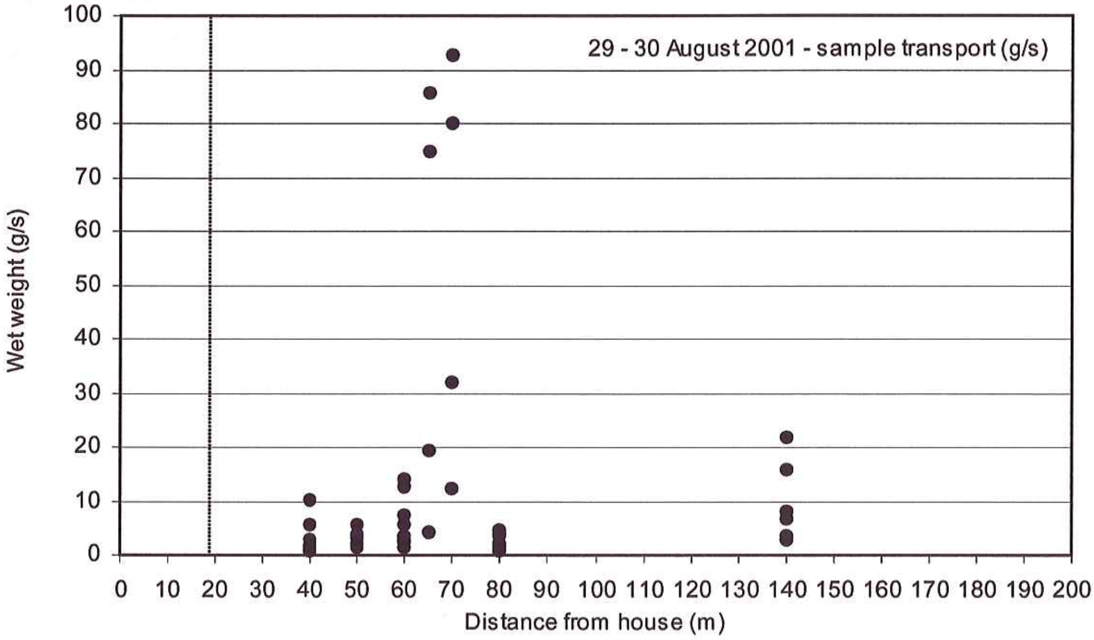




23–24 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	7,5	5	7,5	35	60	Q=442 m^3/s
Mean bedload transport at each station (g/s/m)	3	316	231	339	485	8	42	
Total transport btw. station midpoints (g/s)	40	3155	1734	1694	3637	281	2535	**13076 g/s**

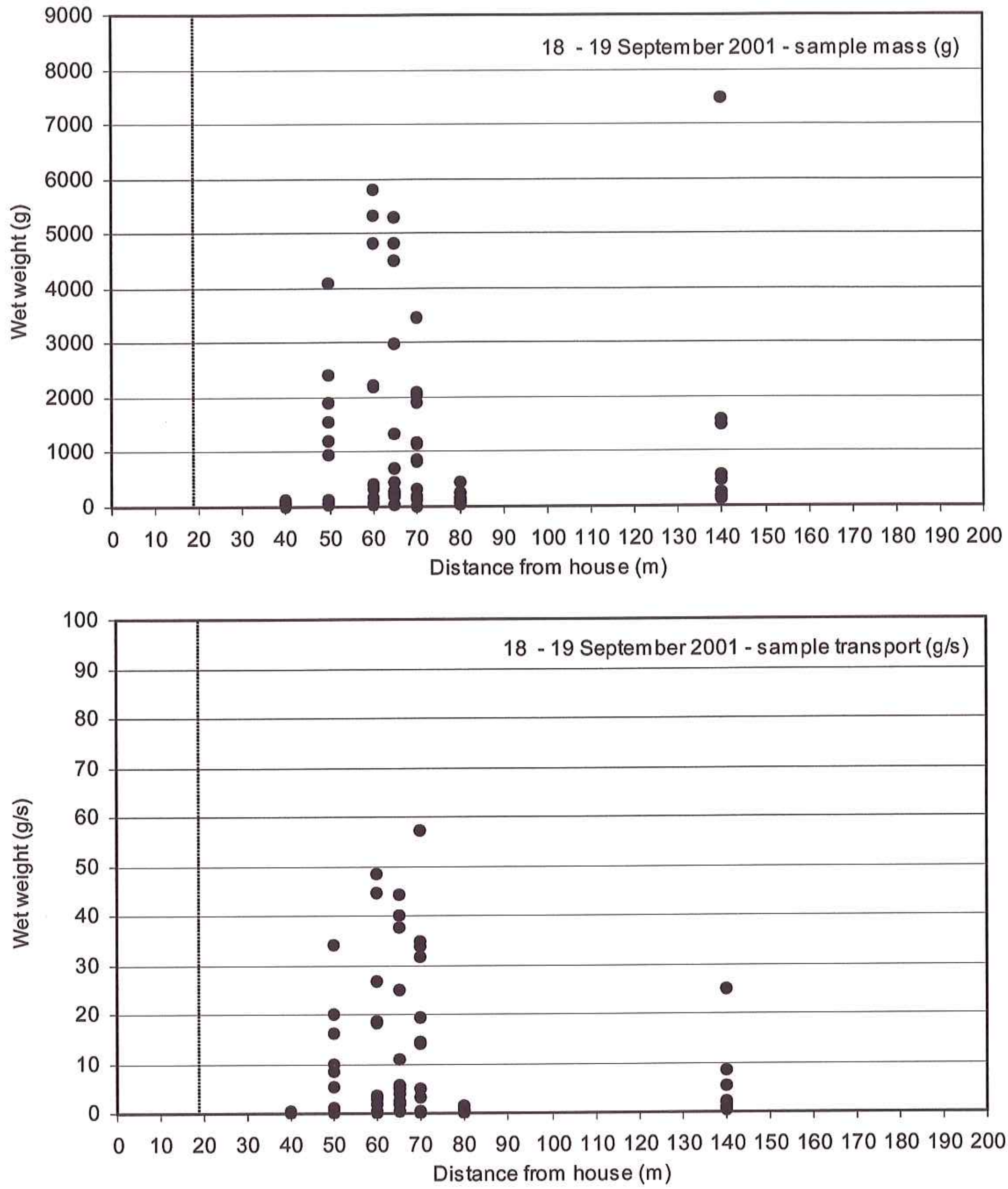
Figure 16. *Results from bedload measurements 23–24 August, 2001.*





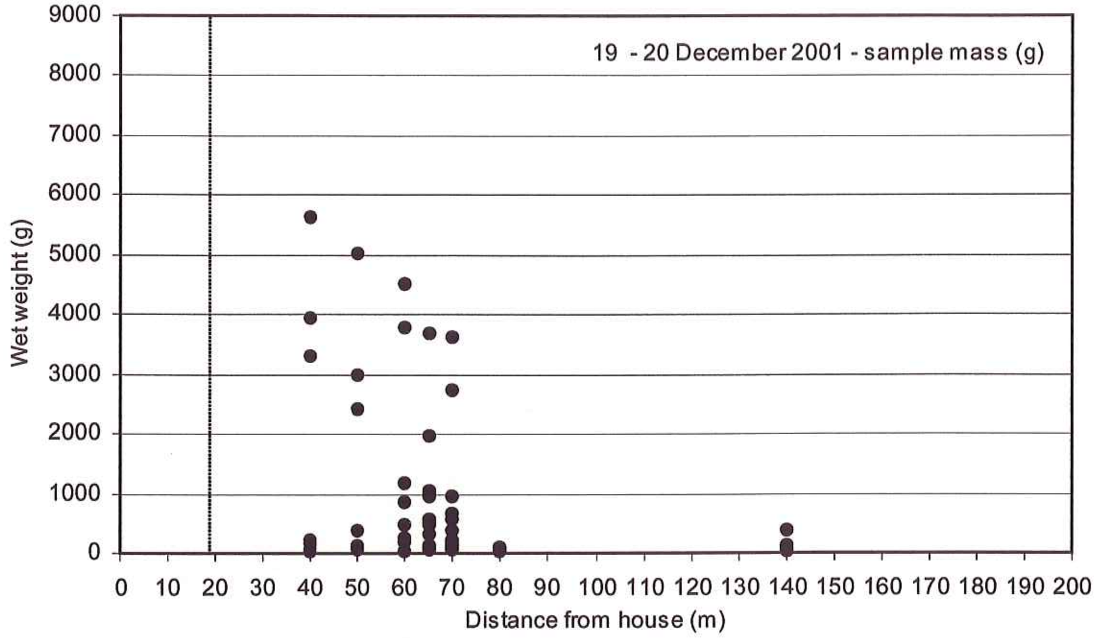
29–30 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	7,5	5	7,5	35	60	Q=342 m^3/s
Mean bedload transport at each station (g/s/m)	3	3	6	248	251	2	108	
Total transport btw. station midpoints (g/s)	42	27	43	1242	1885	85	6463	**9787 g/s**

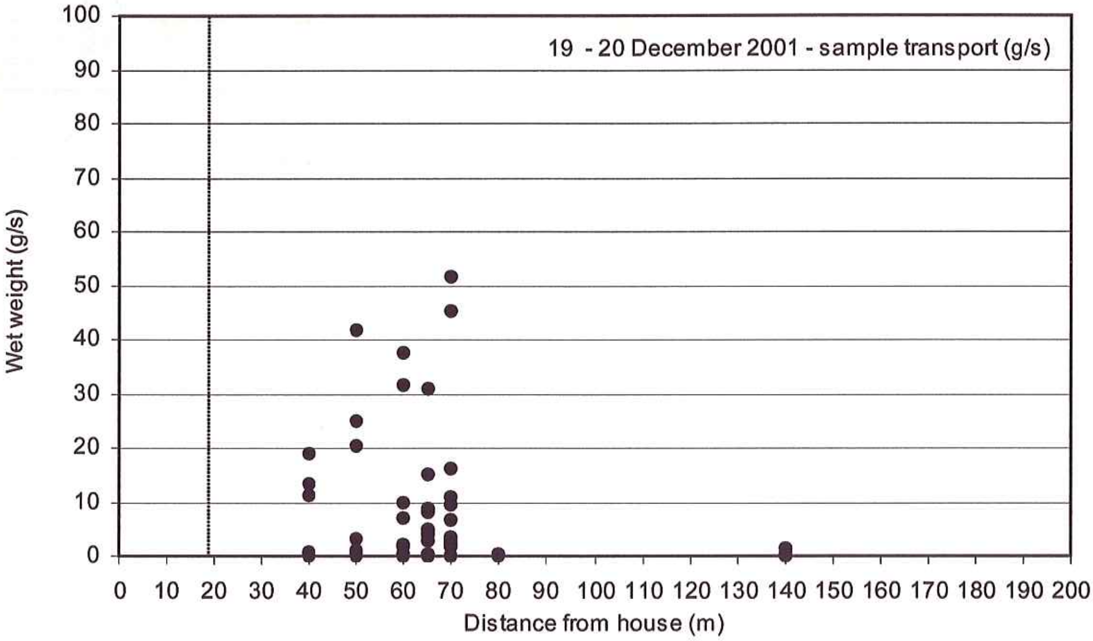
Figure 17. *Results from bedload measurements 29–30 August, 2001.*



18–19 September 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	7,5	5	7,5	35	60	$Q=352\ m^3/s$
Mean bedload transport at each station (g/s/m)	3	106	168	182	254	6	55	
Total transport btw. station midpoints (g/s)	42	1057	1259	908	1907	198	3318	**8689 g/s**

Figure 18. *Results from bedload measurements 18–19 September, 2001.*





19–20 December 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m	Total transport
Width btw. station midpoints	16	10	7,5	5	7,5	35	60	Q=352 m^3/s
Mean bedload transport at each station (g/s/m)	59	124	121	115	197	3	6	
Total transport btw. station midpoints (g/s)	942	1238	910	573	1475	107	357	**5603 g/s**

Figure 19. *Results from bedload measurements 19–20 December, 2001.*

It is clear that the greatest bedload is transported at the 70 m station during all campaigns although the difference is minor during the 29–30 August campaign between bedload transported at 65 and 70 m (Fig. 20A). The transport at 70 m is especially high during the August campaigns, or greater than 450 g/s/m. A change is seen at the 140 m station in late August when bedload increases from less than 3 to between 40 and 70 g/s/m (Figs. 16–18, 20A), but drops again to a minor fraction in December (Fig. 19). Contrastingly, more bedload is transported at the 40 m station in December than during any previous campaign.

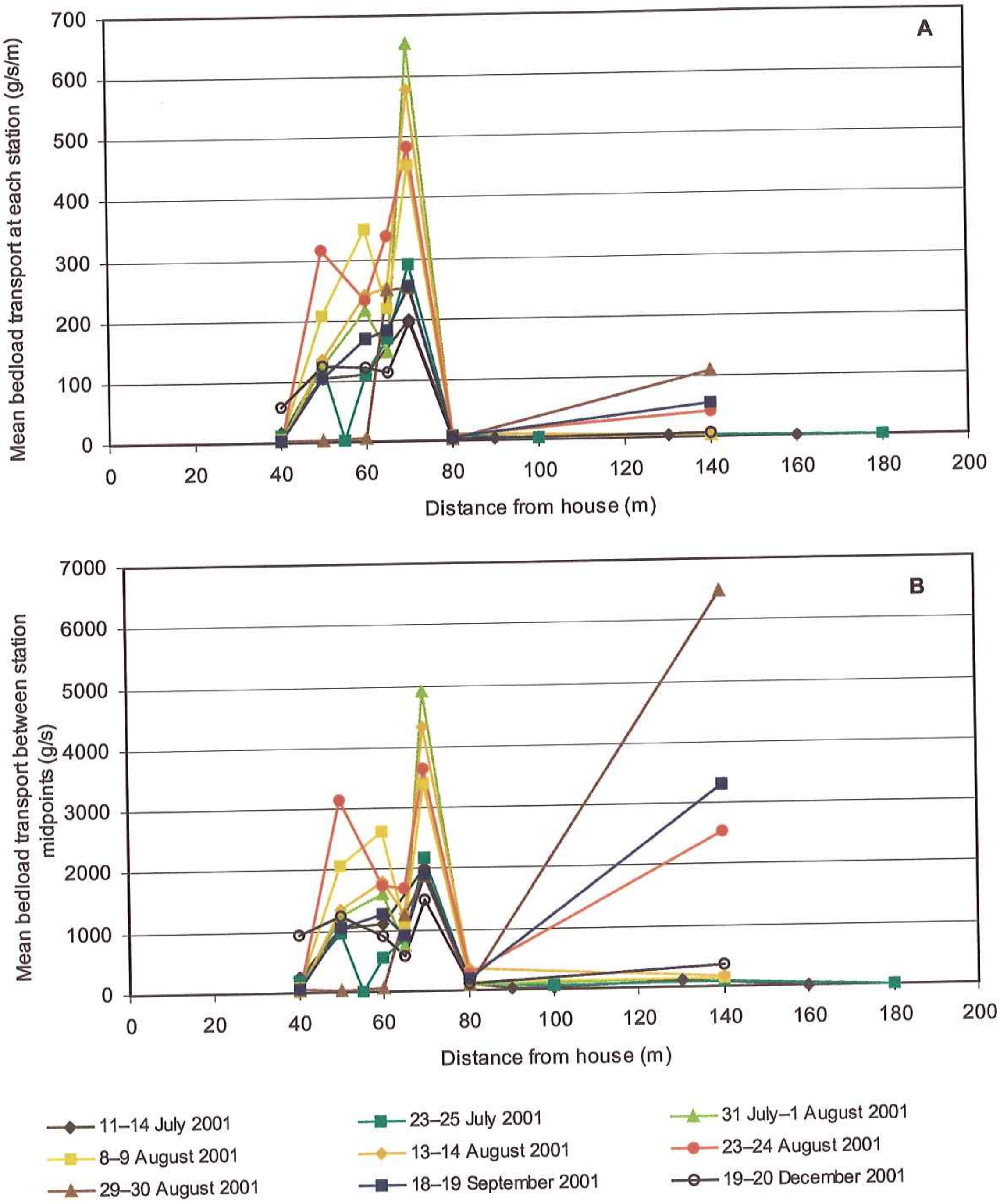


Figure 20. *Bedload transport at Krókur in individual campaigns. A) Mean transport at each station and B) mean transport between station midpoints.*

Table 8. *Results from bedload measurements at Krókur in 2001.*

Campaign date	Station location m from house	Mean discharge (m^3/s)	Total integrated bedload transport (g/s)
11–14 July	40,50,60,70,80,90,100,130,160,180	351	4706
23–25 July	40,50,55,60,65,70,80,100,140,180	320	4992
31–1 August	40,50,60,.65,70,80,140	326	8716
8–9 August	—	327	9523
13–14 August	—	326	9281
23–24 August	—	442	13076
29–30 August	—	342	9787
18–19 September	—	352	8689
19–20 December	—	352	5603

A large difference is seen for some values between parts A and B of Fig. 20. This is especially apparent for the 140 m station where the mean transport between the station midpoints is very high during the three campaigns when the station transport reached values between 40 and 70 g/s/m (campaigns 23–24 August, 29–30 August, and 18–19 September) (Figs. 16–18). These values are amplified on Fig. 20B due to the great distance between station midpoints that the values are integrated over (60 m). It is not known whether bedload was transported at similar magnitude through the entire 60 m section between 110 and 200 m; hence, the numbers for the section may overestimate the transport.

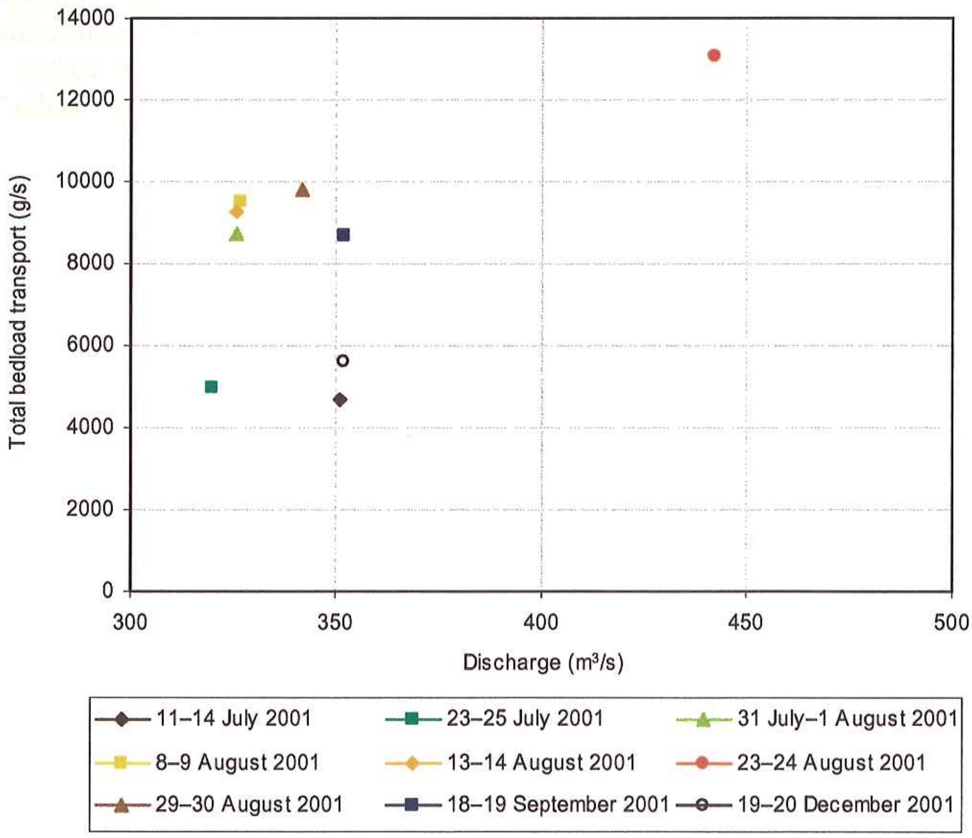


Figure 21. *Total bedload transport and mean discharge during the nine campaigns.*

Figure 21 shows total integrated bedload transport against mean discharge during the nine bedload campaigns. Great distribution of total transport is seen at similar discharge values. For example, at mean discharge around 350 m^3/s the difference is as much as ca. 4000 g/s. It is, however, possible that the total bedload values in at least campaigns 7 and 8 are overestimated due to high transport at station 140 m, but this leads to a greater range of the values. The low correlation is probably to some extent explained by the relatively narrow distribution of the discharge values as all, but one, campaigns were carried out at mean discharge between 320 and 352 m^3/s. This shows that we especially lack data from low and high discharge intervals.

The large distribution of bedload values, i.e. both of the total integrated bedload (Fig. 21) and the sample values in individual campaigns (Figs. 11–19), shows that bedload transport is a sporadic process and the best way to minimize errors in bedload calculations is to collect numerous samples during frequent sampling campaigns at different discharge values.

3.2.2 Comparison with previous bedload studies in Þjórsá

Some bedload samples have been taken from the upper reaches of Þjórsá, i.e. at Sandártunga, Sóleyjarhöfði, and Hreysiskvísl (Fig. 1). The results from these studies are shown in Table 9. Samples were only taken once at 5–8 locations during each of the campaigns so the results are not averaged over many samples as is the case with the Krókur samples. River discharge values were much lower at these three locations than at Krókur, although at Sóleyjarhöfði, where four sampling campaigns were completed, bedload was collected at a wide range of discharge values. Minor bedload was measured in Þjórsá above Hreysiskvísl, but much higher values at Sóleyjarhöfði and Sandártunga. Results from Krókur (Table 8) fall within the range of these higher values even though conditions vary greatly among Krókur, Sóleyjarhöfði, and Sandártunga. Sandártunga is located below the main reservoirs on Þjórsá like Krókur is, whereas Sóleyjarhöfði is located approximately 80 km upstream of Sandártunga. The high bedload at Sandártunga and Krókur is thus unexpected as most of bedload should have been settled in the reservoirs upstream of these locations.

Table 9. *Results from previous bedload studies in Þjórsá. Number in parenthesis is estimated.*

Location	Date	Discharge (m^3/s)	Total integrated bedload (g/s)
Sandártunga	1982.09.21.	140	6391
Sóleyjarhöfði	1982.09.08.	40	(1979)
Sóleyjarhöfði	1983.07.21.	168	7510
Sóleyjarhöfði	1984.08.01.	181	9916
Sóleyjarhöfði	1984.09.24.	85	3968
Above Hreysiskvísl	1984.07.26.	57	141

3.2.3 Grain size of bedload samples

One sample from each station (two samples from each station during September 18) was collected for grain size analysis in the bedload campaigns at Krókur in 2001. These samples were sieved at the Sedimentology Laboratory of the Hydrological Service as was described in a previous section. The results are shown on the following graphs

(Figs. 22–26). All results are calculated using the phi-scale (Φ) (Table 4) for linear representation of the data. The same legend is used in all figures, i.e. each station has a separate color, with added colors during the first two campaigns when samples were taken at ten stations instead of seven in the subsequent campaigns.

As is seen on the cumulative frequency graphs, most of the sediment classifies into grain size categories between 2 and -3.5 Φ (ca. 0.2 to 10 mm), i.e. sand with minor amount of pebbles. The samples taken at the 40 and 140 m stations usually include the finest material. Samples from 80 m usually arrange close to the fine-grained samples, although in occasional campaigns these 80 m samples are relatively coarse. Samples from 50, 60, 65, and 70 m most often include the coarsest material, although the two samples taken on September 18 at 60 m are much coarser than other samples from the same station (Fig. 26).

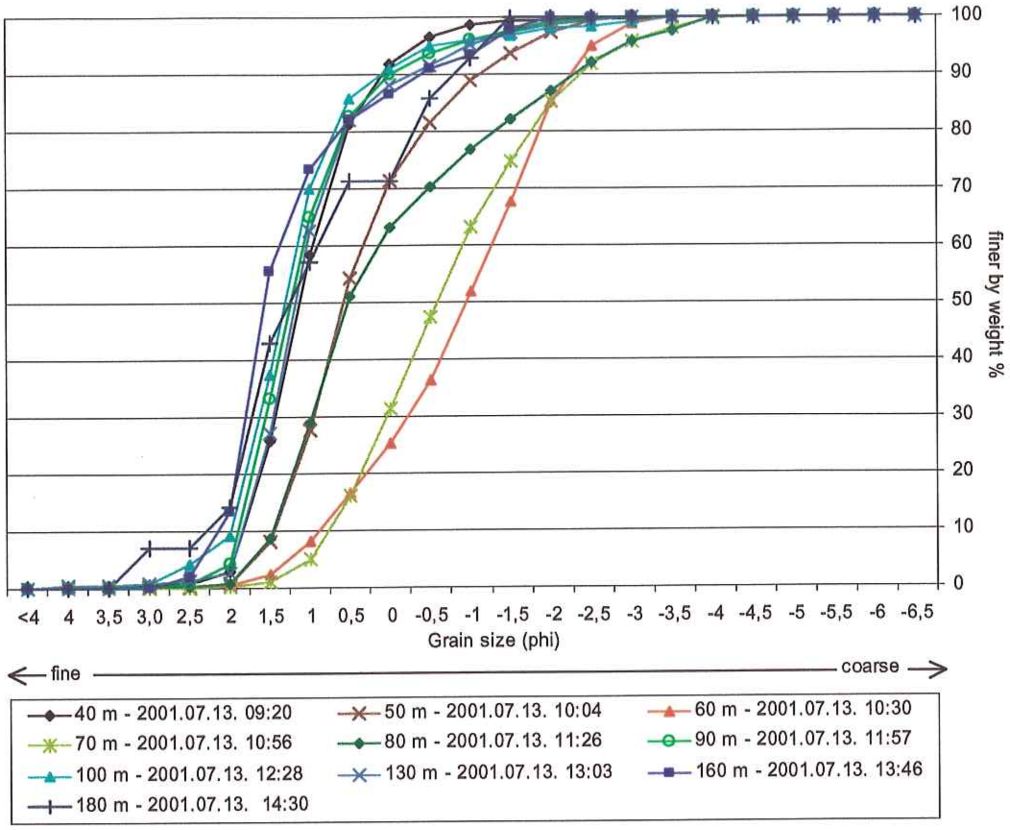
To evaluate grain size values in greater detail, values for mean grain size, sorting and skewness were calculated using the equations for moment statistics in section 2.2.3. These values are summarized in Table 10 and shown in Figs. 27 to 29.

The mean grain size shown in Fig. 27 describes similar trend as is discussed above, i.e. the finest material is found at 40 and 140 m as well as in some of the 80 m samples. Samples from that station show, however, much greater range in mean grain size than the 40 and 140 m samples. The greatest mean grain size is mostly seen in samples from 70 m, whereas stations 50, 60, and 65 m also include relatively coarse material, but with greater range of grain sizes.

Most samples include sorting values between 0.5 and 1.5, or moderately to poorly sorted. Of those, samples from 40 m and 140 m have relatively lowest values, although two of the 140 m samples are higher. Samples from 80 m have, however, by far the greatest sorting values, or up to 2.07. The range of values differs greatly among stations and is moderate for samples from 50, 60, and 140 m, small for samples from 40 and 70 m, but great for samples from 80 m.

Skewness values are variable at each station, but also differ among the stations. Most negative values are seen in samples from 140 m, moderate values are found in samples from 40 and 80 m (except two high ones), whereas the highest (less negative and positive values) are seen in samples from 50, 60, 65, and 70 m. The strongly negative values for samples from 140 m suggest that those samples include a tail of excess coarse material.

When the results of the moment statistics are summarized it is seen that samples taken at each end of the sampling profile (40 and 140 m) are in most cases the finest grained, best sorted, and highly negatively skewed. Samples from 80 m are also relatively fine grained and negatively skewed, but are much more poorly sorted that the 40 and 140 m samples. These data indicate that the stream current is lowest at these stations, and that the 80 m station is close to the boundary where the current picks up in the relatively narrow channel seen in the depth profiles from Krókur (Fig. 9). On the contrary, greatest grain size is seen in samples taken within the channel where the current is greatest (50, 60, 65, and 70 m), similar to what is observed in the suspended sediment samples.



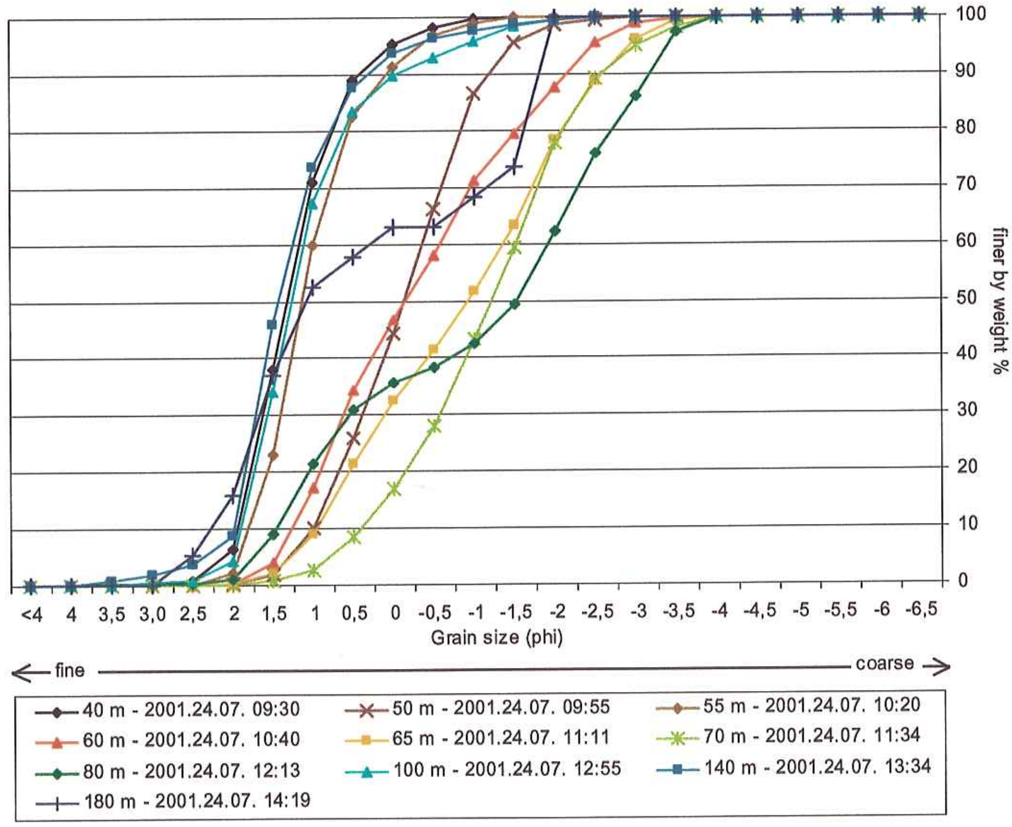
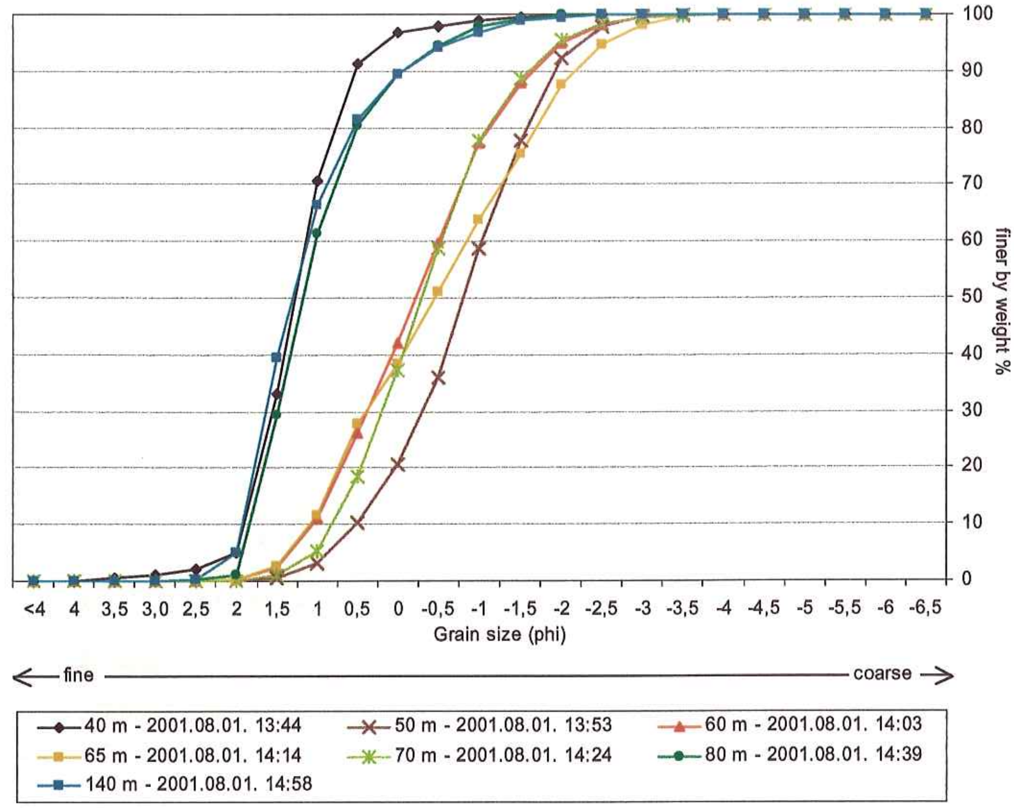


Figure 22. *Cumulative grain size curves for Krókur bedload samples collected July 13 (upper) and July 24 (lower).*



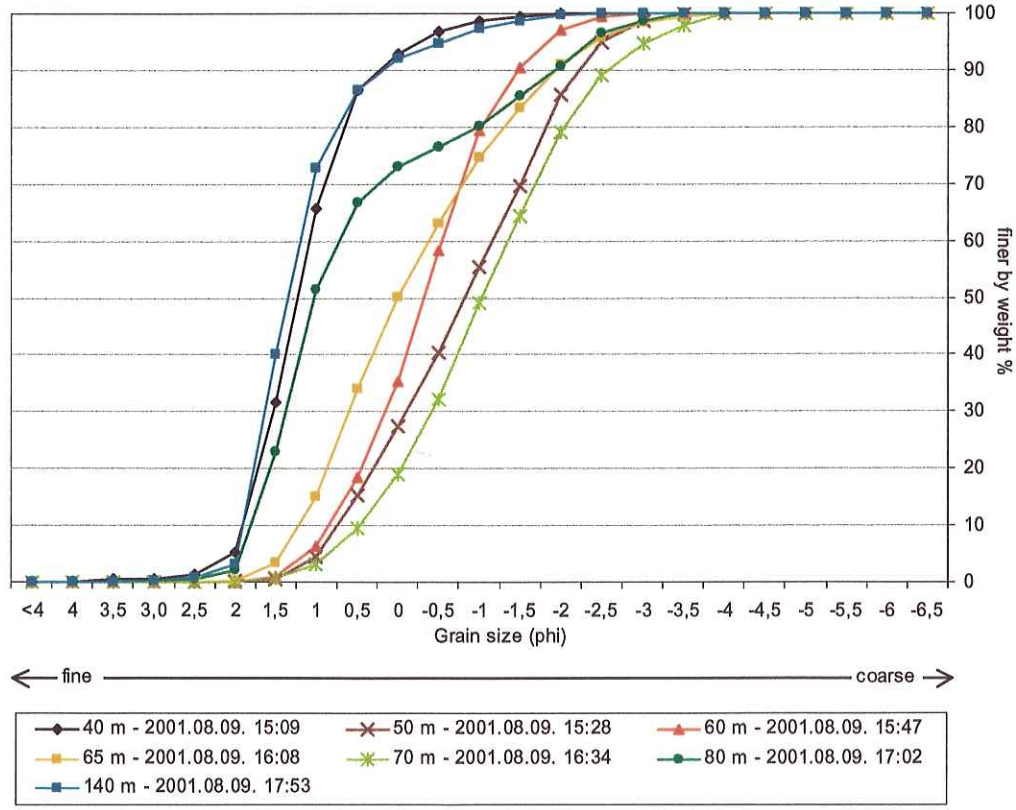
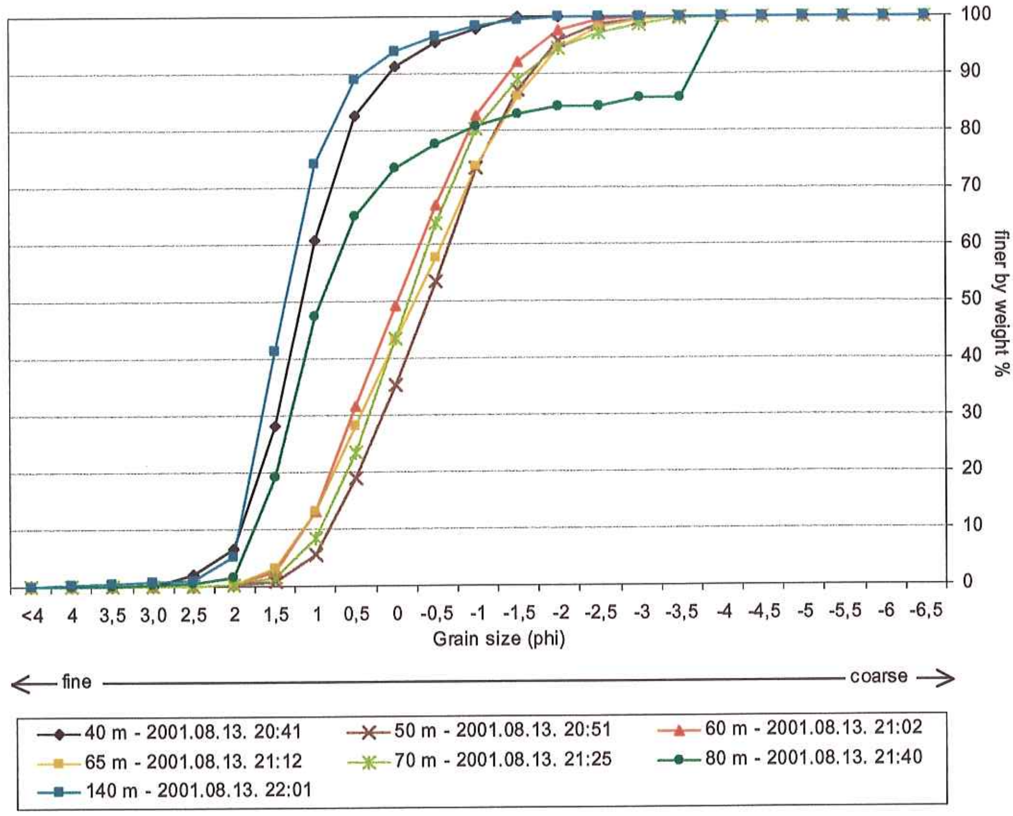


Figure 23. *Cumulative grain size curves for Krókur bedload samples collected August 1 (upper) and August 9 (lower).*



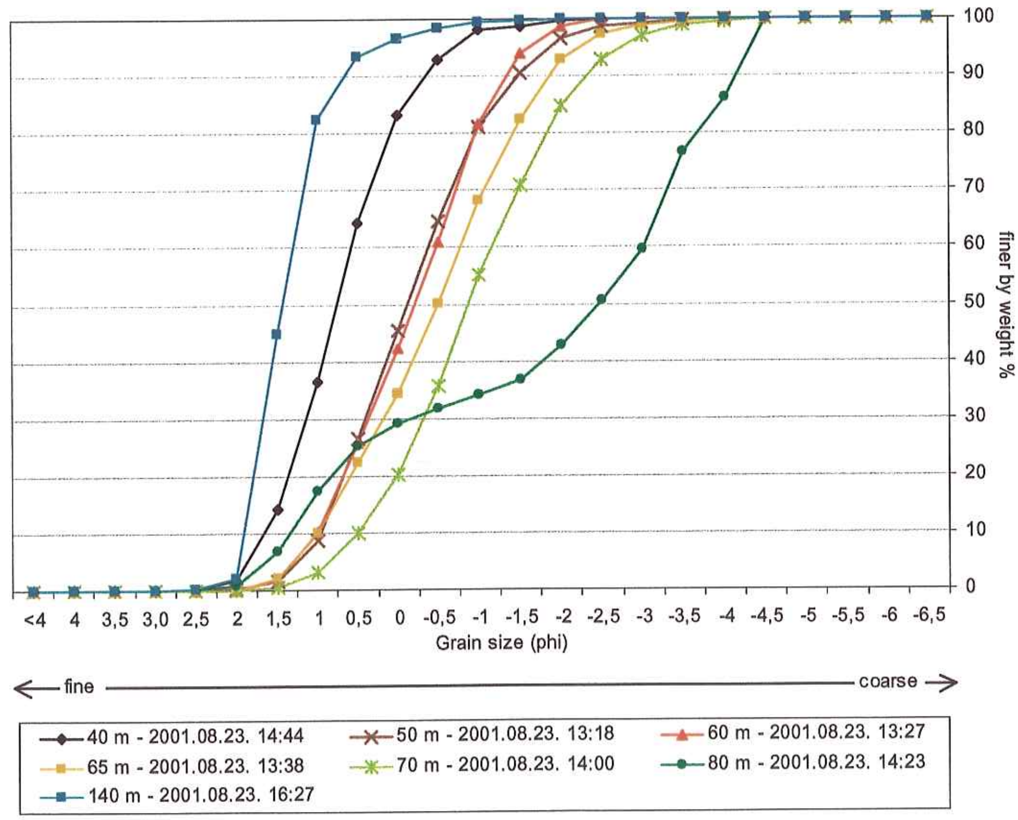


Figure 24. *Cumulative grain size curves for Krókur bedload samples collected August 13 (upper) and August 23 (lower).*

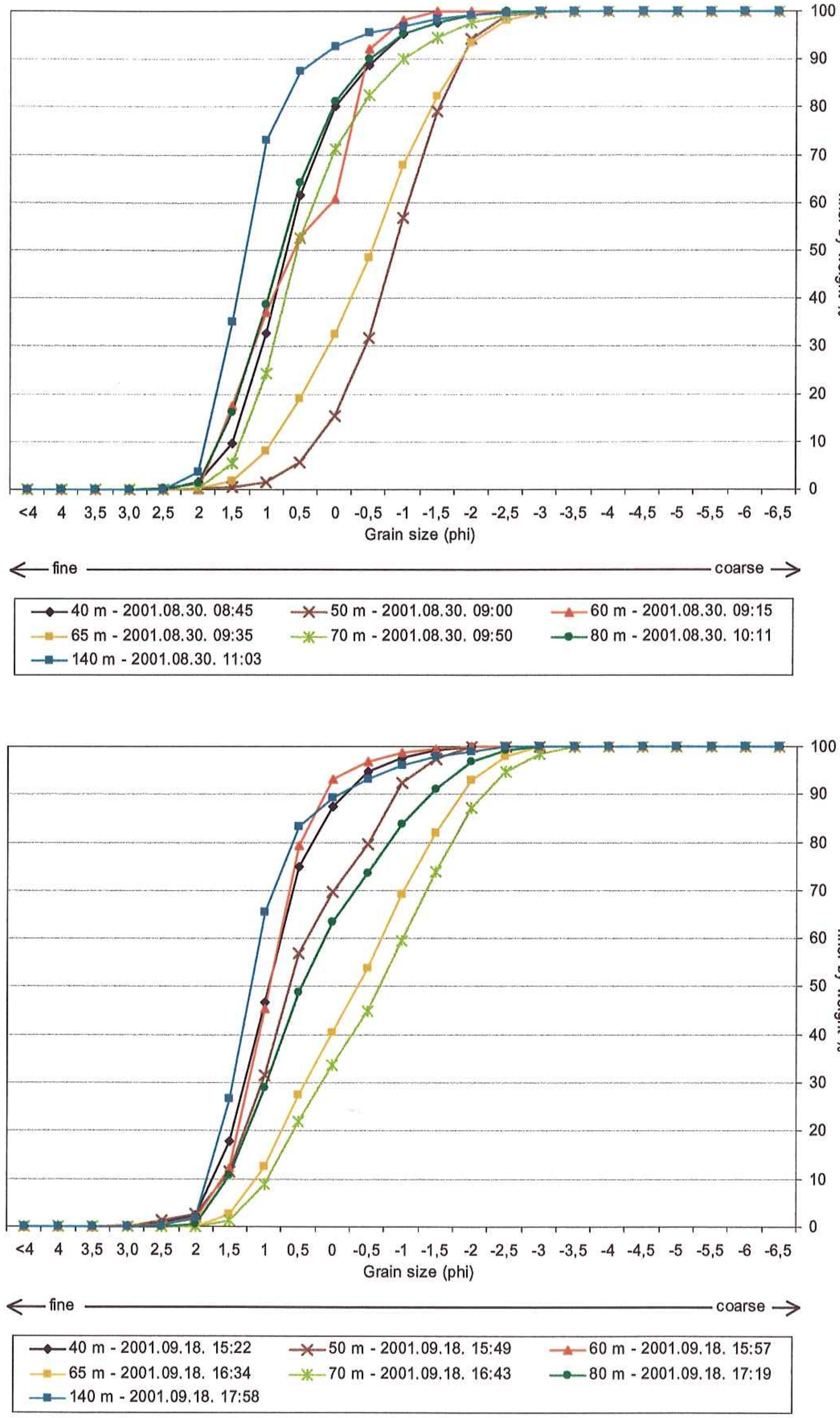
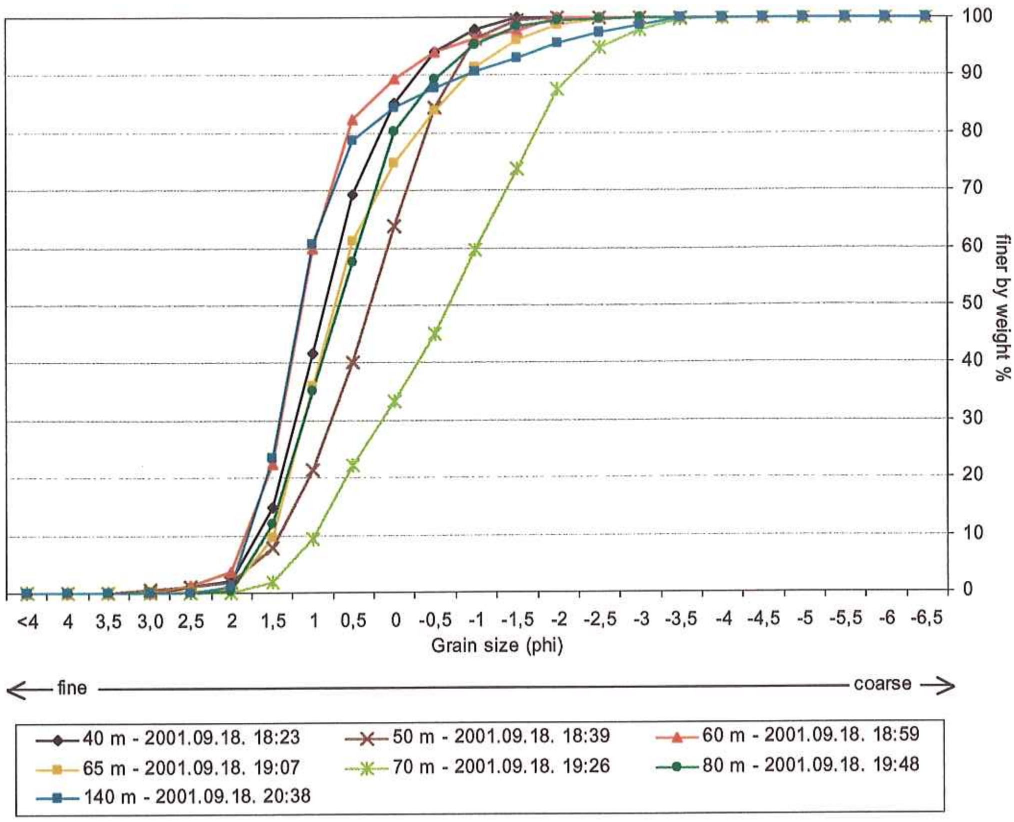


Figure 25. *Cumulative grain size curves for Krókur bedload samples collected August 30 (upper) and September 18 (lower).*



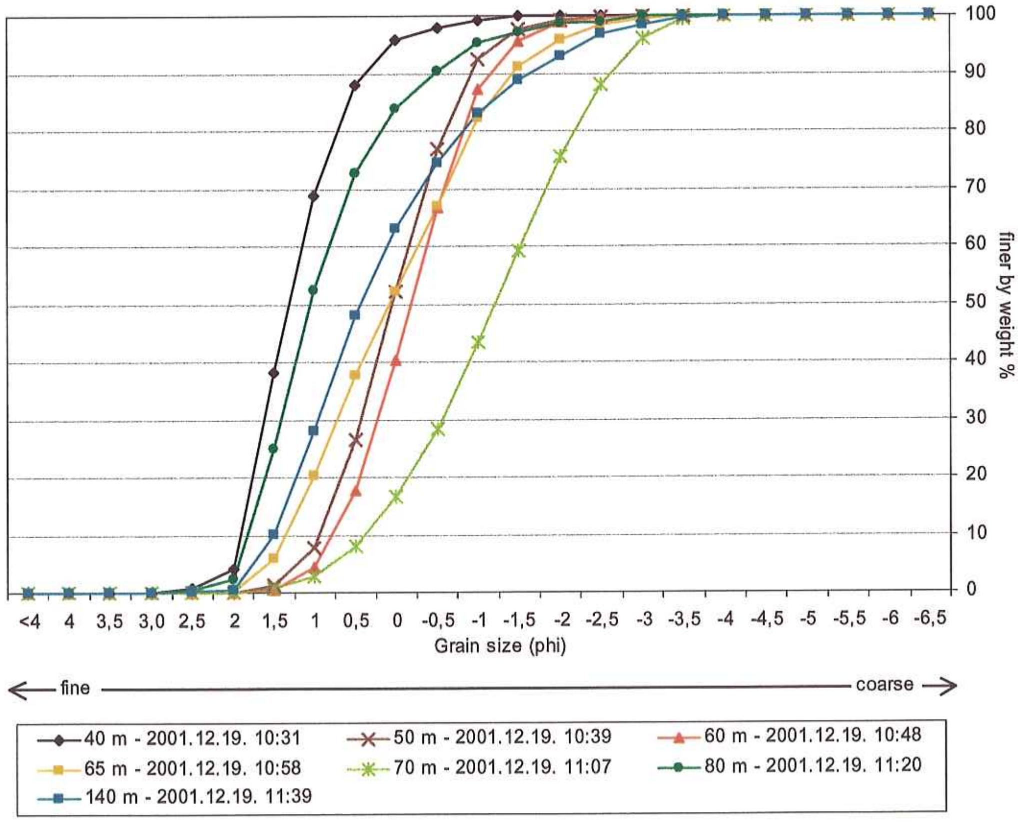


Figure 26. *Cumulative grain size curves for Krókur bedload samples collected September 18 continued (upper) and December 19 (lower).*

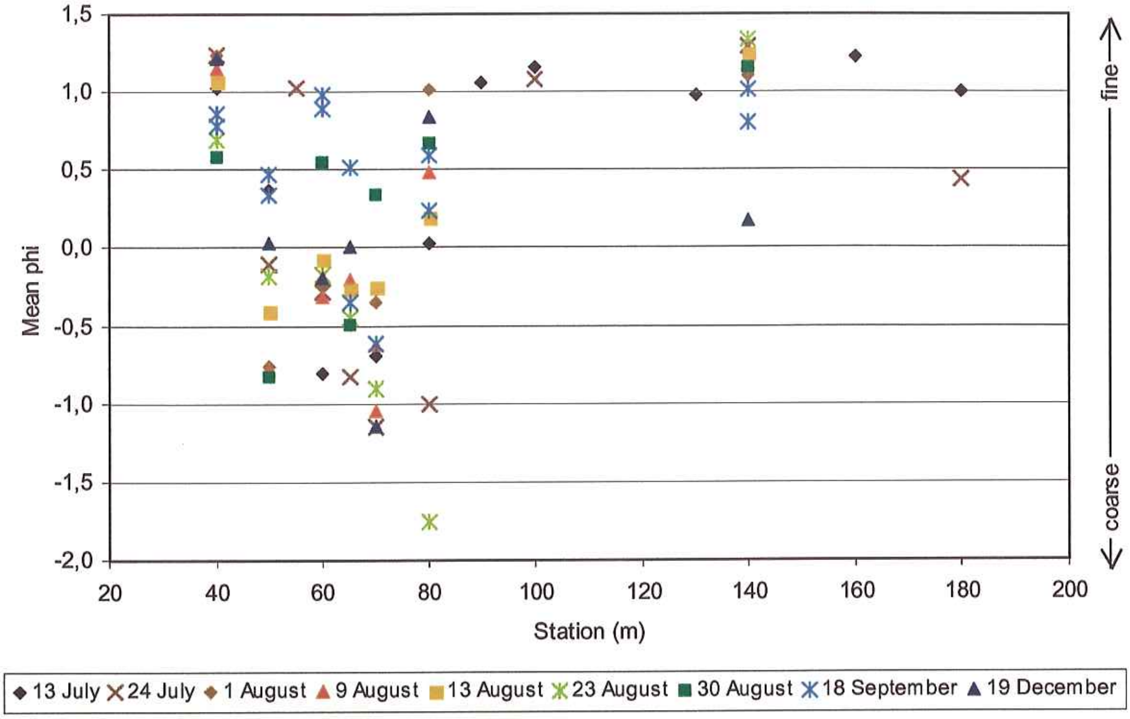


Figure 27. *Mean grain size (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2001.*

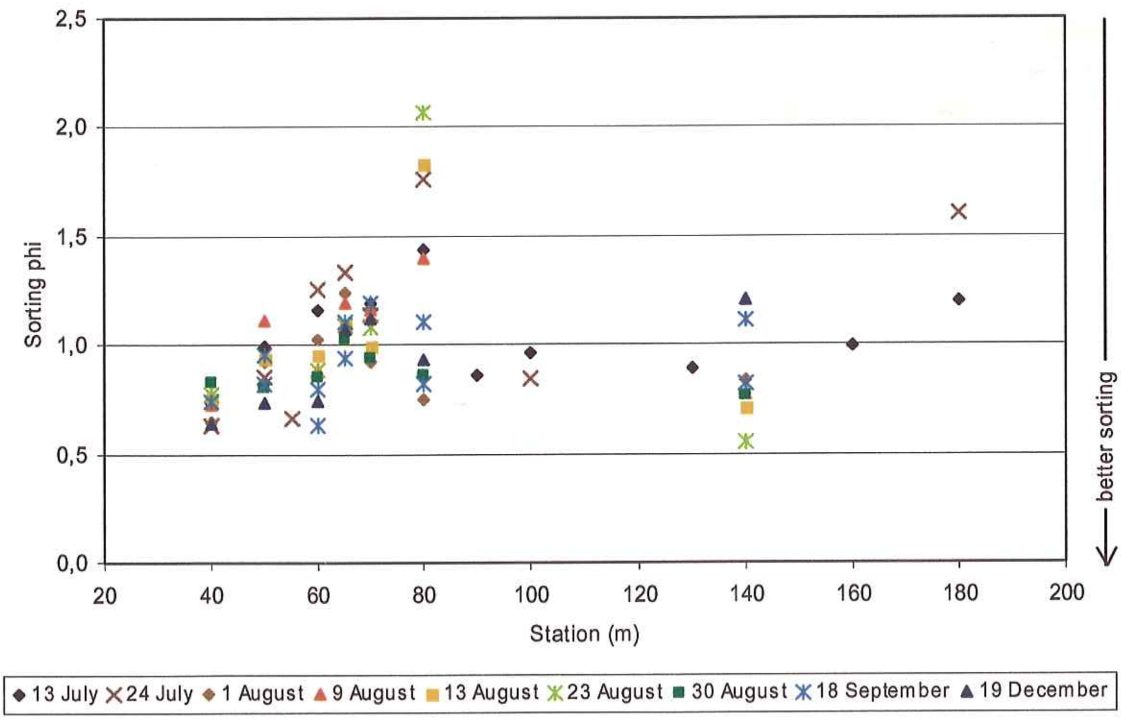


Figure 28. *Sorting values (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2001.*

Table 10. *Results from grain size analyses of bedload samples.*

11–14 July 2001	40 m	50 m	60 m	70 m	80 m	90 m	100 m	130 m	160 m	180 m
Mean Φ	1,02	0,37	-0,81	-0,70	0,02	1,06	1,16	0,97	1,22	1,00
Sorting	0,73	0,99	1,16	1,19	1,43	0,86	0,96	0,89	1,00	1,20
Skewness	-1,20	-0,81	0,34	-0,44	-0,91	-1,49	-1,72	-1,53	-1,38	-0,23

23–25 July 2001	40 m	50 m	55 m	60 m	65 m	70 m	80 m	100 m	140 m	180 m
Mean Φ	1,24	-0,10	1,02	-0,28	-0,83	-1,15	-1,00	1,08	1,29	0,43
Sorting	0,63	0,85	0,66	1,26	1,33	1,13	1,76	0,84	0,82	1,60
Skewness	-0,83	-0,09	-0,95	-0,36	0,04	0,09	0,26	-1,39	-1,02	-0,30

31–1 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m
Mean Φ	1,23	-0,76	-0,25	-0,49	-0,34	1,02	1,10
Sorting	0,65	0,92	1,02	1,24	0,92	0,75	0,83
Skewness	-0,64	0,19	-0,28	-0,18	-0,38	-1,20	-1,34

8–9 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m
Mean Φ	1,14	-0,78	-0,32	-0,20	-1,05	0,48	1,18
Sorting	0,72	1,11	0,88	1,19	1,16	1,39	0,77
Skewness	-0,76	0,13	0,02	-0,54	-0,05	-1,02	-1,59

13–14 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m
Mean Φ	1,07	-0,40	-0,07	-0,26	-0,25	0,19	1,24
Sorting	0,76	0,94	0,95	1,08	0,99	1,83	0,71
Skewness	-0,73	-0,17	-0,29	-0,20	-0,56	-1,31	-1,29

23–24 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m
Mean Φ	0,70	-0,18	-0,17	-0,45	-0,90	-1,76	1,33
Sorting	0,77	0,96	0,88	1,09	1,08	2,07	0,55
Skewness	-0,56	-0,48	0,03	-0,13	-0,19	0,47	-1,82

29–30 August 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m
Mean Φ	0,58	-0,82	0,55	-0,49	0,34	0,67	1,16
Sorting	0,83	0,81	0,85	1,03	0,94	0,86	0,76
Skewness	-0,81	0,31	-0,03	0,04	-0,93	-0,81	-1,96

18–19 September 2001a	40 m	50 m	60 m	65 m	70 m	80 m	140 m
Mean Φ	0,86	0,47	0,89	-0,35	-0,62	0,24	1,01
Sorting	0,74	0,95	0,63	1,11	1,18	1,10	0,82
Skewness	-0,73	-0,32	-0,69	-0,10	-0,04	-0,56	-1,66

18–19 September 2001b	40 m	50 m	60 m	65 m	70 m	80 m	140 m
Mean Φ	0,86	0,47	0,89	-0,35	-0,62	0,24	1,01
Sorting	0,74	0,95	0,63	1,11	1,18	1,10	0,82
Skewness	-0,73	-0,32	-0,69	-0,10	-0,04	-0,56	-1,66

19–20 December 2001	40 m	50 m	60 m	65 m	70 m	80 m	140 m
Mean Φ	1,21	0,02	-0,19	0,00	-1,15	0,84	0,17
Sorting	0,64	0,74	0,74	1,08	1,12	0,93	1,20
Skewness	-0,96	-0,32	-0,21	-0,41	0,21	-1,24	-0,82

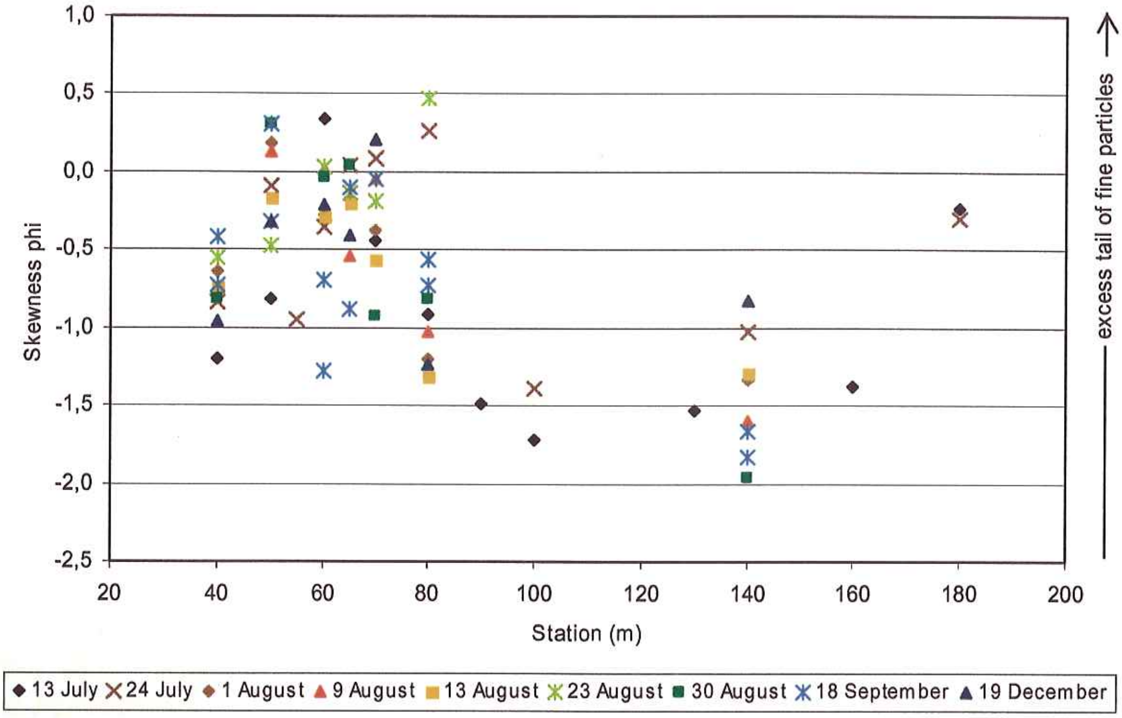


Figure 29. *Skewness values (according to moment statistics) of all sieved samples from Þjórsá, Krókur, sampled in 2001.*

4 CONCLUSIONS

A new cableway was built at Krókur in the lower reaches of river Þjórsá in 2001, which was a prerequisite for an extensive sampling program of bedload and suspended sediment initiated in 2001. The three main objectives of the study were to: 1) obtain additional suspended samples at variable discharge values in Þjórsá; 2) compare results from suspended sediment samples from Krókur and Urriðafoss in order to evaluate whether previous Urriðafoss samples correctly demonstrate sediment concentration in Þjórsá; and 3) carry out the first bedload measurements at Krókur to evaluate bedload transport in Lower Þjórsá.

Nine major sampling campaigns were carried out at Krókur and Urriðafoss in the year 2001, in addition to one shorter suspended sediment campaign. Furthermore, seven additional suspended samples were taken at Urriðafoss as a part of another study and their results are also shown here.

4.1 Suspended samples from Urriðafoss

Sixteen suspended samples were obtained with a handsampler from beneath the bridge on Highway 1. Grain size distribution of the Urriðafoss samples varies greatly among samples. In general, the *sandur* concentration is higher during the winter months (classified from October to June), whereas *leir* concentration is higher during the summer months. Sample concentration appears to be moderately correlated to the discharge recorded at Þjórsártún, and is greatest when the discharge is highest. Lowest sediment concentration is seen in winter samples, probably due to lack of fine-grained glacial sediment during that season.

4.2 Suspended samples from Krókur

Ten suspended sediment samples were taken from the cableway at Krókur in 2001. Each sample was taken at 6–10 locations across the river transect so it was possible to evaluate both variability in grain size distribution among the sampling locations and among the total integrated Krókur samples. Great variability is seen in grain size among all the samples. The coarsest material appears to be concentrated in a gully between the 60 and 80 m stations, especially at the 70 m station.

The *sandur* concentration is very variable in the integrated samples (9–79 %) and indicates that the coarsest suspended fraction is probably transported in pulses where local current conditions determine whether grains are transported as bedload or in suspension. The large mean diameter of the largest particles, e.g. in samples from 2001.08.09. and 2001.12.20, may suggest that occasional bedload grains were incorporated into the samples. The *méla* and *leir* fraction (i.e. sediment <0.02 mm) varies also greatly among the samples, whereas *fínmór* and *grófmór* concentration are very low in all the integrated Krókur samples, or less than 5 %. It is, however, necessary to emphasize the nature of percentage data such as our grain size array; when one variable increases another decreases. Hence, high concentration percentage of coarse sediment is bound to result in a low concentration percentage of the fine fraction.

4.3 Comparison of suspended sediment samples from Urriðafoss and Krókur

Large difference is seen in all grain size classes between the Urriðafoss and Krókur samples. This is seen both in the total sediment concentration and *sandur* percentage, which are lower in all Urriðafoss samples but one. The Urriðafoss samples also include grains with smaller mean diameter than the Krókur samples.

The difference between the samples at Urriðafoss and Krókur is probably to a large extent caused by the different sampling methods used at the two locations. The sediment sampler used at Krókur (P61) collects an integrated sediment from the bottom to the surface, whereas the handsampler used at Urriðafoss (DH48) only collects sediment in the uppermost part of the water column. Even though turbulence is greater at the Urriðafoss location than at Krókur, it does not appear to be great enough to keep the largest sediment grains in suspension. Some of the difference might be related to occasional inclusion of bedload particles in the Krókur samples.

It is apparent that the Urriðafoss samples underestimate the suspended sediment concentration in Þjórsá; however, many more sample pairs need to be analyzed before a reasonable relationship can be established. These results show that great care has to be maintained when previous Urriðafoss samples are used for sediment load calculations.

4.4 Bedload studies

The bedload measurements completed at Krókur in 2001 were the first such studies that have been carried out downstream of Sandártunga in Þjórsá. Samples were taken at 7–10 locations from the new cableway at Krókur and in this report results from ca. 700 bedload samples retrieved in nine sampling campaigns are introduced.

Great difference is seen in bedload transport between different locations on the cross-section. Most of the bedload is transported in a narrow gully between 50 and 70 m whereas only minor fraction is transported at other stations. When the integrated bedload transport is calculated for the sections between station midpoints, similar results are established for all stations excluding the 140 m station section. The distance used for calculations at the 140 m station is much greater than for the other stations so when the bedload transport is integrated over this distance the result is very high. We do not know whether bedload transport is similar for the whole distance; thus the high values for total integrated bedload transport at 140 m may overestimate the transport.

Total bedload transport ranges from ca. 4700 to 13000 g/s. The correlation between total bedload and discharge is poor as we have great distribution of total transport at the same discharge interval. The poor correlation is probably to some extent related to the narrow distribution of discharge values and shows that we especially lack data from low and high discharge intervals.

The great distribution of bedload transport values shows well the stochastic nature of bedload transport, where bedload is transported in pulses rather than as in semi-continuous stream-flow as finer suspended material is transported. Hence, the best way to minimize errors in bedload calculations is to sample frequently and calculate the average transport. For this we need to collect numerous samples over broad discharge values.

Comparison of Krókur sampling and previous bedload sampling at Sandártunga, Sóleyjarhöfði, and Hreysiskvísl shows that bedload is within the same ballpark at Sandártunga, Sóleyjarhöfði and Krókur, but much less at Hreysiskvísl.

Grain size was measured on a set of samples from each campaign. The measurements show that most of the bedload material at Krókur is sand with minor amount of pebbles and cobbles. The finest and best sorted material is transported at 40 and 140 m, whereas the coarsest material is transported between 50 and 70 m where the current is greater. Grain size of samples from the 80 m station was also relatively fine in most campaigns, but sorting values were much higher and varied greatly from one campaign to another.

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SUMMARY IN ICELANDIC

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

Í níu Króksferðum voru tekin skriðaurssýni á 7–10 stöðum á þversniði yfir ána og samanburðarpar af svifaursýnum af Krókskláfnum og af hefðbundna sýnatökustaðnum undir brúnni við þjóðveg 1 ofan við Urriðafoss. Í einni ferð var hinsvegar eingöngu tekið samanburðarpar af svifaur á fyrrgreindum stöðum.

Í skýrslunni er fjallað um niðurstöður þessara sýna en meginmarkmið sýnatökunnar var að meta heildarframburð Neðri-Þjórsár með því að 1) afla betri svifaurssýna svo að hægt verði að leiðrétta svifaursstyrk sýna, sem tekin hafa verið við Urriðafoss með hand-sýnataka og eru talin vanmeta svifaursstyrk árinnar og 2) safna fyrstu skriðaurssýnum úr Þjórsá neðan Sandártungu og áætla með þeim botnskrið árinnar.

Svifaurssýnin frá Urriðafossi voru alls 16 og var kornastærð og svifaursstyrkur þeirra mjög mismunandi. Styrkur sands (>0,2 mm) reyndist vera mestur á veturna (október–júní), en leirstyrkur (<0,002 mm) var hinsvegar hæstur yfir jökulleysingatímann (júlí–september). Styrkur svifaurs var mestur þegar rennsli mældist hæst.

Svifaurssýni voru tekin með punktsýnataka af 6–10 stöðum af nýja rafdrifna kláfnum við Krók og var sýni af hverjum stað greint fyrir sig. Á þann hátt var bæði hægt að gera sér grein fyrir breytileika svifaurs innan farvegsins og á milli sýnatökuferða. Mikill munur var á svifaursstyrk á milli staða og á milli ferða. Grófasti svifaurinn er á ferðinni þar sem farvegurinn er dýpstur, eða í 60 til 80 m fjarlægð frá húsi, en þar er 0-punktur kláfsins (ca. 18 m frá vinstri bakka árinnar). Styrkur heildarsýnis og kornastærðar-flokkanna var reiknaður fyrir heildað sýni úr hverri ferð fyrir sig. Sandstyrkur í heildaða sýninu var mjög mismunandi milli sýnatökuferða, og sveiflaðist frá 9–79 % af heildarsvifaurssýninu. Bendir þetta til þess að grófasti hluti svifaursins ferðist niður ána í sveiflum, en einnig er mögulegt að í einstaka sýnum hafi svifaurssýnatakinn safnað í sig hluta af skriðaur og aukið þar með til muna hlutfall sands í sýninu. Mikill breytileiki sást einnig í kornastærðunum mélu (0,002–0,02 mm) og leir (<0,002 mm) á milli heilduðu sýnanna, en styrkur grófmós (0,2–0,06 mm) og fínmós (0,06–0,02 mm) var mjög lágur í öllum sýnunum.

Samanburður var gerður á heildarstyrk og styrk kornastærðarflokka á milli svifaurssýna sem tekin voru annars vegar með punktsýnataka af rafdrifna kláfnum við Krók og hinsvegar með handsýnataka við brúna ofan við Urriðafoss. Við Urriðafoss eru straumhraði og iðuköst svo mikil að aðeins er hægt að safna sýnum með handsýnataka, en hann nær eingöngu í sýni úr yfirborði árinnar við árbakkann. Þessi sýnatökuaðferð vanmetur því svifaurinn þar sem hann er grófastur næst botni í miðri á þar sem straumhraðinn er mestur. Samanburðurinn sýndi þetta augljóslega og höfðu Krókssýnin í öllum tilfellum nema einu töluvert hærri styrk heildarsvifaurs og sands, auk þess sem meðalþvermál stærsta korns er stærra í sýnum frá Króki. Nokkur skekkja kemur fram í niðurstöðum Krókssýna vegna lítils rúmmáls sumra sýnatökuflaskanna. Hægt væri að meta þessa skekkju betur ef tekin væru tvö pör af Krókssýnum þar sem innihaldi allra flaskna væri hellt saman í öðru sýninu, en hver flaska greind sérstaklega í hinu sýninu og niðurstöðurnar bornar saman. Niðurstöður rannsóknarinnar sýna hinsvegar að nauðsynlegt er að safna mun fleiri samanburðarsýnum af svifaur frá Króki og Urriðafossi ef leiðrétta á styrk Urriðafosssýna aftur í tímann.

Um 700 skriðaurssýni voru tekin af rafdrifna kláfnum við Krók árið 2001. Öll sýnin voru vigtuð á staðnum, en þar að auki var eitt sýni af hverri stöð úr hverri ferð kornastærðargreint á aurburðarstofu Vatnamælinga. Langmestur framburður var á stöðvum 50–70 m, töluvert barst fram á 80 m stöðinni, en mjög lítið á 40 og 140 m. Til að reikna út heildarskriðaursframburð yfir þversniðið þurfti að reikna út framburð á breiddareiningu á milli stöðva. Í þeim útreikningum var heildað yfir mikla fjarlægð fyrir 140 m stöðina og veldur það miklum framburði á því breiddarbili í nokkrum ferðum síðari hluta sumars. Ekki voru tekin önnur sýni á þessu breiddarbili til þess að staðfesta þessar háu niðurstöður og því er mögulegt að þær hækki útreikninga á heildarskriðaursframburði að einhverju leyti.

Heildarskriðaursframburður samkvæmt þessum rannsóknum sveiflast frá ca. 4700 til rúmlega 13000 g/s, en fylgni rennslis og framburðar er léleg. Mikill munur sást t.d. á framburði á mjög svipuðu rennslisbili (ca. 350 m^3/s) sem bendir til þess að skriðaursframburður sé mjög sveiflukenndur. Niðurstöðurnar sýna greinilega nauðsyn þess að safna miklum fjölda sýna, annars vegar á svipuðu rennslisbili til þess að sjá breytileika framburðar við sama rennsli, og hinsvegar á dreifðu rennslisbili til þess að sjá fylgni við rennsli. Eftir mælingarnar frá árinu 2001 vantar sérstaklega sýni sem tekin eru við hátt og lágt rennsli, til viðbótar við sýni tekin við hefðbundið rennsli í Þjórsá.

Samanburður skriðaursframburðar við Krók við fyrri mælingar í Þjórsá sýna að hann er af svipaðri stærðargráðu og við Sandártungu og Sóleyjarhöfða, en mun meiri en á sýnatökustað ofan við Hreysiskvísl.

Kornastærðarmælingar af skriðaur frá Króki sýndu að efnið sem er á ferðinni er að mestu leyti sandur með lítilsháttar möl. Fíngerðustu og best aðgreindu sýnin voru tekin á 40 og 140 m stöðvunum en grófustu sýnin á stöðvum 50 til 70 m þar sem straumhraðinn og dýpið er meira. Sýnin sem tekin voru á 80 m stöðinni voru í flestum tilfellum fíngerð þó að einstaka sýni hafi verið grófari. Mikill munur var hinsvegar á aðgreiningargildum sömu sýna á milli sýnatökuferða.