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Monitoring grain size of suspended sediments in rivers

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ABSTRACT Sampling strategies to investigate grain size distributions of suspended sediments are discussed in this paper.

Particle size influences upon the amount of particle bound matter associated with the sediments and is decisive to the processes governing the sediment movements through the river basins. Size distributions of suspended sediments from stations in the Norwegian monitoring programme are analysed and examined in order to improve sampling strategy and sampling methods.

The sampling profiles included in the programme are essentially of three types: 1. Monitoring stations in natural rivers; 2. Stations with weirs and similar constructions; 3. Installations to monitor the turbine water at hydroelectrical power stations.

There is considerable variability of particle size in various types of rivers. Sediment size is also subject to seasonal variations and short-term fluctuations.

A major problem in natural rivers is the unpredictable change in local velocity and degree of turbulence with discharge. This problem is reduced by using weirs that stabilize flow conditions.

In power stations special arrangements have to be made. A system set up in the Jostedal power station is described.

INTRODUCTION

Due to its relevance in practical applications, grain size distributions of suspended sediments in transport have become increasingly important in monitoring programmes.

Agricultural fertilizers like phosphorus, pesticides and heavy metal contaminants like mercury or lead may be absorbed to clay and silt particles. Radionucleides due to fallout from testing of nuclear weapons or similar activity also tend to be associated with fine fractions. In outfall from ore plants contaminants may be incorporated in particles of larger grain size. During large magnitude floods, river erosion may reactivate contaminated sediments and cause redistribution in new areas.

Variations in the grain size of suspended sediments are also of importance to hydroelectrical installations. Excessive turbine wear due to sediment laden water have ocurred in several large power stations. In the planning and operation of power plants it is necessary to have information not only on total load, but also on grain size composition (Bogen, 1989).

Grain size is a decisive factor in the processes of transport and sedimentation. To predict the movement of contaminants in river basins, detailed knowledge about spatial and temporal variations of grain size is necessary. More information about grain size is also a key to a better understanding and insight into these processes.

Information on grain size distribution of suspended sediments is limited. Existing data indicate a pattern of complex temporal and spatial variations (Walling and Moorehead, 1989).

The purpose of this paper is to discuss sampling methods applied in various types of rivers in Norway and examine both long-term and short-term variations in order to establish a meaningful sampling strategy.

FLOW FIELDS AND PARTICLE MOVEMENT

A suspension of particles in water is a two phase system. Particles do not necessarily move in the same direction as the water flow, due to their weight and momentum. Depending upon grain size, water velocity and degree of turbulence, the concentration of particles will change both in the vertical and in the horizontal direction.

In Norwegian rivers, flow conditions are continuously subject to changes. Alluvial reaches where the velocity in a vertical profile may be described by logarithmic functions, interchange with rapids in irregular channels with high degrees of turbulence. The water discharge is often subject to large variations within short-term periods and both magnitude and direction of the flow fields are continuously subject to changes.

Representative samples should characterize the actual rivers and be independent of local flow conditions at sampling stations. It is assumed here that the most meaningful comparison between rivers with respect to grain size is done when they are compared on maximum carrying capacity of the water discharge in question, i. e. on the rapid reaches of a river where concentration gradients are absent. In the Norwegian Sediment Transport Monitoring Programme, samples collected at river reaches with a high degree of turbulence have been regarded as a satisfying substitute for depth-integrated samples (Østrem, 1975).

When automatic samplers were introduced, it was found that the best regression line with manual samples was obtained when the sampling tube was placed in backwater

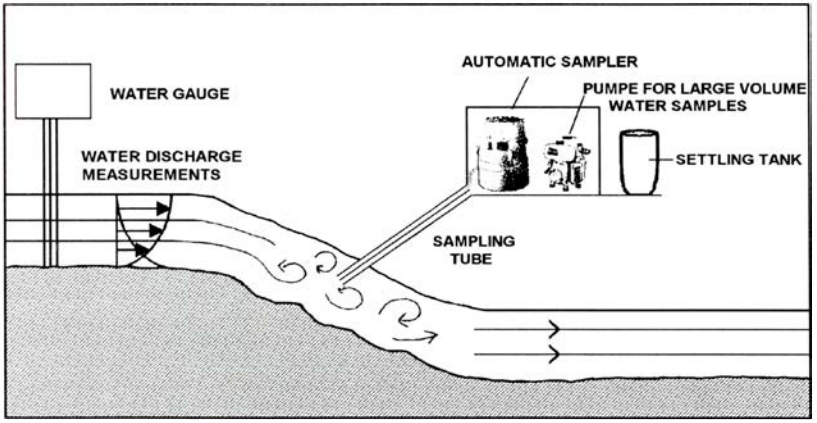

FIG. 1 Sketch of instrument setup at sediment transport monitoring station at turbulent reaches.

vortices on the high turbulent reaches (Bogen, 1986). The monitoring expanded programme that have been build up by NVE from 1985, have with some exceptions been based on this technique (Bogen, 1988). The instrument setup is most often arranged in the manner shown in Fig. 1.

Due to the large and rapid short-term fluctuations in concentration it has been the practice to collect sample four times daily.

Analyses of particle size distribution require a larger amount of material than needed for concentration. Large volume samples of up to 50-100 l are normally collected by a separate water pump once a week and left is a settling tank at the station. Analyses of grain size distribution have been done by sieving of the sand fractions and application of a Shimadsu sentrifuge on the fine fractions. A simple quality control has been carried out by comparing concentrations of the automatic sampler with the concentrations measured on the large volume samples. Large deviations have been found to be due to irregular sampling.

As a consequence of this test, samples for concentration and grain size are now pumped from the same point.

A problem with the irregular reaches is that the direction of the flow may change with water discharge. The compound crump weir (Skretteberg, 1991) that has been built in the river Bayelva will reduce such a problem (Fig. 2). Samples are collected in the vortex in the downstream end of the weir. This station is situated in the high Arctic at Svalbard where permafrost is present. The weir prevents the normal lowering of the riverbed caused by seasonal thawing.

The presence of a weir also give a more uniform flow with less transverse eddies. The pulsations recorded at the monitoring station (Bogen, 1991) is thus due to pulsations in sediment delivery and not local flow conditions.

FIG. 2 The monitoring station with the composite crump weir in river Bayelva at Svalbard in the High Arctic.

At power stations, conditions deviate very much from that of natural rivers. At the Jostedal power station, the hydraulic head is 1200 m and the water velocity exceeds 100 ms^{-1} when hitting the turbine blade. A sediment monitoring station has been built as a part of the power plant. Samples are pumped from below the turbine where the water velocity is reduced. Samples for concentration and grain size is collected once a week in 50 l cylinders (Fig. 3). A turbidity meter records large concentration events when no samples are taken. This measurement is carried out to avoid operations that may lead to excessively high turbine wear.

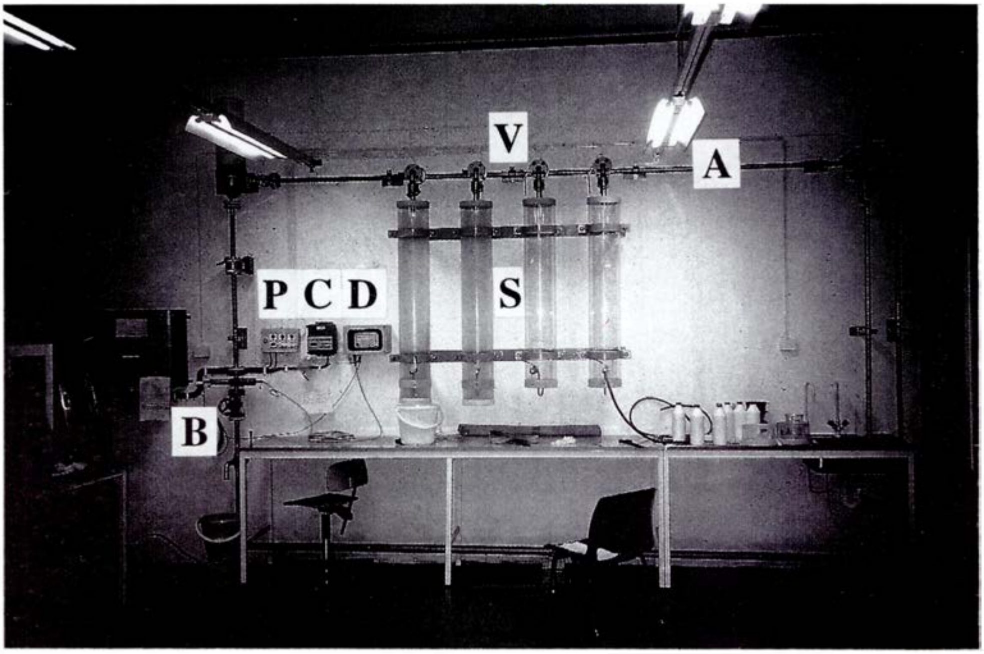

FIG. 3 The monitoring station of suspended sediment transport at Jostedal power station. A: Sampling tube leading to turbine chamber. V: Valves on top of sedimentation cylinders S. Valves are controlled from the panel P. B is an additional valve; C: flowmeter; D: turbidity meter.

SPATIAL VARIABILITY AND SAMPLING METHODS

Grain size composition of suspended sediments in Norwegian rivers is to a large extent controlled by properties of the sediment sources. Sampling conditions are therefore not only determined by hydraulic conditions in the river, but also by the character of sediment sources. This could be why there is no clear distinction between the various types of rivers in a plot of mean grain size versus sorting, (Fig. 4).

The stations classified as glacier outlets are representative for one single source, the glacier upstream from the station. Most of the glaciers on the Norwegian mainland produce material with main modes in the sand and coarse silt fractions. Clay content is normally low except for the glaciers of Svalbard.

Rivers, where the dominating sediment size fractions are supplied from moraines and glaciofluvial deposits of Pleistocene age, are classified as moraine areas. If the drainage

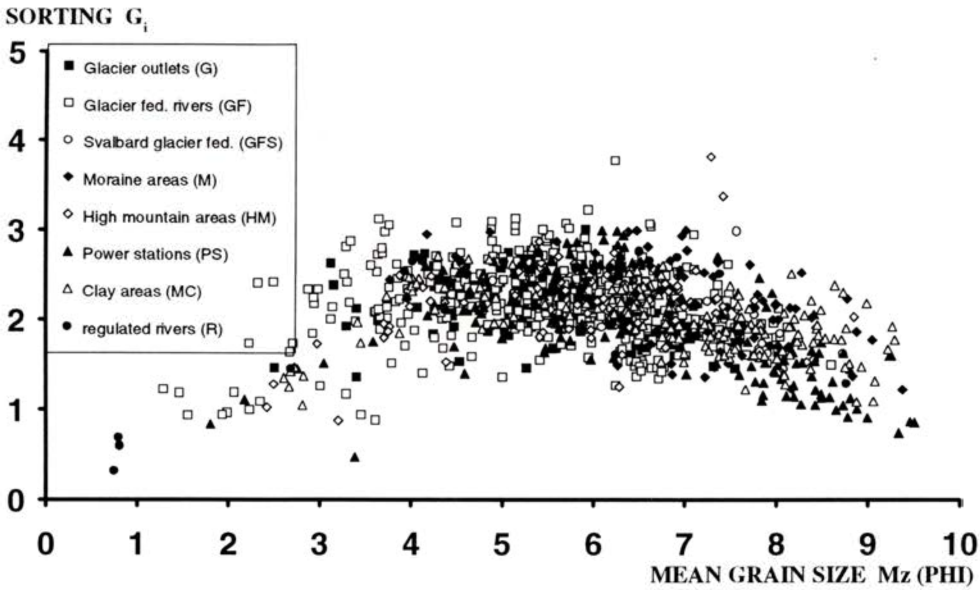

FIG. 4 Mean grain size versus sorting for grain size distribution curves of suspended sediments. Explenation of river classification in text.

TABLE 1 Annual sediment load in different fractions. River classification: See Fig. 4.

river	type	tonnes / km^2	Transp. 1991or 1990*	< 2µm	2 - 15µm	15 - 63µm	63 - 125µm	125 - 250µm	250 - 500µm
			tonnes	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes
Nigardsbreen	G	268	12959	809 6.2%	3758 29.0%	2777 21.4%	2352 18.2%	1509 11.6%	2292 17.7%
Engabreen *	G	777	28115	1915 6.8%	9642 33.7%	5325 18.9%	7112 25.3%	3142 11.2%	959 3.4%
Jostedøla at Haukåsgjelet	GF	84	47870	8246 17.2%	21107 43.1%	10934 22.8%	3693 7.7%	1943 4.1%	1650 3.4%
Blakkåga at Bjørnfossmo	GF	310	106083	11698 11.0%	43532 41.0%	25702 24.3%	20201 19.0%	4360 4.2%	536 0.5%
Bayelva *	GFS	731	23111	4964 21.5%	12807 55.4%	3961 17.2%	963 4.2%	308 1.4%	63 0.3%
Foksâi	HM	2.14	6	0.76 12.7%	2.50 41.7%	1.61 26.8%	0.72 12.0%	0.38 6.3%	0.37 6.3%
Atna at Fossum bridge *	M	3.22	3663	353 9.6%	1678 45.8%	932 25.5%	481 13.1%	116.5 3.2%	104.5 2.8%
Etna at Støytfoss bridge	M	0.42	235	97 41.2%	111 47.1%	19 8.1%	4 1.8%	2 0.9%	2 0.9%
Leira at Krokfoss	MC	167	30020	6650 22.6%	16675 55.9%	5041 15.4%	1035 3.6%	344 1.3%	303 1.1%
Vikka *	MC	54	195	19.21 9.7%	51.46 26.4%	22.21 11.4%	33.92 17.5%	43.35 22.3%	24.5 12.7%
Jostedal powerstation	PS	-	795	88 11.1%	268 33.7%	138 17.4%	198 24.9%	89 11.2%	13 1.7%

basin is situated above the treeline, the rivers are classified as "high mountain". In the glacier-fed rivers several glaciers and also other types of sources contribute to the sediment budget and the sediments are more variable in character.

In rivers in areas underlain by Pleistocene clay deposits the sediment transport is mainly of clay size material in addition to some silt and sand.

The sediment concentration in many Norwegian rivers is subject to strong seasonal and short-term hysteresis effects, and sediment rating curves may often be used for short periods only (Østrem, 1975; Bogen, 1980). Sediment transport is therefore computed from a sampling programme involving two to four samples a day with a linear interpolation between samples.

In table 1, annual sediment loads in different size grades have been calculated. The annual figures are derived by addition of daily loads within each grade. There are big differences between the various stations. The differences are to a large extent due to composition of bedrock and overburden.

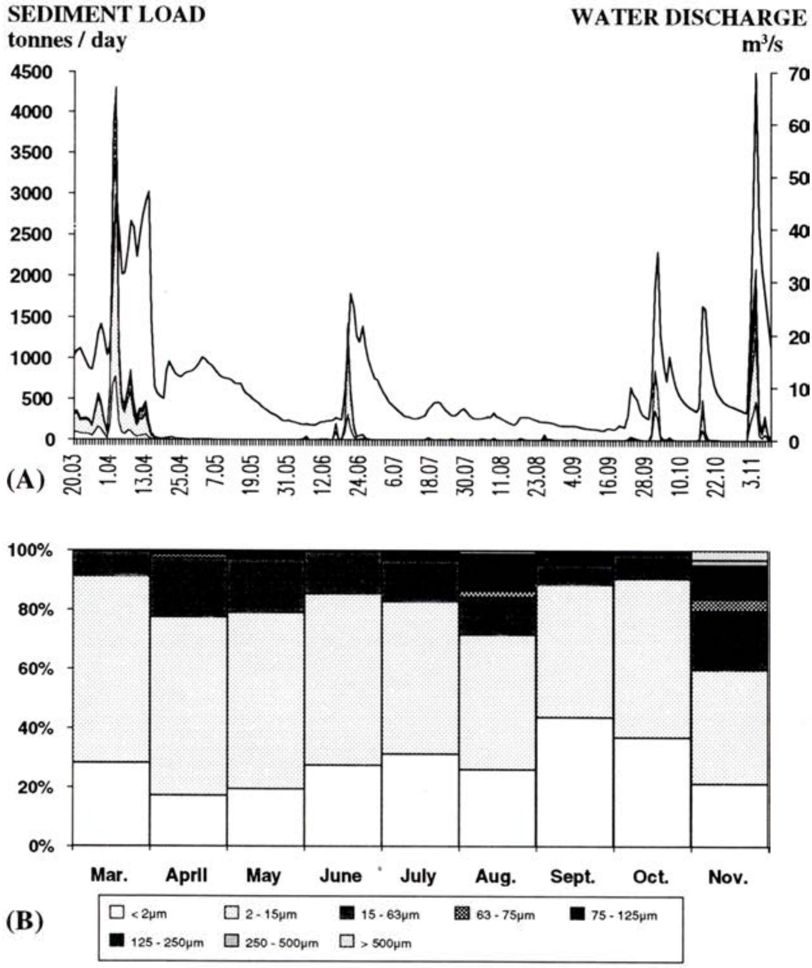

FIG. 5 Suspended sediment transport at Krokfoss on the river Leira in 1991 (A), and seasonal variations in size distribution of suspended sediments (B).

TEMPORAL VARIABILITY AND SAMPLING STRATEGY

Grain size of suspended sediment is subject to significant seasonal variations. An example from Leira, a river located in a clay area, shows that the suspended sediment delivered during snowmelt conditions in spring is more finely grained than during late autumn floods due to rainfall, (Fig. 5). During snowmelt, vegetation is absent and sediment delivery from agricultural land dominates. In autumn, the supply from agricultural land is smaller, and total load is also smaller, and the coarse grained river bed sources may dominate.

Very fine sediments are carried in transport when the water discharge increases in late June after a long period of low water level. The fine grained sediments most probably originate from material that has been deposited in the channels during low discharge. Sediment composition consequently varies with time in a very complex manner. The pattern of variation is dominated by a seasonal influence on sediment supply rather than a simple relationship with discharge. Bogen (1980) found that concentration of suspended silt and clay is not only dependent on discharge magnitude, but also on its past history. The calculations suggested that grain size composition is also subject to

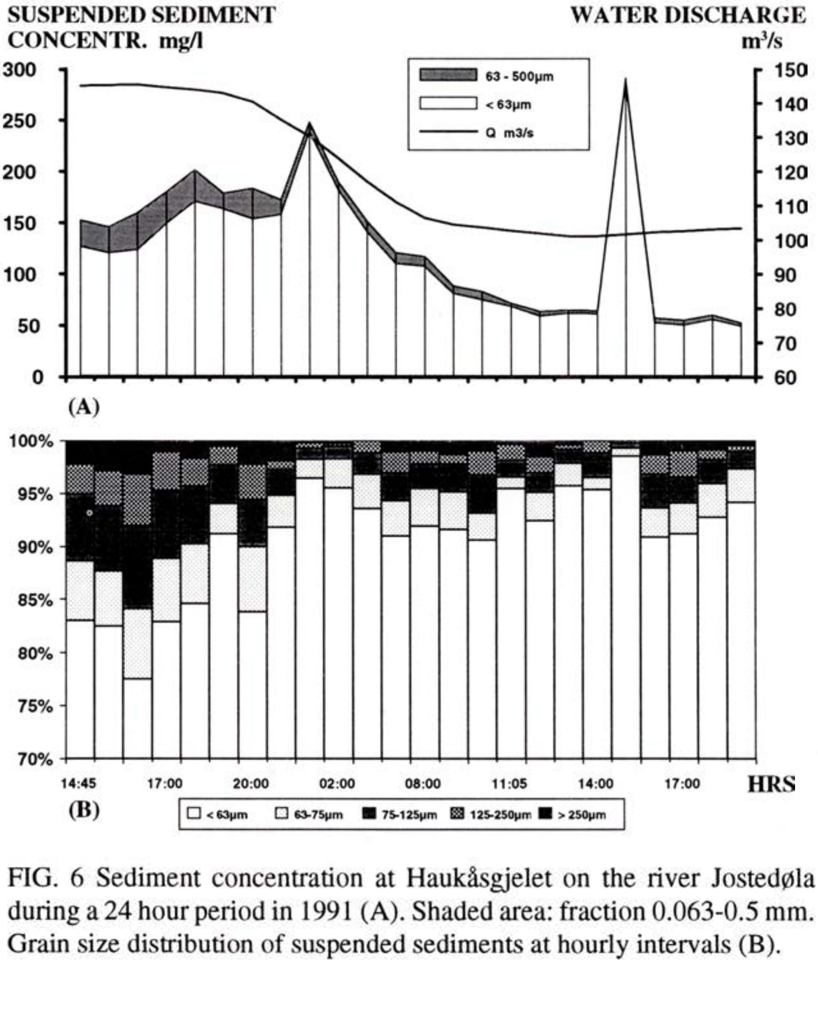

FIG. 6 Sediment concentration at Haukåsgjelet on the river Jostedøla during a 24 hour period in 1991 (A). Shaded area: fraction 0.063-0.5 mm. Grain size distribution of suspended sediments at hourly intervals (B).

hysteresis effects. Short-term variations in grain size composition are illustrated by the example from river Jostedøla in Fig 6. Samples were collected each hour during a 24 hour period and analysed for grain size.

The water discharge is subject to a diurnal fluctuation, but its magnitude is of moderate size. Apart from some short-term pulses, the concentration tend to decrease with decreasing water discharge. Slightly more sand sediments in suspension during the rising stage may be due to the settling of sand particles during decreasing water level. The Jostedøla river has a gravel bed with broad and shallow channels. A discharge fluctuation on low stage may involve a critical change in flow competence. Sand particles may no longer be kept in suspension along the banks of the river.

A predominance of fine fractions occur during the short term pulses of concentration shown in Fig. 6. Most probably the pulses are caused by river bank slumping or similar phenomena and may thus be regarded as sporadic events that are superimposed on a main trend.

Short-term fluctuations recorded in several other rivers confirm this pattern. The grain size composition is continuously subject to complex changes, but not entirely in an arbitrary manner. Both short-term and long-term variations exist.

The present sampling strategy, based on samples for grain size each week, will give a rough record of seasonal changes. It is, however, possible that the sample is collected at a pulse of short-term duration and thus fails to be representative.

It is therefore desireable to increase the number of samples, although time consumption and cost of each analysis is a limitation.

Effective particle size distribution, i. e. particle distributions based on aggregates due to floculation (Walling & Kane, 1984) has not been investigated. As solute content is fairly low, their effect is believed to be limited.

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