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A monitoring programme of sediment transport in Norwegian rivers

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Abstract This paper deals with the instrumentation, measurement techniques and results of a national sediment monitoring programme set up by the Norwegian Water Resources and Energy Administration. Selected river basins covering the main types of Norwegian rivers are included in the programme along with studies of erosion processes and sediment production in small catchments. There are four main types of river in Norway: lowland rivers draining forested till areas, rivers draining clay areas below the postglacial marine limit, glacier rivers, and rivers in arctic and high mountain areas without glaciers. In addition, watersheds on Svalbard in the high Arctic will soon be instrumented. The arctic and high mountain areas are susceptible to erosion due to their sparse vegetation cover. There are currently few data from these types of catchments and the data from these stations may, therefore, be helpful to land use planning in these environments. Analyses of concentrations of suspended organic and inorganic particulate matter, and their size distributions and mineralogy are carried out in the programme. Bed load is estimated from measurements of deltaic growth in lakes. Present knowledge of sediment yield and sediment related environmental problems due to the various activities within the drainage basins are discussed. Methods and techniques for determining the size distribution of suspended sediment in routine samples have been developed. The differences in grain size distribution between the various types of sediment source and their seasonal variability and relation to discharge are discussed in this paper. These results show that grain size is poorly correlated with discharge, and more dependent on the type of sources and the development of the drainage system through the runoff season.

Un programme d'étude des transports solides en Norvège

Résumé Cette communication présente l'instrumentation, les techniques de mesures et les résultats d'un programme national d'étude des transports solides mis en oeuvre et conduit par l'Administration des Cours d'Eau et de l'Energie de la Norvège. Les bassins de rivière sélectionnés, typiquement norvègiens, sont inclus dans le programme avec des études des processus d'érosion, et de la production des sédiments. Il y a quatre types de rivières en Norvège: les rivières du bas pays traversant des moraines Pleistocènes, les rivières de régions argileuse, en dessous de la limité marine postglaciaire, les rivières à régime glaciaire et les rivières des régions arctiques et de haute montagne sans glaciers. En plus, des stations à Svalbard dans le haut arctique seront bientôt aménagées. Les régions arctiques sont sensibles à l'érosion à cause de la faible densité de la couverture végétale. Il y a peu d'observations provenant de ces types de bassin de réception. Des analyses de concentration de matières en suspension organiques et minérales, et de leurs granulométrie et minéralogie font partie du programme. Le charriage de fond est estimé à partir de la mesure du développement des deltas lacustres. On analyse la production de sédiments et les problèmes d'environnement liés aux transports solides et résultant de diverses activités dans les bassins versants. Des méthodes et des techniques pour l'analyse de la granulométrie de sédiments en suspension à partir d'échantillons de routines sont mises au point. Les différences granulométriques entre les divers types de sources de sédiments, leur variabilité saisonnière et leurs relations avec les débits sont discutées dans cette communication. Ces résultats montrent que la granulométrie n'est pas contrôlée par le débit mais est plutôt dépendante du type de source et du développement du système versant pendant la saison d'apport.

INTRODUCTION

Throughout the last few decades, several river basins in Norway have been subject to a number of activities that have influenced sediment production and sediment flow through the system. A generalized sediment routing model illustrating the flux of sediment from natural and anthropogenic sources is shown in Fig. 1. Power plants involving river diversions, river regulation gravel mining have reduced the intensity of the processes of erosion and transport with consequent ecological changes. Equally, a number of activities may increase the sediment load of rivers. For example, accelerated erosion following low drawdown levels in reservoirs, road construction, forestry, mining and the impact of cross country vehicles.

Suspended sediment may carry particle-bound nutrients such as phosphorus carbon and nitrogen, and metals such as iron, manganese calcium and lead that are adsorbed onto, or incorporated into, the particles. The presence of particles also influences light conditions and photosynthesis and thus affects primary production and the fish habitat. Deposition of fine sediments may also affect spawning conditions.

A report dealing with these problems was commissioned by the Norwegian Water Resources and Energy Administration and the Norwegian National Committee of Hydrology. The objectives were to assess the

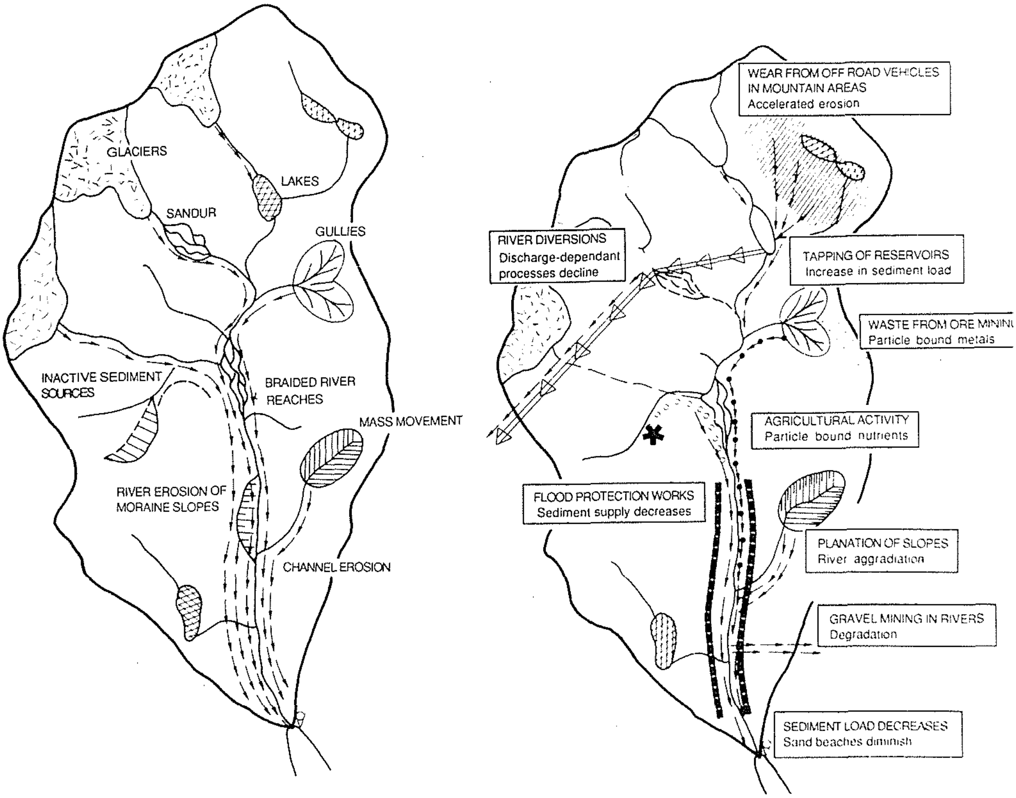

Fig. 1 Generalized sediment routing models illustrating natural (left) and anthropogenic (right) sediment sources in a river system.

significance of erosion and sediment transport processes for river management in Norway (Bogen, 1986a).

It was suggested in this report that most of the problems may be reduced or avoided if thorough planning were to be carried out. Since planning presupposes a certain amount of basic knowledge, it was recommended that a monitoring programme of sediment transport should be established in selected river basins, covering the main types of Norwegian rivers. Thus, a national sediment monitoring programme was set up by the Norwegian Water Resources and Energy Administration (NVE), (Fig. 2). Previously, short term sediment transport measurements had been undertaken mainly by the University of Oslo. Long term monitoring had been carried out by NVE, but only in glacier meltwater rivers.

METHODS

Representative sampling of particulate matter suspended in river water involves isokinetic, time-integrated and at certain locations depth-integrated sampling. Frequent sampling is necessary as sediment concentrations are often subject to large variations within short time intervals.

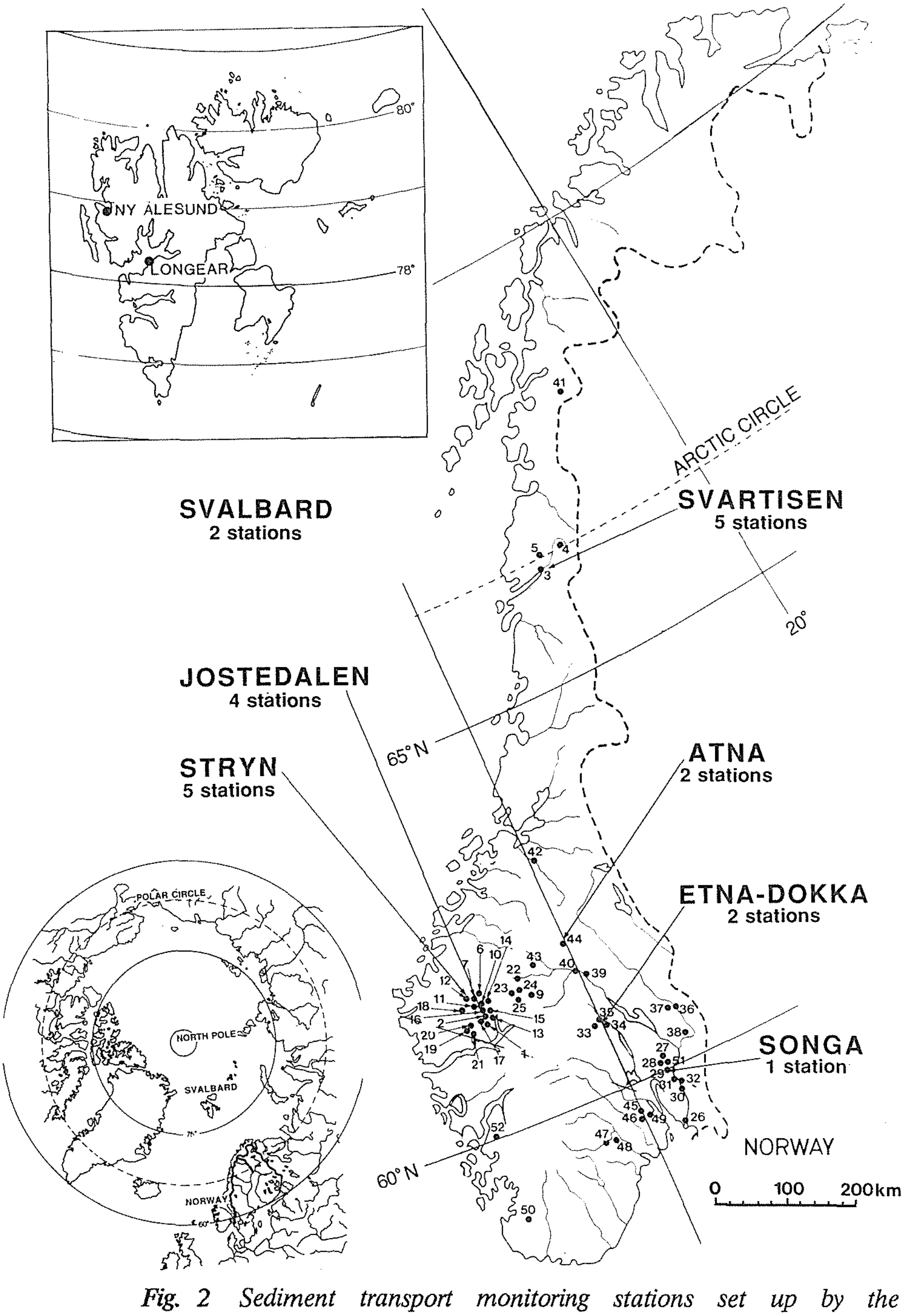

Fig. 2 Sediment transport monitoring stations set up by the Norwegian Water resources and Energy Administration (NVE). Arrows: Stations active in 1987 and 1988. Dots: Stations closed down. Some of these stations have been set up by the University of Oslo.

In recent years ISCO automatic pumping samples have been used to meet the requirement for high resolution. This type of sampler has been used in highly turbulent sampling profiles without concentration gradients. Testing (Bogen, 1986b) has shown that the best results are obtained when the sampling tube is placed in backwater vortices. The tube is placed inside a metal tube that enters the river at an angle of about 45° (Fig. 3). In rivers where the water discharge is subject to frequent variations, as in the glacier meltwater streams, the normal sampling frequency is four samples a day. Thus the base of the ISCO sampler, which contains 24–28 sampling bottles, is changed once a week.

Fig. 3 The sampling station on the Tverrelvskardet stream in Stryn, western Norway. A: ISCO automatic sampler. B: Water level recorder. C: Sampling tube and pressure transducer.

Water samples are filtered through Whatman GF/C filters and the concentration of organic and inorganic particulate matter is determined by repeated weighing and by ignition at 500°C for 2 h. Analyses of the particle size distribution require a larger amount of material than needed for concentration. Large volume samples, (up to 50–100 l) are normally collected by manual procedures once a week. The samples are filtered through Millipore 0.22 μm filters. The size distribution curve is obtained by sieving the sample to 0.063 mm, and analysing the fine fractions less than 0.063 mm with a Shimadzu centrifugal particle analyser. The Shimadzu analyser is coupled on-line to a microcomputer.

The low concentration of particulate matter is a major problem in routine automatic size analysis of particle suspensions in water samples. The Shimadzu was applied because of its ability to carry out analyses on concentrations as low as 30 mg l^{-1}.

Shimadzu size-distribution results are almost identical to those produced by traditional pipette or hydrometer methods. However, the clay fraction may be underestimated. This effect is only noticeable in samples containing a large proportion of particles <0.002 mm, but is much less than that evidenced by the comparable Coulter counter and laser instruments (Silas, Malvern). Sedigraph X-ray analysers are impractical for this application since they require large sample concentrations.

SEDIMENT SOURCES AND SEDIMENT YIELDS

As shown in Fig. 4, the largest suspended sediment yields in Norwegian rivers are derived from subglacial erosion. However, the variability between various types of glacier is large. For the igneous and metamorphic rocks of Precambrian age, the largest intensity of erosion occurs beneath large valley glaciers with several tributaries like the Engabreen, Erdalsbreen and Tunsbergdalsbreen. The sediment yield associated with smaller cirque plateau glaciers like the Vesledalsbreen and Hogtuvbreen is one order of magnitude

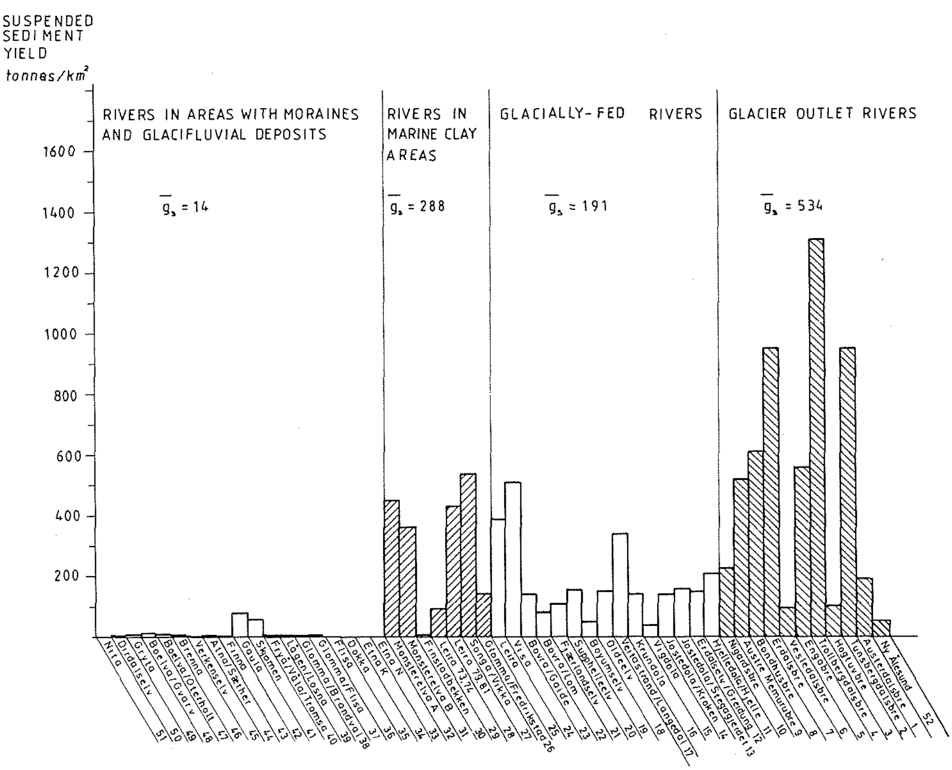

Fig. 4 *Sediment yield of Norwegian rivers (from Bogen & Nordseth (1986). River basin numbers refer to locations in Fig. 1.*

lower. However, erosion by the small cirque-like Trollbergdalsbreen in the schistose rocks of the Svartisen area provides the highest measured sediment yield from Norwegian glaciers. In most glacially bed rivers, glacial sediments dominate the sediment budget. Even if their importance decreases with increasing distance from the glaciers, a large amount of glacial material is stored in the bed and banks of these rivers and is readily available during flood conditions.

In the lowland river basins characterized by coniferous forest and no glaciers, sediment yields are to a large extent controlled by the availability of loose material and the protective effect of the vegetation. The group of rivers receiving their sediment supply from Pleistocene deposits may be subdivided into rivers draining areas of marine clay, and those eroding moraines and glacifluvial deposits. The rivers investigated in the latter group show yields ranging from 2 to 10 t km^{-2} $year^{-1}$. The coniferous forests in the lowland areas of south eastern Norway afford efficient protection against erosion. If the vegetation is for some reason destroyed, the yields may increase considerably. This may take place during rain floods of extreme intensity or as a response to forestry, road construction or agricultural activity. Fluvial erosion during drawdown of regulated lakes and reservoirs may reach considerable magnitude when compared to the natural conditions for this category of river. Mosevoll & Torsethaugen (1976) measured a suspended transport of 16.9 t in 1975 at the Bjerka power station located at the outlet of Lake Målevatn in Rana. The erosion and redistribution of sediment within the lake itself was probably one magnitude larger. In the marine clay areas, the processes of erosion are in general more intense than in the forested till area, and the average sediment yield is 288 t km^{-2} $year^{-1}$. The highest natural sediment yield recorded in the clay areas is 530 t km^{-2} $year^{-1}$ in the Songa/Vikka streams and 350–450 t km^{-2} $year^{-1}$ in Mønsterelva. The clay-like soils in these watersheds are subject to intense gullying. The dominant sediment sources are earth slumping, sheet sliding and soil creep that take place during snowmelt conditions in spring.

Agricultural activity is abundant within the marine clay areas. During the last decade, extensive regrading of the land has been carried out in order to employ modern machinery. In the catchment area of the Songa stream, a pronounced increase in sediment load occurred after grading. During mean water discharges of 0.8 m^3 s^{-1}, the concentration increased from 500 mg l^{-1} in the years before planation to around 2000 mg l^{-1} in the following years. Downstream from the regraded areas, increased floodplain deposition and channel changes have occurred. Sediment originating from soil erosion due to agricultural activity may carry nutrients which promote eutrophication of lakes and reservoirs and create disturbances in lake ecosystems. Throughout the last decade, Lake Øyeren, which is situated downstream from the marine clay areas of Romerike in southern Norway, has experienced eutrophication due to increased soil erosion in these areas.

The Jostedøla River basin is selected here as an example of a river system where the large sediment load plays an important role in river management. A power plant is under construction and water and sediment are diverted through tunnels and galleries from the eastern part of the river basin (Fig. 5).

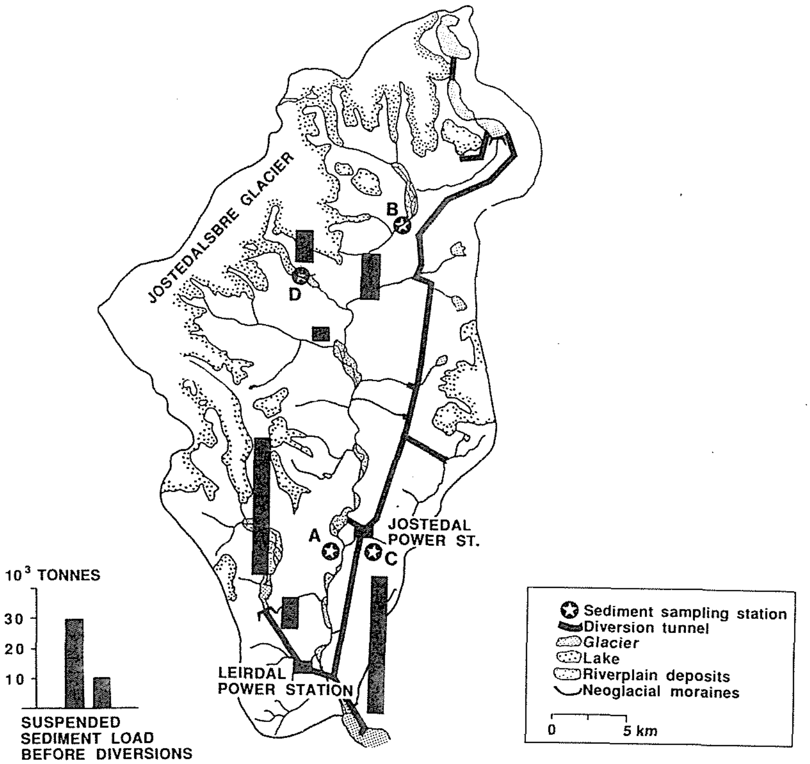

Fig. 5 Sediment monitoring station in the Jostedøla River basin.

The changes in the sediment load caused by river regulation are monitored at stations A and B. The sediment load in the diverted water is to be monitored at the power station (C). The sediment load supplied from glacial erosion of lake Nigardsbreen is monitored at station D.

Two stations are under construction on Svalbard in the High Arctic: one on the Bayelva River in New Alesund and another in Longyearbyen. The stations are not yet operational. One of the main problems in measuring sediment transport in Arctic stations is the presence of permafrost and ice on the river bed. Because the upper layer is thawing, the relationship between water stage and discharge is steadily changing throughout the runoff season. Unlike most areas in mainland Norway, frost weathering of the bedrock supplies a significant amount of material to these rivers. The vegetation is sparse and the sediment budget is very sensitive to environmental factors.

GRAIN-SIZE DISTRIBUTION

Information on grain-size distributions of the suspended sediment in transport is of importance in practical applications. Particle-bound nutrients, pesticides and metals are associated with the clay and silt fractions of the suspended particles. Several workers have pointed to the large spatial and temporal variability of grain-size characteristics and the need for more data from various types of river (cf. Peart & Walling, 1982; Walling & Moorehead, 1987).

In power plants turbine wear is dependent upon the amount of sand in the sediment reaching the power station. Thus, design and location of sandtraps and settling basins should be based on considerations of not only sediment load, but also its grain-size distribution and mineral composition.

There is a considerable variability in the particle size characteristics of suspended sediment in the various types of river in Norway (Fig. 6). The most fine-grained suspended sediment occurs in the marine clay areas. In the Nitelva River the D_{50} of the suspended sediment is as low as 4 μm, and 35% of the particles are less than 2 μm. However, the suspended sediment in rivers on Svalbard in the high Arctic are also characterized by a high proportion of fines, and one of the size distribution curves is almost identical to that from Nitelva. Glacial erosion of the igneous and metamorphic rocks in southern Norway produces relatively coarse particles shown by curves F and G in Fig. 6. In the lowland areas without modern glaciers, the sediments are derived from erosion of till deposited from Pleistocene glaciers.

Figure 7 is an illustration of the relation between median grain size

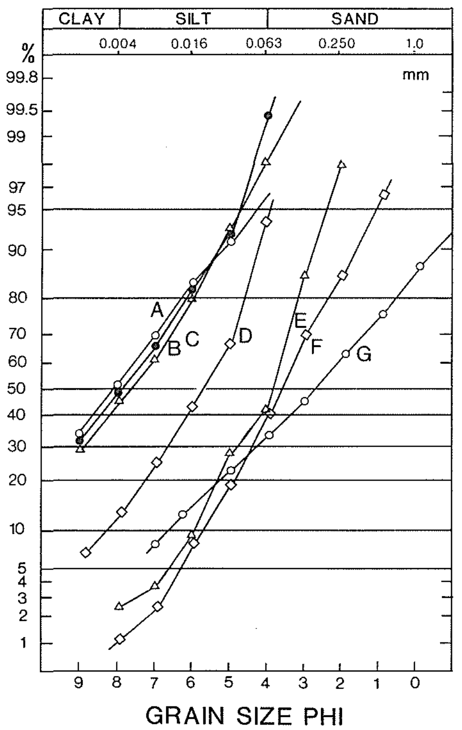

Fig. 6 Typical particle size distributions for the suspended sediment transported by various types of Norwegian river. Relationships between median grain size and water discharge at A — Nita (51), B — Kartdalen, Svalbard, c — Leira (25), autumn, spring, E — Atna (44), F — Tunsberdalsbre (2), and G — Bondhus bre (8).

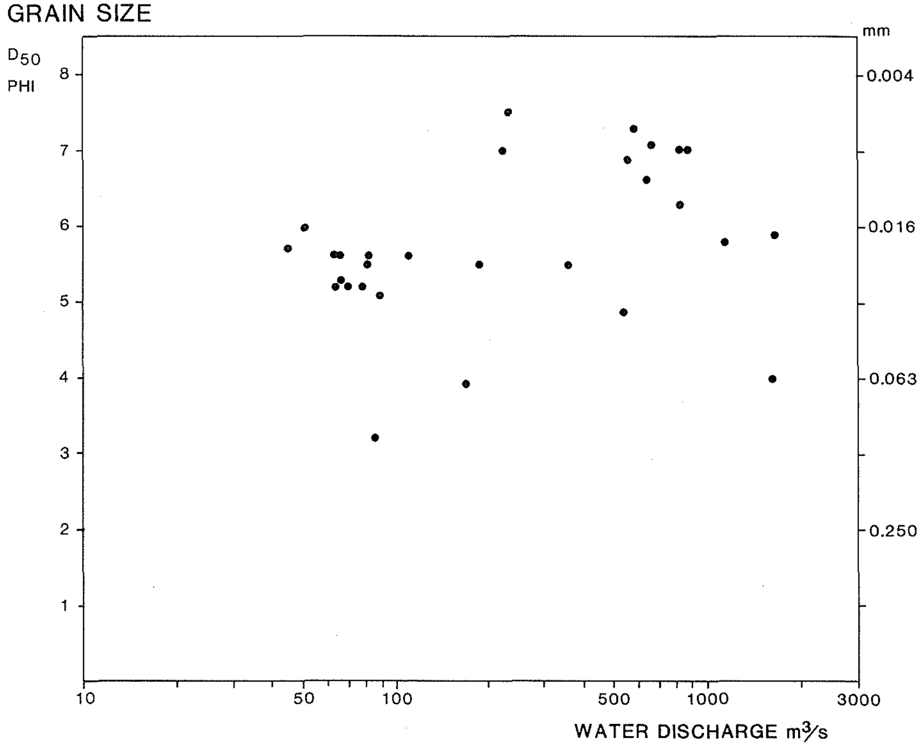

Fig. 7 Relationships between median grain size and water discharge at the time of sampling at Station A (Haukåsgjelet) in the Jostedøla River basin (see Fig. 5).

water discharge in the River Jostedøla. There is a considerable variation through time and no direct relation to discharge. The grain size is controlled by the availability and the type of material supplied from the sources.

The debris produced by glacial abrasion of igneous and metamorphic bedrock on the Jostedøla area tends to have one of its main modes in the interval 8–32 μm (Bogen, 1987). A number of the samples are located inside this interval. Grain-size distribution is now included as a routine parameter in the monitoring programme. Thus more information on this aspect will be available when the programme has been operative for some time.

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