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Measurement of sediment yield and transport in mountain torrents in Japan

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ABSTRACT Sediment problems due to the imbalance between sediment inflow and outflow have become serious in Japan and include disasters due to sediment discharge in mountain regions, siltation in reservoirs, degradation in reaches downstream from dams, and erosion at coastal locations. It is necessary to measure accurately sediment transport and sediment yield in mountain torrents in order to produce an adequate plan for basin management. It is sometimes difficult to apply the sediment measurement methods employed in lowland rivers, for instance sediment samplers, to shallow and steep mountain torrents. Therefore Sabo (erosion control) dams and reservoirs are used as large bed load traps. Data obtained from sampling of wash load, observation of flow discharge and river bed surveys provide the basic information for developing models of water and sediment routing. This paper outlines the methods used by the Ministry of Construction and presents some of their results.

Mesure du débit et du transport des sédiments dans des torrents de montagne au Japon

RESUME Le déséquilibre entre les apports et l'évacuation des sédiments crée de nombreux problèmes au Japon, notamment de véritables désastres résultant des apports de sédiments dans les zones montagneuses, l'envasement de réservoirs, la dégradation des zones en aval et l'érosion des régions côtières. Pour définir un plan raisonnable de gestion des bassins, il est nécessaire de mesurer avec précision le débit et le transport solide mais il est difficile d'appliquer certaines méthodes aux torrents rapides et peu profonds des montagnes. C'est pourquoi on utilise les barrages et les réservoirs pour le contrôle d'érosion (Sabo). L'analyse d'échantillons, l'observation des débits et les études des berges ont permis de fournir des informations et de mettre au point un modèle de l'écoulement le long de la rivière de l'eau et des sédiments. Ce résumé présente les mesures et les résultats obtenus par le Ministère de la Construction.

INTRODUCTION

Many sediment problems such as debris floods, siltation in

reservoirs, degradation in reaches downstream from dams, lack of sand for constructional purposes, and consequent erosion along coastlines have become serious in Japan. The materials associated with these problems are not always the same. Some problems arise from coarse materials transported as bed load and others from fine materials transported as suspended load. Therefore it is necessary to measure not only the total sediment yield but also the grain size of the sediment. However, such measurements are sometimes difficult to accomplish, especially in the case of bed load. In these circumstances it is necessary to adopt alternative strategies. The processes of runoff of water and sediment in a basin are shown in Fig. 1. The flow chart reveals that disasters resulting from sediment discharge are caused by unexpected amounts of sediment deposition at points of gradient change or at other locations. To assess the degree of danger in study basins, measurements have been conducted of each component indicated in Fig. 1.

MEASUREMENT PROGRAMME

As indicated in Fig. 2, many kinds of measurement have been undertaken:

(a) The amount of rainfall recorded by autographic raingauges.

(b) Flow discharge ($H \sim Q$ curves) determined by water level gauges and measurements of current velocity with current meters and floats.

(c) Sediment concentration of wash load and suspended load by direct sampling.

(d) The change of river bed elevation (which represents differences between sediment inflow and outflow) by surveying along streams and in Sabo dams, and by soundings in reservoirs.

(e) The amount of sediment production caused by surface erosion and landslides from the study of aerial photographs and by direct surveying (the values derived from aerial photographs are less accurate).

(f) The amount of sediment yield from bare and vegetated lands from experimental plot studies.

(g) The distribution of the grain size of bed materials, sampled sediment and materials on slopes by sieve analysis.

Data from these measurements were analysed and applied as shown in Fig. 2.

The Ministry of Construction measurement sites used in this study are distributed as shown in Fig. 3.

RESULTS

Through systematic measurements, the following findings have been obtained.

Sediment concentration of wash load

The relationship of sediment concentration of wash load to flow discharge is shown in Fig. 4. The two lines show the domain

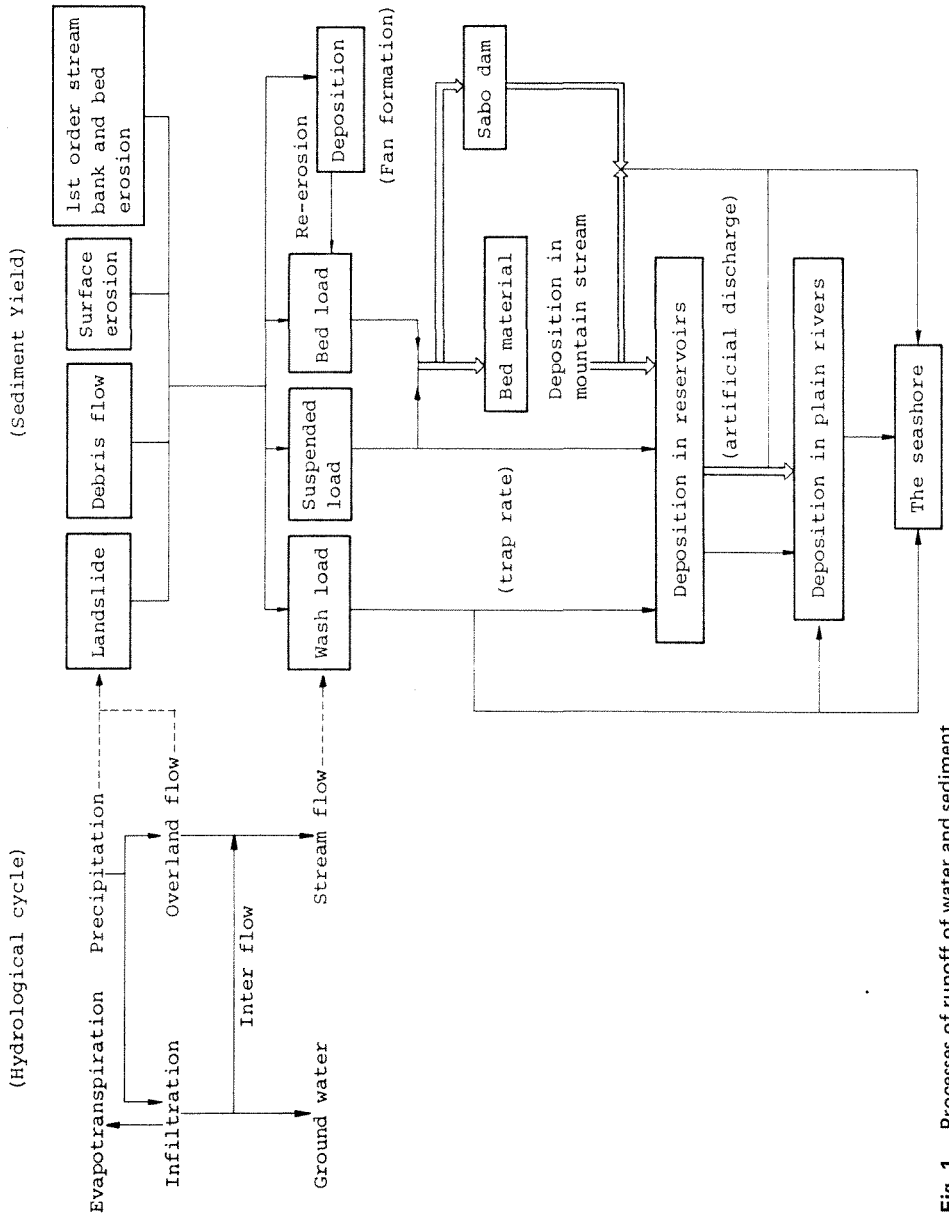

Fig. 1 Processes of runoff of water and sediment.

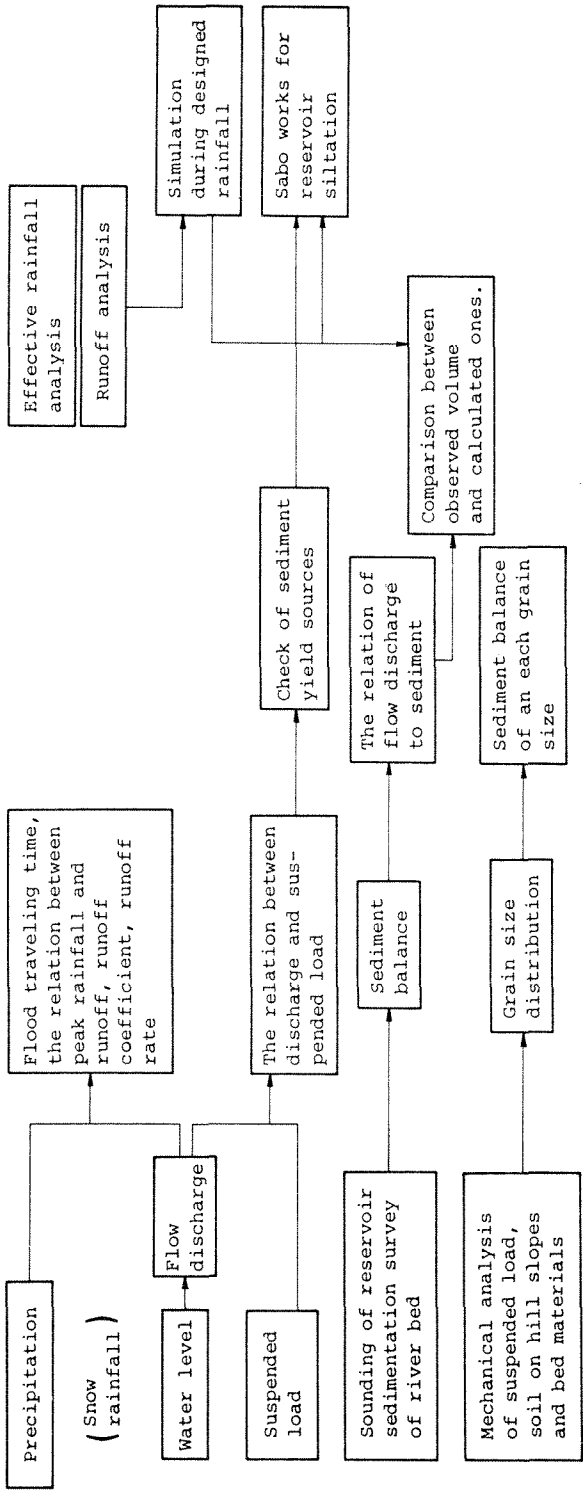

Fig. 2 Components of the survey and their application to Sabo works.

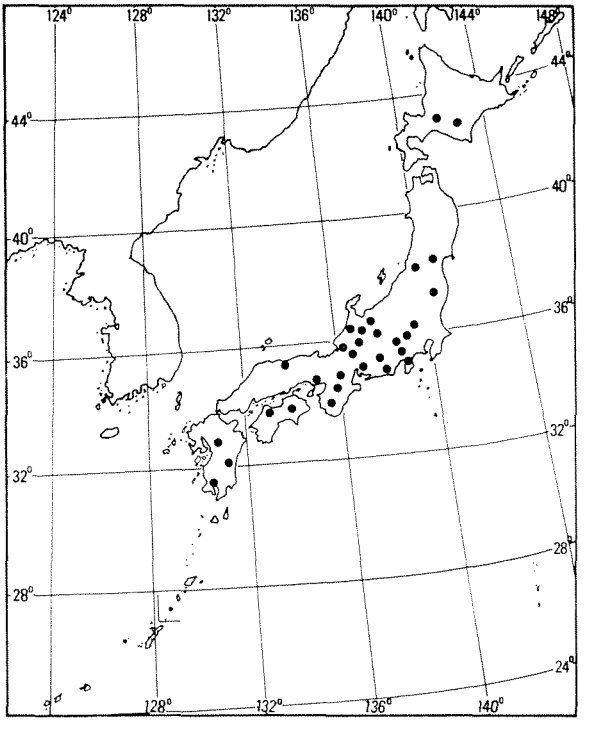

Fig. 3 Observation sites.

of data from large rivers and these may be represented by the following equation:

$$C = Qs/Q = (4 \times 10^{-8} \sim 6 \times 10^{-6})Q \quad (1)$$

where C = sediment concentration in volume, Qs = sediment discharge ($m^3\ s^{-1}$), and Q = flow discharge ($m^3\ s^{-1}$). Data from mountain basins are scattered above and below this relationship, and it is clear that more severely eroded basins are associated with higher sediment concentrations. The degree of erosion may be represented by the percentage of bare area, which is related to the coefficient α(=C/Q) as shown in Fig. 5 and described by:

$$-\log\alpha = 10^{(-0.35\log Ca/A + 0.54)} \quad (2)$$

Comparison of grain size distributions

Grain size distributions of bed material, sediment sampled from wash load, and materials on slopes are shown in Fig. 6. These reveal that the minimum diameter of bed material is about 0.1 mm, whereas the maximum diameter of sampled sediment is 0.1 mm. Furthermore, the materials on mountain slopes and in river banks contained a considerable fine fraction, with 20-30% of the grains having diameters less than 0.1 or 0.2 mm. Particle size analysis has shown that measurements of fine material are required for the successful completion of sediment mass balances in the study basins.

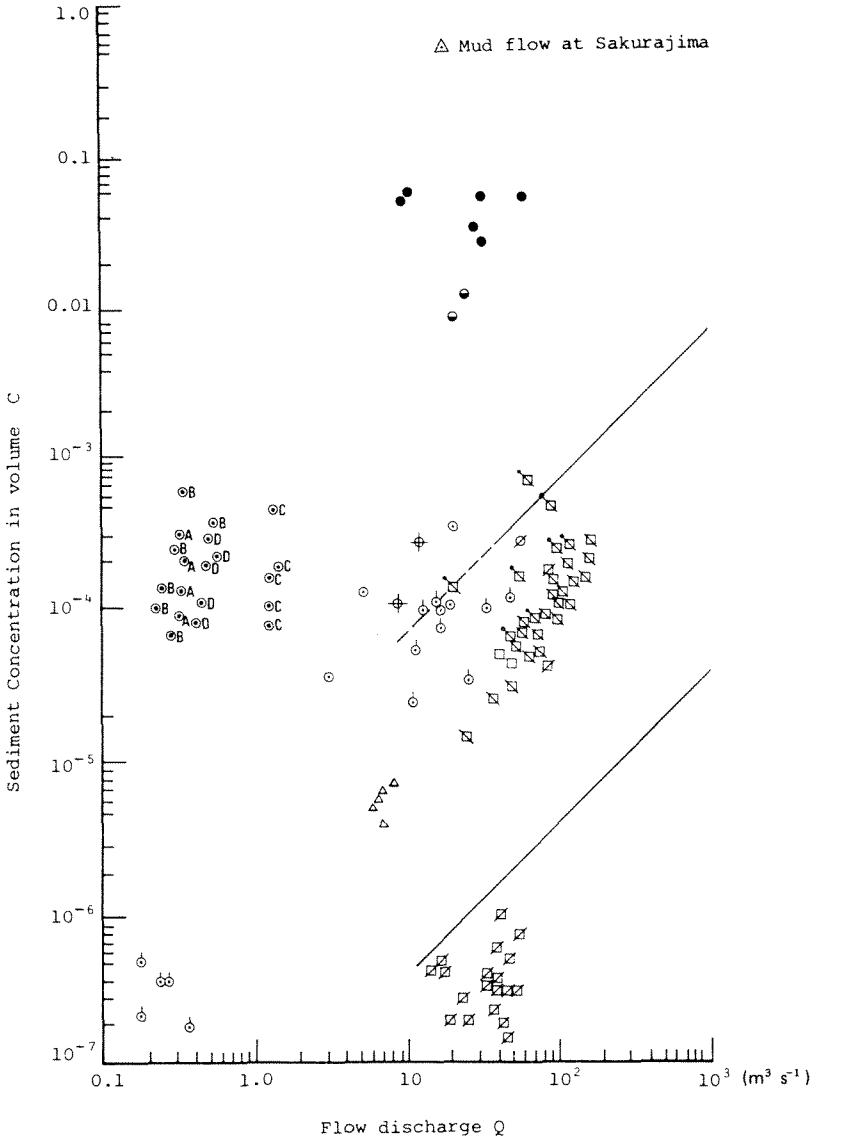

Fig. 4 Relationships of sediment concentrations in wash load to flow discharge.

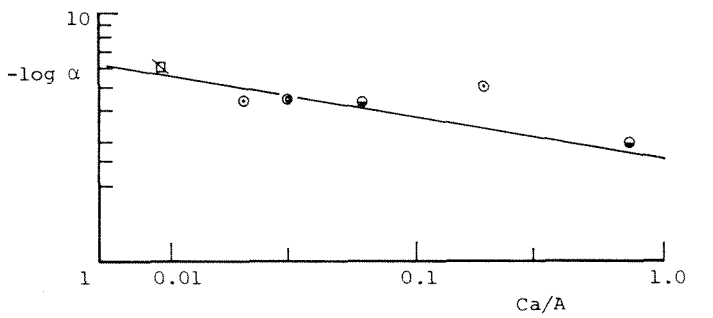

Fig. 5 Relationship of the coefficient α to the proportion of bare land.

Data from reservoir sedimentation studies

A selection of the data collected from reservoir studies are presented in Fig. 7. These provide a useful indication of the total sediment yield from basins, but it is also recognized that variations in the trap-efficiency of reservoirs and in the density of sedimentation must be considered before these data may be used

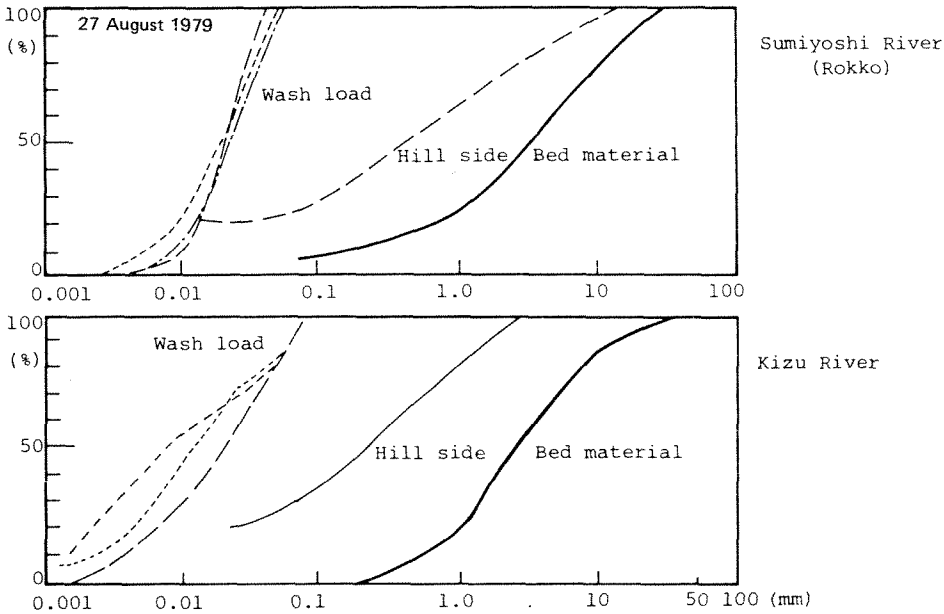

Fig. 6 Grain size distribution of materials in two study basins.

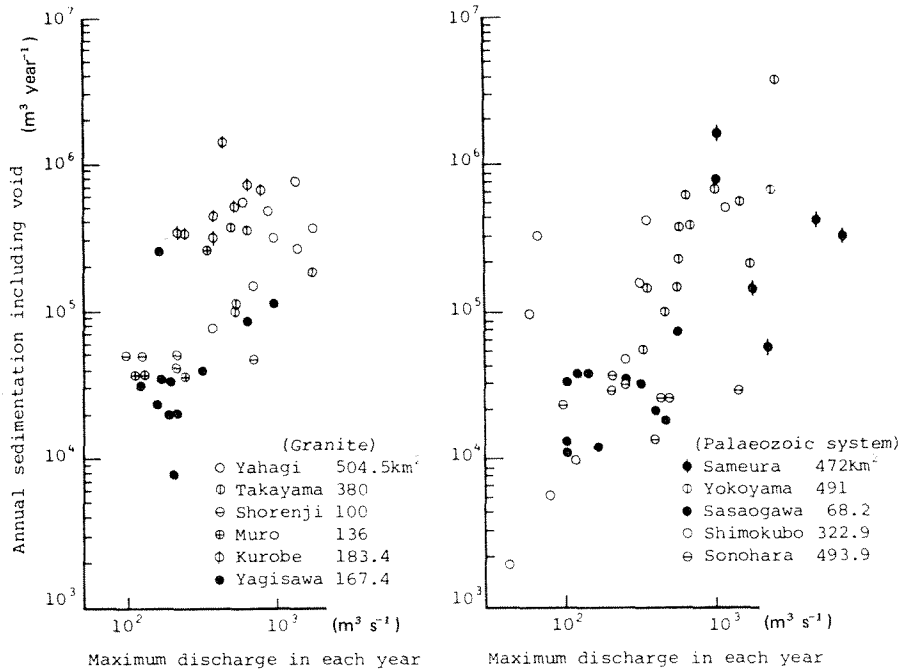

Fig. 7 Data from reservoir sedimentation studies.

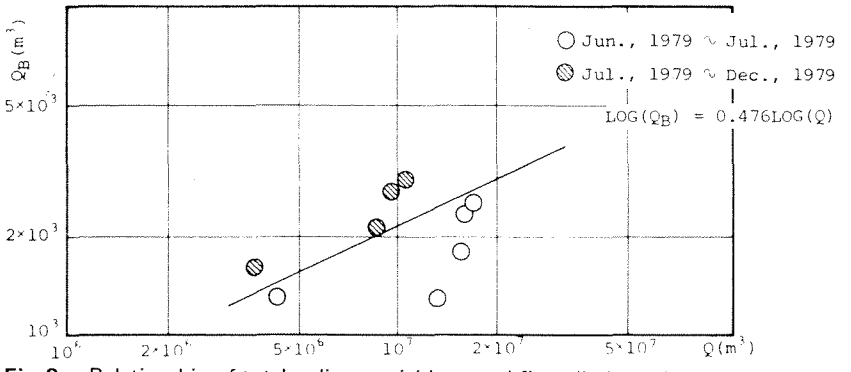

Fig. 8 Relationship of total sediment yield to total flow discharge in the Minamidaio River.

in mass balance calculations. Annual sediment accumulation has been plotted against maximum flood discharge in each year (Fig. 7) as a preliminary stage of analysis, although it is clear that many other factors influencing sediment accumulation in reservoirs will have to be investigated.

Surveying of rivers and Sabo dams

Surveying of changes in bed elevation of rivers and Sabo dams has been used to determine sediment transport and especially bed load movement. Figure 8 illustrates a relationship between sediment yield and flow derived from these measurements in a selected study basin. The data in Fig. 8 conform to a Meyer-Peter, Müller type bed load formula, if the coefficient in the formula is changed from 8 to 3. This alteration is needed to account for low rates of sediment production in the catchment headwaters.

CONCLUSION AND DISCUSSION

The methods of sediment measurement conducted in Japan have been outlined and some results given, but in conclusion some points require emphasis. It is clear that measurements must be both comprehensive and complementary. However, it is difficult to measure bed load and suspended load directly, therefore instantaneous sediment discharge must be estimated from the total amount of sediment deposited in Sabo dams or reservoirs during certain periods. In order to achieve this objective, data for flow discharge at some points are essential. The present study is aimed at the successful measurement of total sediment transport and sediment yield in Japanese basins, rather than at detailed techniques for assessing individual components of sediment mass balances.

ACKNOWLEDGEMENTS The authors were largely responsible for planning the measurement programme and analysis of results in this study. However, measurements have been undertaken by officials from every Sabo work office in Japan. There were many dangers in measuring sediment concentration during floods, and the authors would like to express their strongest respect and gratitude to all those who helped in the study.