A Study on Sedimentation Processes in Takase Dam Basin

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Abstract

Since sediment management is one of the most important issues for dams in operation, it is essential for considering countermeasures against sedimentation flowing into a reservoir to investigate characteristics of sediment production, transportation and deposition processes in a mountain river basin, which has steep topography and a severe erosion problem.

The study area, Takase Dam basin is surrounded by mountains higher than 2500m in elevation. Characterized by steep topography and weak geology consisting of deteriorated granites, the area is one of the major sediment runoff areas in Japan.

Focusing on the Nigorisawa-Fudosawa basin which is a part of Takase Dam basin and main source of sedimentation in the reservoir, this paper discusses erosion characteristics of slope failure sites, erosion and deposition processes in streams, and the overall situation of sediment balance of the basin, based on aerial photographs, slope erosion data obtained from measuring sticks and seasonal changes of water turbidity in rivers.

Key Words: *Takase dam, mountain river basin, sediment production, transportation, deposition*

1. INTRODUCTION

The Takase dam basin (131 km^2, Fig. 1) is located in the uppermost part of the Takase River in the Shinano River System. It is one of the major sediment runoff areas in Japan, characterized by steep sloped topography and weak geologic configuration.

Takase dam was completed in 1978 as upper dam of the Shintakase Pumped Storage Hydropower Plant with maximum output of 1280 MW. During 1978 to 2004, however, a total of about 16 200 000 m^3 of sediment was deposited in Takase dam reservoir and caused a reduction of about 20% (below High Water Level) of the total storage capacity, i.e. 76 200 000 m^3.

Of the 16 200 000 m^3 sediment, 4 800 000 m^3 came from the Takase River, 8 900 000 m^3 from the Nigorisawa-Fudosawa rivers and the remainder from other streams (Fig. 2). The specific sedimentation rate, which can be obtained by dividing the total volume of sediment deposited by catchment area of 131 km^2 and then by 26 years elapsed, is 4 750 m^3/km^2/year.

This value is far greater than the average value for all mountain areas in Japan, i.e. 300 m^3/km^2/year. It indicates the severity of sediment runoff in the Takase Dam basin. The specific sedimentation rate for the Nigorisawa-Fudosawa basin, which is 12.8 km^2 in area, is quite high of 26 970 m^3/km^2/year.

It is essential to investigate the present state of sediment runoff and prediction of future conditions, in order to take appropriate actions for maintaining the reservoir. Moreover, in a large reservoir, loss of storage capacity due to sedimentation is not the only problem caused by sediment runoff; it also causes the problem of reservoir water turbidity by fine soil particles in large quantities transported during flood. Prolonged turbidity of water downstream is causing serious environmental consequences in Japan.

This paper focuses on the Nigorisawa-Fudosawa basin, an active sediment production area in the Takase Dam basin, and discusses erosion characteristics of slope failure sites, sedimentation and erosion

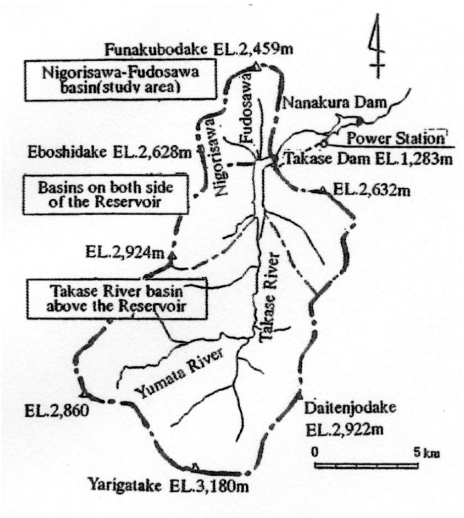

Fig. 1 Takase Dam basin

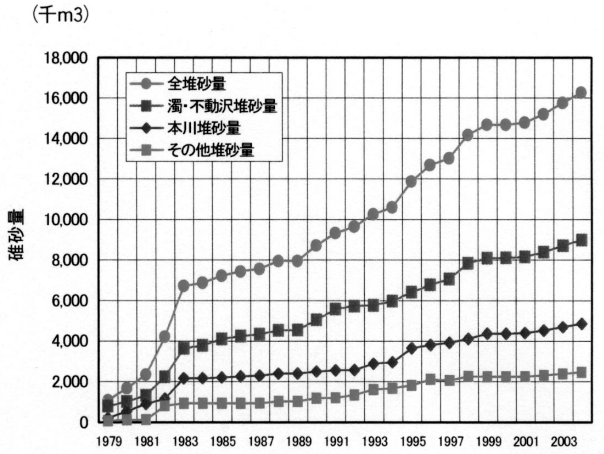

Fig. 2 The volumes of sediment deposited in Takase reservoir

processes in the river system, and the sediment balance of the river basin based on field measurement data.

2. CHARACTERISTICS OF SEDIMENT PRODUCTION

2.1 Slope Failure Sites in the Nigorisawa-Fudosawa Basin

The Takase dam basin is located in a mountainous region and is surrounded by mountains higher than 2800 m in elevation. The boundary of the basin lies above the forest line. The area consists primarily of bare slopes, grasslands, and alpine shrubs. In winter, the entire basin is covered with snow, and snow remains even in summer in some sections of the basin. Average annual precipitation and temperatures at the dam site are around 2100 mm and -16 to 30˚C, respectively.

Most of the slopes in the river basin are steeper than 30˚. Geologically, more than 90% area of the basin consists of Cretaceous to Paleogene granites. Partially, there are volcanic rocks, alluvial sand and gravel deposits. Slope failure sites, which are a major source of sediment, are highly concentrated in the Yumata River (slope failure area ratio=15%) and the Nigorisawa(25%)-Fudosawa(20%) area, where there are hydrothermally altered and fragile granites.

The distribution of slope failure sites in the Nigorisawa-Fudosawa basin, based on aerial photograph interpretation, is shown in Fig. 3. The rocks at these sites are hydrothermally altered and fractured under the influence of volcanic rock intrusion and have developed fine cracks. The cracks contain clay minerals and the rocks have been weathered to considerable depths. Rainwater infiltration and freeze-and-thaw action in winter have accelerated the weathering of these slopes, causing considerable decreases in strength.

Fig. 4 shows changes in the area of slope failure over the years. As shown in Fig.4, the area of slope

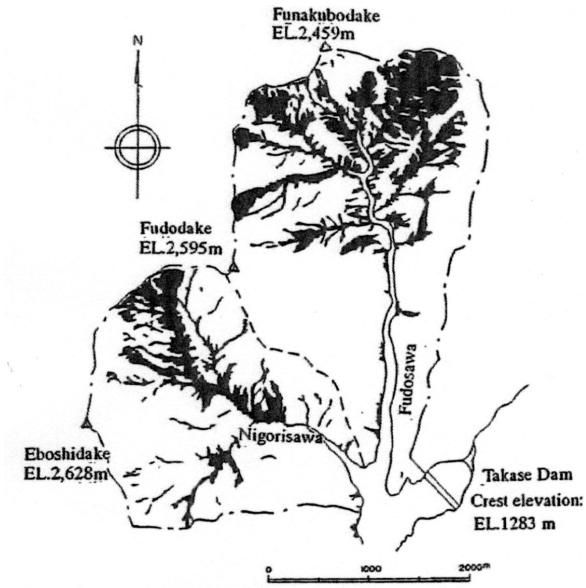

Fig. 3 Distribution of slope failure sites in the Nigorisawa-Fudosawa basin (1983)

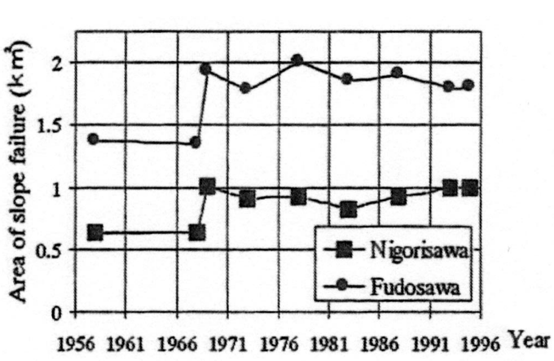

Fig. 4 Changes over the years in the area of slope failure in the Nigorisawa-Fudosawa basin

failure increased due to the expansion of preexisting slope failure areas caused by extremely heavy rain in August 1969. After 1969, aerial photograph interpretation was done at five-year intervals to investigate changes in the area of slope failure. The result indicates that variations in the area of slope failure ranges from only ±1 to 4% per year.

2.2 Characteristics of Erosion of Bare Failed Slopes Based on Measuring Stick Data

While the ratio of new and expanded slope failure areas was as small as 1 to 4% per year, the volume of sediment produced as a consequence of expanded slope erosion was about 17% of the average volume of sediment deposited per year in the reservoir.

In 1984, measuring sticks (steel bars) were installed at three locations on a rock slope of the Fudosawa basin to observe the state of erosion and deposition situations at the bare failed slope. The measurements were carried out from June (rainy season) to October (before snowy season).

The measurement results are shown in Fig. 5 and Fig. 6. The results have shown that there are differences in the rate of erosion or sedimentation along the locations of the measuring sticks on the slope. Characteristics of slope failure can be summarized as follows:

(1) At the upper part of the slope, erosion is in progress (F1-4). The rate of erosion is higher in the winter-snowmelt season (November to the beginning of June) than in the rainy season (the latter part of June to October). The average erosion rates in the rainy season and the winter-snowmelt season in 1986 to 1990 are 1.7 cm/year and 8.6 cm/year, respectively.

(2) At the middle part of the slope, deposition and erosion cycles are occurring. In the winter- snowmelt season, sediment eroded from the upper part of the slope is deposited at the middle part of the slope. Intense rains wash the deposits away to river during early days of the rainy season. Subsequent rains caused erosion and deposition. Maximum depth of erosion up to about 15 cm has occurred in rainy season. The large deposition data (F1-3, F3-1) were obtained from locations subject to concentration of surface water and sediment because of the spoon-shaped topography. The long-term erosion tendency data (F1-1, F2-2) were obtained from hollow-topography areas.

(3) The above mentioned results indicate the following: Deterioration of the surface layer caused by freeze-and-thaw cycles, rainwater infiltration and others are in progress on a bare slope consisting of softened materials. Factors such as rains, snow movement and separation by self-weight during the snowmelt season cause erosion of the upper part of the slope. The eroded sediment moves down slope and is deposited. Intense rainfalls in and after June, when snow on the ground in the ravine area below the slope disappears, cause further down slope movement of sediment deposits on the slope and erosion of the slope. As a result, the eroded sediment mows down onto the riverbed.

3. CHARACTERISTICS OF TRANSPORTATION OF SEDIMENT ON MOUNTAIN RIVER BASIN

3.1 Deposition and Erosion of Sediment in River Basin

Changes in elevations of the slope failure sites and the river beds in the Nigorisawa-Fudosawa basin were examined by using aerial photographs. The 1:15 000-scale aerial photographs were taken in October 1983, 1993, and 1995. The 1983 photographs were taken immediately after a large amount of sediment flowed into the reservoir (Fig. 7). The 1993 photographs were taken after two relatively dry years when the amount of sediment that flowed into the reservoir was small. The 1995 photographs were taken immediately after the intense rainfall (Fig. 7).

Fig. 8 shows the deposition and erosion patterns during two periods, one before 1993 and the other after 1993. Fig. 9 shows changes in the elevation of the beds of the two rivers plotted on a longitudinal profile of the riverbed

From the obtained results, characteristics of the changes of the failed slopes and the riverbed in the Nigorisawa-Fudosawa basin can be summarized as follows:

(1) Erosion occurred on almost all failure slopes throughout the observation period. Temporary deposi-

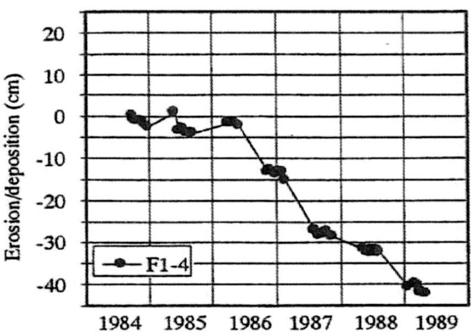

Fig. 5 Results of measuring stick measurements carried out in the upper part of the failed slope

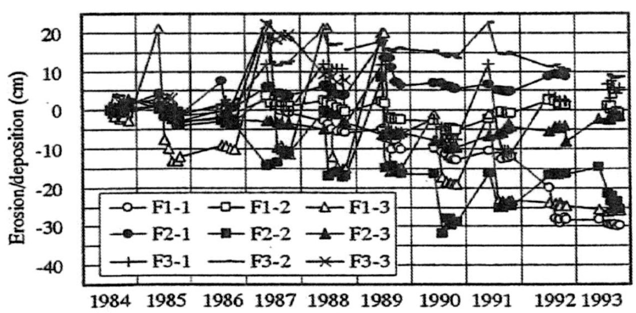

Fig. 6 Results of measuring stick measurements carried out at the middle part of the failed slope

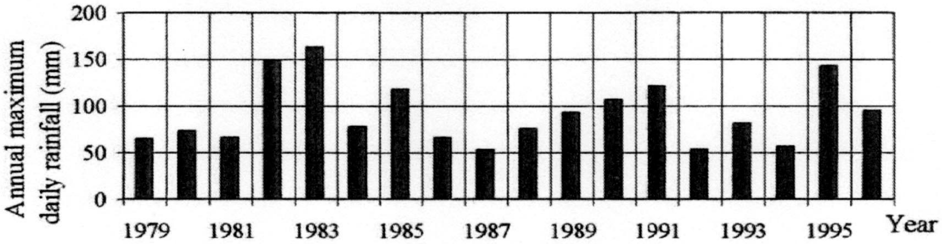

Fig.7 Changes over the years of annual maximum daily rainfall at Eboshidake station

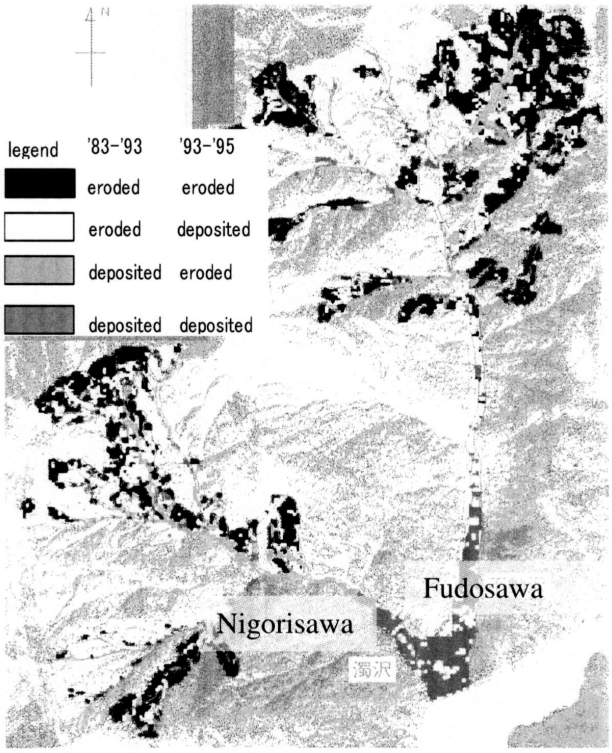

Fig. 8 Deposition and erosion patterns (1983-1993-1995)

tion of sediment occurred at the places subjected to concentration of eroded sediment, such as hollow-shaped areas and locations on gentle slopes where the slope angle changes.

(2) During the period from 1983 to 1993, the bed of the Nigorisawa river in an upstream section (distance from the reservoir; TD more than 1,000 m) and the bed of the Fudosawa river in an upstream section (TD more than 3800 m) rose considerably. Later, the trend was reversed and erosion became predominant and resulted in wash-outs of a major part of the deposits. Since all of these river sections adjoining large-scale failure sites, the supply of sediment to the riverbed is prominent. In addition, usual discharges in rivers over these sections are low because of the smaller catchment area. The bed slopes of rivers are greater than 15°. The riverbeds are narrow, and the duration of sunshine is short. According to field observation results, sediment is dammed by huge boulders and the river beds are covered with snow and ice. Heavy rainfall triggers runoff of deposited sediments together with ice and snow as debris flow. The volumes of sediment deposited in the above-mentioned sections of the Nigorisawa and the Fudosawa rivers during 1983 to 1993 were about 220 000 m^3 and 60 000 m^3, respectively. The volumes of sediment eroded during the period from 1993 to 1995 were about 260 000 m^3 and 100 000 m^3, respectively (Table 1).

(3) On the bed of the Fudosawa river from TD3900 m to 1700 (bed slope: 7 to 15°), riverbed gradation or degradation occurred near the junction with the tributary and near the locations where bed slope or river width changes. Throughout two observation periods, however, the magnitude of change in elevation was not very large.

(4) The Nigorisawa river section from TD1000 m downstream and the Fudosawa river section from TD1700 m down to the reservoir (bed slope: 2 to 7°) form a compound alluvial fan. In these sections, deposition remained predominant throughout the two observation periods.

Changes in the pattern of deposition at the entrance to the reservoir are shown in Fig. 10.

Results indicate that the riverbeds upstream of the reservoir have a tendency to rise under the influence of the reservoir.

Table 1 compares the volumes of sediment inflow into the Takase reservoir obtained from the sediment balance of the Nigorisawa-Fudosawa basin based on aerial photogrammetry with the measurement results

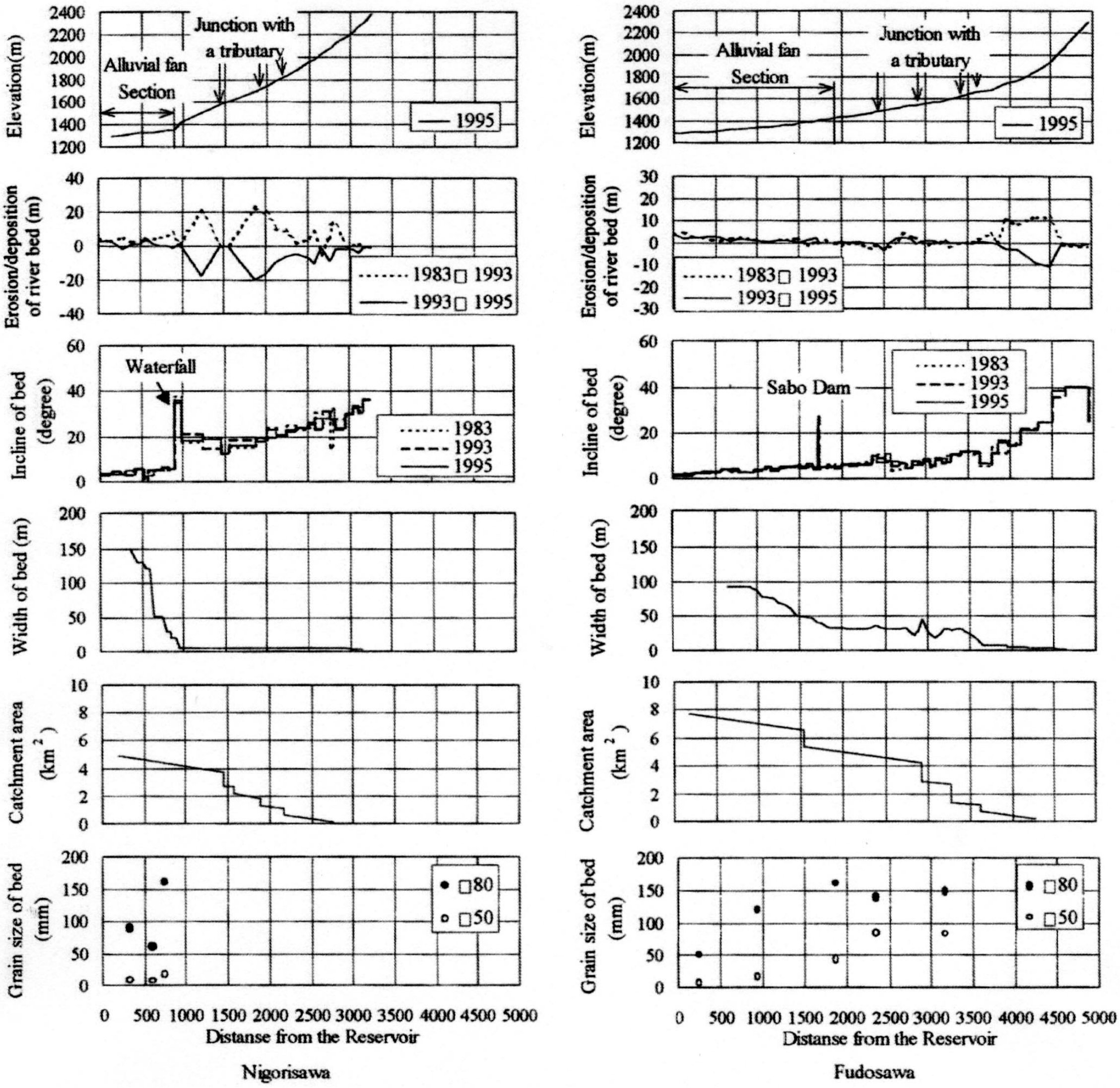

Fig. 9 River bed erosion/deposition profiles

Table 1 Sediment balance of the Nigorisawa-Fudosawa basin based on aerial photogrammetry

【×10³m³ +Deposition -Erosion】

Name of Stream	Location	1983～1993	1993～1995	1983～1995	Remarks
Nigorisawa	Failed slope	-1,143	-464	-1,561	Values obtained by multiplying with the volume expansion factor of 1.3
	River bed($\theta \geqq 15°$)	222	-258	-36	
	River bed($\theta < 15°$)	280	289	568	Mostly in alluvial fan areas of $\theta < 7°$
	Subtotal	-641	-433	-1,029	
Fudousawa	Failed slope	-1,563	-853	-2,303	Values obtained by multiplying with the volume expansion factor of 1.3
	River bed($\theta \geqq 15°$)	64	-104	-33	
	River bed($\theta < 15°$)	147	439	586	Mostly in alluvial fan areas of $\theta < 7°$
	Subtotal	-1,352	-518	-1,750	
Total		-1,993	-951	-2,779	Corresponding to sediment inflow into the reservoir (below HWL)
Measured sediment inflow into the reservoir (below HWL)		2,176	651	2,827	

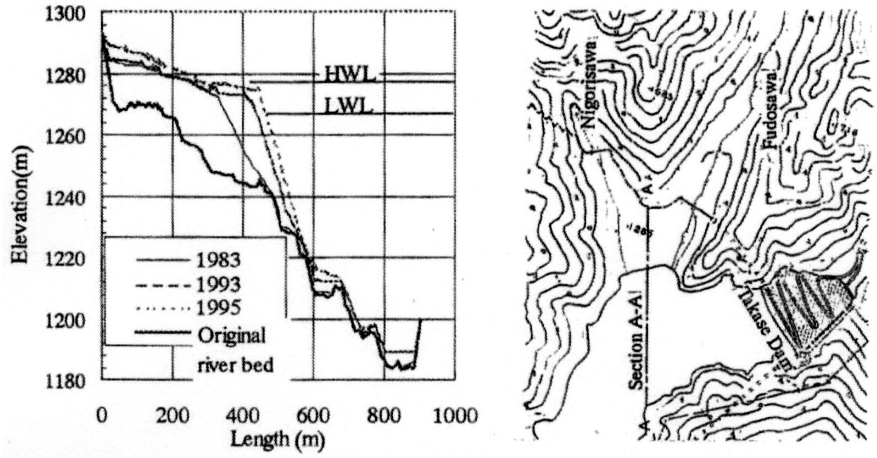

Fig.10 Changes in pattern of deposition at entrance to reservoir (section A-A)

Table 2 Average annual erosion depths at slope failure sites based on aerial photogrammetry

cm/year

Name of Stream	1983～1993	1993～1995	1983～1995
Nigorisawa	8.8	17.8	10.0
Fudosawa	6.7	18.2	8.2
Average	7.4	18.1	8.8
	(6.4)	(13.1)	(7.6)

* The numbers in parentheses were calculated from reservoir sedimentation

obtained in the reservoir. As shown, the two sets of values show fair agreement.

Most of the sources of sediment are the failure slopes and sediment yield varies depending on rainfall history. Part of the sediment eroded from the slope is retained temporarily on the slope or in the upstream river sections, and is washed away during intense rains. During 1983 to 1995, most of the sediment washed away from the slope was deposited in the reservoir or on the alluvial fan at the entrance to the reservoir.

The amounts of erosion (Table 1) on the failure slopes were determined by aerial photogrammetry for the period of 1983 to 1995. The results show an erosion rate of 8.8 cm/year. This value is slightly greater than the value of 7.6 cm/year calculated from the volume of sediment deposited in the reservoir. (Table 2) This difference is close to the volume of sediment deposited on the riverbed in the alluvial fan and other areas (about 670 000 m^3).

3.2 Seasonal Changes in Sediment Transport

In order to investigate the seasonal changes in sediment inflow into the reservoir, seasonal changes in the turbidity of river in the Nigorisawa and the Fudosawa were examined.

The results show the relationship between turbidity of river water and discharges (Fig. 11). However, turbidity of water tends to increase in and after June in cases where snow coverage is lower than 20%. The average change in the snow coverage ratio in the river basin is shown in Fig. 12. Upstream main source of sediment are covered almost completely at the beginning of June.

Fig. 13 shows average changes in the elevation of the riverbed in the alluvial fan section of the Fudosawa during the period from December 1997 to August 1998.

According to Fig.13, during the winter-snowmelt season from December to June, the riverbed became lower, because of scouring due to supply of less sediment loaded flow from upstream. Later, in the summer month of July, the trend was reversed and the riverbed began to rise.

These facts indicate the following: Sediment runoff is closely related to the snow conditions on the sediment production areas along the upper reaches in the basin and the runoff of deposits and slope sediment is not severe under snow cover. As the snow melts under influence of air temperatures and precipitation, sediment begins to flow into the river and results in deposition of large volumes of sediment in the reservoir.

4. CONCLUSIONS

Sediment production and transport processes in the Nigorisawa-Fudosawa basin, a steep and high-sediment-yielding mountain basin that flows into the Takase reservoir, were investigated. The conclusions drawn from the study are summarized as follows:

(1) The Nigorisawa-Fudosawa basin comprises 30-degree-or-steeper slopes made up of granite. Slope failure sites on the basin are concentrated in areas where rocks are affected by hydrothermal alteration.

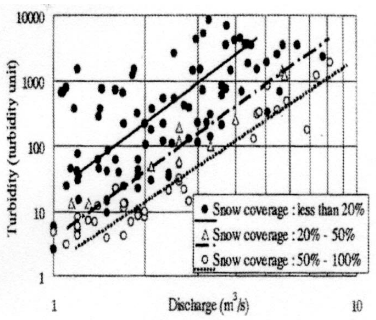

Fig. 11 Relationship between river discharge and turbidity

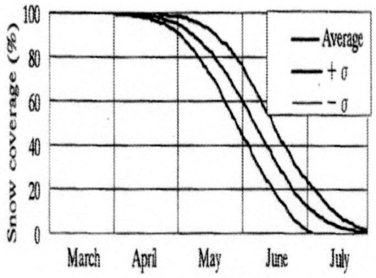

Fig. 12 Monthly changes in the snow coverage in the river basin

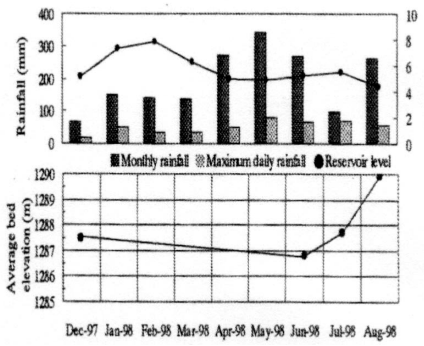

Fig. 13 Seasonal changes in river bed elevation in Fudosawa alluvial fan

The area of slope failure portions of the basin increases or decreases by about 1 to 4%. Thus, changes in the area of slope failure are small. During very intense and long-lasting rainfall, however, the area of slope failure increases considerably.

(2) In existing slope failure areas, erosion occurs during both winter-snowmelt season and rainy season. The upper part of the slope is dominated by erosion mainly due to freeze-and-thaw action. Sediment is deposited mainly on the middle part of the slope. In the latter season, when snow on the ground disappears, intense rains trigger sediment runoff and cause erosion.The sediment is transported and deposited on the river bed and gently sloping areas.

(3) In steep-sloped (more than 15°) ravines where failure slopes are concentrated, large-scale deposition occurs. Possible causes of such deposition include the yielding of large volumes of sediment, low river discharges, narrow river channel that can be easily dammed by huge boulders, a short duration of sunshine and ice and snow remaining on the river bed even in summer. Most of the sediment deposited on the lower part of the slope and on the river banks is washed away downriver during intense rains.

(4) Changes in riverbed elevation on the middle part of the basin, where the bed slope ranges from 7 to 15°, are small. The alluvial fan downstream, which has a slope of less than 7°, tends to undergo deposition under the influence of the reservoir. As sediment runoff is directly related to the snow conditions on the sediment production area along the upper reaches, the riverbed become lower during the winter-snowmelt season.

(5) The sediment balance obtained from aerial photogrammetry of the slope failure site and in the riverbed shows fair agreement with the measured volume of sedimentation in the reservoir.

Sediment production sources are mostly located in the failure slope and the average annual depth of erosion of the failure slope was found to be about 8.8 cm/year from the past 12 years' data. Sediment eroded from the failure slope surface was retained temporarily on the middle and lower parts of the slope or on banks. During 1983 to 1995, most of the sediment eroded from the slope was deposited in the reservoir or on the alluvial fan.

Reference

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