

Sediment-related Disaster Caused by Typhoon 0310 (Etau) in Hidaka Region of Hokkaido, Japan

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On August 9 and 10, 2003, Typhoon 0310 (Etau) hit the Saru and Appetsu river basins in the Hidaka region of Hokkaido. Mountain districts experienced disasters caused by washouts of sediment and woody debris produced by shallow landslides and debris flows. We conducted field surveys, aerial photography, satellite data analysis, and a fact-finding survey of the basin's inhabitants in order to reveal the actual magnitude of the disasters. The storm-induced shallow landslide volume (excluding void volume) in the Saru Basin was estimated as $13 \times 10^6 \text{ m}^3$. The amount of resulting woody debris in the Saru River Basin was estimated as approximately $190 \times 10^3 \text{ m}^3$, and less than 10% of the debris reached the Nibutani Dam reservoir. The occurrence of shallow landslides tended to increase when the total rainfall exceeded 330 mm and also when the hourly rainfall intensity increased. The sediment budget for a small catchment (2.1 km^2 in area) of the Saru River during the August 2003 storm revealed that approximately $100,000 \text{ m}^3$ of sediment was generated by landslides, and 80% of this was stored within the catchment, especially in downstream higher-order channels; the budget also revealed that only 20% of the generated sediment was discharged from the catchment. The woody debris budget of the Appetsu River basin showed that $65,000 \text{ m}^3$ of woody debris was newly produced from living trees on slopes or floodplains. An amount of $23,377 \text{ m}^3$ originated from slope failures on mountain slopes or bank erosion; $10,604 \text{ m}^3$, from riparian forests; and $12,278 \text{ m}^3$, from old timber deposits along the river's course. Approximately $30,000 \text{ m}^3$ of woody debris was considered to remain upstream or to flow into the sea. In the Appetsu River basin, most shallow slope failures occurred during the period when the rain intensity reached 40 to 50 mm/h. There seemed to be no time lag between the occurrence of slope failures and the inflow of debris to the basin.

1. INTRODUCTION

On August 9 and 10, 2003, Typhoon 0310 (Etau) hit the Saru and Appetsu River Basins in the Hidaka region of Hokkaido and caused the largest amount of rainfall on record. The total maximum daily rainfall was 358 mm and the maximum hourly rainfall was 76 mm (at the Asahi AMeDAS station).

Mountainous stream area experienced disasters caused by the washouts of the sediment and woody debris produced by shallow landslides and debris flows (Photo-1), while the middle and lower reaches of the stream suffered large-scale flood damage. In the basin of the Nukabira River, a tributary of the Saru River, more than 4000 shallow landslides occurred and they led to large amounts of sediment and woody debris being washed into river channels and reservoirs (Photo-2). In the Appetsu River basin, enormous amounts of woody debris were washed into rivers, which increased destruction by damaging bridges and houses. The sediment and woody debris budgets in the Nukabira River Basin were revealed by using GIS to combine aerial photography and satellite image data. Data on

the shallow landslides were compiled as GIS data. The data were used together with additional details—landslide area, type of geology, slope gradient, elevation, slope aspect, and vegetation cover. Multivariate analysis was conducted to find the contribution ratio of the rainfall and topographic factor to the slope failure factor.

In order to determine the routes and rates of sediment movement through drainage basins, sediment transport and storage along the channel network with adjacent hill slopes were investigated for a small catchment of the Saru River watershed. The woody debris budget throughout the Appetsu River basin was investigated by field survey and aerial photograph analysis. The time of supply of the sediment and woody debris from upstream of the basin was examined by a fact-finding survey of the basin's inhabitants.

2. CHARACTERISTICS OF SHALLOW LANDSLIDES AND WOODY DEBRIS BUDGET IN SARU RIVER BASIN



Photo.1 Over 3,000 shallow landslides occur in the Appetsu river basin (taken on 13th Aug. 2003 by Dr. Watanabe)



Photo.2 50,000 m³ of drift wood accumulated in the Nibutani dam reservoir (taken on 10th Aug. 2003 by the Hokkaido development bureau)

From August 9 to 10, 2003, most of the Saru River Basin experienced torrential rainfall exceeding 300 mm. The precipitation recorded at the Biratori observation station was 306.2 mm during a 48-h period; this was the most intense rainfall since measurements started in 1962. At the Nibutani dam reservoir (A = 1,215 km²), a maximum inflow of 6,400 m³/s (peak specific discharge of 5.26 m³/s/km²) was recorded and 50,000 m³ of woody debris were deposited. Figure 1 shows the locations of shallow landslides with total rainfall contour of the Nukabira River Basin. The total precipitation in most parts of the Nukabira Basin from August 9 to 10 was over 300 mm and exceeded 400 mm in a particular part of the basin. This storm event triggered over 4,000 shallow landslides in the Nukabira River Basin.

Figure 2 shows the changes in the shallow landslide area and shallow landslide ratio (landslide area/target area) in the Nukabira River Basin. The bar charts for 1955, 1978, 1993, and 1999 are

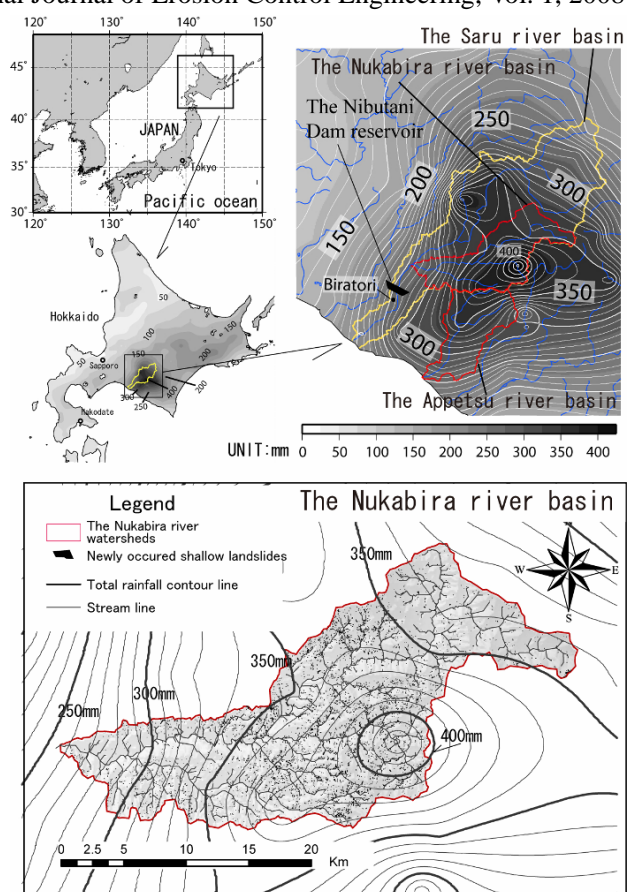


Fig. 1 Typhoon ETAU total rainfall map (August 9-12, 2003.), constructed using data provided by Ministry of Land, Infrastructure and Transport.

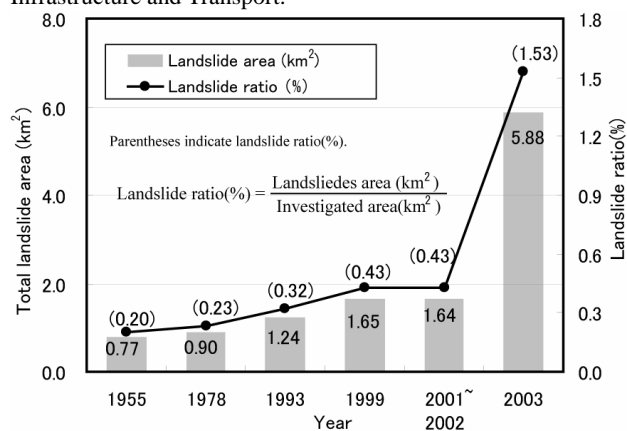


Fig. 2 Changes in landslide area and ratio in the Nukabira river basin (Murakami & Nakatsugawa, 2004)

obtained on the basis of the photointerpretation; the bar chart for 2001~2002 is derived from IKONOS satellite image analysis, and that for 2003 is obtained from the interpretation of aerial photos. The bar chart in 2003 indicates that the shallow landslide area increased as compared to the previous year by a factor of 3.6.

The sediment and woody debris budgets were estimated by examining the shallow landslides in the Nibutani Dam Basin, excluding the upper reaches of the Pankenushi, Chiroro, and Nukabira rivers, using SPOT satellite image captured on 16

June 2005. The volume of sediment produced in the Nibutani Dam reservoir was estimated by multiplying the averaged shallow landslide thickness, obtained from field survey of 35 sites, with the shallow landslide area; the total amount of sediment produced was 18.4~19.3 million cubic

meters (Figure 3). The woody debris newly generated from all the shallow landslides, estimated by multiplying the timber volume of forests by the shallow landslide area, was estimated to be 186,000~196,000 m³. Field investigation results suggested that approximately 7,000 m³ of the woody debris in the Nibutani Dam Reservoir was identified as newly generated from forests on mountain slopes. This suggested that most of the woody debris remained in the upper reaches of the river.

The rainfall intensity, geology, vegetation, and topography are four important factors that determine the occurrence of shallow landslides. This study attempts to clarify the relationship between the occurrence of shallow landslides due to Typhoon 0310 (ETAU) and each of these four factors in the Nukabira River Basin.

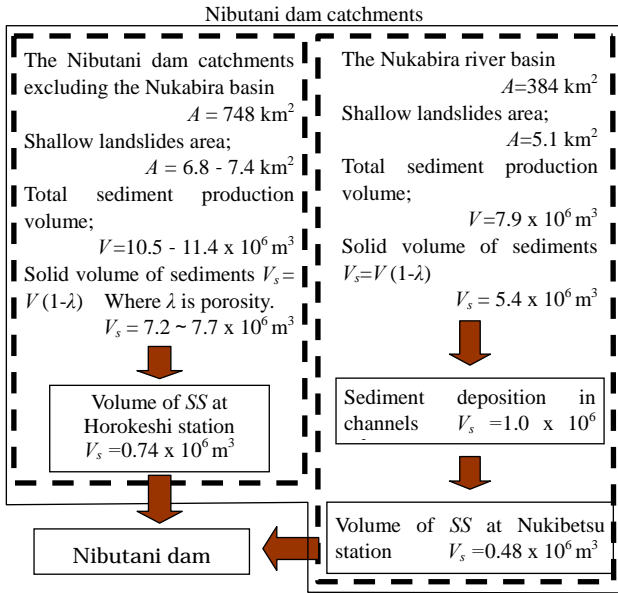


Fig.3 Sediment budget of Nibutani dam basin (August 9th-12nd, 2003.). Where $\lambda=1-1.8(t/m^3)/2.65(t/m^3)$, SS is

(1) Relationship between shallow landslides and total rainfall

The upper left of the figure 4 shows the area of landslides in relation to the number of landslides of the various total rainfall ranks. The lower left of the figure 4 shows the shallow landslide density (the number of landslides per unit area, or area of landslides per unit area), which indicates that the shallow landslide density tends to increase when the

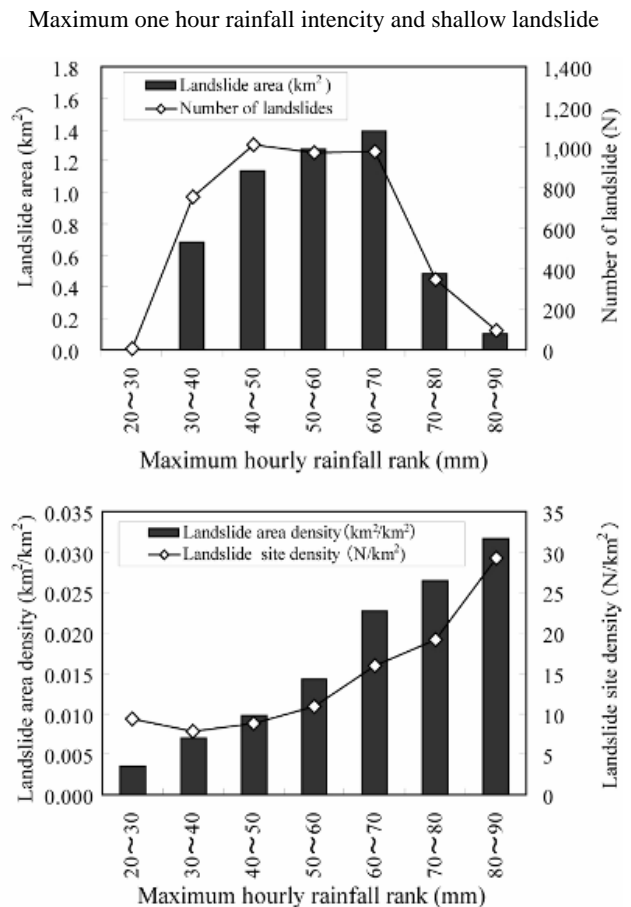
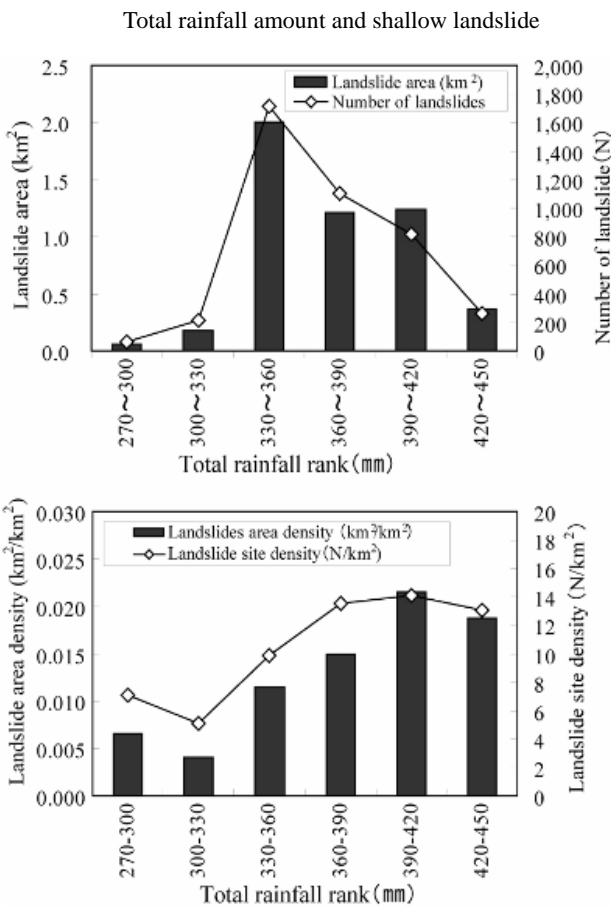


Fig. 4 Relationship between slope failure and total/short rainfall factors (Murakami & Nakatsugawa, 2004)

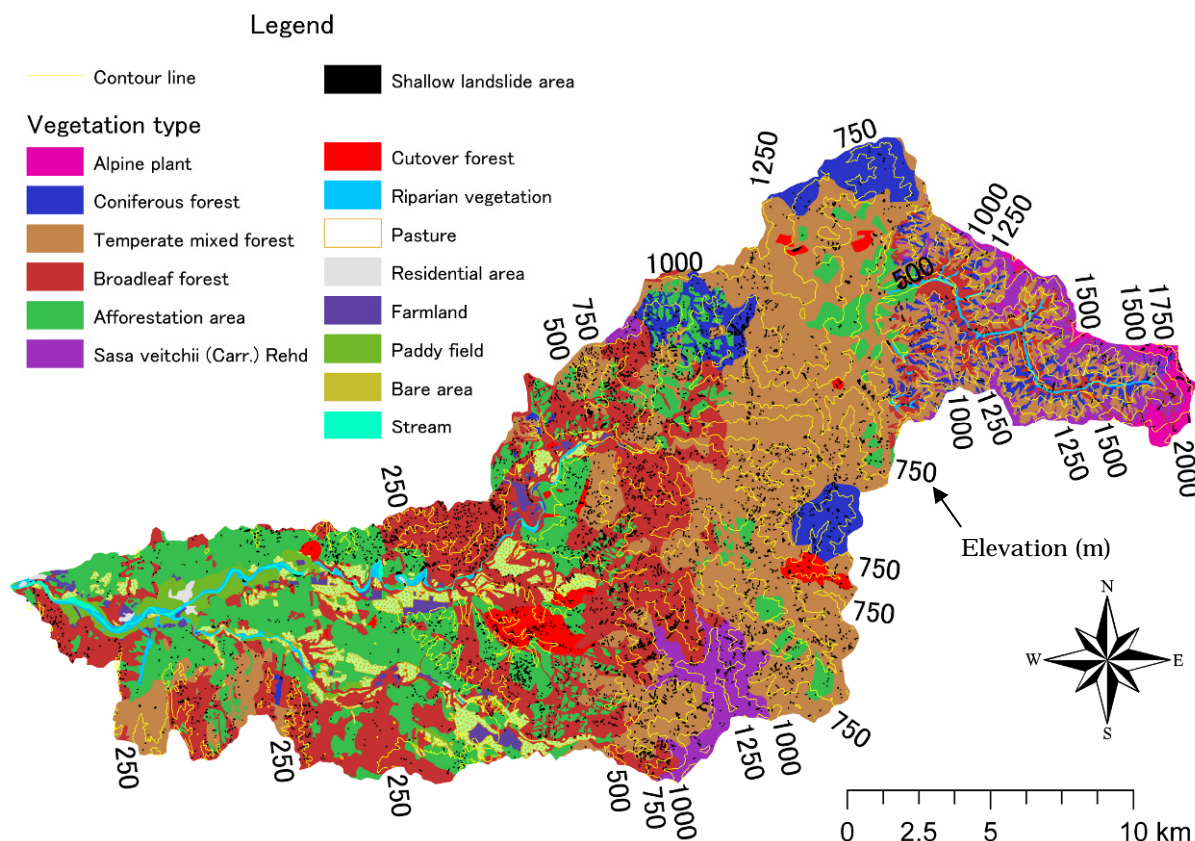


Fig.5 Shallow landslides and vegetation map of Nukabira river basin. Vegetation map was modified from “Actual vegetation map” of YUBARIDAKE and URAKAWA, 1/50,000, Ministry of the Environment Japan.

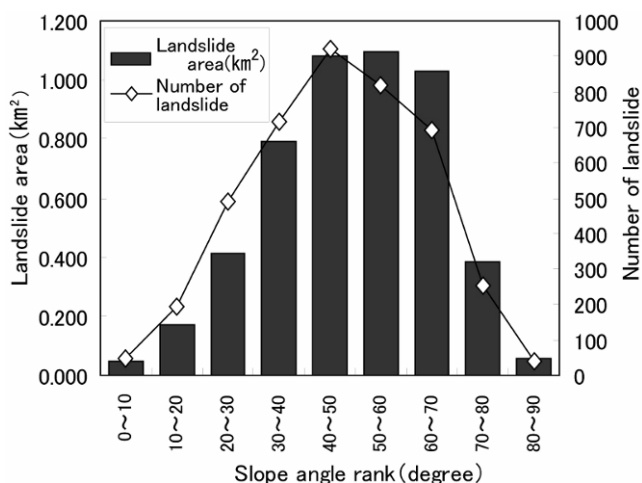


Fig.6 Histogram of shallow landslides barycenter with slope angle (Murakami & Nakatsugawa, 2004)

total rainfall amount exceeds 330 mm.

(2) Relationship between shallow landslides and maximum hourly rainfall.

The upper right of figure 4 shows the area of shallow landslides in relation to the number of landslides of the various maximum hourly rainfall on the basis of radar rain gauge data (2.5-km resolution, calibrated with ground rainfall data) for the period from August 8–10, 2003. The lower right graph of figure 4 shows the shallow landslide density (the number of landslides per unit area, or

area of landslides per unit area), which indicates that the shallow landslide occurrence has a tendency to increase with the maximum hourly rainfall intensity.

(3) Relationship between shallow landslides and geology

Shallow landslides in the Nukabira River Basin were plotted on a geological map (not shown). It was found that shallow landslides tend to occur on accretionary prisms and cretaceous sediment rocks as compared to other geologic rocks. The shallow landslide density in the Nukabira River Basin also indicated the same tendency.

(4) Relationship between shallow landslides and vegetation

Shallow landslides in the Nukabira River Basin were plotted on vegetation maps. It was found that approximately 75% of the shallow landslides occurred in mixed or broadleaf forests. The shallow landslide density of the afforested area in the Nukabira River Basin was slightly lower than that of natural forests such as mixed and broadleaf forests.

(5) Relationship between shallow landslides and topography

A digital surface model (DSM) obtained through

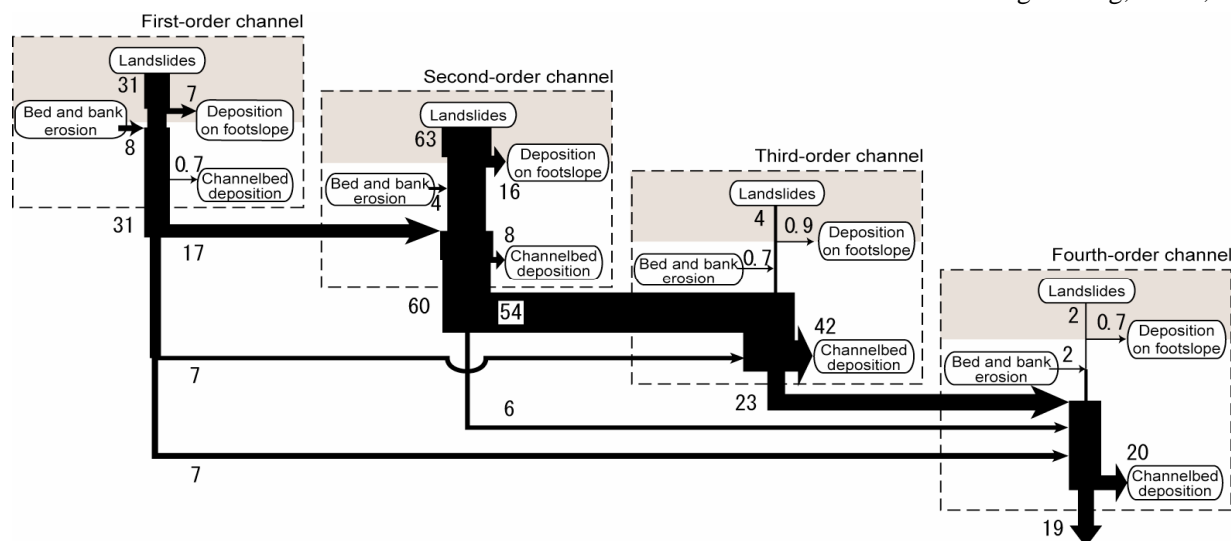


Fig.7 Flowchart illustrating sediment budgets constructed for basins of each channel order and sediment transfer between these basins during the August 2003 rainstorm in the fourth-order Rubeshubenai Creek. Line widths are proportional to the amount of sediment transferred, and values are shown in $\times 10^3 \text{ m}^3$.

the generation of orthorectified images from aerial photos was used to determine the relationship between shallow landslides and the slope gradient. Slopes with gradients of 30° to 70° had a high landslide density, with the peak occurring at gradients of 50° to 60° (Figure 6).

3. SEDIMENT BUDGET AND ROUTES FOR A SMALL CATCHMENT OF SARU RIVER

Pre- and post-rainstorm field surveys along the channel reaches, including adjacent slopes, allowed us to precisely measure the sediment transport and storage triggered by the rainstorm. By this method, the type and location of sources, delivery routes, location of deposition, and amount of sediment were investigated in the 2.1 km^2 watershed of the fourth-order Rubeshubenai Creek.

The Rubeshubenai channel network comprises a fourth-order channel, two third-order channels, five second-order channels, and 27 first-order channels. One of the five second-order channels directly drains into the fourth-order channel, and five and nine of the first-order channels directly link to third- and fourth-order reaches, respectively.

Figure 7 illustrates the sediment budgets prepared for the basins of each channel order and the sediment transfer between these basins during the August 2003 storm. In the first-order basins, landslides generated $31,000 \text{ m}^3$ of sediment, $7,000 \text{ m}^3$ of which was deposited on footslopes. Similar amounts were produced from channel-bed and bank erosion. Eventually, a total of $31,000 \text{ m}^3$ of sediment was transferred out of the first-order basins. An amount of $17,000 \text{ m}^3$ was transferred

into second-order channels; $7,000 \text{ m}^3$, into the third-order channels; and $7,000 \text{ m}^3$, into the fourth-order channel.

On slopes adjacent to second-order channels, two large and some small landslides occurred. These produced $63,000 \text{ m}^3$ of sediment, 25% of which remained on footslopes and 75% of which entered the channels. The erosion and deposition in the second-order channels contributed only a small amount to the sediment budget. Landslide-supplied sediment added to the sediment transported from first-order channels and thus, $60,000 \text{ m}^3$ of sediment moved downstream from second-order channels.

A total of $61,000 \text{ m}^3$ of sediment from second- and first-order channels entered the third-order reaches. Of this amount, $42,000 \text{ m}^3$ was deposited in the third-order channels, which aggraded remarkably. In the third-order channels, landslide and channel erosion produced only small amounts of sediment.

Approximately $23,000 \text{ m}^3$ of sediment from the third-order channels, $6,000 \text{ m}^3$ from second-order channels, and $7,000 \text{ m}^3$ from first-order channels were introduced into the fourth-order reach. Of this, $20,000 \text{ m}^3$ of sediment was deposited in the fourth-order channel, and an estimated $19,000 \text{ m}^3$ was discharged from the watershed.

In the Rubeshubenai catchment, $42,000 \text{ m}^3$ of sediment was deposited in the third- and fourth-order channels during the August 1992 rainstorm that was the last large-scale event before the 2003 one (Shimizu, 1998). Therefore the amount of sediment deposited in the same channel reaches during the 2003 storm was 1.5 times that of the 1992 storm.

Most of the sediment that was transported during the 2003 rainstorm originated from several landslides in the first- and second-order basins. This sediment passed through these lower-order channels and was then stored in the third- and fourth-order channels. In particular, the two large landslides that were initiated adjacent to second-order channels evolved into debris flows, which filled the downstream third-order streambeds with a considerable amount of sediment. The sediment yield from the entire watershed was 19,000 m³ during this storm. Within the watershed, however, the sediment yield varied widely with the basin order due to the spatial distribution of the sediment sources and sediment storage.

4. DEPOSITS OF WOODY DEBRIS ON FLOODPLAINS AND THEIR SOURCES IN APPETSU RIVER BASIN

A large amount of woody debris flowed along the river course, and it destroyed bridges and houses in the Appetsu River basin (Sato *et al.*, 2006). We mapped the slope failures by using aerial photographs and satellite images, quantified the woody debris by field surveys, and estimated the extent of riparian forests lost to estimate the source of the woody debris and the inputs and outputs of woody debris at the river basin. We divided the Appetsu River basin into five sub-basins: Ribira River, Piu River, Motokambe River, upper-middle reach of the main stream, and middle-lower reach of the main stream.

The area for which we were able to investigate slope failures with the aid of aerial photographs and satellite images was 82% of the total forested area (23,002 ha) of the Appetsu River basin. The ratio of the area of the slope failure caused by Typhoon

0310 to the investigated area was 1.7%. If the slope failure ratio in the noninvestigated area is assumed to be the same as that in the investigated area, the slope failure area in the entire basin is estimated to be 396.8 ha; this value is obtained by multiplying the total forested area by the slope failure ratio. We obtained the average tree volume per hectare from the records of national and private forests. Subsequently, the volume of woody debris resulting from slope failures was estimated to be 57,100 m³ in the entire basin.

We investigated the condition of the riparian forests along the main stream of each sub-basin. Their distribution was assessed by aerial photographs taken before the typhoon. Riparian forests with green trees were considered as “intact” areas; areas with dark brown trees were considered to comprise fallen trees (hereafter referred to as “fallen” areas). Areas without any trees and colored light brown (similar to flood water) were considered to have lost their vegetation (hereafter referred to as “lost” areas). We measured the tree volume in eleven natural riparian forest plots to obtain the standard tree volume per hectare of a natural forest (142 m³/ha). We obtained the tree volume of planted riparian forests from the records of national and private forests. Stem breakage was observed in 50% of the “fallen” riparian forest plots. In the forests where stem breakage was observed, 70% of the tree volume was considered to be lost. Considering these ratios, 35% of the tree volume of “fallen” riparian forests was considered to be lost. All the trees in “intact” forests were assumed to be retained and all the trees in “lost” forests were assumed to be lost. Thirty-three hectares (15%) of the total area of riparian forests (223.5 ha) in the Appetsu River basin was estimated to be “lost” and 67.2 ha (30%) was estimated to be “fallen.” An area

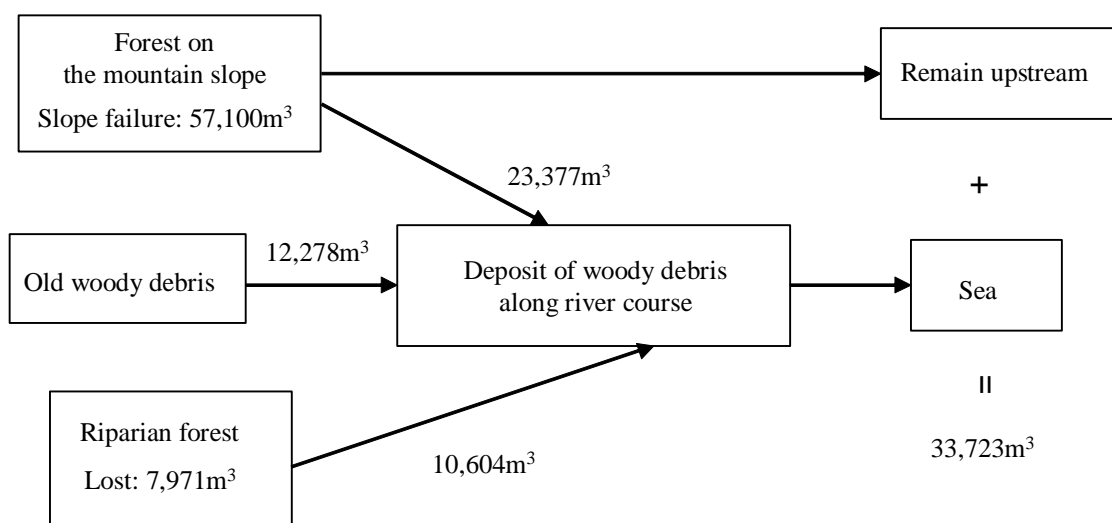


Fig.8 Summary of the movement of woody debris

of 31.8 ha in “lost” areas and 66.2 ha in “fallen” areas comprised natural forests. From the values mentioned above, 7,971 m³ of woody debris was estimated to be lost from riparian forests.

The distribution of woody debris along the main stream for each sub-basin was investigated by establishing investigation plots and grouping each plot into two groups according to the deposition pattern. At locations where woody debris was piled up, we measured the volume of a representative pile, counted the number of piles in the investigation plot, and regarded the product of these two quantities as the volume of woody debris in the plot. At locations where woody debris was scattered, we established a representative square plot, measured the volume of woody debris in the square plot, and obtained the volume of woody debris in the investigated area from the ratio between the area of the square plot and the investigated area. Totally, thirty-one investigated plots were established to have piled debris and thirty investigated plots were established to have scattered debris. We chose 20 pieces of wood randomly from each plot with piled debris, or from each square plot with scattered debris; we then identified the tree species and determined whether it became woody debris due to Typhoon 0310 or whether it was woody debris even before the typhoon, and we measured the diameter of the midpoints of the pieces of wood. *Salix* spp, *Alnus hirsuta* and *Fraxinus mandshurica* var. *japonica* were assumed to originate from riparian forests. Other species were considered to originate from slope failures on mountain slopes. The total volume of woody debris was 46,260 m³ in the Appetsu River basin. The amount of new woody debris from mountain slopes was 23,377 m³ (51%), that from riparian forests was 10,604 m³ (23%), and old woody debris was 12,278 m³ (26%).

Based on these results, the movement of woody debris can be summarized as shown in Figure 8. Approximately 23,400 m³ of the 57,100 m³ volume, which was contributed by slope failures on mountain slopes, was deposited as woody debris along the river’s course. Most of the remainder (33,723 m³) was considered to remain upstream and some part was considered to flow into the sea. The volume (7,971 m³) lost from riparian forests exceeded the woody debris derived from them (10,604 m³). This difference may be due to an error in the estimation of the volume lost from riparian forests or the woody debris volume. It was assumed that most of the wood lost from the riparian forest was deposited along the river’s course as woody debris.

5. TIMING OF SEDIMENT DISCHARGE UPSTREAM OF APPETSU RIVER

Along the Appetsu River, most slope failures occurred upstream of the main stream, Ribira River tributary streams, the Wenteshikan River, the Biu River, and other mountain streams along each tributary stream. The total volume of sediment produced along the basin was estimated to be 1,800,000 m³ (Yamada, 2004). The modes of the slope failures were mostly shallow landslides in forest soils with thicknesses of 10 to 50 cm located at the base of steep slopes (from 30° to 40°).

A fact-finding survey was performed among several inhabitants who lived in various areas of the basin to determine the time when they heard sounds that might be attributed to slope failures and debris flows, the time when sediment hit their houses, or the flood flow level in tributary streams and main stream river channels (Yamada, 2004). Samples of the information obtained from inhabitants upstream on the Ribira River are listed below.

Inhabitant A: “I heard a thunder-like sound from the mountain between 9 PM and 10 PM on August 9. When I went out of my house around 10 PM, there was a considerable amount of woody debris. The river almost burst its banks. At approximately 12 AM, water flowed near my house. At approximately 9 PM, a significant volume of water was flowing along the river channel.”

Inhabitant B: “Before 9 PM on August 9, I heard a ‘crumbling’ sound like thunder.”

Inhabitant C: “At around 9 pm on August 9, I heard a sound like thunder and a ‘crumbling’ sound like a tree trunk splitting, and knee-deep muddy water flowed in front of my house.”

Overall, most shallow slope failures occurred between 9 PM and 11 PM on August 9 (corresponding to the period when the rain intensity reached 40 to 50 mm/h), and sediment and woody debris were predicted to flow into tributary streams and river channel main streams. There seemed to be no time lag between the occurrence of slope failures and the occurrence of debris flows in the basins. These events coincided with the time when the water levels in the tributary streams were almost at their peaks, approximately 3 to 4 h before the main peak. At that time, large amounts of woody debris and sediment were deposited in the upstream tributaries of the Ribira River, Biu River, and Appetsu River. If we assume that the mean flow

velocity of the main stream was 3 m/s, the flood would arrive near Bukema Bridge (in the lower reach, approximately 5 km from the confluence of the main stream and the Biu River) in approximately 1.5 h, coinciding with the time when the Bukema Bridge was blocked by woody debris according to the inhabitants' testimonies.

In the middle and lower reaches of the Appetsu River basin, the river bed aggradation ranged from 20 cm to 50 cm, while the river bed aggradation of the main stream was approximately 20 cm. The main stream bed deposits comprised mostly sand. Many deposits containing stones with a size of approximately 15 cm were located in the middle and lower reaches of the tributary streams. Sediments from the Ribira River and the upstream Biu River mainly contained sand and gravel. The gravel tended to move and accumulate downstream in tributary river channels because it entered the river channel when the water levels of the tributary streams were close to their peak levels; the time of entry corresponded to the time when the tractive force was the greatest.

6. CONCLUSION

- (1) The storm-induced sediment solid volume in the Saru Basin was estimated as 13×10^6 m³. The amount of newly produced woody debris in the Saru River basin was estimated as approximately 190×10^3 m³, and less than 10% of this amount reached the Nibutani Dam reservoir. There was a tendency for shallow landslides to occur when the total rainfall exceeded 330 mm and also when the hourly rainfall intensity increased. The landslide density on slopes with gradients of 30° to 70° was high, with the peak occurring at gradients of 50° to 60°.
- (2) The sediment budget for a small catchment (2.1 km² in area) of the Saru River during the August 2003 storm revealed that approximately 100,000 m³ of sediment was generated by landslides, and 80% of this amount was stored in the catchment, especially in downstream higher-order channels; the sediment budget also revealed that only 20% of the generated amount was discharged from the catchment.
- (3) The woody debris budget of the Appetsu River basin demonstrated that 65,000 m³ of woody debris was newly produced from living trees on slopes or floodplains. An amount of 23,377 m³ of woody debris originated from slope failures on mountain slopes or bank erosion; 10,604 m³, from riparian forests; and 12,278 m³, from old timber deposits along the river's course.
- (4) Most shallow slope failures occurred when the rain intensity reached 40 to 50 mm/h in the Appetsu River basin. There seemed to be no time lag between the occurrence of slope failures and the occurrence of debris flows in the basin.

REFERENCES

- Murakami, Y. and Nakatsugawa, M. 2004: Report of sediment-related disasters caused by Typhoon 10, Etau, in Hokkaido by the Committee on Hydrosience and Hydraulic Engineering of the Japan Society of Civil Engineers, pp. 4566. (in Japanese)
- Sato, H., Nagasaka, Y., Asai, T. and Terazawa, K. 2006: Quantification of the woody debris in Appetsu river basin by Typhoon 0310, Etau, Journal of the Japan Society of Erosion Control Engineering, Vol. 58, No. 6, Ser. No. 263, pp. 11–17. (in Japanese with English abstract)
- Shimizu, O. 1998: Sediment budgets to analyze sediment transport processes through drainage basins, Res. Bull. Hokkaido Univ. For., Vol. 55, No. 1, pp. 123–215. (in Japanese with English abstract)
- Yamada, T. 2004: Report of sediment-related disasters caused by Typhoon 0310, Etau, in Hokkaido by the Committee on Hydrosience and Hydraulic Engineering of the Japan Society of Civil Engineers, pp. 66–82. (in Japanese)