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Estimation of erosion and sediment outflow in the recent past

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Abstract The mountains surrounding Kyoto and its vicinity were completely devastated until about 100 years ago because of over-logging for firewood and lumber. The area's bedrock of weathered granite was bare in those days, and the mountains were white as if covered with snow. The production of large volumes of sediment raised riverbeds downstream and caused frequent flooding. Intense hillside sabo works (erosion control works), comprised of terracing and tree plantations, have been implemented for the last 100 years. Today, the area is almost completely covered with vegetation. Erosion rates in the area have been measured for the last 30 years. The data obtained were analysed and an erosion prediction method was developed. The method uses rainfall, topography of the slopes and basins, and the condition of vegetation as parameters. The method was applied to the area to estimate the erosion and sediment outflow 100 years ago. Riverbed elevation changes are also estimated using a sediment routing method based on the estimated erosion as a boundary condition.

Key words air photos; bedload; erosion; hillside works; historical map; riverbed elevation change; sediment routing; suspended load; washload

INTRODUCTION

The Tanakami Mountains near Kyoto City were devastated up until 100 years ago, because of over-cutting of trees for fuel and lumber. Since then, intensive hillside works involving terracing and tree planting have been implemented, and at present there are almost no bare slopes. The devastated condition of the mountains in the early 1900s was estimated from historical maps and old aerial photos. Sediment production rates were obtained from measurements over the last 30 years, and applied to the late 1800s and early 1900s using the percentage of devastated area as a parameter.

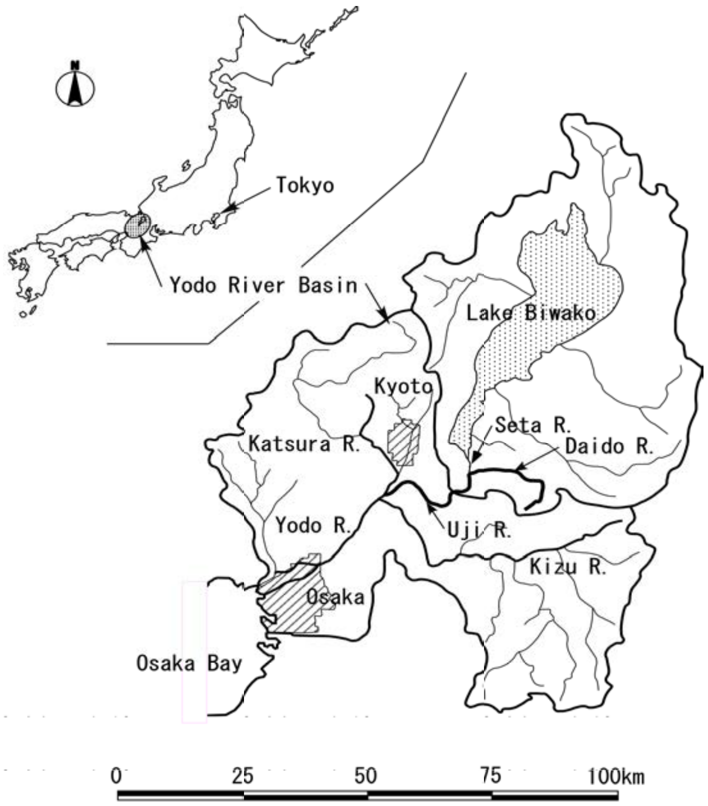


Fig. 1 Map of the study area.

STUDY AREA

Over-cutting of the forest in the mountains around Kyoto City took place from approximately 800 AD to 1900 AD because the inhabitants of Kyoto, the capital city at that time, and surrounding areas needed firewood and lumber. The bedrock of weathered granite in those areas was a major reason for the devastation. The less cohesive topsoil on the slopes was easily washed away by rains after deforestation. In the early 1900s, the engineer J. Drijke was invited from The Netherlands to provide advice on the implementation of hillside works in the mountains to prevent sediment outflow to the Yodo River and Osaka Harbour (Fig. 1). One of those projects was carried out in the Tanakami Mountains in the upstream area of the Uji River basin. Figure 2 is a historical map showing the bare slopes in the devastated areas in 1878.

CHANGE OF THE AREA BY HILLSIDE WORKS

Hillside works to reduce erosion have been conducted intensively in the study area for more than 100 years. Figure 3 shows the change in the area of bare soil estimated from aerial photos taken several times since 1947. Figure 4 shows an example of the slopes before and after the hillside works. The success of the hillside works is due to the efforts of people and the mild, humid climate. The hillside works involve terracing the bare slopes, planting trees (Japanese black pine and Japanese green alder), followed by continued maintenance.

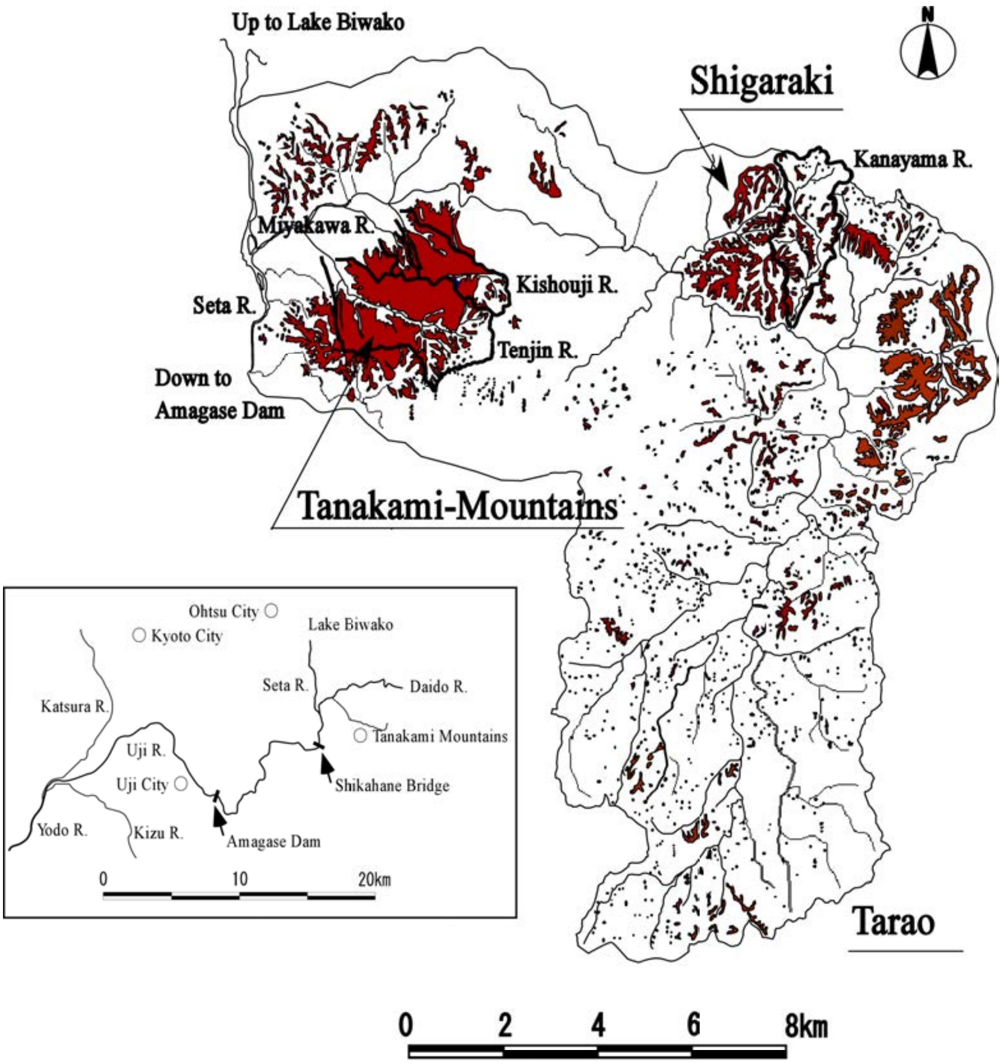


Fig. 2 Historical map showing the devastated areas in the Tanakami Mountains in 1878.

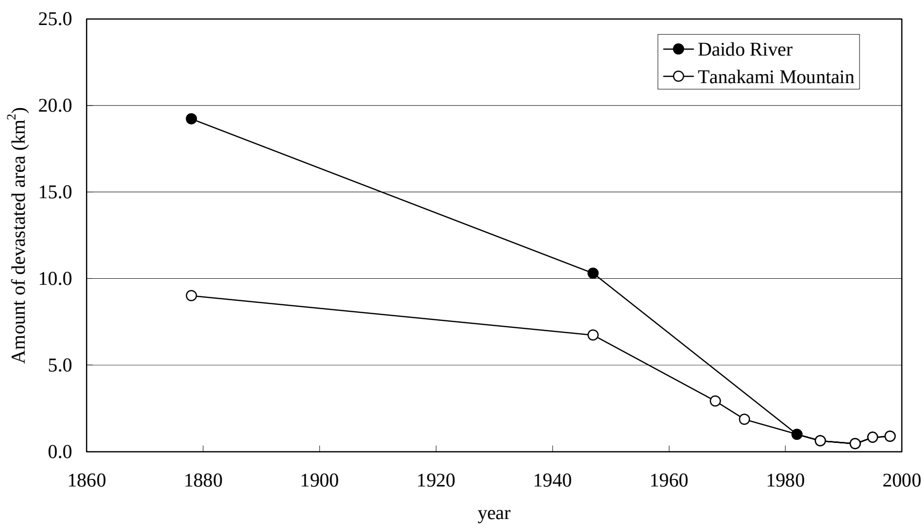


Fig. 3 Change in area of bare slopes resulting from hillside works in Tanakami Mountains.

Fig. 4 The Tanakami Mountains before and after hillside works.

MEASUREMENT OF SEDIMENT PRODUCTION

Sediment production rates have been measured directly with sediment traps at the downstream ends of the experimental slopes, and at the outlets of small basins, with surface conditions ranging from bare soil to dense forest. Figure 5 shows the sediment production rate (m^3 year^{-1}) for more than 30 years. The sediment production rate was reduced remarkably by the hillside works. The early, large drop in the sediment production rate in Fig. 5 is likely the result of terracing.

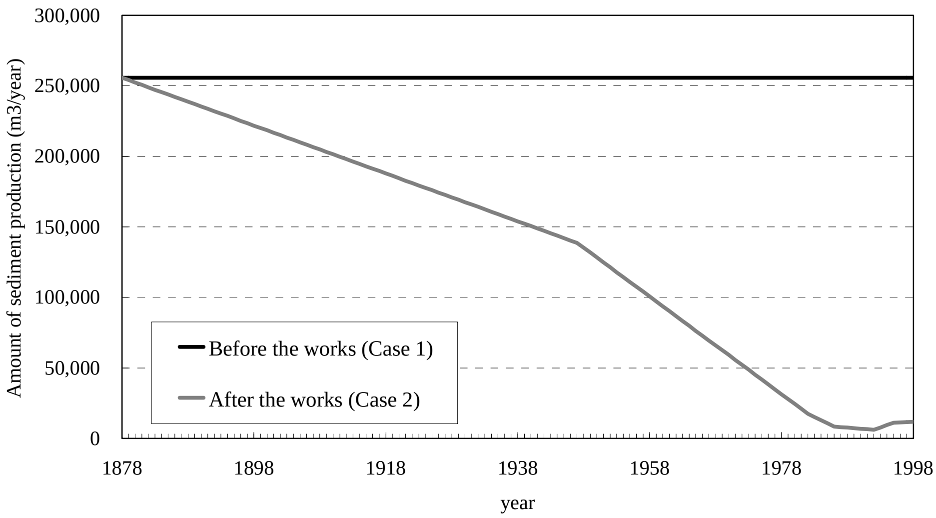


Fig. 5 Changes in sediment production rates.

CALCULATION OF SEDIMENT OUTFLOW AND RIVERBED ELEVATION

Sediment production in the mountain areas and outflow to downstream areas through the Uji River for the last 120 years was calculated using the Ashida-Michiue’s bedload and suspended load equations (Ashida & Michiue, 1971). The water surface profiles were calculated as non-uniform flow. Conditions for the calculation are as follows:

(a) Reach calculated: the downstream end is the junction of three rivers: the Katsura, the Uji and the Kizu (37 km upstream from the mouth of the Yodo River). The upstream end is the junction of the Daido River and the Seta River (69 km). The length of the reach for the calculation is 32 km.
(b) Duration calculated: 120 years, from 1878 to 1998.
(c) Initial river profiles: the oldest available data were used. The initial riverbed was treated as immobile.
(d) Sediment properties: the grain size distribution at the source area (Fig. 6) was adopted.
(e) Discharge and hydrograph: the measured discharge from 1979 to 2000 at Kurotsu at the upstream end of the calculated reach was applied repeatedly for 120 years. Water discharge was increased along the river in proportion to its drainage area.
(f) Sediment production: two scenarios were used to estimate sediment production. Case 1 assumed that the sediment production rate in 1878 continued for the entire period of 120 years and Case 2, which is the actual situation, assumed that sediment production decreased as hillside works progressed.
(g) Sediment supply: the sediment supply was given at the upstream end as equal to the smaller of sediment production and sediment transport capacity.

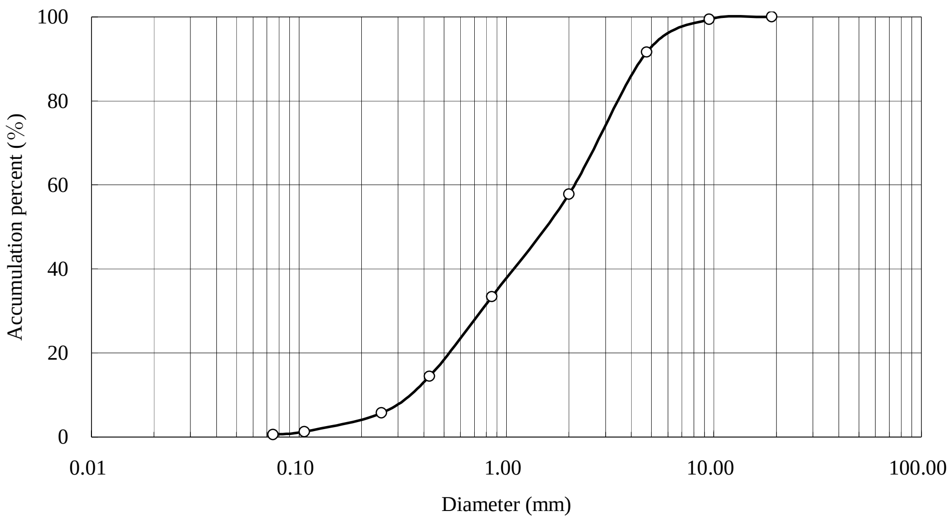


Fig. 6 Grain size distribution at the source area.

Calculated longitudinal profiles and riverbed elevation changes for both sediment production scenarios (Case 1 and Case 2) are illustrated in Figs 7 and 8. Volumes of sediment are summarized in Table 1. Sediment production, the sediment supply at the upstream end and sediment that was not transported by flow and remained at the upstream section are shown Fig. 9. No differences in Case 1 and Case 2 are seen until after 100 years. Sediment deposition decreased remarkably at the upstream reach in Case 2 over the last 20 years.

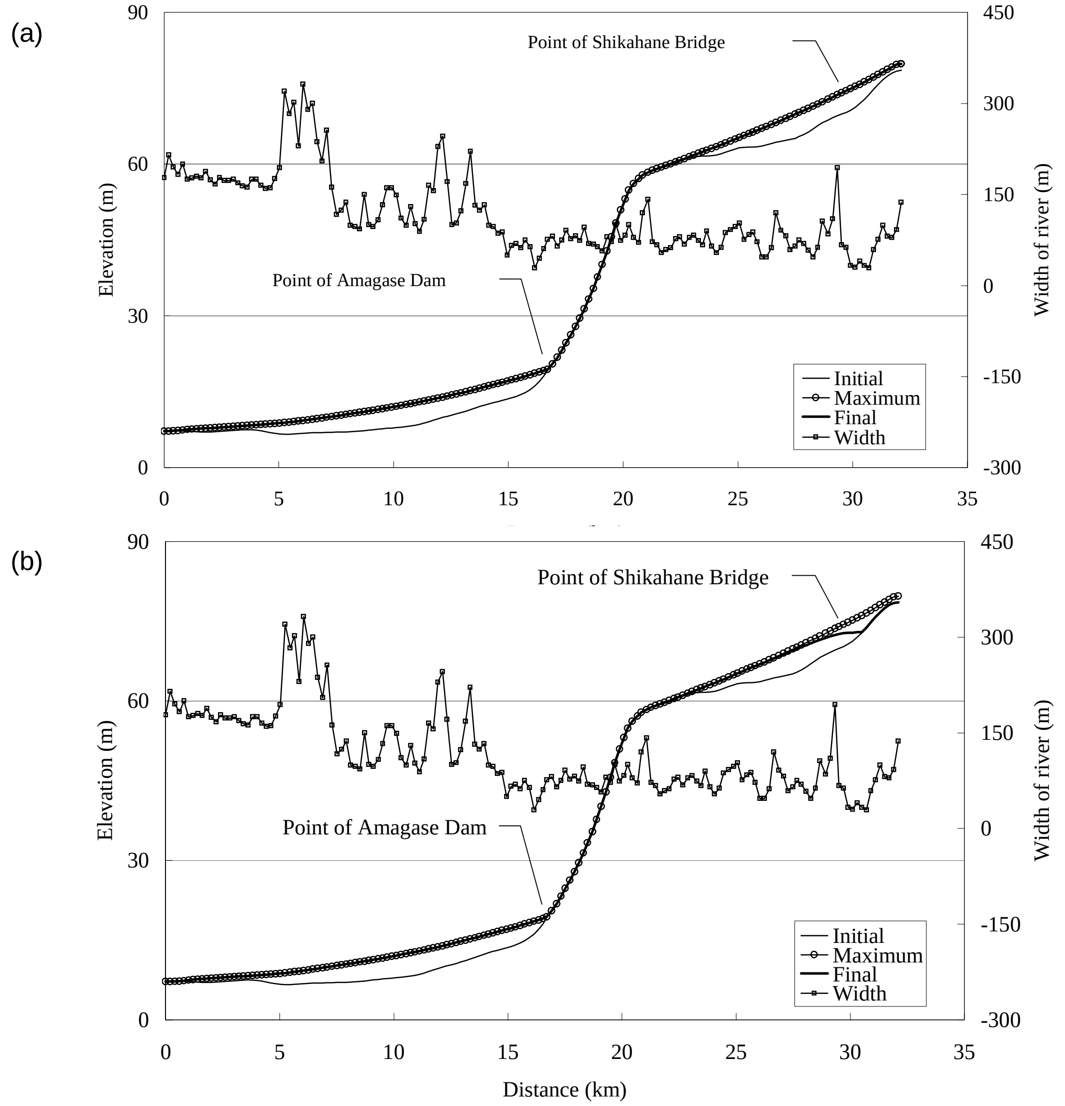


Fig. 7 Longitudinal profiles and riverbed elevation changes for (a) Case 1 and (b) Case 2.

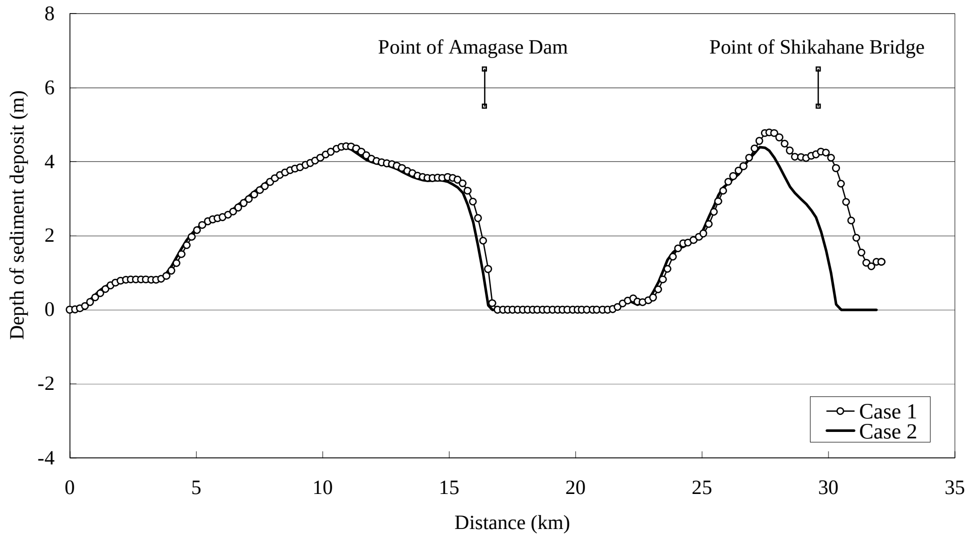


Fig. 8 Thickness of sediment deposited on the riverbed.

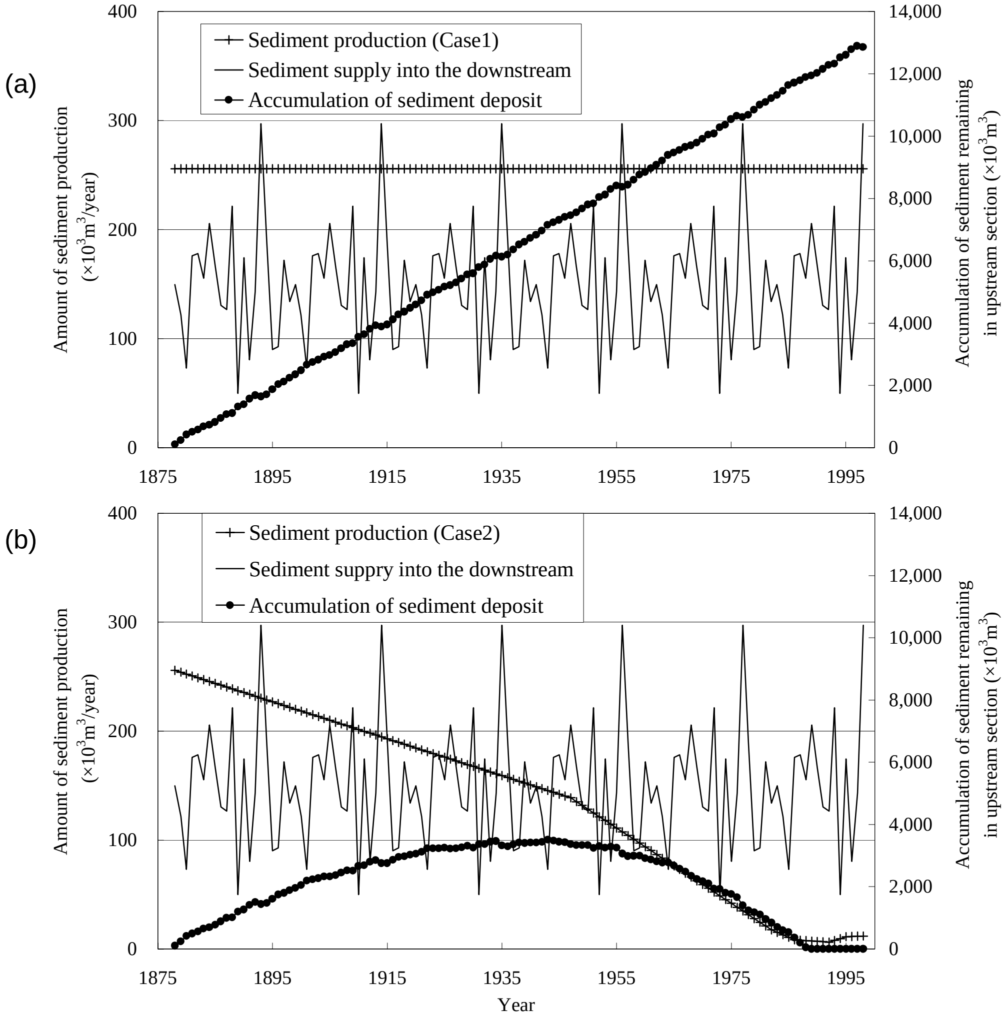


Fig. 9 Sediment production, sediment supply and sediment remaining at the upstream section: (a) Case 1 and (b) Case 2.

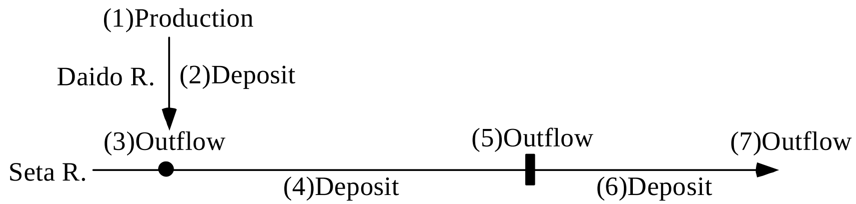
WASHLOAD MEASUREMENT

Washload was measured at the Kurotsu Bridge of the Daido River from 1975 to 1996 (Nakamura *et al*., 2000). When washload is presented as a function of water discharge ($Q_s = \alpha Q^{\beta}$), β was almost constant with an average value of 1.85, whereas α decreased gradually from 4.76×10^{-6} in 1978 to 8.75×10^{-7} in 1993 (Fujita *et al*., 1999). This observed trend is in agreement with the calculated results.

CONCLUSIONS

Sediment production in the past, from the 1880s to the present, was estimated from data for the most recent 30 years. The results show that 250 000 m^3 of sediment was produced and transported downstream, which raised the riverbed by 12 cm $year^{-1}$ 120 years ago. Hillside works, consisting of terracing and planting, did not have much influence immediately after the works started in the early 1900s. In the upstream reach, the works have only been effective in the last 20 years.

Table 1 Volumes of sediment ($\times 10^3$ m^3) in Cases 1 and 2.



Period	Phenomenon / Place	Production (1) In the Daido River basin	Deposit (2) In the Daido River basin	Outflow (3) From the Daido River	Deposit (4) In upper river	Outflow (5) At the Amagase Dam	Deposit (6) In downstream river	Outflow (7) Into the Yodo River
Case 1:								
From 1878 to 1964 before construction of Amagase Dam		21 992	8 634	13 358	2 121	11 237	5 419	5 818
From 1964 to 1998 after the construction		8 950	4 502	4 448	274	4 174	1 871	2 303
From 1878 to 1998 Total volume of sediment		30 942	13 137	17 806	2 395	15 411	7 290	8 121
Case 2:								
From 1878 to 1964 before construction of Amagase Dam		15 554	2 972	12 582	2 065	10 517	5 103	5 414
From 1964 to 1998 after the construction		1 081	–2 714	3 794	–296	4 091	2 050	2 041
From 1878 to 1998 Total volume of sediment		16 635	259	16 376	1 768	14 608	7 153	7 455

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