Extraction of Debris-Flow-Prone Mountain Streams Using High-Resolution Elevation Data



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Introduction

Railway tracks in Japan cross numerous mountain streams. When debris-flows occur in such streams during or after intense rainfall (e.g., *Figure 1*[1]), they can damage or deform tracks and other railway structures and, in some cases, result in prolonged service suspensions during recovery work. Ideally, preventing such damage requires detailed field surveys of individual streams, followed by assessments of the likelihood and potential scale of debris-flow events and, where necessary, the implementation of protective measures. In practice, however, the large number of stream crossings makes it essential to first narrow down and prioritize candidate sites through desk-based screening.

The Geospatial Information Authority of Japan (GSI), an extraordinary organization of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), has made high-resolution elevation data covering Japan publicly available[2]. These data can be used to generate detailed topographic maps and readily perform analyses to quantitatively evaluate landform characteristics, such as slope gradients and the area of flat ground.

Against this background, RTRI has developed a desk-based method that utilizes high-resolution elevation data provided by GSI to extract mountain streams along railway tracks that are potentially susceptible to debris-flow hazards.

High-resolution elevation data developed by GSI

Elevation data for the ground surface are commonly referred to as a digital elevation model (DEM). In Japan, a DEM with 50-m meshes was first published in 1993[3], and nationwide coverage was achieved by 1999. This DEM was generated by extracting elevation values at approximately 50-m intervals from 1:25,000 topographic maps (corresponding to about 2-mm intervals on the maps).

Subsequently, a DEM with 5-m meshes was published in 2003[4]. Development initially focused on urban areas and gradually expanded outward, currently, most areas along railway tracks are covered, except for some mountainous regions. The currently available 5-m mesh DEM has been generated mainly using airborne laser scanning*. Compared with the conventional 50-m mesh DEM, the 5-m mesh DEM offers significantly improved resolution. This higher resolution enables the detection of fine surface features, such as landforms indicative of past debris flows. Taking advantage of this capability, the developed method uses the 5-m mesh DEM.

Method for extracting debris-flow-prone mountain streams

The developed method uses the 5-m mesh DEM published by GSI to identify de-

*** Airborne laser scanning**
Airborne laser scanning is a method for measuring the distance between an aircraft and the ground surface based on the time required for laser light emitted from a laser scanner mounted on the aircraft to travel to the ground, be reflected, and return to the scanner. By combining this measurement with GNSS (Global Navigation Satellite System) and IMU (Inertial Measurement Unit), which accurately determine the position and attitude of the aircraft, the elevation of the ground surface can be obtained. This enables the creation of accurate, high-resolution DEMs.



Figure 1 Debris-flow event that occurred near Ryugamizu Station on the Nippo Main Line in August 1993[1) (trimmed)]

bris-flow-prone mountain streams from two perspectives (*Figure 2*): (1) the susceptibility of mountain streams to debris-flow events (hazard level assessment) and (2) the degree of impact on railway tracks in the event of a debris flow (impact level assessment). A key feature of this method is that it relies solely on publicly available data as inputs, enabling extraction of debris-flow-prone mountain streams without conducting any preliminary field surveys.

Hazard level assessment: susceptibility of mountain streams to debris-flow events

The hazard level assessment (*Figure 3*) first assesses the susceptibility of mountain streams to debris-flow events by identifying the presence or absence of landforms called alluvial cones on maps generated from the 5-m mesh DEM. An alluvial cone is a fan-shaped landform found at the outlet of a mountain stream and is considered to have formed through past debris flows.

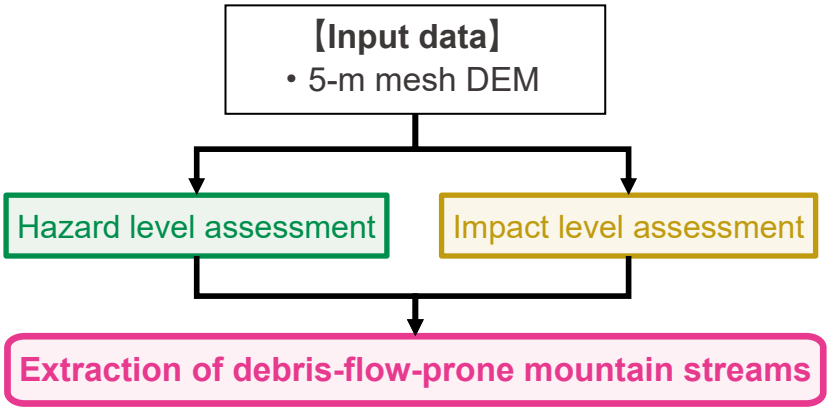


Figure 2　Method for extracting debris-flow-prone mountain streams

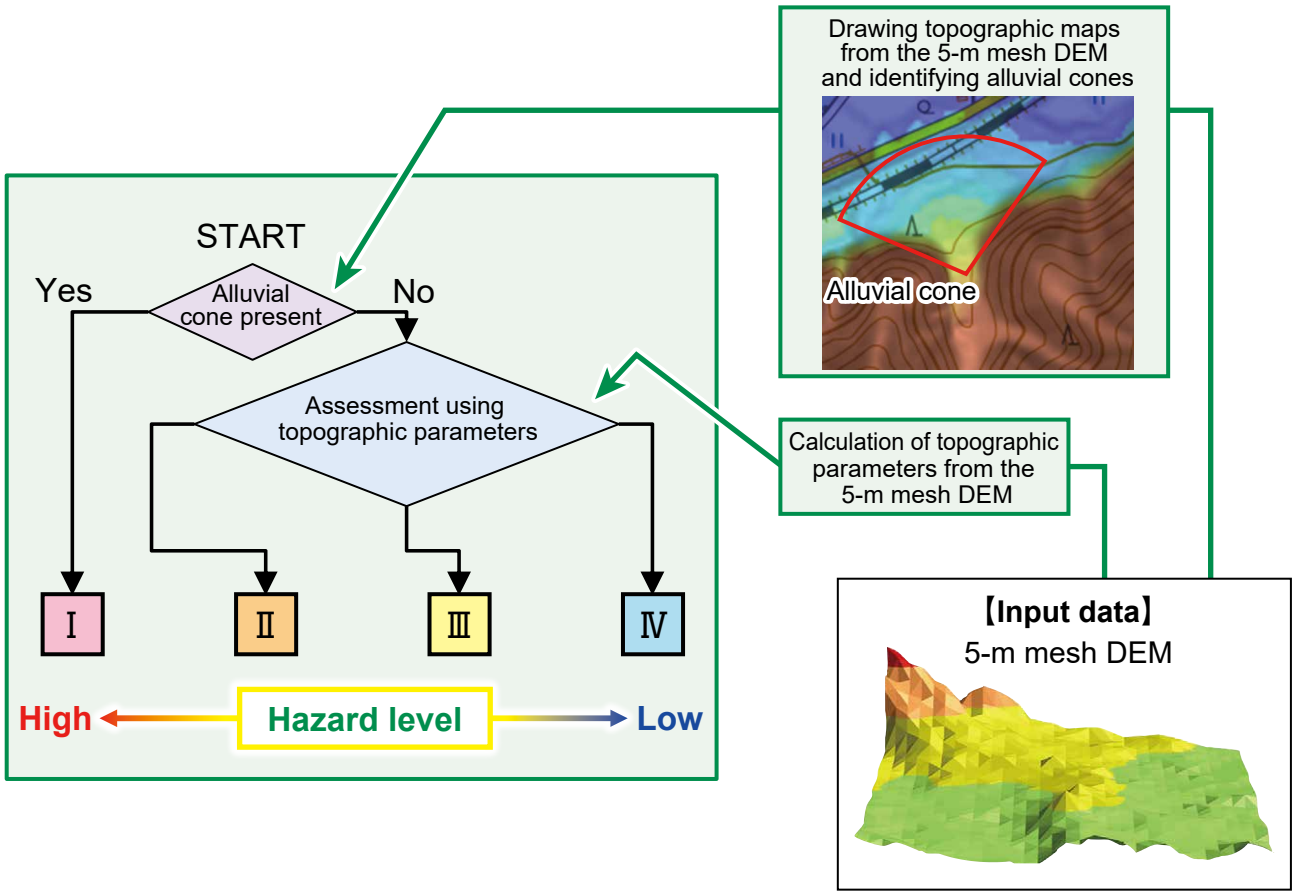
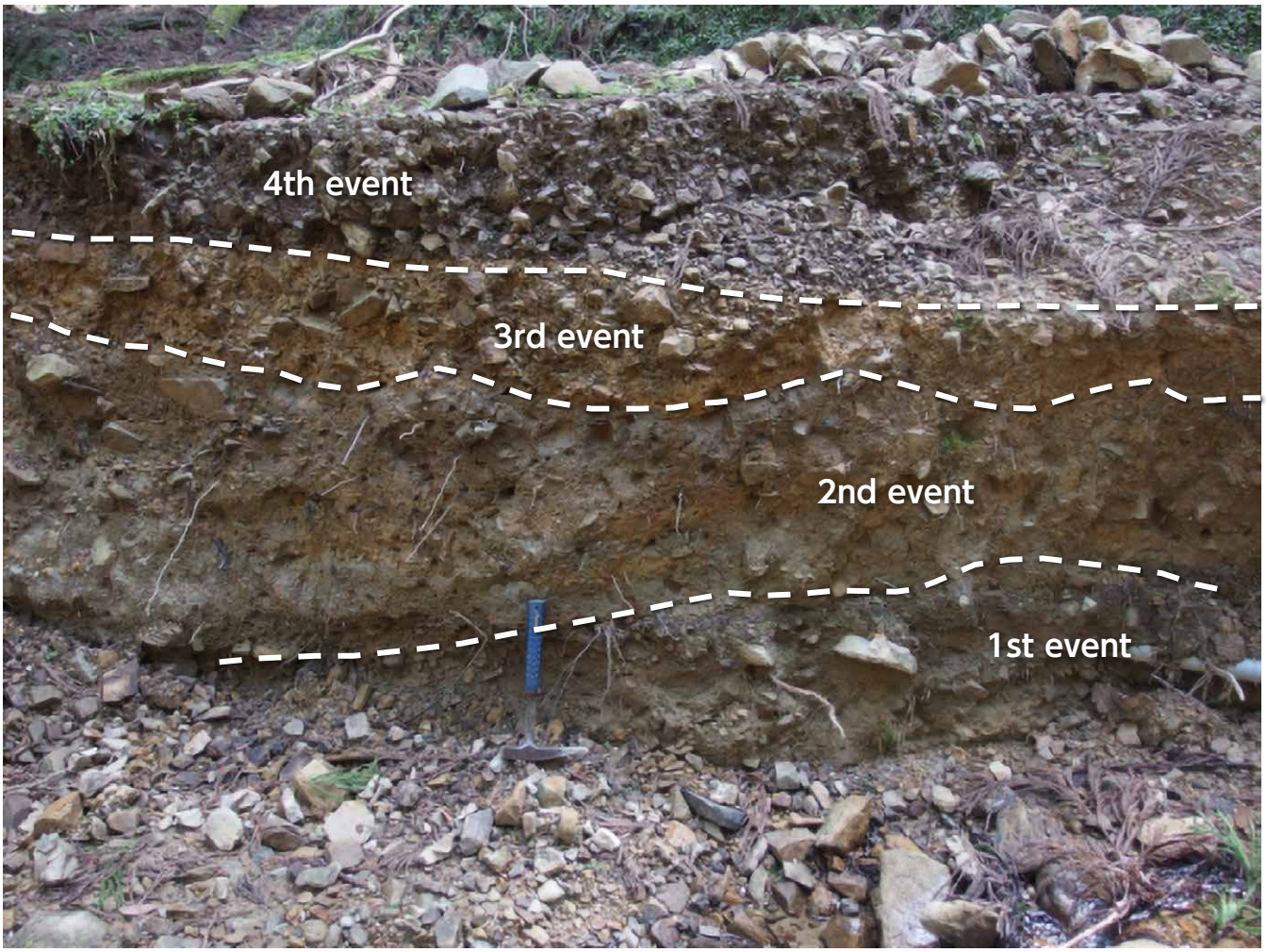


Figure 3　Method for hazard level assessment

When no alluvial cone is identified, the hazard level is further classified into three categories using indices representing landform characteristics calculated from the DEM (hereinafter referred to as "topographic parameters"). These topographic parameters include various indicators such as those related to slope gradient and valley density. After examining the relationship between these topographic parameters and past debris-flow events, those showing strong correlations are selected for hazard level



The numbers indicate the order of debris-flow events inferred from the condition of the deposits.

Figure 4 Cross-section of deposits at a stream outlet

assessment.

A key feature of this assessment method is that the identification of an alluvial cone —evidence of past debris flows—results in a high hazard level classification. This reflects the tendency of debris flows to recur in the same mountain stream. Cross-sections of deposits at stream outlets (*Figure 4*) reveal evidence of multiple debris-flow events.

As described above, the hazard level is assessed in four categories using only the 5-m mesh DEM.

Impact level assessment: degree of impact on railway tracks in the event of debris flow

The impact level assessment (*Figure 5*) evaluates the degree of impact on railway tracks in the event of a debris flow based on the estimated volume of sediment generated during the debris-flow event and the estimated volume that would be retained within the stream channel before reaching the track.

To estimate the volume of sediment generated during debris-flow events, topographic parameters calculated from the 5-m mesh DEM are also utilized. Topographic parameters that are correlated with sediment discharge volumes from past debris-flow events are selected, and these parameters are then used to estimate the generated sediment volume.

Part of the generated sediment is deposited on gently sloping areas within the stream channel, and the remaining sediment may reach the railway track. Therefore, the volume of sediment retained within the stream channel before reaching the railway

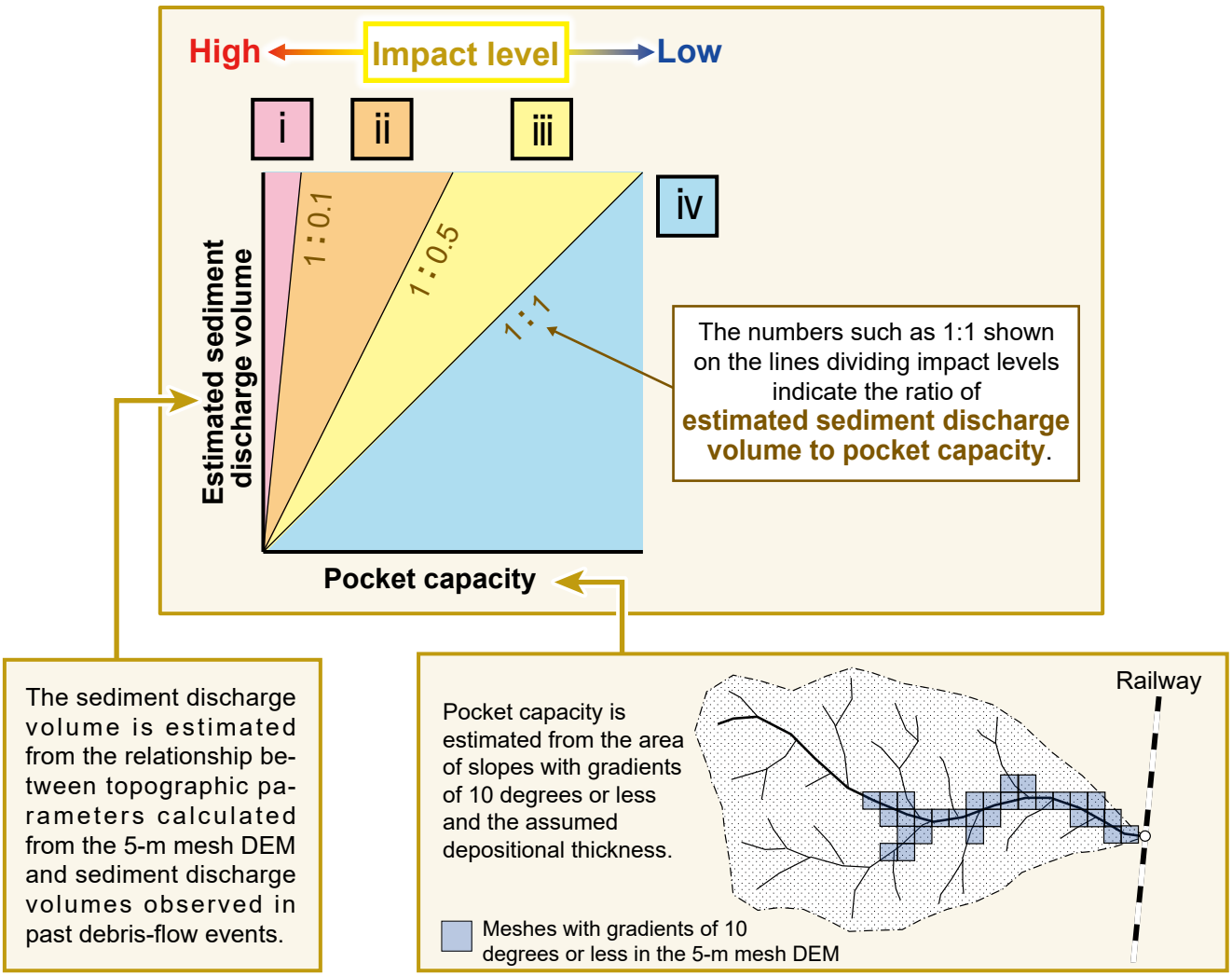


Figure 5 Method for impact level assessment

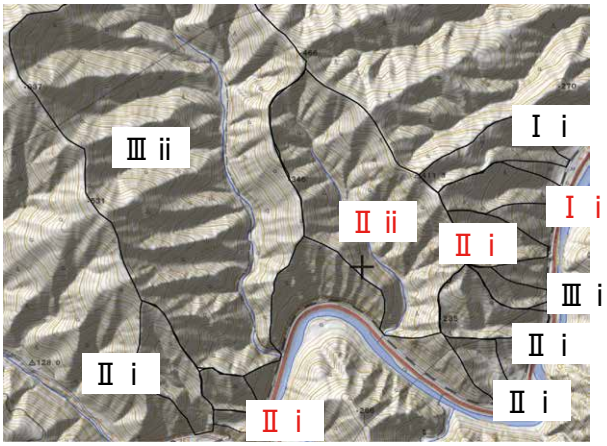
track (hereinafter referred to as "pocket capacity") is estimated from the area of slopes with gradients of 10 degrees or less and an assumed depositional thickness. The area of slopes with gradients of 10 degrees or less can be calculated from the DEM, and the assumed depositional thickness is set at 0.1 m based on field survey results.

Using the estimated volume of generated sediment and the pocket capacity obtained as described above, the impact level is assessed in four categories, with a higher impact level assigned when the estimated sediment volume exceeds the pocket capacity by a greater amount.

Extraction of debris-flow-prone mountain streams

Figure 6 shows the results obtained by combining the hazard level of mountain streams with the impact level for railway tracks in the event of a debris flow. For each mountain stream, the hazard level is classified from I to IV and the impact level from i to iv, with their combinations shown in *Figure 6* Among these, the results shown in red represent mountain streams where debris flows have actually occurred.

Table 1 shows the results obtained by applying this analysis to an entire railway section and summarizing the resulting hit rates. Here, the hit rate is defined as the percentage of mountain streams where debris flows have actually occurred. The results indicate that actual debris-flow-events fall within the range of hazard levels I–II and impact levels i–iii, indicating that this method can effectively identify debris-flow-prone mountain streams.



Red text：Mountain streams where debris flows have occurred

Black text：Mountain streams where debris flows have not occurred

Figure 6　Example application of the method for extracting debris-flow-prone mountain streams

Table 1　Verification example of the method for extracting debris-flow-prone mountain streams

Hit rate		Hazard level			
		Ⅰ	Ⅱ	Ⅲ	Ⅳ
Impact level	i	25%	43%	0%	0%
	ii	50%	60%	0%	0%
	iii	50%	100%	0%	0%
	iv	0%	0%	0%	0%

*Hit rate = number of mountain streams with debris-flow events / number of mountain streams in each category

Conclusions

This report presented a method for extracting debris-flow-prone mountain streams by utilizing high-resolution DEM data published by GSI. Since fiscal year 2023, the publication of 1-m mesh DEM data has also been in progress. In anticipation of these government data development plans, RTRI will explore potential applications of the new data in railway fields such as hazard prevention, enabling their effective use as soon as they become available to further enhance the safety and reliability of railway systems.

References

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3) Shimoyama, Y., Iida, S., Kawase, K., “Verification of the 50 m Grid DEM Data’s Accuracy,” Journal of the Geospatial Information Authority of Japan, No. 84, pp. 64-72, 1995 (in Japanese).
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