EXTRACTION OF HAZARDOUS LOCATIONS IN MARCH, 2018 HOKKAIDO ICE JAM FLOOD

TARO KOIKE
KITAMI Institute of Technology, Kitami, Japan, m1952200121@std.kitami-it.ac.jp

YASUHIRO YOSHIKAWA
KITAMI Institute of Technology, Kitami, Japan, yoshi@mail.kitami-it.ac.jp

HIROSHI YOKOYAMA
Civil Engineering Research Institute for Cold Region, Sapporo, Japan, yokoyama-h22ab@ceri.go.jp

ABSTRACT

An ice jam occurs when river ice flows downstream from an upstream reach where the river was frozen and accumulates downstream, resulting in rapid water level rises and subsequent flood disaster. Such ice-jam disasters occur in countries where temperatures get down to 0°C or below freezing. Disaster suffered by a sudden rise of water level from an ice jam occurred recently in Hokkaido, Japan. In this study, we tried to extract hazardous locations associated with the March, 2018, ice-jam occurrence by calculating the ice-jam scale (S_{ij}) which can be calculated using hydrologic variables, river width, slope, discharge, and water level. The ice-jam scale proposed here, one can determine a possible location of ice-jam for any river even if we do not have sufficient field information. S_{ij} was designed as a simple formula to allow fast calculation for an actual river. We did on-site inspections of the ice-jam-occurrence hazardous locations along the Bebetsu, Furebetsu, and Saru Rivers as determined by use of the scale. Our field observation confirmed, we confirmed that ice jams readily occur at sandbars, at a slope change point, on a mild slope, around a structure in the river, or in a meander section. S_{ij} was also applied at known accident or ice-jam occurrence sites and around these locations. We were able to successfully extract ice-jam-occurrence hazardous locations using S_{ij}.

Keywords: ice jam, ice-jam scale, hazardous location, frozen river, river ice

1. INTRODUCTION

Decreases in air temperature as well as flow velocity in winter cause ice formation in rivers in cold regions. When temperature and flow velocity subsequently increase, the ice in those rivers begins to melt, break, flow, and accumulate downstream. Such an ice-jam event occurred in Hokkaido, Japan, in March, 2018 (Yokoyama et al., 2018).

After this ice-jam related disasters in Hokkaido, a survey was performed to understand a demand of local government for mitigating such natural disasters. The result suggested a strong demand of a software to predict possible location of ice-jam in rivers.

We propose the ice-jam scale, which can be calculated by using hydrologic variables, to predict a possible location of ice-jam in rivers. In this study, we tried extraction of ice-jam-occurrence hazardous locations using the ice-jam scale (S_{ij}) (Yoshikawa et al., 2018) calculated from the hydrologic variables river width, river slope, discharge, and water level. Our target subject for extraction is the past ice-jam-occurrence location in March, 2018, in Hokkaido, Japan. S_{ij} can detect a possible ice-jam location on any river with even less information. The formula's simplicity was intended to enable it to do the calculation quickly for an actual river.

2. CALCULATION OF ICE-JAM SCALES

Watching the situation at particular spots while also watching weather data closely can be one way to prevent damage from a potential ice jam after having determined an ice-jam-outbreak danger point. Focusing on the ice jam that occurred in March 2018, we calculated S_{ij} to numerically express the scale of the next potential ice jam and also examined the ice-jam occurrence spot.

The ice-jam scale is calculated by

$$S_{ij} = \frac{1}{F_{ri}\sqrt{\frac{B_d}{B_i}}\sqrt{\frac{C_D}{2}\left(\frac{H_i}{L_i}\right)^2 + C_f\left(\frac{H_i}{L_i}\right) + \frac{C_L}{2}}} \quad (1)$$

where,

$$F_{ri} = \frac{U_i}{\sqrt{\frac{\rho_w - \rho_i}{\rho_w} g H_i}} \quad (2)$$

U_i is the speed of the ice sheet; ρ_w is the density of the ice sheet (1000 kg/m^3); ρ_i is the density of the flowing water (917 kg/m^3); g is gravitational acceleration (9.8 m/s^2); H_i is the ice thickness; B_i is the ice width (m); L_i is the ice length (m) of the maximum vertical-section direction; B_d is the downstream river width (m); C_D is the shape-resistance coefficient (0.4); C_f is the friction-resistance coefficient (1.0); and C_L is the lift coefficient (0.4). These are input based on local observational data and past study.

In this investigation, for the calculations, we obtained input values as follows. We got values for flow quantity along river edges of upper reaches; got water-level data at downstream edges; and calculated a nonconstant current, speed U_w, and water depth H_w for each section of the river. Each sectional speed and depth of the water were calculated by one-dimensional unequal flow calculation. For U_i, supposed that it was U_w, because maximum U_i is U_w. Where a lump of ice (of thickness H_i) was likely to attach to another lump of ice, we supposed that the water was deep and calculated while also considering the thickness of the lump of ice that could become attached, thus assuming H_i is the minimum H_w. B_i is the width of a river section (one of B_d upper reaches) assumed to be the river width at its maximum. For L_i, we used 10 m.

3. CALCULATION RESULTS OF ICE-JAM SCALE

3.1 Calculation method of ice jam scale

For the calculation of the ice-jam scale, we input the river widths and the hydraulic gradient. In this study, we obtained river widths and hydraulic gradient by using Google Earth.

The rivers targeted for this study were Bebetsu, Furebetsu, and Saru Rivers. Figure 1 shows the positions of the images of the target rivers shown in the three satellite images (Figure 2, 3, and 4).

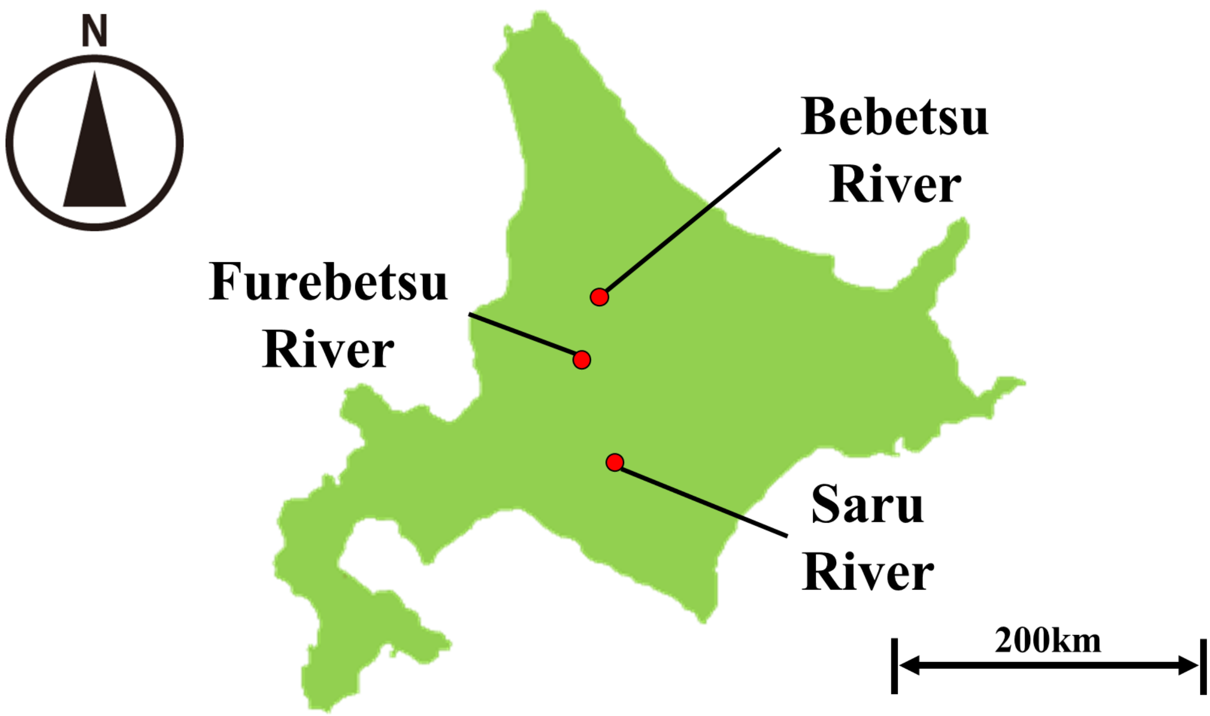

Figure 1 Positions of images of target rivers.

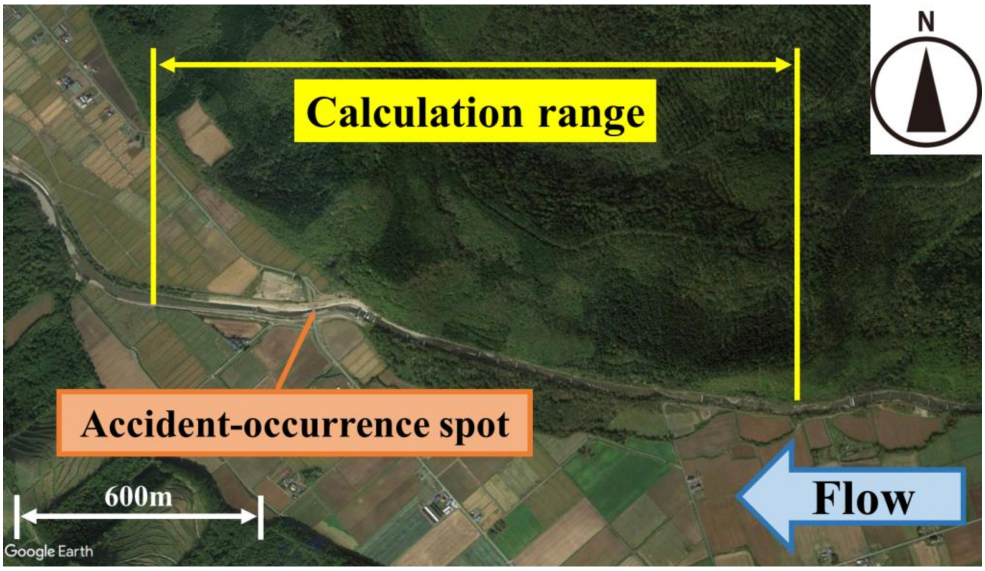

Figure 2　Satellite image of Bebetsu River.

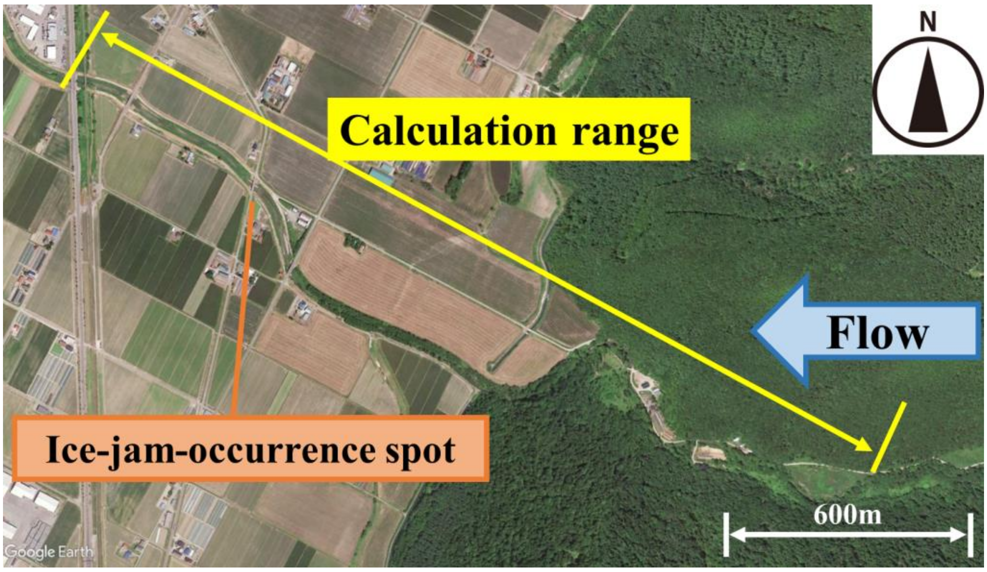

Figure 3　Satellite image of Furebetsu River.

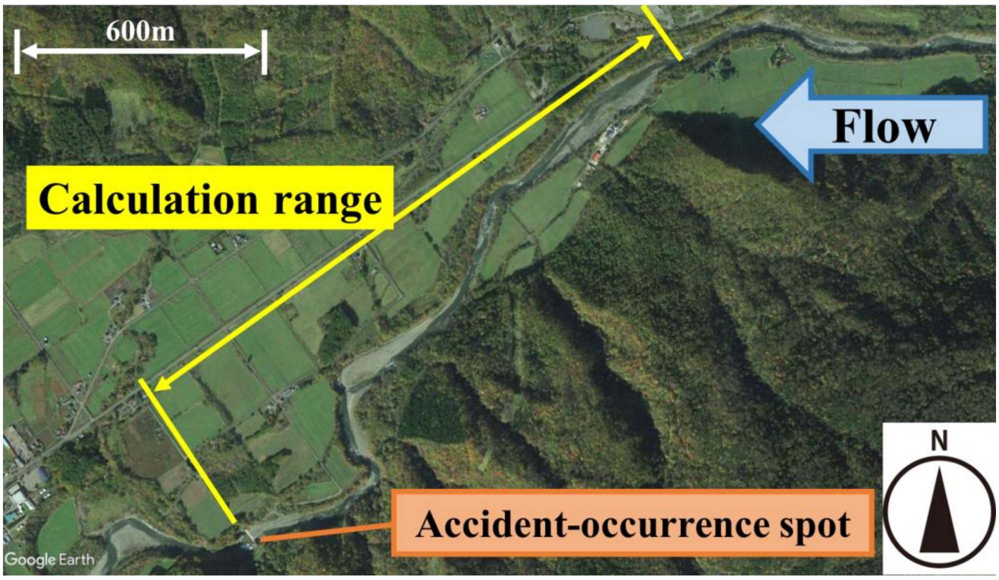

Figure 4　Satellite image of Saru River.

3.2 Calculation results

3.2.1 Bebetsu River

Bebetsu River widths and hydraulic gradient (measured via Google Earth) are plotted in Fig. 5, and the river's calculated ice-jam scale, in Fig. 6; both figures also show the accident-occurrence location.

There are two locations where the calculated ice-jam scale is large. One is at the accident scene, where we assume river ice suddenly flowed because the riverbed incline sharply increased in the nearby upper reaches. The other location is vertical section distance 370 m (Fig. 6), where the river becomes narrower (Fig. 5). We conclude that because the river width is much wider in the directly upstream segment, extensive river ice formed and presumably would flow down and redeposit during a thaw. Thus we were able to extract ice-jam-hazard locations by calculating and applying the ice-jam scale.

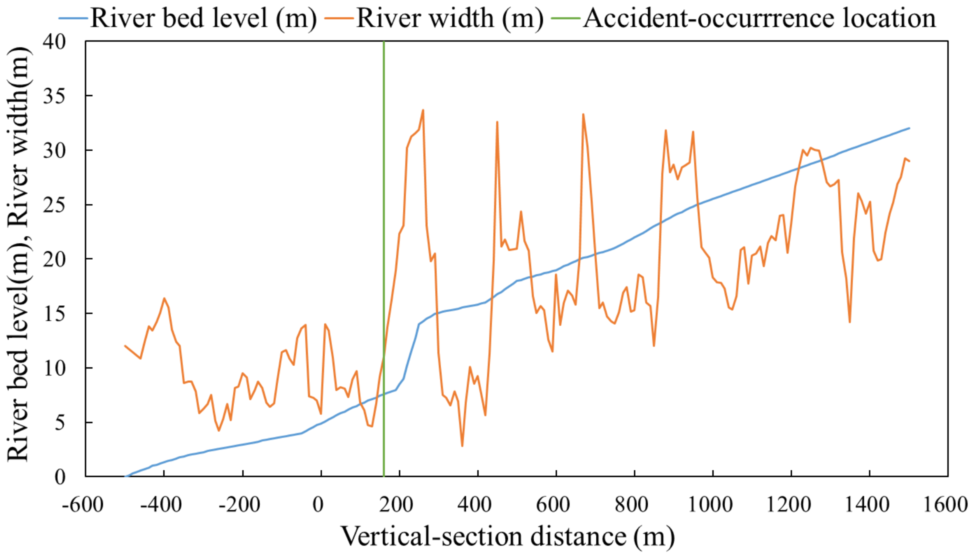

Figure 5 Bebetsu River widths and hydraulic gradient. [Distance measured from Kyusen bridge]

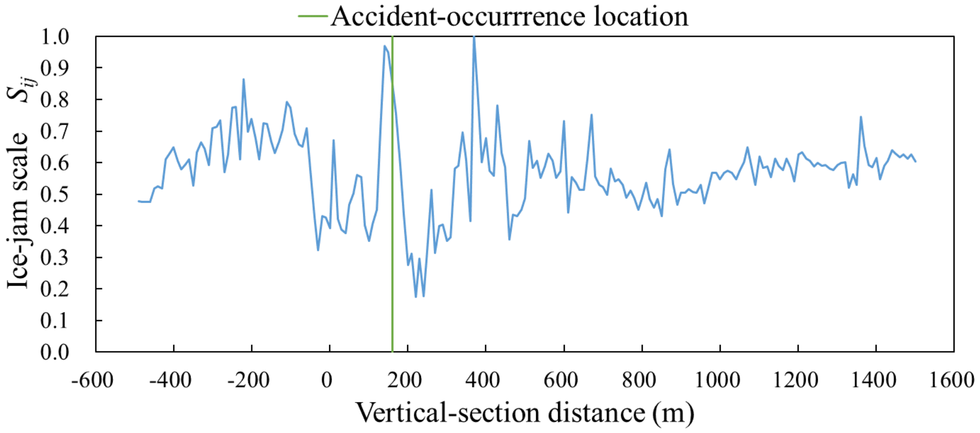

Figure 6 Bebetsu River ice-jam scale. [Distance measured from Kyusen bridge]

3.2.2 Furebetsu River

Furebetsu River widths and the hydraulic gradient (measured via Google Earth) are plotted in Fig. 7, and the river's calculated ice-jam scale, in Fig. 8; both figures also show the ice-jam-occurrence location.

The point at which the ice-jam scale has a large value is 160 m downstream from Ohgiyama bridge (Fig. 7). The fact that the ice-jam scale does not match the accident location is because in the real phenomenon, an ice jam occurs by the river ice first drifting from the upper reaches, then being deposited against a supporting pier of the Ohgiyama bridge, after which the water level rises and the river overflows its banks. In this case, we supposed that the influence of the bridge pear was significant. However, in this study, we have relied on small ice-jam scale values where we did not need to consider the influence of a mid-river structure. We also found that because the river narrows downstream from Ohgiyama bridge and the incline is gradual, the value of the ice-jam scale increases. Accordingly, we assume that it is a hazardous situation in a river channel made more dangerous by the influence of the bridge pier.

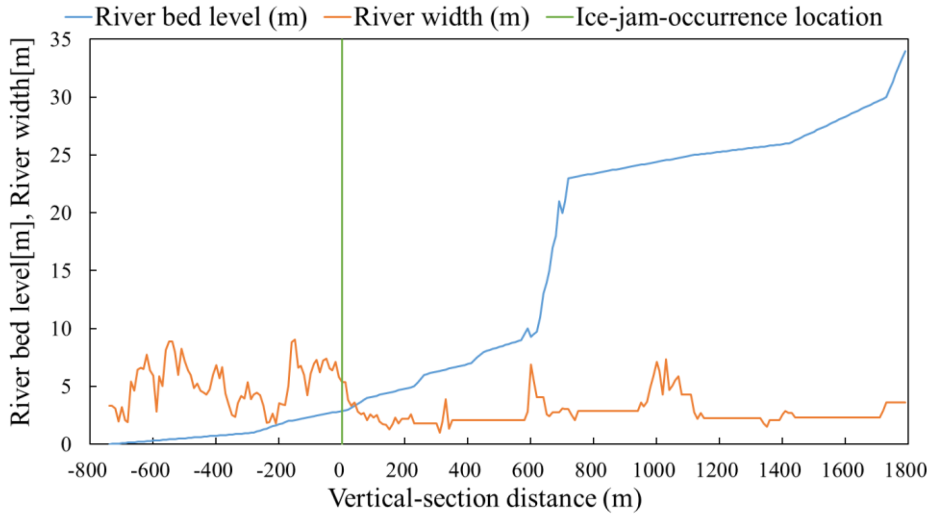

Figure 7 Furebetsu River widths and hydraulic gradient. [Distance measured from Ohgiyama bridge]

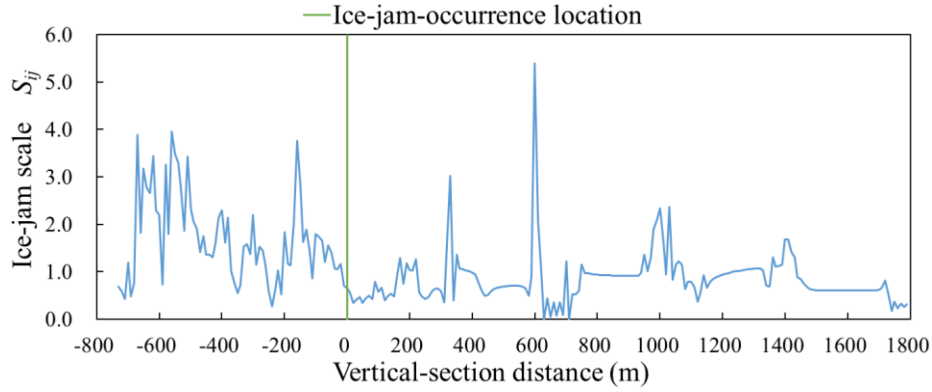

Figure 8 Furebetsu River ice-jam scale. [Distance measured from Ohgiyama bridge]

3.2.3 Saru River

Saru River widths and the hydraulic gradient (measured via Google Earth) are plotted in Fig. 9, and the river's calculated ice-jam scale, in Fig. 10; both figures also show the accident-occurrence location.

The distance (from the weir) at which the ice-jam scale has the largest value is 1030 m, and other large values are in the section that is 110–450 m downstream. We found that the ice jam collapsed after river ice was deposited at ~1030 m, and, given the curved section farther downriver that has large ice-jam-scale values, we considered the possibility that the river ice flowing downstream might reach the water-intake dam.

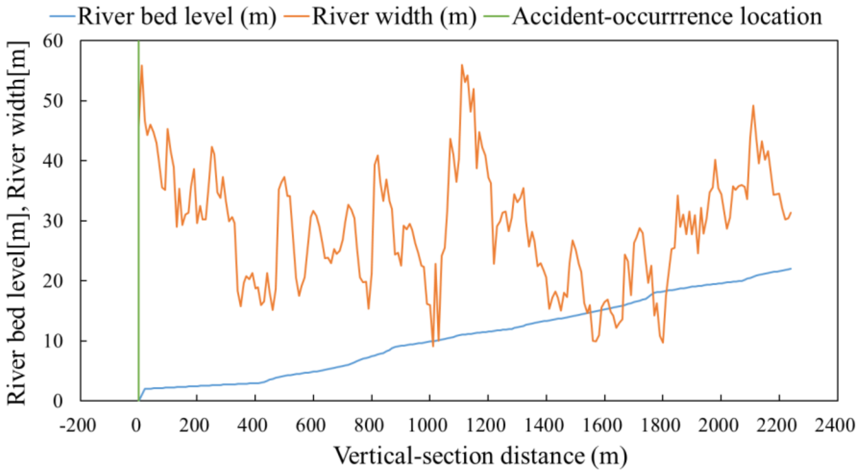

Figure 9 Saru River widths and hydraulic gradient. [Distance measured from Hidaka weir]

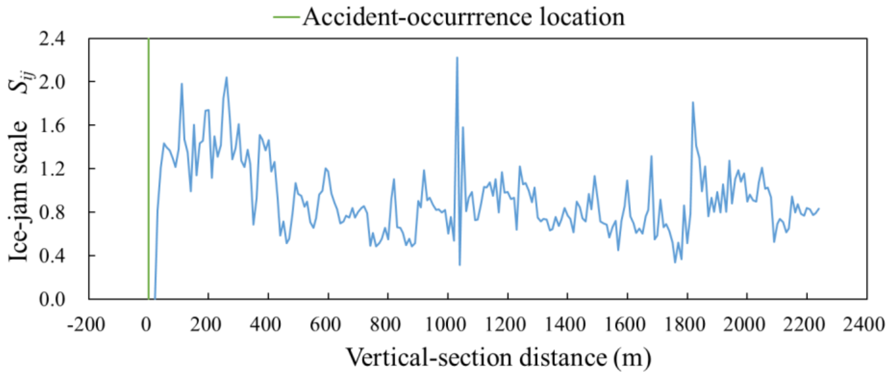

Figure 10 Saru River ice-jam scale. [Distance measured from Hidaka weir]

4. CONCLUSIONS

By field observation and ice-jam scale, we confirmed that ice jams easily formed at sandbars, at slope-change points, on a mild slope, at mid-river structures, or in a meander section.

We investigated the ice-jam-occurrence hazardous locations by calculating the ice-jam scale S_{ij} for the Bebetsu, Furebetsu, and Saru Rivers.

The ice-jam scale was reconstructed at accident- or ice-jam-occurrence points and near these points.

We were able to extract ice-jam-occurrence hazardous locations by calculating and using the ice-jam scale.

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