Advances in River Sediment Research – Fukuoka et al. (eds)
 ISBN 978-1-138-00062-9

Study on the width of rivers in valley bottom plains

T. Sakaguchi
Graduate School of Science and Engineering, Chuo University, Tokyo, Japan

S. Fukuoka
Research and Development Initiative, Chuo University, Tokyo, Japan

ABSTRACT: Flood disasters caused by torrential rainfalls have recently been increasing in Japan. One of the representative disasters is Yosasa River flood disaster in 1998. Far exceeding capacity of flow made river widths and channel shape change by severe bank erosions. But, there are few observation data such as discharge and the water level hydrographs of flood disasters in the middle and small-scale rivers. Quantitative investigations on appropriate river width and water depth have not been conducted sufficiently.

In this study, we applied two-dimensional flood flow analysis for the 1998 flood occurred in the Yosasa River and proposed a decision method of river width required for large floods in rivers flowing valley bottom plains.

1 INTRODUCTION

Flood disasters caused by torrential rainfalls have been increasing in Japan. Especially, flood flows in the middle and small-scale rivers flowing through the valley bottom plains appear to cause great damages in floodplain. One of the representative disasters is Yosasa River flood disaster in 1998. The Yosasa River lying on the northeast of Tochigi Prefecture (see Fig. 1) is one of the tributaries of the Naka River and has a drainage area of about 343.5 km^2. Far exceeding capacity of flow causes severe bank erosions, and it made markedly river widths and channel shape change. After the flood, the Yosasa River was improved up to the level of one in fifty. But, because there are few observation data such as discharge and water level, the appropriate river width and water depth in the rivers through valley bottom plain has not been investigated so far.

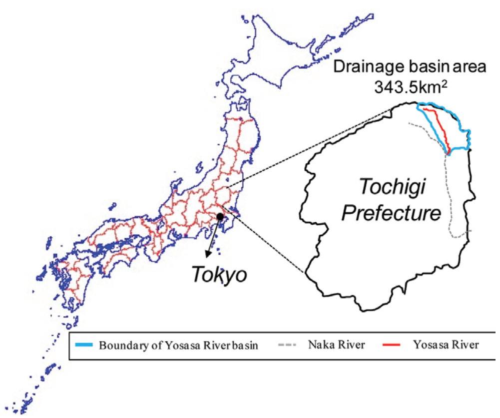

Figure 1. Map of the Yosasa River basin.

There are several researches on the Yosasa River disaster in 1998. For example, Suga et al. (2001) investigated causes of the lateral erosion damages. Nakagawa et al. (2000) estimated the discharge hydrograph of the 1998 flood by using the tank model for the upstream area of the Yosasa River. They also estimated the maximum river width after the flood by using one dimensional bed variation analysis and the regime theory. And, they examined the channel variation process of the Yosasa River from comparison between the above calculations and aerial photographs taken after the flood.

In this paper, we assume that the largest flood in the past had formed the present valley width and the landform, and the valley bottom has changed by many large floods but the valley width has remained nearly unchanged. We believe that the 1998 Yosasa River flood is a sufficiently large flood, but it would be small enough compared with the past largest flood which had formed the valley width. On the standpoint that the above concept is acceptable for the study of the river width in the valley bottom plain, we discuss the river width required for the 1998 Yosasa River flood. We regard the 1998 flood discharge as the channel-forming discharge, which formed the landform of the valley bottom after the 1998 flood.

In the valley bottom plains, there are some areas where the flow velocity and depth on the inundation area have extremely small compared with the main stream. Actual flow width where flood water was flowing must be estimated.

At first, we applied two-dimensional flood flow analysis for the 1998 Yosasa River flood and examined an evaluation method of the flow width which required for the flood by considering the flow velocity and depth in the inundation area. Then, we present a decision method of appropriate river width for large floods flowing valley bottom plains.

Figure 3. State of flood flow around 6.0 km.

2 DESCRIPTION OF THE YOSASA RIVER DISASTER IN 1998

Figure 2 shows aerial photographs in the reach from 3.8 km to 7.0 km upstream of the junction of the Naka River and the Yosasa River. Upper photograph and lower photograph were taken before (Aug. 1993) and after (Oct. 1998) the flood, respectively. Yellow lines shown in the photographs indicate the main channel width at the time before the flood and flow width evaluated from the aerial photographs taken after the flood. The upper photograph also shows that the river channel width was approximately 20 m to 30 m at the time before the flood. The lower photograph shows that the flood flows overflowed the banks and made the new channels, and water width of the main channel expanded several times. Figure 3 shows the state of the right bank around 6.0 km and white broken line shows the center line of the main channel before the flood occurred. The flood flow made a cutoff channel over the floodplain and washed away the houses there. At 5.3 km (Point P shown in Fig. 2), there were houses and vegetations, but these were carried away by the flood flow.

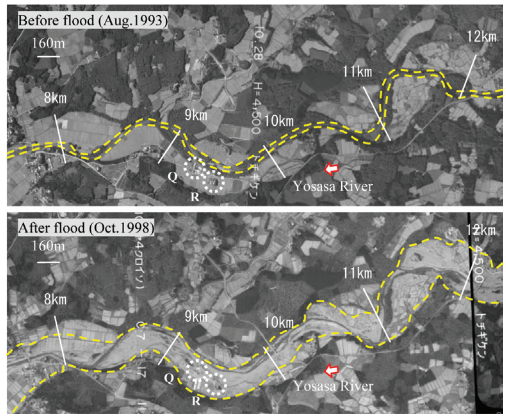

Figure 4. Comparison between aerial photographs before (upper) and after (lower) 1988 flood.

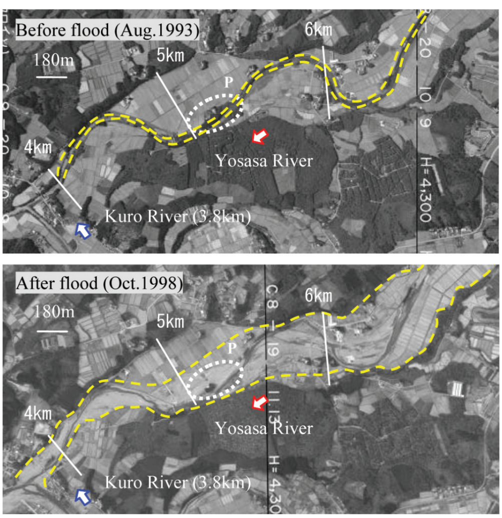

Figure 2. Comparison between aerial photographs before (upper) and after (lower) 1988 flood.

Figure 4 shows the comparison of aerial photographs before and after 1998 flood in the reach from 8.0 km to 12.0 km. The inundation flow washed out vegetations and caused bed scouring at the meandering reach around 10.3 km and 11.5 km. Vegetations were dense along the channel in the reach from 9.0 km to 12.0 km, but these were drifted by the flood. Some vegetations remain in the outer bank of meandering reach around 9.5 km, and a house located behind these vegetations remained there (Point R shown in Fig. 4). On the other hand, houses along the river channel were carried away (Point Q shown in Fig. 4). So, 1998 Yosasa River flood overflowed the banks and expanded throughout the valley bottom plains, and it changed the planar shape of the main channel by severe bank erosions and formed new channels.

3 TWO-DIMENSIONAL FLOOD FLOW ANALYSIS

3.1 *Analysis conditions and bed elevation data*

In the flooding on valley bottom plains, there are many areas where the flow velocity and depth on the inundation area are extremely small compared with the main stream. It is difficult to estimate the velocity and depth distributions on the inundation area from cross-sections and flood marks data obtained after the flood. Therefore, we conducted the steady two-dimensional flood flow analysis using the peak discharge of the 1998 flood and calculated velocity and depth distributions on the inundation area. Then, we investigated the flow width (river width) which should be considered as the channel-forming discharge. Here, the bed elevation data measured after the flood was used for the analysis on the following assumption. The landform in the valley bottom plains observed after the flood would be formed in the peak of the flood. The study area is from 4.5 km to 13.0 km where the flood flows overflowed the banks and expanded on the floodplain (shown in Fig. 5). The upstream boundary condition was given by the peak discharge 1,740 m^3/s and downstream boundary condition was given by the height of flood marks. The peak discharge was estimated by the Tochigi Prefectural Government from the storage function model on the precipitation data obtained at rainfall gauging stations in the Yosasa River basin and its neighborhood. It was much larger discharge than the average capacity of flow (400 m^3/s) in the study area. After the flood, Tochigi Prefectural Government surveyed the cross-sections and the flood marks every 100 m. But, the cross-sectional survey was conducted only the main channels and its neighboring part indicated by the black line in Figure 6. These survey data are not sufficient for the analysis which includes the inundation area. Then, we utilized topographic maps of 1:1000 scale (shown in Fig. 7) prepared in March 1969. Bed elevations in the map were described by points and contour lines every 0.1 m and 1 m, respectively. Because the land use of the floodplain in the study area has been paddy fields since around 1955 (Sato, 2001), the landform of the floodplain remains unchanged since 1969. For this reason, the landform in the floodplain shown by the brown line in Figure 6 was created on the basis of bed elevation data in the topographic map. The Manning's roughness coefficients were set to 0.049 for main channel and 0.054 for the floodplain so that longitudinal distribution of the flood marks and observed edge of the inundation water could be reproduced.

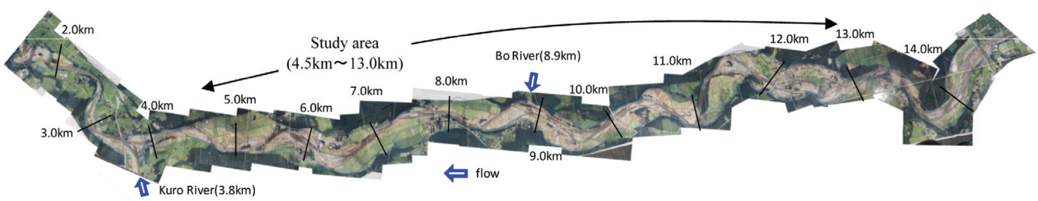

Figure 5. Study area in the Yosasa River.

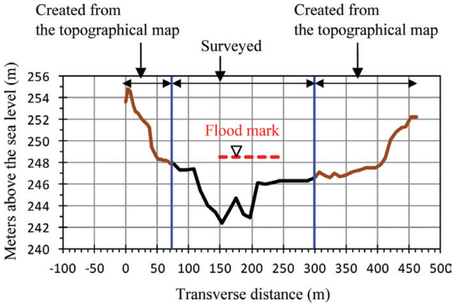

Figure 6. River cross section in the Yosasa River.

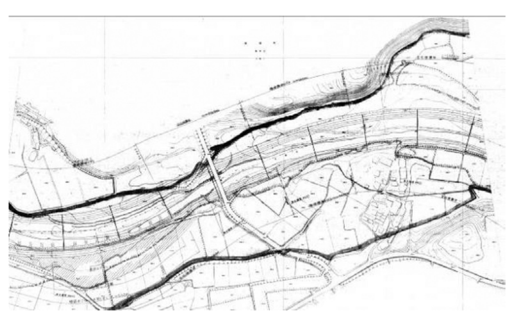

Figure 7. Topographic map of 1:1000 scale.

3.2 *Analysis results*

Figure 8 shows the comparison between flood marks and calculated water surface profile in the reach from 4.5 km to 13.0 km. Although the calculated water surface profile seems to coincide with the flood marks on the whole, the difference between them is noticeable around 6.5 km and reaches about 4 m in the maximum. Figure 9a, b shows the cross-sectional forms at 5.9 km and 10.5 km sections. The Yellow points shown in Figure 9a, b are the height of the edge of inundation water. In the reach where the calculated water surface profile coincides with the flood marks, the flood mark almost coincides with the height of the edge of inundation water as shown by Figure 9b. On the other hand, the flood mark greatly differs from the height of the edge of inundation water as shown by Figure 9a in the reach where the difference is relatively large. If the water level had reached to the height of the flood mark, the inundation area should have further expanded on the floodplain. For this reason, it is judged that there was the error in flood mark observations in the reach from 5.0 km to 6.5 km. Figure 10 shows the comparison between observed and calculated edge of the inundation water. The relation

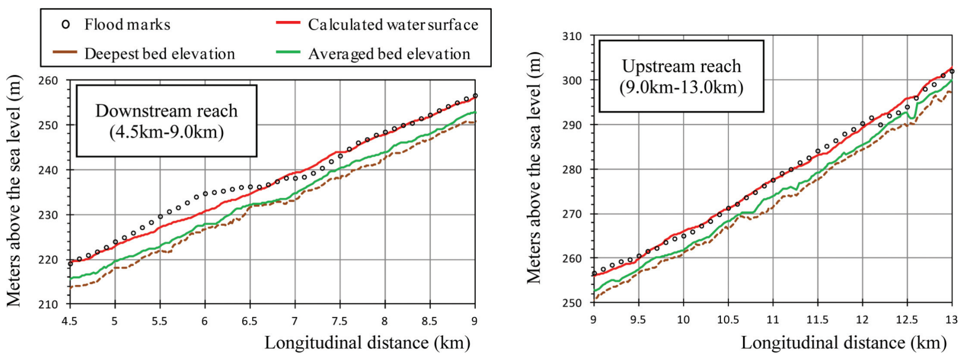

Figure 8. Comparison between observed and calculated water surface profiles.

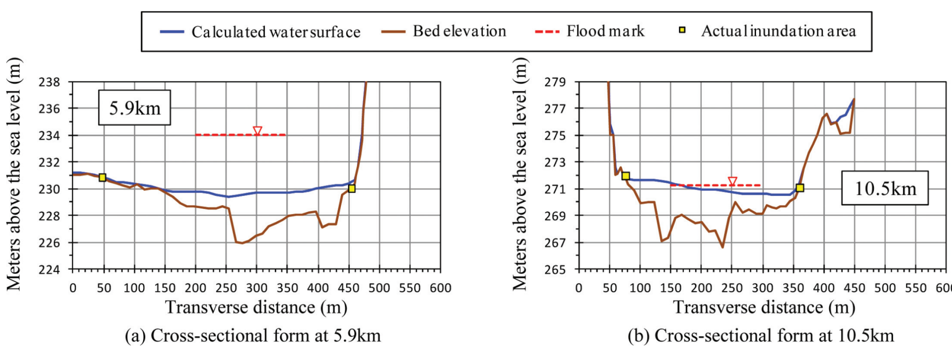

Figure 9. Correspondence relationship between the height of water edge and flood mark.

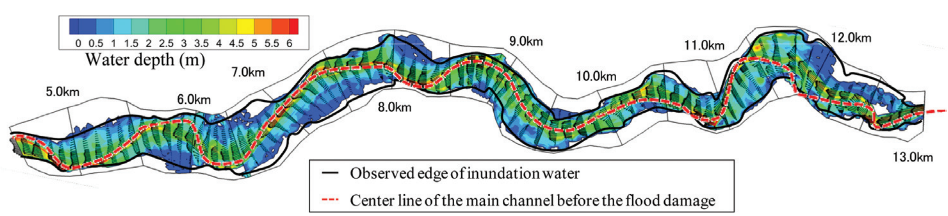

Figure 10. Comparison between observed and calculated edge of inundation water.

between them shows good agreement on the whole, although there is the reach which cannot be reproduced the observed edge of the inundation water such as around 6.9 km and 12.2 km points.

The red broken line and velocity vectors in Figure 10 show the center line of river channel before the flood damage and calculated depth-average velocity vectors at the peak discharge, respectively. The maximum velocity vectors do not coincide with the red broken line in the curved reach around 5.0 km, 6.0 km, 8.5 km, and 11.5 km. It is understood that the flood flows took a cut-off route over the channel and flowed through the whole width of valley bottom plain. The calculated velocities range from 3 m/s to 5 m/s in the main stream. On the other hand, the water width was expanded and inundated around 5.3 km, 7.5 km and 12.0 km and the water depth is about 0.3 m and the velocity is 0.5 m/s near the water edge of these places. It is assumed that the flow did not cause the bank erosion and bed scouring at the water edge of these places even in the flood peak. We believe that the water edge of these places does not correspond to the flow width (river width) for the channel-forming discharge.

4 FLOW WIDTH OF THE YOSASA RIVER IN 1998 FLOOD

The flow width corresponding to the channel-forming discharge is investigated based on the analysis results of the 1998 flood. Whether the flow causes bank erosions and bed scouring at the water edge would depend on the magnitude of water depth and velocity. However, it is not appropriate to use the water depth and velocity changing at respective locations as the condition for determining the flow width. Therefore, the flow width is evaluated by following method. First, the calculated unit discharge is integrated transversely from the inner bank to the main stream at each cross-section in meandering reach such as 7.5 km section in Figure 11a and from the both left and right banks to main stream in the straight reach such as the 6.9 km section in Figure 11b. When the integrated discharge becomes a certain percentage of the total discharge at integrated transverse distance, the length which subtracts the integrated transverse distance from the total water surface width is a flow width to be determined.

Figure 12 shows the calculated lines of water edge in which the 99% and 97% of the peak discharge are assumed to flow in the river. Figure 13 shows thus determined longitudinal distributions of the water width. Observed edge of inundation water spreads about 400 m in the meandering reach (around 6.0 km, 9.3 km, and 12.0 km) as shown by the blue line of Figure 12. The purple line shows the distribution of the flow width B_{99} in which the 99% of the peak discharge flows. There are plateaus at the both sides of river in the reach around 10.0 km which consists mainly of simple cross-sectional channel. The difference between the

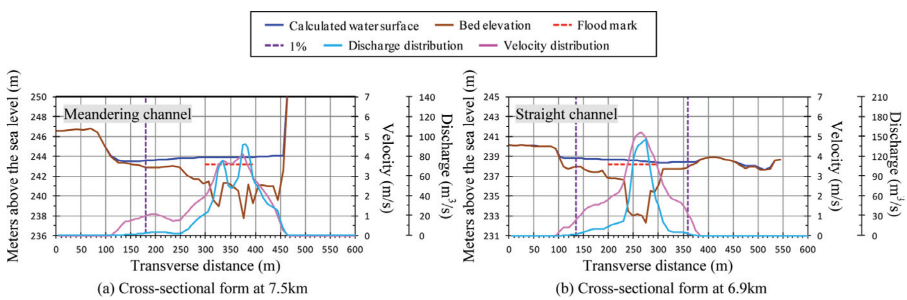

Figure 11. Evaluation method of the flow width in straight and meandering channels.

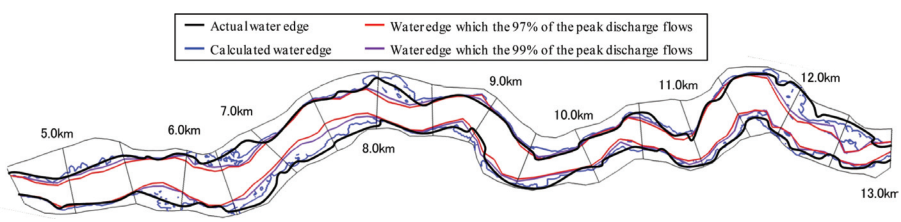

Figure 12. Comparison between the lines of water edge which the 99% and 97% of the peak discharge flows.

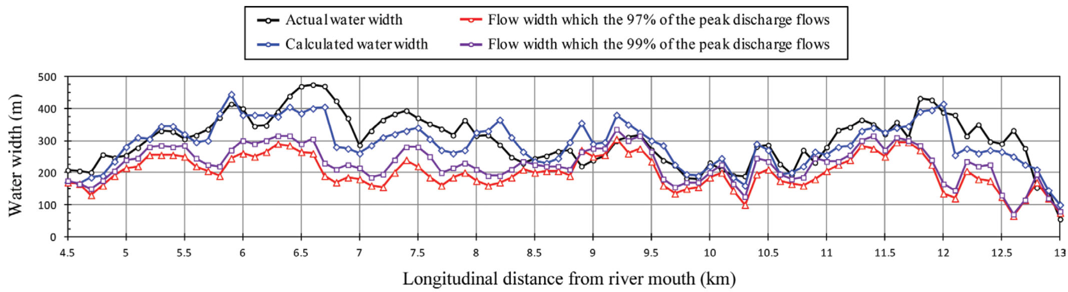

Figure 13. Longitudinal water width profiles.

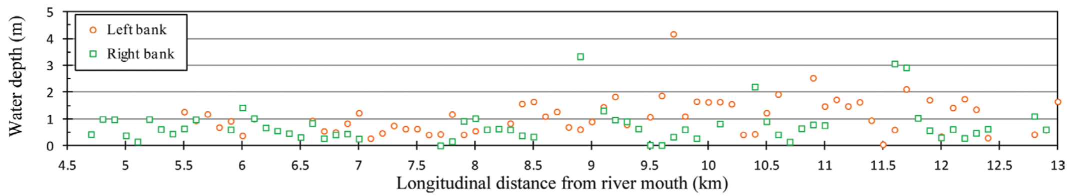

Figure 14. Water depths at water edge.

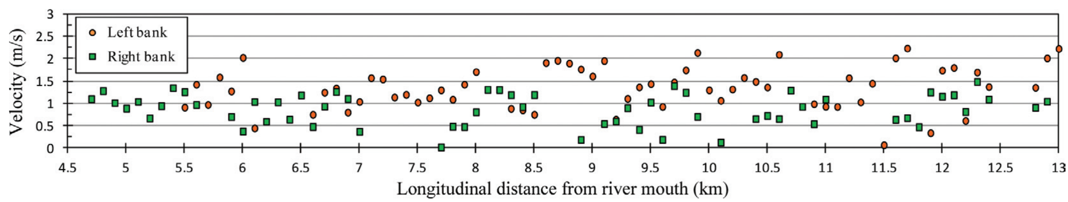

Figure 15. Flow velocities at water edge.

actual water width and flow width B_{99} is relatively small. On the other hand, the flow width B_{99} is considerably narrower than the actual water width in the reach from 5.0 km to 9.0 km and around 12.0 km. But, the flood hardly flows in floodplain in these reaches. In addition, the flow width B_{99} is relatively uniform compared with the actual water width. The red line in Figure 13 shows the flow width B_{97} in which the 97% of the peak discharge flows. There is almost no difference between the flow width B_{99} and B_{97}. Figures 14 and 15 show the longitudinal distributions of the water depth and velocity at the water edge in which the 99% of the peak discharge is assumed to flow in the river. Here, the water edge of the outer bank of meandering reach is removed from the figures. Since the velocity is about 1.0 m/s and the water depth is about 1 m at the water edge, the flow would cause the bank erosion and bed scouring. Therefore, we assume that the flow width B_{99} of the 1998 flood is regarded as the river width determined by the channel-forming discharge. We examine the relationships of the dimensionless width and depth versus the dimensionless channel-forming discharge by Fukuoka (2010, 2012, 2012) in the following Section 5.

5 THE RELATIONSHIPS AMONG DIMENSIONLESS RIVER WIDTH AND WATER DEPTH VERSUS DIMENSIONLESS CHANNEL-FORMING DISCHARGE

Fukuoka (2010, 2012, 2012) has derived the relationships of dimensionless river width and depth versus dimensionless channel-forming discharge in alluvial rivers, considering floods and river basin characteristics and it can be represented with Equations 1, 2. Furthermore, Fukuoka has indicated that the desirable range of cross-sectional form of alluvial rivers is represented by the Equation 1, 2.

$$2.80\left(\frac{Q}{\sqrt{gId_r^5}}\right)^{0.40} \le \frac{B}{d_r} \le 6.33\left(\frac{Q}{\sqrt{gId_r^5}}\right)^{0.40} \quad (1)$$

$$\frac{h}{d_r} \le 0.14\left(\frac{Q}{\sqrt{gId_r^5}}\right)^{0.38} \quad (2)$$

where Q = discharge; B = river width; h = water depth; I = energy slope; d_r = representative particle diameter; and g = gravitational acceleration. Figure 16 shows the relationships of the dimensionless river width and depth versus dimensionless discharge corresponding to the flow width B_{99}. Data plotted are 86 sections of every 100 m in the reach from 4.5 km to 13.0 km. Particle diameter d_{60} (0.2 m) is used as the representative diameter. The slope I was given by the energy slope I_e. The blue colored plots show the relationships of dimensionless values where the plateaus are approaching the both sides of river (around 13.0 km, 10.0 km, and 4.5 km). Because the flow width is unable to expand due to the geographical and geological effects, the dimensionless river widths are plotted in the lower region. The yellow colored plots show the relationships of dimensionless values where the difference between the actual water width and flow width B_{99} shown by Figure 13 is relatively small (around 9.0 km and 11 km). The dimensionless river width is larger than that indicated by the blue plots in these sections. Since the 1998 Yosasa River flood is the smaller than the past large flood which was considered to form the present valley width, the dimensionless river width is distributed around the upper limit indicated by the blue line in Figure 16. The green colored plots show the relationship of dimensionless values where the flow width B_{99} is considerably narrow compared with the actual water width (around 6.0 km and 8.0 km). Because the area having an extremely small velocity and water depth were excluded from the investigation of the flow width, the dimensionless river width becomes almost the same as yellow plots. The plots are distributed over a wide range because of the geographical and geological effects such as the valley width and the river terrace, but the plots range around the upper limit on the whole.

From the above discussions, the relationship among the dimensionless river width and depth and the dimensionless channel-forming discharge in the valley bottom plain which was formed in the narrow and long valley are the similar to those of alluvial channels. It means that Equations 1, 2 are useful for determination of width of rivers through valley bottom plains.

The flow width expands to the dimensionless river width shown in Figure 16 when a large flood would occur. It would be possible to decrease the flood damage in the important areas by taking measures so as to suppress the spreading of inundation water along the purple line of Figure 12 even when the flood discharge increases.

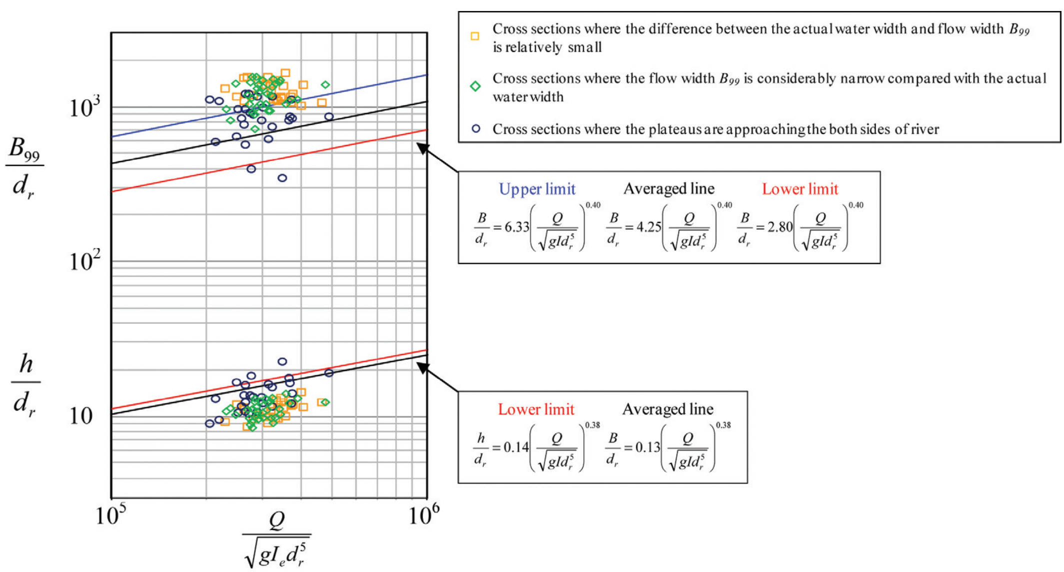

Figure 16. Relationships between dimensionless river width and depth versus dimensionless discharge.

6 CONCLUSIONS

Principal conclusions are drawn as follows.

I. In the middle and small-scale rivers with a few basic data, topographic maps of 1:1000 scale are useful for re-creating landforms in inundation areas required for the flow analysis.
II. We investigated the relationships between the dimensionless flow width and dimensionless channel-forming discharge to the 1998 Yosasa River flood and clarified that these relationships in the rivers through valley bottom plain were similar to alluvial channel relationship derived by Fukuoka.

REFERENCES

Fukuoka, S. 2010. River engineering adaptations against the global warming—towards generalization of close-to-nature rivers, *Journal of JSCE, JSCE, F. Vol.* 66, *No.* 4*: pp.* 471–489 (in Japanese).

Fukuoka, S., Sakaguchi, T. 2012. Desirable range of dimensionless width and depth versus dimensionless discharge and application to rivers at design and improvement stages, *Annual Journal of Hydraulic Engineering, JSCE. Vol.* 56*: pp. I*_1423–*I*_1428 (in Japanese).

Fukuoka, S. 2012. Dimensionless width and depth and sediment transport rate in stable rivers, 3*rd International Symposium on Shallow Flows, Iowa city, USA, CD-ROM.*

Ito, K., Suga, K., and Ikeda, H. 2001. Practical Consideration on bank erosion and channel shift by a big flood of low frequency in the Yosasa River, *Annual Journal of Hydraulic Engineering, JSCE. Vol.* 45*: pp.* 781–786 (in Japanese).

Nakagawa, H., Takahashi, T., and Satofuka, Y. 2000. Channel Variation of the Yosasa River Tributary of the Naka River due to 1998 flood, *Annual Journal of Hydraulic Engineering, JSCE. Vol.* 44*: pp.* 395–400 (in Japanese).

Sato, T. 2001. Flood damage and land conditions in the Nakagawa River basin, Japan caused by heavy rainfall at the end of August 1998, *Natural disaster research report, the National Research Institute for Earth Science and Disaster Prevention. Vol.* 37*: pp.* 137–216 (in Japanese).