FLOOD CONTROL EFFECT AND HABITAT CREATION IN THE MIDDLE BASIN OF THE YODO RIVER USING A RETARDING BASIN

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ABSTRACT

Once, the Ogura-Ike Pond (area of 794 ha, and maximum water depth of 1.1 m), located in the southern part of Kyoto Prefecture, possessed a flood control function because of being connected to the Uji River through a braided channel, and inhabited various organisms of the Yodo River basin. After being diked in 1941, the pond lost its flood control function and living things disappeared from it. Recently, heavy rainfall has been occurring more frequently than expected in various areas in Japan. Flood disaster risk is increasing in the middle basin of the Yodo River, which acts as the junction of three rivers (Katsura, Uji, and Kizu), including the former Ogura-Ike Pond basin. Thus, besides the current river improvement plan, the Yodo River basin requires new flood control measures. Through the analyses conducted using iRIC, a two-dimensional flood flow analysis software, we considered plans to confirm the effect on both flood control and environmental conservation measures to see if the retarding basin can be developed in the current Ogura-Ike drained land. The retarding basin was established on iRIC Nays2D Flood (ver.5.0). The flow rate used for the flood analysis using iRIC Nays2D Flood was the flow rate that is 1.2 times the estimated high-water flow rate of the Uji River. The result of the flood analysis showed the flood water was found to be stored in the retarding basin. At that time, fish habitats were created in the retarding basin through the habitat evaluation analysis, using the Maxent model. It was shown that the retarding basin can also be utilized as an evacuation site for aquatic organisms in case of flooding.

Keywords: Green infrastructure, integrated watershed management, biodiversity, land conservation, habitat evaluation

1. INTRODUCTION

Recently, Japan experienced massive flood disasters, such as heavy rains in western Japan in 2018 and Typhoon 19 in 2019 that could not be mitigated using the existing infrastructure. Based on these floods, the Ministry of Land, Infrastructure, Transport and Tourism proposed that the results of climate change forecasts should be used to set rainfall and discharge in flood control plans (the Ministry of Land, Infrastructure, Transport and Tourism, 2019). In addition, the Ministry announced that the river improvement plan for the Naka River and Kuji River of eastern Japan, which were collapsed by Typhoon 19, will incorporate the use of open levees (The Asahi Shimbun, 2020). This will lead to storage of water on the land outside the river channel, in addition to the conventional flood control plan based on in-channel storage. The Japan Society of Civil Engineers also announced a switch to river basin flood control, integrating rivers, flood control, and local areas and cities, as a proposal for future disaster prevention and mitigation (the Japan Society of Civil Engineers, 2020). In the future, management of the whole river basin will be required. In the future disaster prevention and mitigation, green infrastructure, which is a nation-forming method that contributes to the society and economy by making judicial

use of natural powers and mechanisms, is attracting attention (Science Council of Japan, 2014). One of the green infrastructures is a retarding basin, which accounts for both flood control and ecosystem conservation.

The Lake Biwa-Yodo River Basin is in the center of the Kinki District, Japan, and has an area of 8,240 km². The City of Osaka is in the lower reaches of the basin, while Kyoto City is in the middle reaches, forming the foundation of society, economy, and culture of the Kansai region. The Yodo River Basin has long-grown as a center of politics and economics in Japan and contributed to people's lives and cultural development. In the Lake Biwa-Yodo River Basin, it is necessary to plan a new flood control method for possible future floods exceeding the designed level.

The authors of this study focused on the Ogura-Ike Pond, which was located at the middle basin of the Lake Biwa-Yodo River Basin. This pond, which once existed near the Yodo River at the junction formed by the Katsura, Uji, and Kizu rivers, was connected to the Uji and Kizu rivers (Land improvement district of Ogura-Ike, 2001). Considerable water flowed into the pond when the rivers swelled, and this area was flood-prone. The Ogura-Ike Pond, where the water of the rivers flowed, was a thriving ecosystem for fish and other organisms, where fishing and sightseeing using these were also performed. Even after the pond was reclaimed in 1941, the risk of floods was high, and thus, it is necessary to consider possible future floods exceeding the designed level measures. The authors have set up a new retarding basin in the Ogura-Ike Reclaimed Land and have been conducting research on flood control and ecosystem creation in the Lake Biwa-Yodo River Basin. In this study, the flood control function of the Ogura-Ike retarding basin in the event of a flood exceeding the designed level is examined using flood analyses and the habitat function of the retarding basin is examined using habitat analyses.

2. METHODS

2.1 Study area

The study area is the three-river junction area, including the Ogura-Ike drained land of the Lake Biwa-Yodo River Basin in Kinki District, Japan (Figure 1). The analyses were conducted over an area of 75.2 km², including the water-level observatories of the three rivers, located upstream from the junction point (0–5.4 km for Katsura River, 34–50 km for Uji River, and 0–5.6 km for Kizu River).
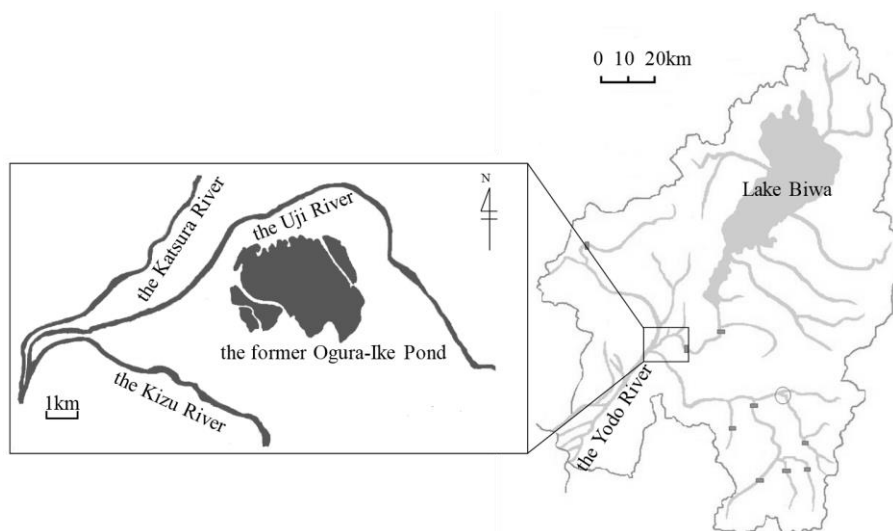

Figure 1. Location of the Ogura-Ike Pond in the junction area of three rivers in the Lake Biwa-Yodo River Basin. The square shows the flood and habitat analyses area.

2.2 Flood analyses using the iRIC software

In this study, flood and habitat analyses of the Ogura-Ike Pond Basin were conducted using the iRIC plane two-dimensional flood analysis software (ver.2.3, Mizuho Information & Research Institute, 2015). An understanding of the flood characteristics of the current state of the river channels and the flood control effects when the pond changes into a retarding basin were considered using the Nays2DFlood solver (ver.5.0) in iRIC. Nays2DFlood is a two-dimensional, flood flow simulation modeling program that considers boundary-fitted coordinates over a rectangular coordinate system or a general curvilinear system (Inoue et al., 2012).

This model is based on the following equations:

Continuity equation:

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = q + r \tag{1}$$

Motion equations:

$$\frac{\partial (uh)}{\partial t} + \frac{\partial (hu^2)}{\partial x} + \frac{\partial (huv)}{\partial y} = -hg\frac{\partial H}{\partial x} - \frac{\tau_x}{\rho} + D^x \tag{2}$$

$$\frac{\partial (vh)}{\partial t} + \frac{\partial (huv)}{\partial x} + \frac{\partial (hv^2)}{\partial y} = -hg\frac{\partial H}{\partial y} - \frac{\tau_y}{\rho} + D^y \tag{3}$$

$$\frac{\tau_x}{\rho} = C_f u\sqrt{u^2 + v^2} \quad \frac{\tau_y}{\rho} = C_f v\sqrt{u^2 + v^2} \tag{4}$$

$$D^x = \frac{\partial}{\partial x}\left[v_t \frac{\partial (uh)}{\partial x}\right] + \frac{\partial}{\partial y}\left[v_t \frac{\partial (uh)}{\partial y}\right] \tag{5}$$

$$D^y = \frac{\partial}{\partial x}\left[v_t \frac{\partial (vh)}{\partial x}\right] + \frac{\partial}{\partial y}\left[v_t \frac{\partial (vh)}{\partial y}\right] \tag{6}$$

where h is the water depth; t is the time; u is the flow velocity in the x-direction; v is the flow velocity in the y-direction; q is the inflow through a box culvert, a sluice pipe, or pump per unit area; r is rainfall; g is gravitational acceleration; H is water surface elevation; τ_x is riverbed shear stress in the x-direction; τ_y is riverbed shear stress in the y-direction; C_f is the riverbed friction coefficient; v_t is the eddy viscosity coefficient; and ρ is the density of water.

A 5-m-mesh digital elevation model (5-m DEM) of the base map information obtained by the Geographical Survey Institute was used as the topographic data. The highways obstructed using the laser profiler data were interpolated to match the ground height, while the river channels were partially corrected from the longitudinal survey data of the Uji River.

From the database of the Water Information System of the Ministry of Land, Infrastructure and Transport, the hydrograph from 12:00 August 10 to 11:00 August 11, 2014, at the 11th typhoon was used as flood discharge (Case 1). The model 1 flow was prepared by adjusting the water level to the estimated high-water level of the three rivers (Cases 2 and 3). The water level of the Uji River, which was 1.2 times the estimated high-water level, was prepared as Model 2 flow (Cases 4 and 5).

A retarding basin was installed in a portion of the Ogura-Ike drained land. An overflow levee of 200 m width, whose height was the estimated high- water level, was set up in the place where the riverbank was broken in 1953. A levee that surrounds the northeastern part (with few houses in the urbanization control area) was set up. This area, as a retarding basin, is approximately 530 ha, which is equivalent to the Amagase Dam in the Uji River for a total water storage capacity, by flooding to a 5-m depth, 2628×104 m^3. These analysis conditions are shown in Table 1.

2.3 Species distributions using Maxent model

Maxent is a method used for constructing a species distribution model from only presence data (Steven et al., 2006), and can be used for analysis even in cases of little data. In this study, we used Maxent (ver. 3.4.1) to predict the presence of habitats of freshwater minnows, *Zacco platypus*, in the retarding basin during floods, which is a dominant species in the river basin. The environmental factors used in the analyses included the water depth and current velocity obtained from the Nays2DFlood results, as well as the elevation obtained from the DEM data. The freshwater minnows' presence data were obtained from the River Environmental Database (Ministry of Land, Infrastructure, Transport and Tourism, 2019).

3. RESULTS AND DISCUSSION

3.1 Results of the Nays2DFlood simulation

Case 1 was analyzed to examine the suitability of the topographic data used for this study. The two hydrograph forms both actual flood and result of Case 2, were almost same in the three rivers, and thus, the application of these topographic data is validated.

Table 1 Analyses conditions of the three rivers.

Data items		Parameters
Flood flow	Case 1	The hydrograph of the 11th typhoon in 2014
		2,036 m^3/s for the Katsura River
		1,670 m^3/s for the Uji River
		1,967 m^3/s for the Kizu River
	Case 2 (Existing channel)	Model 1
	Case 3 (Retarding basin)	2.7 times as much as the hydrograph of Case 1 for the Katsura River
		Case 1 for the Uji River
		2.4 times as much as the hydrograph of Case 1 for the Kizu River
	Case 4 (Existing channel)	Model 2
	Case 5 (Retarding basin)	2.7 times as much as the hydrograph of Case 1 for the Katsura River
		1.2 times as much as the hydrograph of Case 1 for the Uji River
		2.4 times as much as the hydrograph of Case 1 for the Kizu River
Analysis areas		75.2 km^2
		Including the following reaches:
		0.0–5.4 km for the Katsura River
		34.0–50.0 km for the Uji River
		0.0–5.8 km for the Kizu River
River channel conditions		Surveyed river channel in 2016
		5-m DEM data in 2016
Downstream end setting		Water level of 34.8 km for the Yodo River at the 11th typhoon in 2014
Water level observatories		42.3 km for Hazukashi, the Katsura River from mouth of the Yodo River
		50.9 km for Uji, the Uji River from mouth of the Yodo River
		52.7 km for Ino-oka, the Kizu River from mouth of the Yodo River
Analysis meshes		25 × 25 m^2
Manning's roughness coefficient of high-water channels and drained land		0.04 m$^{-1/3}$/s
Manning's roughness coefficient of low water channels		0.03 m$^{-1/3}$/s
Distribution of trees		River environment information map in 2016
The retarding basin area		About 530 ha
		The area was set up in the northeastern part with few houses in the urbanization control area
The surrounding levee		19.8 m elevation (as same as the riverbank elevation of the Uji River)
The overflow levee		1.965 m (H.W.L) cutting down height and 200 m width

In Case 2, the water depth was increased at the peak flood (after 41,400 s). Especially, water overflowed from the Katsura River to the Uji River over the separation levee at the junction area of the three rivers.

In Case 3, the flow of the Uji River overflowed into the Ogura-Ike Pond Basin from the overflow levee after 32,400 s. With time, the water spread along the lower ground, and continued to enter the retarding basin at a peak discharge of 41,400 s (Figure 2) and to enter until 48,600 s. The ground level of the southeastern part of the retarding basin was high along the expressway, and thus, the water did not flow to the south side because it was blocked by the expressway. Furthermore, the ground level was high on the west side along another expressway, and did not flow to the west.
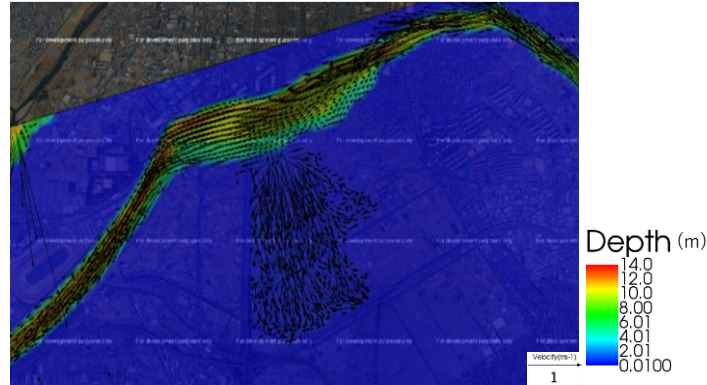
Figure 2. Distribution of the water depth after 41,400 s in Case 3 by Nays2DFlood.

Even in Case 4, the water did not overflow from the river channel at the peak discharge (Figure 3). However, the water levels of Mukaijima and Yodo sites of the Uji River and Nouso site of the Katsura River were over the estimated high- water levels. This means that the water flowed to the free-board part of the river levee.
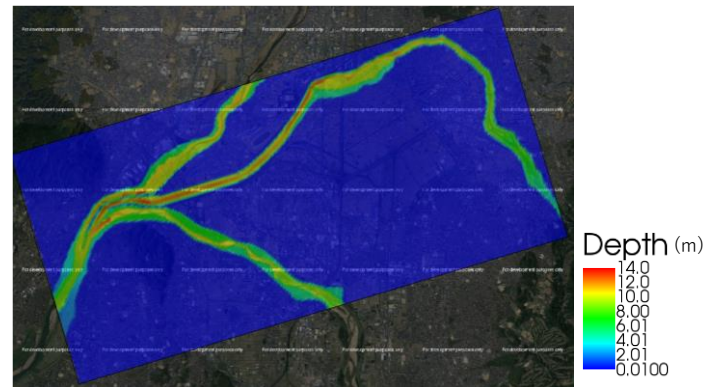

Figure 3. Distribution of the water depth after 41,400 s in Case 4 by Nays2DFlood.

In Case 5, the water flowed to the retarding basin after 30,600 s and to the eastern part along the expressway, similar to the occurrence in Case 3. At the peak discharge after 41,400 s, half part of the retarding basin was flooded. After the peak discharge, the water level of the river channels was decreased, and then, the water flow into the retarding basin stopped after 50,400 s. At the end of the analysis, the maximum water depth in the retarding basin was approximately 1.3 m and a water volume of approximately 120×10^4 m^3 was stored. At that time, the flooded area was approximately 2.3 ha, and the water was stored in half part of the retarding basin (Figure 4).
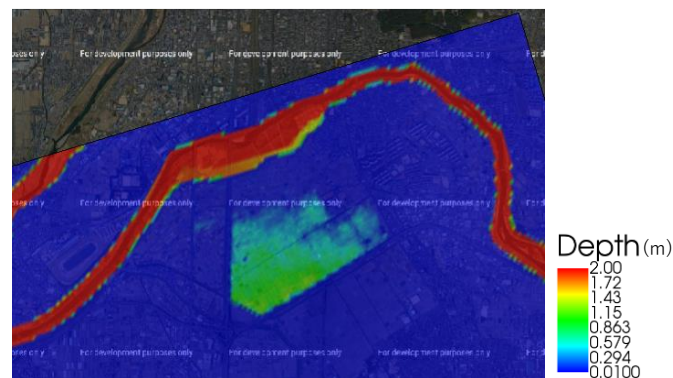

Figure 4. Distribution of the water depth after 82,800 s in Case 5 by Nays2DFlood.

A comparison of Cases 4 and 5 at Mukaijima site of the Uji River showed that the water level of the peak discharge was 17.203 m in Case 4, whereas the water level was 17.120 m in Case 5 with the retarding basin, showing a decrease of approximately 10 cm from that in Case 4 (Figure 5). In addition, the water level was 16.705 m at Yodo site in Case 4 and 16.618 m in Case 5, with a decrease of approximately 10 cm (Figure 6). It is considered that the water level decreased due to the water flowing into the retarding basin from the overflow levee. There was little change at the other sites.
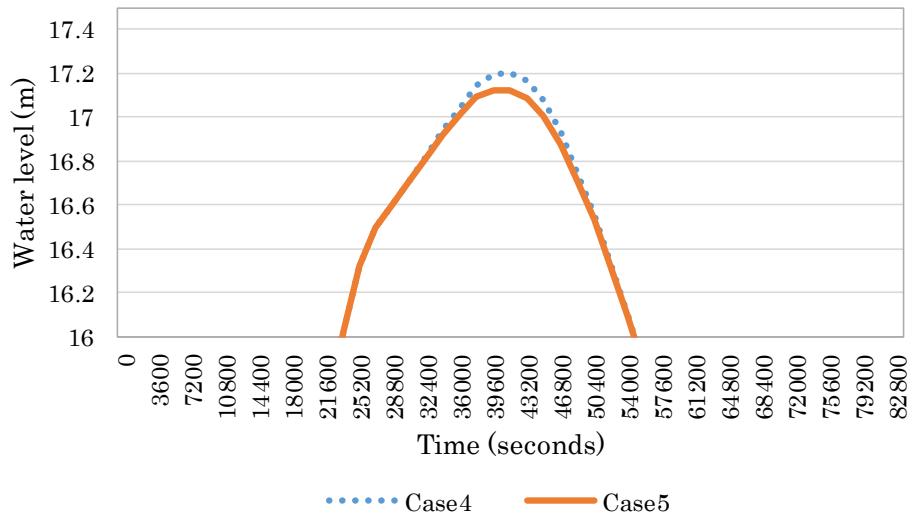

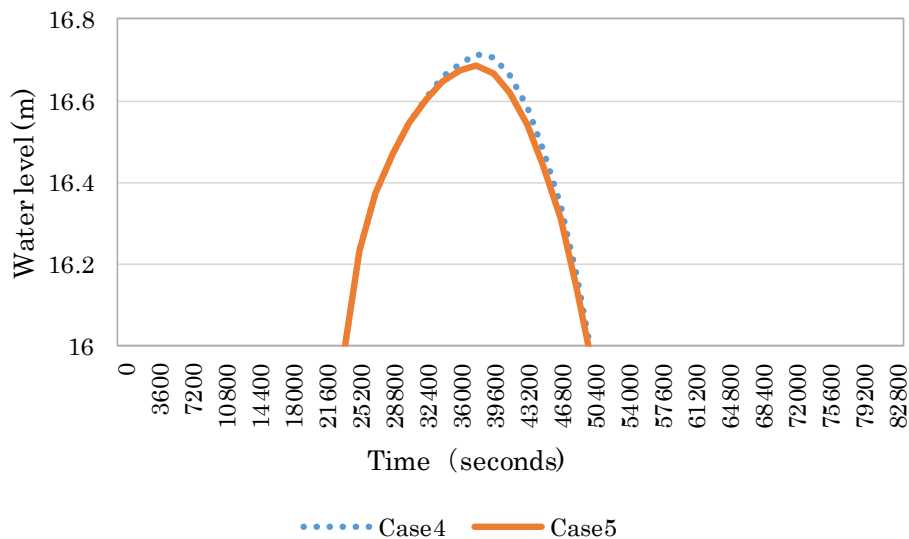Figure 5. Water levels of Mukaijima Site in Cases 4 and 5.

Figure 6. Water levels of Yodo Site in Cases 4 and 5.

In Cases 4 and 5, the analysis was conducted by assuming unprecedented floods by increasing the flow rate of the Uji River by 1.2 times. In this study, as the overflow levee was installed at the height of the estimated high-water level, the flow according to the current maintenance plan will pass through the river channel and the amount exceeding that will pass into the retarding basin. By drawing the water exceeding the estimated high-water level into the retarding basin, the risk of levee collapse can be reduced, and houses can be protected. In these analyses, the effect of decreasing the water level by approximately 10 cm was observed in the Uji River, but it is thought that the inflow into the retarding basin can be increased by setting an increased width of the overflow levee. In addition, the increase in the inflow will lower the water level of the Uji River, allowing the Katsura River and Kizu River to first flow downstream, decreasing the risk of flood risk in the middle and downstream of the Yodo River Basin areas.

3.2 Results of Maxent

Figure 7 shows the predicted distribution of freshwater minnows after 82,800 s after flooding, equivalent to the estimated high-water flow (Case 3). A high probability of suitable conditions for the species was observed in the retarding basin. The probability of presence was higher in the middle reaches of the Kizu River than that in

the retarding basin. When the distribution prediction model was evaluated by ROC analysis, the AUC value was as high as 0.971. Regarding environmental factors affecting the distribution of freshwater minnows, the water depth increased to 93.8%. The contribution rate of water velocity was 5.9%.
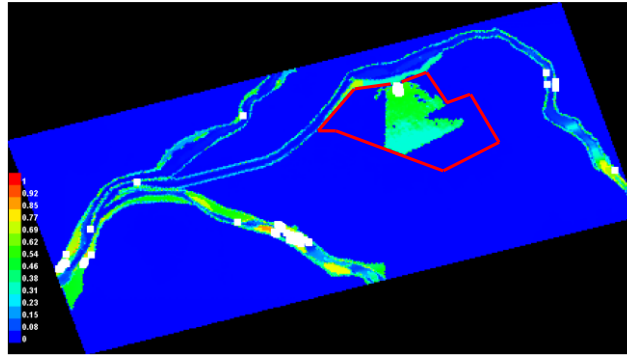

Figure 7. Predicted distribution of freshwater minnows after 82,800 s by Maxent in Case 3.

Figure 8 shows the predicted distribution of freshwater minnows after 82,800 s after flooding larger than that expected (Case 5). A high probability of suitable conditions for the species was shown in a wide area of the retarding basin. The probability of presence was higher in the middle reaches of the Kizu River than that in the retarding basin. When the distribution prediction model was evaluated by ROC analysis, the AUC value was as high as 0.972. Regarding environmental factors affecting the distribution of freshwater minnows, the contribution rate of water velocity was 100%.
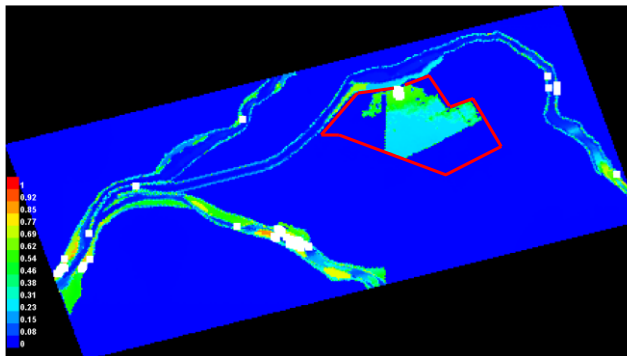

Figure 8. Predicted distribution of freshwater minnows after 82,800 s by Maxent in Case 5.

In Case 5, freshwater minnows showed a high probability of presence at a water depth of 1.5 m or less. The contribution of water depth was found to be high because the water depth preferred by freshwater minnows was widely distributed. In Case 5, there was no contribution of water depth, but as in Case 3, a high probability of presence was shown at a water depth of 1.5 m or less. The analysis of Case 5 showed a high probability of presence at a flow velocity of approximately 2 m/s. It is known that freshwater minnows has a high preference at 0.5 m/s or less during normal flow. It may be possible to live in places with high water velocity during floods, but the results need to be scrutinized.

In each analysis, elevation had a low contribution rate, similar to the environmental factor. In this analysis area, the elevation of the place with the water surface was approximately 10 m, therefore it is probable that there was no difference between the habitat and the place where it was not.

4. CONCLUSION

In this study, we conducted flood analyses for determining the effects of flood control and habitat analyses for the ecosystem when a part of the Ogura-Ike reclaimed land was used as a retarding basin, as a new flood control method for the Lake Biwa-the Yodo River basin. The study result showed that the retarding basin is effective in decreasing the water level of the river channel against large-scale floods. Although the analysis of fish habitats is limited to only one species, the retarding basin could be used as an evacuation site during floods. For habitat analysis, it is necessary to scrutinize the details of the analysis in the future.

Given the recent nationwide flood disaster trends, it is highly probable that floods exceeding the estimated high-water discharge will occur in this basin in the future. For such floods, it is necessary to minimize the damage rather than prevent it. In Japan, the damage caused by Typhoon 19 in 2019 required flood countermeasures that exceeded the planned scale of the river. The use of the Ogura-Ike retarding basin, as a countermeasure for excess flooding in the Lake Biwa-the Yodo River basin is expected to help reduce flood risks in the downstream basin.

REFERENCES

The Asahi Shimbun (2020) Revised the Naka River and Kuji River improvement plans, "Open levees" to outline plan. https://digital.asahi.com/articles/ASN1R470PN1RUJHB00N.html?_requesturl=articles%2FASN1R470PN1RUJHB00N.html&pn=4 (in Japanese)

Inoue, T., Iwasaki, T., Hamaki, M., Omura, K., and Kakegawa, E. (2012) Nays2D Flood Solver Manual. iRIC Project, 1-25. http://iric.org/en/download/get/KNwWfa

The Japan Society of Civil Engineers (2020) Proposal for future disaster prevention and mitigation based on Typhoon 19 disaster in 2019 -Conversion to river basin flood control, integrating rivers, flood control, and local areas and cities-. http://www.jsce.or.jp/strategy/files/hagibis_20200123.pdf (in Japanese)

Land improvement district of Ogura-Ike (2001) *Sixty years' history of Ogura-Ike draining*. Land improvement district of Ogura-Ike. (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism (2019) Proposal of flood control plans based on climate change. https://www.mlit.go.jp/river/shinngikai_blog/chisui_kentoukai/pdf/02_honbun.pdf (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism (2019) River Environmental Database. http://www.nilim.go.jp/lab/fbg/ksnkankyo/ (in Japanese)

Mizuho Information & Research Institute (2015) iRIC Software User's Manual, 1-231. http://i-ric.org/en/download/get/CKyk8w

Science Council of Japan (2014) Suggestions: Ecology on reconstruction and national resilience. http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-22-t199-2.pdf (in Japanese)

Steven J. Phillips, Robert P. Anderson, Robert E. Schapire (2006) Maximum entropy modeling of species geographic distributions. Ecological Modelling, 190:231-259.