# BASIC STUDY ON DRAINAGE METHOD FROM A RETARDING BASIN TO THE UJI RIVER

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## ABSTRACT

In September 1953, Typhoon No. 13 caused extensive flood damage to the Ogura-Ike Reclaimed Land after the collapse of a levee on the left bank of the Uji River in the Yodo River basin. Since then, floods have not occurred in this area, but in recent years, various parts of Japan have experienced flooding owing to unprecedented heavy rains. The risk of flooding in the Uji River owing to such abnormal weather is also quite high. The Ogura-Ike Reclaimed Land targeted in this study was converted from a pond to field land in 1941. The current elevation of this area is not considerably different from when it was reclaimed; as such, this area represents the lowest point in the wider Yamashiro Basin. In this study, the use of the Ogura-Ike Reclaimed Land as a retarding basin to reduce the water level in the Uji River was investigated through simulations. It was shown that a water level rise in the Uji River and the flooded time in the basin both depend on the time at which drainage is initiated from the retarding basin into the Uji River downstream. The results of this study can serve as a reference for further investigations into the flood control effect of using the Ogura-Ike Reclaimed Land as a retarding basin on the Uji River, as well as the impact on the fields within the basin.

*Keywords*: Ogura-Ike Reclaimed Land, Ogura-Ike retarding basin, Drainage method, Simulation, Nays2DFlood of iRIC

## 1. INTRODUCTION

In Japan, river improvements are implemented based on the river improvement basic policy and the river improvement plan that were established with the revision of the River Law in 1997. However, in recent years, several parts of Japan have experienced floods and overflows owing to unprecedented weather phenomena, and the lives and property of several residents have been lost. In October 2019, the Ministry of Land, Infrastructure, Transport and Tourism (MLITT) implemented "Flood Control Plans Considering Climate Change: Recommendations" and presented a new flood control plan policy based on these recent phenomena, which are commonly referred to as abnormal weather.

This study focuses on the Uji River, which flows through the middle part of the Yodo River basin, which itself is a part of the larger Yamashiro Basin. The Yodo River is a midstream region where the Uji River, Kizu River, and Katsura River join to form the Yodo river before flowing into the Osaka Bay. Lake Biwa, the largest lake in Japan, is located upstream of this region on the Uji River. The Yodo River passes through some of the most economically important cities in Japan, including Kyoto in its middle reaches and Osaka city in its lower reaches. Typhoon No. 19 in October 2019 caused devastating damage to the Kanto Koshinetsu and Tohoku regions in northern Japan, and the effects of this damage spread throughout the country. Similarly, it is feared that direct damage to the Kansai economic zone due to flooding in the Yodo River basin will also affect the whole of Japan. It therefore is essential and urgent to improve the safety of flood control measures in the Yodo River basin.

In the Yodo River tributaries (the Katsura River and the Kizu River), recent abnormal weather has caused the overflow of both levee and non-levee areas. Along the Katsura River, for example, this has resulted in damage to the popular Arashiyama area tourist destination. In the Katsura River basin, these events include the 2013 Typhoon No. 18 (MLITT Kinki Regional Development, 2013) and the 2014 Typhoon No. 11 (MLITT Kinki Regional Development Bureau, 2014). In the Kizu River basin, these events include the 2017 Typhoon No. 21 (MLITT Kinki Regional Development Bureau, 2017). The Uji River, on the other hand, has not suffered a major flood in recent years. However, the situation is far from safe, with the 2013 flood causing a leak in the Uji River levee system (MLITT Kinki Regional Development Bureau, 2019). In the past, the Uji River levee collapsed due to a flood caused by the heavy rains of Typhoon No. 13 in 1953. The break point of the levee was about 2 km downstream of Kangetsu Bridge, or about 43.2 km upstream of the mouth of the Yodo River, opening about 450 m of the embankment and flooding about 2880 hectares of the Ogura-Ike Reclaimed Land for 25 days. Since then, this area has not suffered a similar flood due to the construction of the Amagase dam and river improvement works. Still, the increasingly heavy rains in recent years suggest a high probability of flooding along the Uji River.

In this study, we propose the use of the Ogura-Ike Reclaimed Land as a retarding basin as part of a new flood control facility. The Ogura-Ike Pond was reclaimed as primarily field land during the early Showa period (1941). The current elevation of this land today is not considerably different from what it was at the time of reclamation; thus, it represents the lowest point in the wider Yamashiro Basin. As a result, Ogura-Ike drainage station and Kumiyama drainage station were installed to combat flooding in this area. As water collects south of the bend in the Uji River, it flows north, downhill toward the river, only to be trapped by the river's left levee, making the Ogura-Ike Reclaimed Land a place where flood waters easily gather. However, most of this area is still used as fields and can continue to be used as such in the proposed flood control facility; only in the case of emergency, it would be necessary to use it as a retarding basin.

The objectives of this research are follows: (1) Most of the current Ogura-Ike Reclaimed Land consists of fields. If it is assumed that this land will continue to be used as fields except during floods. The duration for which flood water is accumulated in the retarding basin may affect crops and fields. Therefore, the fastest possible timing for draining the overflow water flooded into the Ogura-Ike Reclaimed Land back into the Uji River is examined using a simulation. The operation rules of the currently installed drainage stations (Kumiyama and Ogura-Ike) are not considered. (2) The effects of the timing of the start of drainage from the Ogura-Ike Reclaimed Land retarding basin were also evaluated on the water level reduction in the Uji River.

## 2. METHODS

### 2.1 Flood analyses using the iRIC software and Equations

In this study, a flood analysis of the Ogura-Ike Reclaimed Land was conducted using iRIC Software (Ver.3.0), which can provide plane two-dimensional flood analysis. The Nays2DFlood solver (ver.5.0) in iRIC was used as a solver for flood flow analysis based on unsteady plane two-dimensional flow calculations using boundary-fitted coordinates in general curve coordinates. This model is based on the following continuity equation:

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

and equations of motion:

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

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

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

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

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

where $h$ is the water depth in the river, $t$ 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, sluice pipe, or pump per unit area, $r$ is the amount of rainfall, $g$ is the gravitational acceleration, $H$ is the water surface elevation of the river, $\tau_x$ is the riverbed shear stress in the x-direction, $\tau_y$ is the riverbed shear stress in the y-direction, $C_f$ is the riverbed friction coefficient ($C_f = \frac{gn^2}{h^{1/3}}$, where $v_t$ denotes the eddy viscosity coefficient, $\rho$ denotes water density, and $n$ denotes Manning's roughness coefficient.

## 2.2 Conditions

The study area comprises the three-river junction area, including the Ogura-Ike Reclaimed Land, in the Lake Biwa-Yodo River Basin in the Kinki District, Japan (Figure 1). The simulation conditions are defined in Table 1. The boundary conditions at the upstream ends of the three rivers set the flow (Figure 2). The flow rate was set in consideration of the Uji River adjacent to the Ogura-Ike Reclaimed Land. The target flood was considered as the one that included the highest flood data value (21:00 on August 10, 2014) among those recorded at the Uji Observatory upstream of the Uji River. In this study, this flow rate was multiplied by 1.15 to generate an unexpected flow rate. The flow at the upstream ends of the Katsura River and Kizu River was set to the corresponding flows measured during the period selected for the upstream end of the Uji River. Three retarding basin areas were evaluated based on the existing land use situation. The location and section of the overflow levee were assumed to be the same as the location (2 km downstream of Kangetsu Bridge, at 43.2 km upstream of the mouth of the Yodo River) and section (450 m) that collapsed because of Typhoon No. 13 in September 1953. The height set for the overflow levee was the same as that corresponding to the planned high-water flow (1500 $m^3/s$) established in the river improvement plan. Drainage from the retarding basin into the Uji River was assumed to be conducted by a pump. The drainage capacity was assumed to be the same as the current installed drainage capacity (maximum of 200 $m^3/s$) of the drainage stations located in the Ogura-Ike Reclaimed Land.

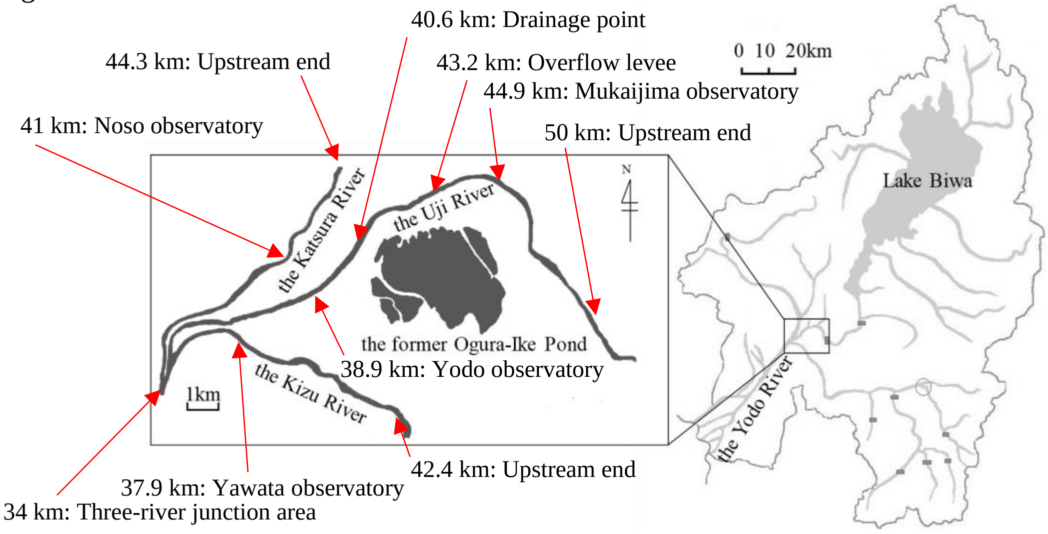



Figure 1. Location of Ogura-Ike Pond in region of confluence of three rivers in Lake Biwa–Yodo River Basin. The enlarged square region depicts flood-analysis region.

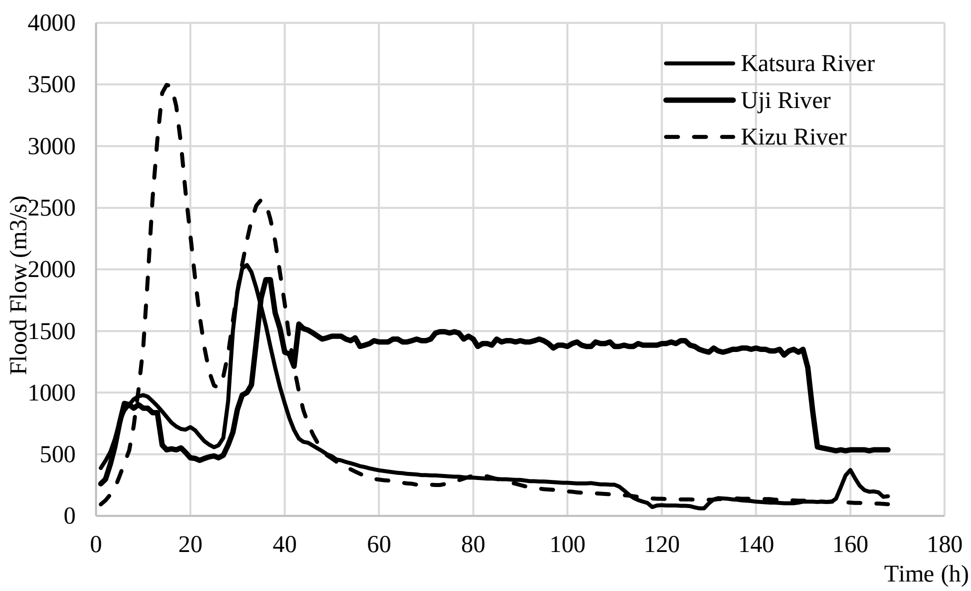



Figure 2. Variations in flood flow with time at the upstream ends of the three rivers.

Table 1. Analysis conditions of three rivers.

| Data items | Parameters |
|---|---|
| **Analysis areas** | 77.4 $km^2$<br>Including the following reaches:<br>34.0–44.3 km for the Katsura River<br>34.0–50.0 km for the Uji River<br>34.0–42.4 km for the Kizu River |
| **River channel conditions** | River channel survey from 2015<br>Digital elevation model (DEM), 5-m mesh from 2016 |
| **Flood flow (Upstream end setting)** | Hydrograph of Typhoon No. 13 in 2014 (8/9 10:00 to 8/16 9:00):<br>Max 2,036 $m^3$/s for the Katsura River<br>Max 1,917 $m^3$/s for the Uji River (※1,667×1.15)<br>Max 3,497 $m^3$/s for the Kizu River |
| **Downstream end setting** | 34.0 km for the Yodo River, free discharge |
| **Analysis meshes** | 25 × 25 m |
| **Manning's roughness coefficient** | 0.025 $m^{-1/3}$/s |
| **Retarding basin area** | Case A: 306 × $10^4$ $m^2$ (1,315 ×$10^4$ $m^3$)<br>Case B: 432 × $10^4$ $m^2$ (1,733 ×$10^4$ $m^3$)<br>Case C: 614 × $10^4$ $m^2$ (2,578 ×$10^4$ $m^3$) |
| **Surrounding levee** | 18.6 m elevation (as same as the elevation of the Uji River levee)<br>The retarding basin was established in the northeastern part of the reclaimed land where few houses exist in the urbanization control area |
| **Overflow levee** | 15.2 m elevation and 450 m width, 43.2 km upstream of the mouth of the Yodo River |
| **Water level observatories** | Three-river junction area: on the Yodo River, 34 km upstream of the mouth of the Yodo River<br>Yodo Observatory: on the Uji River, 38.9 km upstream of the mouth of the Yodo River<br>Overflow levee: on the Uji River, 43.2 km upstream of the mouth of the Yodo River<br>Mukaijima Observatory: on the Uji River, 44.9 km upstream of the mouth of the Yodo River<br>Noso Observatory: on the Katsura River, 41 km upstream of the mouth of the Yodo River<br>Yawata Observatory: on the Kizu River, 37.9 km upstream of the mouth of the Yodo River |

## 3. RESULTS AND DISCUSSION

### 3.1 Timing for initiating basin draining: Basin drainage and flooded times

To determine the optimal timing for draining the Ogura-Ike Reclaimed Land to the Uji River, a series of simulations were performed evaluating 12 cases (Cases A-1 to A-4, Cases B-1 to B-4, and Cases C-1 to C-4), where Cases A, B, and C were as defined in Table 1. Cases A-1, B-1, and C-1 were evaluated under conditions in which pump drainage was not performed; the starting time for pump drainage was determined based on these results. In Cases A-2, B-2, and C-2, pump drainage was initiated when the water level in the river upstream of the overflow levee reached its the maximum value and began to decrease. In Cases A-3 and A-4, B-3 and B-4, and C-3 and C-4, pump drainage was initiated when the water level at the overflow levee fell below the planned high-water level. An example using Case B is illustrated in Figures 3–5 and discussed below.

As can be observed in Figure 3, the water level change per hour in the Uji River at the overflow levee from the start of drainage at 39 h to 54 h (near the planned high-water level) is larger in Case B-2, in which drainage was performed from the retarding basin to a downstream point on the Uji River, than in Case B-1, in which no drainage was performed. After 54 h, the water level in the Uji River near the overflow levee tends to falls in Case B-1 until 76 h, but rises in Case B-2 over the same period. This can be attributed to the rise in the water level at the drainage point on the Uji River owing to the drainage from the retarding basin to the river, as shown in Figure 5; this backs up the flow of the river upstream. In Case B-3, from the start of drainage at 56 h to 73 h, the Uji River water level also shows a rising trend, as in Case B-2. In Case B-4, from the start of drainage at 76 h to 94 h, the Uji River water level shows a rising trend, whereas Cases B-1, B-2, and B-3 all show a falling trend during this period. This is reflected in the reduction in drainage flow in Cases B-2 and B-3, as shown in Figure 4, compared with Case B-4, which still shows the maximum drainage flow. This difference in drainage flow rate clearly affects the water level in the Uji River as the flood waters pass.

Table 2 shows the drainage and flooded time. It was confirmed that the drainage time was shorter in Case B-4, when draining was initiated once the water level in the Uji River fell below the planned high-water level, than when draining was initiated earlier. As is clear from Figures 3 and 4, in Case B-2, the Uji River water level at the time of drainage was still higher than the overflow levee; hence, the inflow into the retarding basin continued even as drainage was being conducted into the Uji River downstream. However, the flooded time was the shortest under Case B-2, as the water in the basin was drawn down while the river was falling. In Case B-3, the water level of the Uji River also continued to exceed the height of the overflow levee and thus, water continued to flow into the basin. However, in Case B-4, the water level in the Uji River spent the least time above the elevation of the overflow levee once drainage was initiated. Thus, the longer drainage time in Case B-3 than in Case B-4 can be considered to be a result of the flow characteristics under the upstream end conditions. Cases A and C were also confirmed to exhibit the same general tendencies as Case B did.

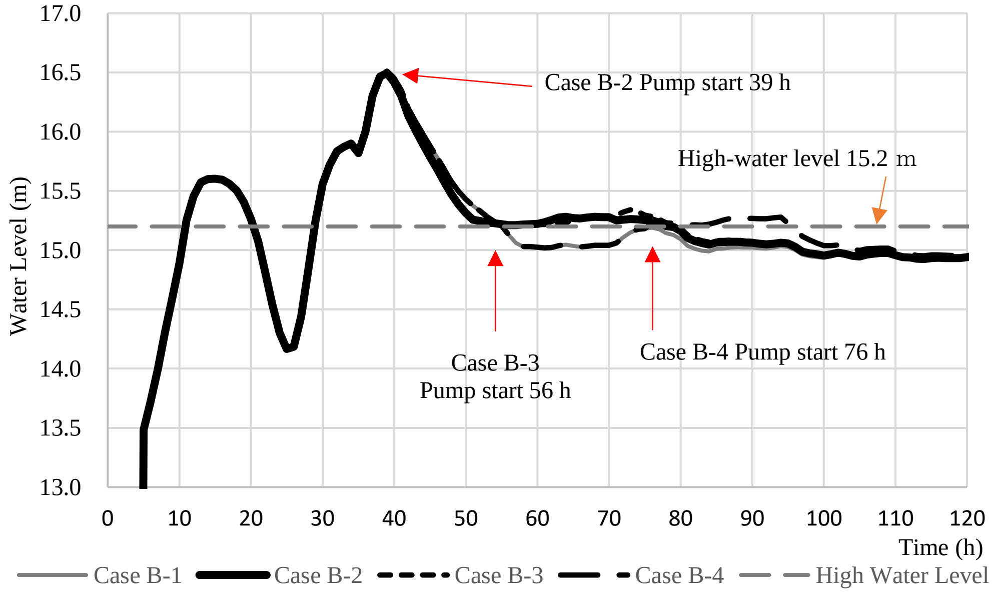



Figure 3. Change in water level of Uji River near overflow levee according to Case B drainage start times.

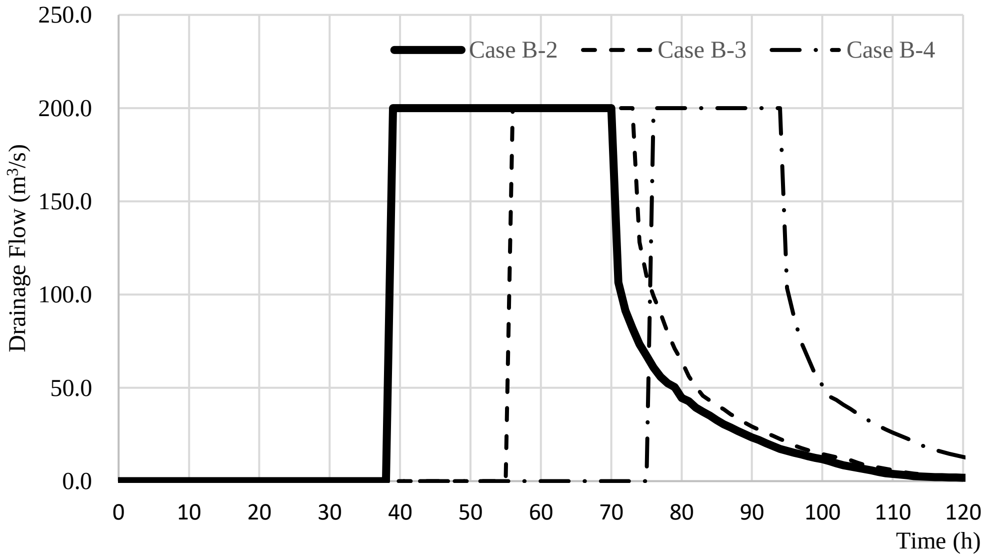



Figure 4. Time change in drainage flow according to drainage start time (Cases B-2, B-3, and B-4) .

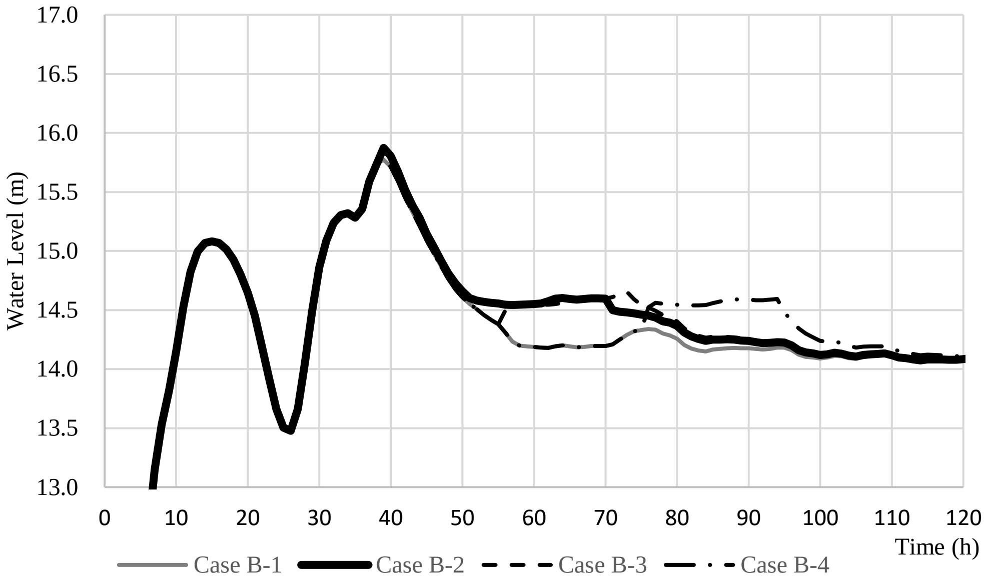



Figure 5. Water level of Uji River at drainage point (from Case B-2 to Case B-4).

Table 2. Drainage time and flooding time of the Ogura-Ike Reclaimed Land.

| Case | Overflow start(h) | Drainage start(h) | Drainage stop(h) | Drainage time(h) | Flooding time(h) |
|---|---|---|---|---|---|
| **A-2** | 11.0 | 39.0 | 85.0 | 46.0 | 74.0 |
| **A-3** | 11.0 | 54.0 | 87.0 | 33.0 | 76.0 |
| **A-4** | 11.0 | 76.0 | 107.0 | 31.0 | 96.0 |
| **B-2** | 11.0 | 39.0 | 112.0 | 73.0 | 101.0 |
| **B-3** | 11.0 | 56.0 | 115.5 | 59.5 | 104.5 |
| **B-4** | 11.0 | 76.0 | 133.5 | 57.5 | 122.5 |
| **C-2** | 11.0 | 35.0 | 110.0 | 75.0 | 99.0 |
| **C-3** | 11.0 | 56.0 | 114.5 | 58.5 | 103.5 |
| **C-4** | 11.0 | 76.0 | 131.5 | 55.5 | 120.5 |

### 3.2 Timing for initiating basin draining: Uji River water level

Figure 6 shows the changes in the maximum Uji River water level above and below the overflow levee located at 43.2 km above the mouth of the Yodo River under the different evaluated cases. The case with no overflow levee installed is termed “No overflow levee”. Note that in Cases A-1, B-1, and Case C-1, the position, height, and width of the overflow levee are the same; only the timing of basin drainage is varied as previously defined.

At 34.0 km, where the three-river junction (Uji River, Katsura River, and Kizu River) is located, a water level reduction of about 10 cm was confirmed using any river overflow case. This result shows that the effect of suppressing the rise in water level is small downstream of the overflow levee. Note that the Katsura River and Kizu River have the same or better flow capacity than the Yodo River. Therefore, the effects of the Katsura River and Kizu River are further clarified later in this section.

At the 43.2 km point (location of the overflow levee), the water level reduction effect of Case A-1, Case B-1, and Case C-1 was determined to be about 36 cm, 71 cm, and 124 cm, respectively, for retarding basin areas of $306 \times 10^4$ m$^2$, $432 \times 10^4$ m$^2$, and $614 \times 10^4$ m$^2$, respectively. Assuming that the elevation of the surrounding levee is the same as that of the Uji River levee, it was clarified that the larger the basin, the more the rise in water level can be suppressed.

At the 44.9 km point, the water level reduction effect of Case A-1, Case B-1 and Case C-1 was determined to be about 36 cm, 70 cm, and 115 cm, respectively. It was thus clarified that the effect of the overflow in the retarding basin extends upstream along the Uji River.

Figure 7 shows the changes in the water level in the Katsura River and Kizu River when the highest water level was recorded. The results indicate that the area of the retarding basin or even the presence of the overflow levee had no effect on these rivers.

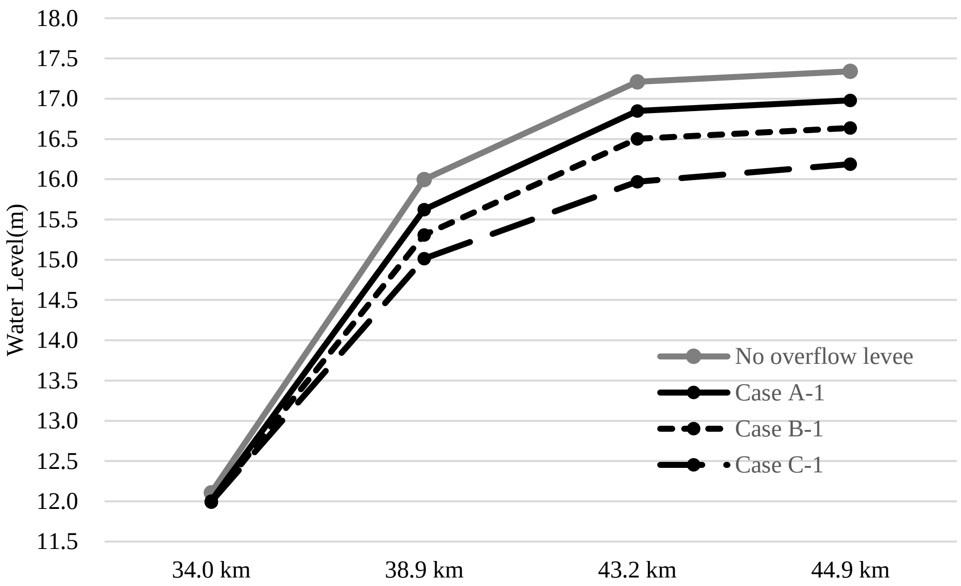
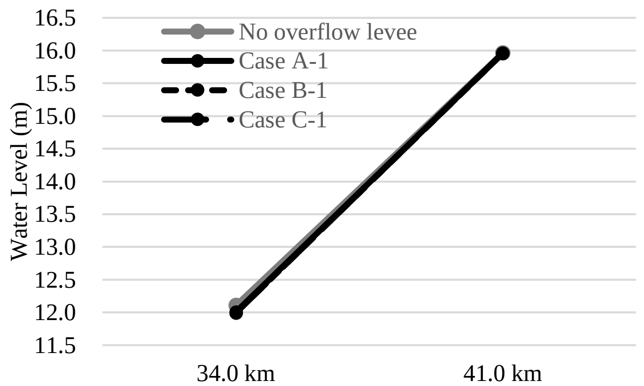



Figure 6. Water level of Uji River at time of highest water level (horizontal axis denotes distance from mouth of Yodo River, 34 km denotes location of confluence of three rivers, and 43.2 km represents location of overflow levee).



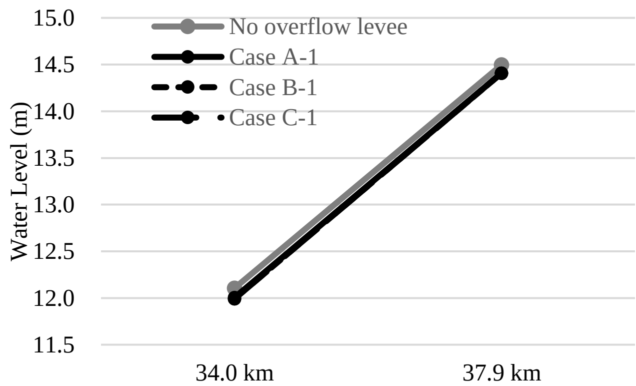




Figure 7. Water level of Katsura (left) and Kizu (right) rivers at time of highest water level of Uji River (horizontal axis denotes distance from mouth of Yodo River and 34 km denotes location of confluence of three rivers) .

## 4. CONCLUSIONS

In this study, we investigated the ability to ensure agricultural business continuity when using the Ogura-Ike Reclaimed Land as a retarding basin, focusing on the duration for which the basin is flooded according to when drainage operations are initiated. The operating time of the drainage pump was found to be shorter when drainage was initiated after the flow from the Uji River into the retarding basin had stopped. However, considering the corresponding burden on fields and crops, it was clarified that the flooded time was shorter when drainage was initiated earlier, once the water level in the Uji River began to fall from its maximum.

In terms of effect of the retarding basin area on the water level reduction in the Uji River, it was determined that the larger the retarding basin, the greater the water level reduction effect of the basin. Note that the levees of the Uji River are mostly composed of soil materials; the lower the water level, the smaller is the burden on the levee. It was demonstrated in this study that the suppression of the rise in water level due to the establishment of the retarding basin extends from the overflow levee in both the upstream and downstream direction along the Uji River. Additionally, it was clarified that the use of the Ogura-Ike Reclaimed Land as a retarding basin could not be expected to have any effect on the suppression of the rise in water level in the Katsura River or Kizu River. However, by cooperating with other flood control facilities such as the Hiyoshi Dam located upstream on the Katsura River and another dam and basin located upstream on the Kizu River, the proposed Ogura-Ike retarding basin can be expected to aid in managing water levels in the Yodo River basin during a flood event.

The authors expect that the results of this study will be helpful as a reference for further investigations of the Uji River flood control system and the impact of flooding on the fields of the Ogura-Ike Reclaimed Land when used as a retarding basin.

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