HISTORICAL RIVER COURSE CHANGES AND PADDY FIELDS DEVELOPMENTS IN THE ARAKAWA RIVER BASIN, JAPAN AND THE ROLE OF SECOND EMBANKMENTS IN THE RECENT 2019 FLOODING EVENT

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ABSTRACT

During the Edo Era in Japan (around 150-420 years ago), river course changes were conducted in the Kanto Plain, where capital Tokyo now exists, and new paddy fields were developed. As this river course change significantly changed the flooding risk, many secondary embankments (SEs), open levees (OLs), or polders for controlling flood inundation were constructed after the river-course change. This is especially in the Arakawa River. The objective of this study was to quantify the role of the still existing SEs and OLs in terms of flood management. A two-dimensional flood model was applied to the middle reach of the Arakawa River basin to clarify the change in flooding risk area before and after the change of the Arakawa River course (Arakawa-Seisen). After the change of the river course, around a river confluence with branches (Wadayoshino River, Ichino River, Iruma River) with the Arakawa River, overtopping from river embankment was increased by backwater phenomenon. It changed the Yoshimi and Kawajima area to flood-prone areas. Although large floods had not occurred around recent 100 years till 2019, breaching of the embankment by the recent 2019 typhoon occurred in four locations in this river basin. Although the flood inundation pattern differs in the past, OLs in the Tokigawa River and Nagarakutei Embankment (part of the Kawajima Polder, which is the second embankment for Ichino River now) have proved to have still the roll to store water in the area and reduce flood inundation area downstream.

Keywords: Flooding risk, polder, second embankments, river confluence, historical changes

1. INTRODUCTION

After the change of river course in 1629, from Moto-Arakawa River to the present Arakawa River in Japan (Arakawa-Seisen reconnection, hereafter AR), flood inundation frequently occurred in the Arakawa River basin; a frequency of around once in ten years, till hundred years ago. Many secondary embankments for controlling flood flow in the hinterland of river embankments were constructed, especially in Yoshimi and Kawajima Town. After the large floods in 1910 and 1913, diversion channels, high embankments, dams, etc. were constructed and in the past hundred years, large floods by breaching of the embankment of the main river did not occur. However, from the river capacity, sensible flooding risk is still located there when design level floods occur. Many secondary embankments still exist, and the roles of these embankments are not clarified (Tanaka et al., 2019). Tanaka et al. (2019) concluded that sensible flooding risk area against the recurrent flood period of 200 years is located in a similar area although the present levee height became quite high (6-8 m), compared with that (around 3 m) around 100-400 years ago. The study demonstrated that the historical second embankments still can store the inundation flow and delay the flooding in the downstream region around 1-8 hours for the simulated flood conditions.

Typhoon Hagibis in 2019 caused severe damage to many large rivers in East Japan. Arakawa River was one of those large rivers affected. Breaching of river embankment also occurred in the basin. Therefore, the objective of this study was to clarify how secondary embankments, also known as Kasumitei bank or open levee (hereafter noted as KB), played a role in controlling the flood inundation. For that objective, a numerical simulation in the Arakawa River basin was conducted to elucidate the sensible flooding risk in the area and compare this to the situation of the inundation pattern by the 2019 Typhoon Hagibis.

2. MATERIAL AND METHODS

This study adopted a two-dimensional non-linear depth-averaged flow model in the Arakawa region (continuity equation: Eq.(1), momentum equations: Eqs.(2)–(5)), the same with Tanaka et al. (2019).

$$\theta \frac{\partial \eta}{\partial t} + \frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y} = 0 \tag{1}$$

$$\frac{\partial Q_x}{\partial t} + \frac{\partial}{\partial x}\left(\frac{{Q_x}^2}{\theta(\eta + h)}\right) + \frac{\partial}{\partial y}\left(\frac{Q_x Q_y}{\theta(\eta + h)}\right) + \theta g(\eta + h)\frac{\partial \eta}{\partial x} + \theta \frac{\tau_{bx}}{\rho} = 0 \tag{2}$$

$$\frac{\partial Q_y}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q_x Q_y}{\theta(\eta + h)}\right) + \frac{\partial}{\partial y}\left(\frac{{Q_y}^2}{\theta(\eta + h)}\right) + \theta g(\eta + h)\frac{\partial \eta}{\partial y} + \theta \frac{\tau_{by}}{\rho} = 0 \tag{3}$$

$$\tau_{bx} = \frac{\rho g n^2}{(\eta+h)^{7/3}} Q_x \sqrt{{Q_x}^2 + {Q_y}^2} \tag{4}$$

$$\tau_{by} = \frac{\rho g n^2}{(\eta+h)^{7/3}} Q_y \sqrt{{Q_x}^2 + {Q_y}^2} \tag{5}$$

where x and y are the horizontal coordinates in a Cartesian coordinate system; subscript x or y means the direction of the respective value; Q the discharge; τ_b the bed shear stress; t the time; η+h the total water depth; h the local still water depth (on land, the negative height of the ground surface); η the water surface elevation; g the gravitational acceleration; ρ the density of seawater; n the Manning roughness coefficient.

The elevation and the linkage of the Arakawa main river and branches are modelled in the two-dimensional non-linear depth-averaged flow model. A set of the model equations was solved by the finite-difference method using a staggered leap-frog scheme. An upwind scheme was used for nonlinear convective terms in order to maintain numerical stability. A semi–Crank-Nicholson scheme was used for the bed friction, drag, and eddy viscosity terms. The assumed discharge hydrographs of which recurrent probability is 2 years, has time series similar to that of the 1947 typhoon, that caused severe damage to the Arakawa River (1947-type flood). For the sensitive flood risk in old times, 2 year return period of flood is selected as the embankment height is around 1-3 m around 400 years ago, and peak values are assumed not so large as flooding occurred in the upstream of the boundaries in many locations.

Field investigations was conducted after the 2019 Typhoon Hagibis, which caused severe damage in Japan. In our study site, breaching occurred at four locations within the Iruma River basin.

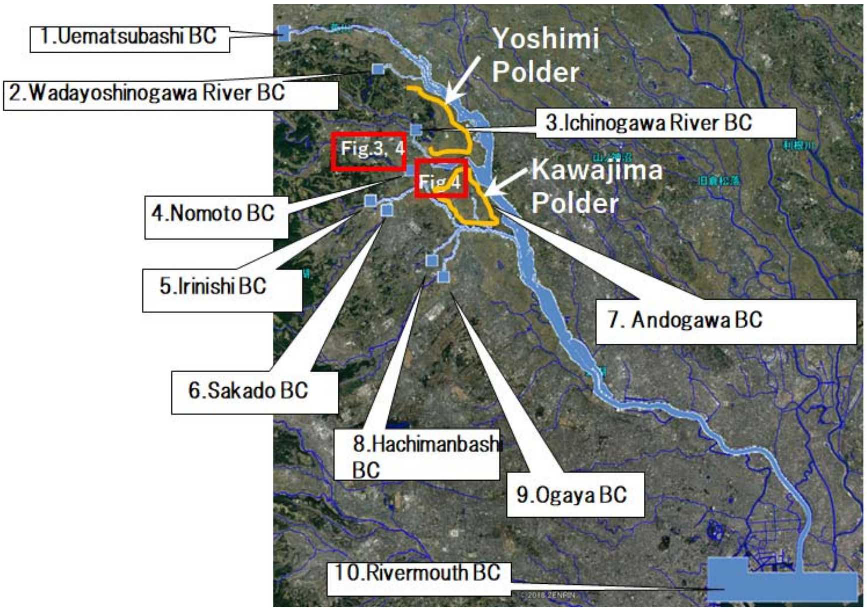


Figure 1. Schematic figure of the flood inundation model in the Arakawa River basin. The area with the red rectangle shows the flood inundation area more specifically in Figure 3 and 4.

3. REPRODUCTION OF SENSIBLE FLOODING RISK IN EDO ERA BEFORE AND AFTER ARAKAWA-SEISEN (RIVER-COURSE CHANGE: AR)

3.1 Change in flood risk area by Arakawa-Seisen

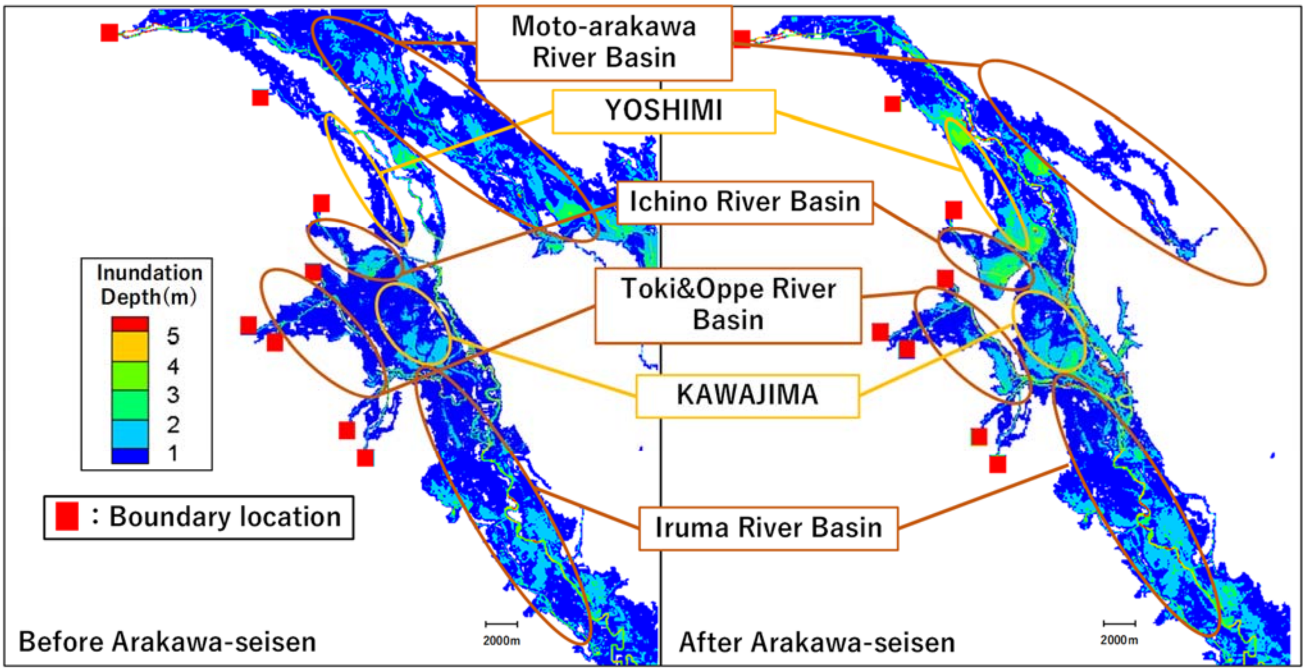
Figure 2 shows the flood inundation pattern before and after AR at 47TF (recurrent period of floods is 2 years). Before AR, breaching occurred on the left-hand side of the Arakawa River (Moto-Arakawa River area). However, inundation became severe at the right-hand side of the Arakawa River after AR. Especially, the inundation depth became larger in the Yoshimi area and Kawajima area. In the Toki & Oppe and the Iruma River basin, flooding risk itself does not change much.

Tanaka et al. (2019) discussed the present sensible flooding risk area for 1947-type flood (here recurrent period of floods is not 2 years instead it was 200 years) and confirmed the simulated inundated area is similar to that in the historic 1910 flood event, although the flood type was not the same. Historically, two polders (Yoshimi Polder and Kawajima Polder) were constructed in these areas with around 3-4 m in bank height. Even though the embankment height has been increased (now around 5-8 m in height), the flooding occurs in a similar area when recurrent flood level is around 200 years.

These sensible flooding risk locations were generated by the river course change around 400 years ago, and these locations were severely attacked by floods around once in ten years, 100-400 years ago. So many SEs and OLs were constructed in the area. Although the embankment height became high and flow capacity largely increased, the sensible flooding risk was supposed to exist in the region when flood level exceeds the capacity of the river.

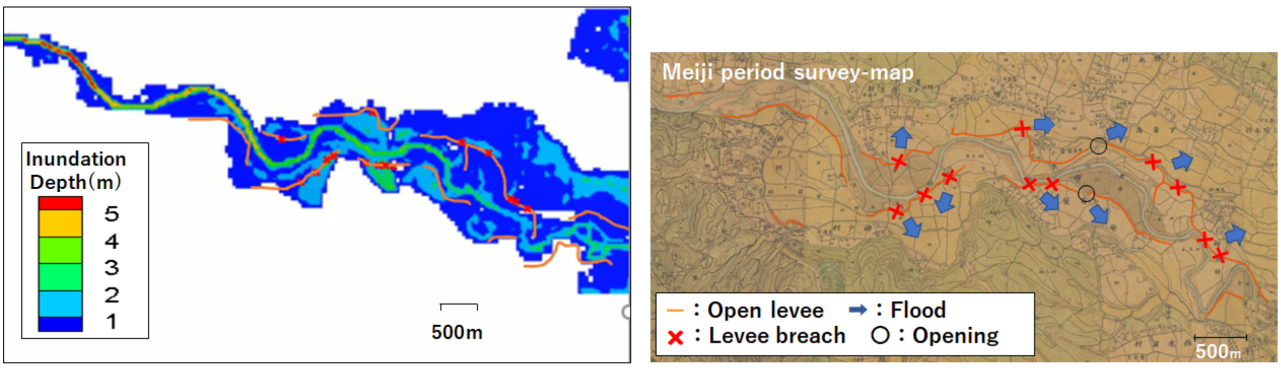
3.2 Effects of Kasumitei open levees (OLs) in the Tokigawa River

Flood inundation in the OLs area in the Tokigawa River under the scenario of 1947-type floods with 2-years return period of floods before AR is shown in Figure 3. Although the OLs had a role in storing floodwater, they are assumed to be breached at flood events in this simulated scenario. The inundated water runs along the river and accumulated at the North-side of Kawajima Polder (Nagarakutei Embankment).



(a) (b)

Figure 2. Flood inundation area under the scenario of 1947-type floods with 2-years return period of floods when the embankment height was low. (a) Before Arakawa-Seisen reconnection (AR), (b) after AR



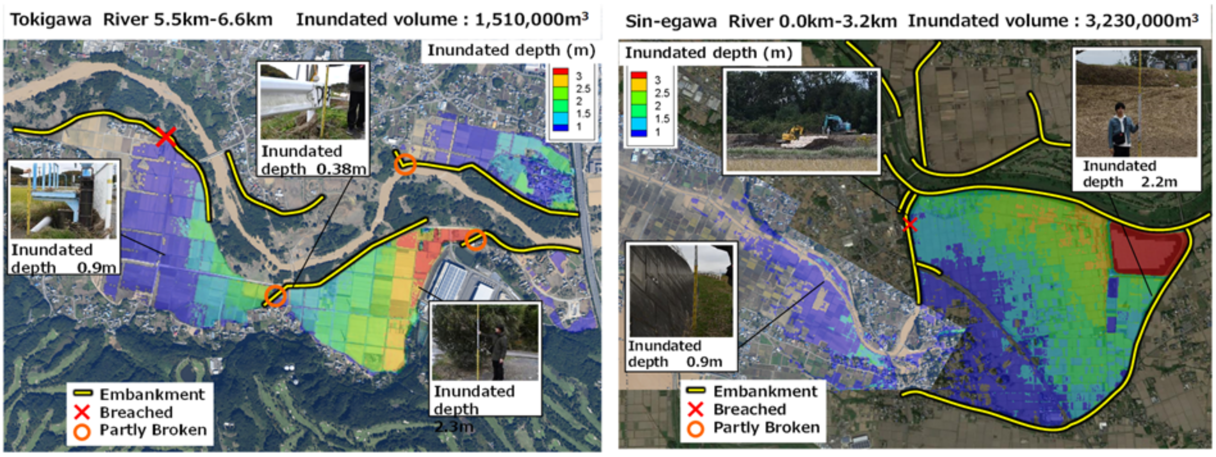
(a) (b)

Figure 3. Simulated flood inundation area in the OLs area in the Tokigawa River under the scenario of 1947-type floods with 1/2 recurrent period of floods when the embankment height was low. (a) Inundation area before AR, (b) breached point and the flow direction before AR

4. FLOOD INUNDATION AREA AT TYPHOON HAGIBIS EVENT

At the event of 2019 Typhoon Hagibis, the area shown in Figure 4 were inundated. Similar flood inundation for the Ichinogawa Region and the Toki and Oppe Region in Figure 2 were also observed. For the risk in the main Arakawa River, it did not appear this time as the embankment is high in the main Arakawa River and flood discharge was relatively low.

Using flood inundation area map by Ministry of Land, Infrastructure, Transport and Tourism Japan (MLIT), the inundated areas around the Tokigawa River by the 2019 Typhoon Hagibis are estimated. Using the inundated map and the land elevation data (5-m grid data) measured by Laser Profiler (MLIT), the inundated volume was estimated. Estimated inundated volume on the right-hand side of the Tokigawa River and North of Nagarakutei Embankment are 1,510,000 m^3 and 3,230,00 m^3, respectively. A large amount of floodwater was stored in this region. If there are no SEs (especially Nagaralutei Embankment), the inundation was also assumed to occur in the Kawajima Town (inside Kawajima Polder). Although Arakawa River has a large flood retention lake, which can store around 39,000,000 m^3 of water, it was almost full by the 2019 typhoon event (35,000,000 m^3). If the flood inundation did not occur in the middle area of the Iruma River basin, it has some possibility to affect the downstream flood situation. The Nagarakutei Embankment is a part of Polder constructed around 400 years ago, and now, it is not directly used as an embankment for the Ichinogawa River, a branch of the Arakawa River, it still has a role to manage floods in this area.



(a) (b)

Figure 4. Flood inundation area and the inundated volume at 2019 Typhoon Hagibis. (a) At OLs in the Tokigawa River, (b) north part of the Nagarakutei Embankment

5. CONCLUSIONS

Although the flood inundation pattern differs a little, OLs in the Tokigawa River and Nagarakutei Embankment (Part of the Kawajima Polder, which is the second embankment for Ichino River now) has proved to have still the roll to reduce flood inundation area. Therefore, the historical flood management system should be kept or strengthened for mitigating future flood inundations.

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