Evaluating potential flood mitigation effect of paddy field dam in Naruse River Basin

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1. INTRODUCTION

In recent years, severe floods occurred almost every year in Japan, heavy rain caused by typhoon 19th in 2019 induced severe flood in the Naruse River basin, where the total rainfall during the event was 343.0 mm. To prevent and mitigate such extreme flooding events, one of the flood control facilities named paddy field dam with high effect and low cost has recently been considered in Japan. Through reducing the cross-sectional area of the drain outlet to temporarily stored rainwater in the paddy field. To evaluate water storage in the paddy field dams based on water movement, Miyazu et al. (2012) developed a numerical model for the paddy field dam. However, since existing models are developed for application in small areas, they are detailed and require many structural data of paddy fields and channels. To consider the paddy field dam for an entire basin water management, evaluation of the paddy field dam's effect on flood control in the whole basin is required. Therefore, the objective of this research is firstly to develop a simple paddy field dam model that can be applied for the whole basin, and secondly to evaluate the potential flood mitigation effect of the paddy field dam.

2. STUDY AREA

The Naruse River basin located in the northern part of Miyagi prefecture, including three first-class rivers. The catchment area of the basin is approximately 1980 km^2. **Fig 1** shows that the upper reach of the basin is mountains, and mostly covered with forests and lower basin with many paddy fields or farmlands is relatively flat. 21% of the land is farmlands and paddy fields. The location of gauging stations and dem of the Naruse River basin showed below.

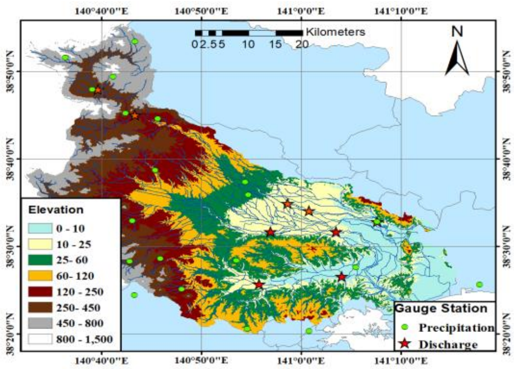

Fig.1. Naruse River basin, showing the location of precipitation and discharge stations (Merit DEM)

3. METHODOLOGY

2.1. Paddy Field Dam Model

The developed paddy field dam model is a simple one-dimensional model to be applied for the whole basin for assessing the potential effect of water outflow through the paddy field dam to confirm the effect of water storage capacity.

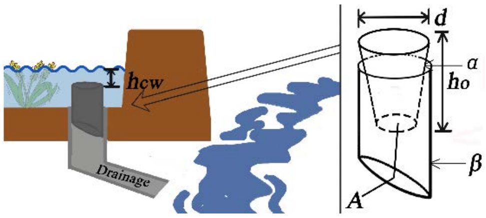

Fig.2. Runoff control device for free-drain system

The structure of the paddy field dam includes two parts: a cone with an orifice (α) and a cylindrical free-drain pipe (β), as shown in **Fig.2**. The orifice is used to reduce the cross-sectional of the drain outlet. The cylindrical free-drain pipe, which is against the inside of cylindrical weir, is used to adjust the height of free-drain. According to the water level of the paddy field, the factors of outflow from the paddy field dam will be changed from the cylindrical weir to the orifice. In other words, the cylindrical weir is the limiting factor for outflow unless the outflow through the orifice that is set up inside the pipe of the free-drain is exceeded. Therefore, with the consideration of the size of the free-drain, the outflow rates of the two were calculated sequentially using equation (1) for orifice and equation (2) for cylindrical weir, and select the smaller one as the outflow from the free-drain (Q).

$$q_{PO}=C_{PO}A\sqrt{2g(h_{CW}+h_O)} \qquad 1)$$

$$q_{PCW}=\sqrt{C_{PCW}gd^5(h_{cw}/d)^3} \qquad 2)$$

where C_{PO} is flow coefficient of orifice; C_{PCW} is flow coefficient of cylindrical weir; h_{CW} is height from hole to water level; h_O is height of orifice; d is diameter of hole; A is area of hole; g is gravitational acceleration.

To estimate the potential of the paddy field in this whole basin approximately, two scenarios were formulated. The first scenario was to change the height of free-drain, which changed water storage below the outlet of free-drain and drainage by changing from 5cm to 10cm, 15cm, 20cm, 25cm, 30cm. Moreover, the second scenario was to change the proportion of paddy fields applied for paddy field dam in the case of 15 cm height of the free-drain to evaluate how much proportion of paddy field should be applied to mitigate extreme flood event in 2019. There were five scenarios: 20%, 40%, 60%, 80%, 100% of paddy field mesh have been installed paddy field dam.

2.2. Rainfall-Runoff-Inundation Model

RRI Model is a two-dimensional model which can simulate rainfall-runoff and inundation simultaneously (Sayama et al (2012)). The model assumes that both river and slope are located at the same grid cell where the river channel is located. This model considers slopes and river channels independently. The channel is discretized as a single line along the centerline of the slope grid cell. The flow on the slope grid cell is calculated by the two-dimensional diffusion wave model, and the channel flow is calculated by the one-dimensional diffusion wave model simultaneously.

Keywords: Paddy field dam model, RRI model, Naruse River basin, flood control
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4. RESULTS AND DISCUSSION

To evaluate the potential flood mitigation effect of paddy field dam, total water storage in the whole basin and maximum inundation volume was calculated for each scenario. **Fig.3** is for the first scenario which changing the height of the free-drain, and **Fig.4** is for the second scenario which changing the installation proportion. The storage volume in **Fig.3** is the total water storage in the paddy field dam of the whole basin under Typhoon 19th event. The assumed water storage is the total volume under the outlet of free-drain. In other words, it is equal to the area of paddy field times the height of free-drain. Besides, the maximum inundation volume is the total volume of inundated water.

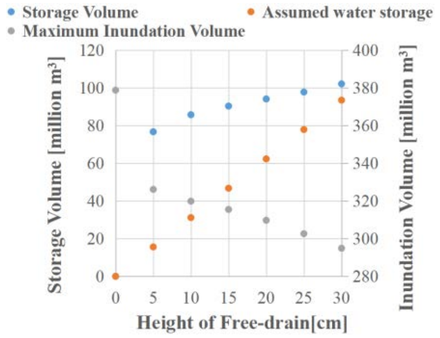

Fig.3. Water storage volume in different height of free-drain

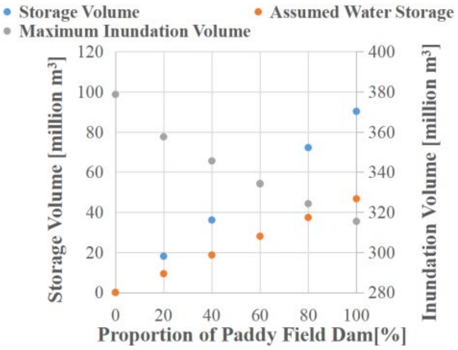

Fig.4. Water storage volume in different proportion of paddy field dam

In **Fig.3**, when all paddy fields were applied for the paddy field dams, 15 cm of free-drain could store 90 million m^3, while assumed water storage under the outlet of free-drain was more than 40 million m^3, and it had mitigated about 50% of inundated water, from 90 million m^3 to 40 million m^3. Total stored water increased by higher height of free-drain, but the difference between assumed water storage and storage volume was getting close because outflow from the paddy field was mainly regulated by free-drain. This meant that to evaluate the mitigation effect of paddy field dam, such a numerical simulation was required to consider not only water stored under free-drain but also the effect of temporal water storage upper than outlet regulated by free-drain.

In **Fig.4**, when the installation proportion increased, its effect of mitigating flooding was getting higher. Changing trends were linear even for inundation volume. Comparing **Fig.3** with **Fig.4**, increasing the height of free-drain from 15 cm to 30 cm increased total stored water by 20 million m^3 which was almost the same with the effect of increasing installation rate by 20%.

Fig.5 showed the distribution of decreasing the peak discharge, the effect of peak cut is strong in the upstream of Naruse river basin. It shows that the paddy field dams applied upstream were more effective in temporary storing water. In other words, applying more paddy field dams upstream, which can also alleviate the probability of flooding downstream effectively.

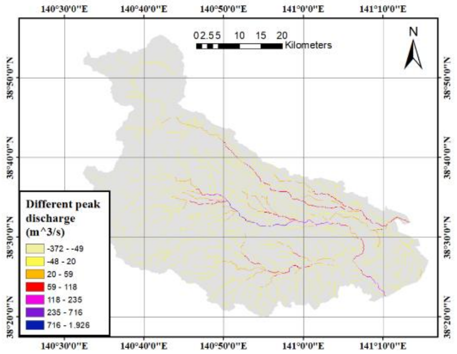

Fig.5. Distribution of peak cut effect by paddy field dam

5. CONCLUSIONS

From the above explanation, it could be concluded as follows:

1. The scenario of 15 cm height of the free-drain, while 100% of paddy field was applied for the paddy field dam, could store 90 million m^3 rainwater, and mitigated about 50% of inundated water. As the height of the free-drain increase, the storage volume and assumed water storage volume were getting close.
2. The distribution of peak cut effect of paddy field dams is significant along the Naruse river and certain effects along the Yoshida river. And installing paddy field dams upstream can effectively alleviate floods downstream.

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