Detailed Flood Inundation Modeling for Paddy Field Dams

〇Shuangtao WANG, Takahiro SAYAMA, Pingping LUO

1. Introduction

In recent years, large-scale floods have occurred frequently due to the increasing occurrence of concentrated rainstorms, and the economic losses caused by material and human losses are expected to increase in the future. The paddy fields themselves are believed to have an innate flood control function. Paddy dams stabilize and control the amount of water falling by installing drainage holes in paddy fields, smoothing peak runoff during storms and mitigating downstream flooding. The main objective of this study is to establish a detailed hydrodynamic model to quantify the effect of paddy field dams on water level reduction and channel flow reduction.

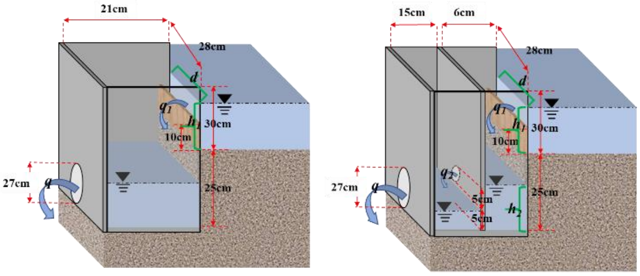
2. Method

2.1 Simulation Framework

The model consists of three modules: (1) Two-dimensional module, which calculates surface runoff based on two-dimensional shallow water equation and unstructured mesh; (2) One-dimensional module, calculating river/channel flow based on one-dimensional Saint-Venant equation; (3) Paddy field dam module, weir (hole) formula is used to calculate the interactive flow between surface and channel.

2.2 Mechanism of Paddy Field Dam

If the runoff control device is not installed in the paddy field during the rainy season, the surface water runoff of the paddy field is determined only by the length and width of the rectangular weir set at the entrance of the drainage box, thus determining the depth of the paddy field (Figure 1a). In the case of a runoff control device, the runoff is regulated by the rectangular weir or the orifice size of the runoff control device (Figure 1b).



(a) Control devices are not installed

(b) Control devices are installed.

Figure 1 Paddy field drainage system.

The discharge through the paddy field dam can be calculated using the following formula:

$$q_1 = \mu_1 h_1 \sqrt{2g(h_1 - 0.1) \times d} \tag{1}$$

$$q_2 = \begin{cases} \frac{2}{3}\mu_2 \sqrt{2g}(h_2 - 0.05) \times l & (h_2 - 0.05) < \frac{l}{2} \\ \mu_3 \sqrt{2g(h_2 - 0.05)} \times A & (h_2 - 0.05) \geq \frac{l}{2} \end{cases} \tag{2}$$

$$q = q_2 \tag{3}$$

Where, μ_1, μ_2 and μ_3 are the flow coefficient of the weir (orifice) equation, l is the circumference of the hole, A is the area of the hole, and g is the gravitational acceleration. Other variables are indicated in Figure 1.

2.3 Input Rainfall

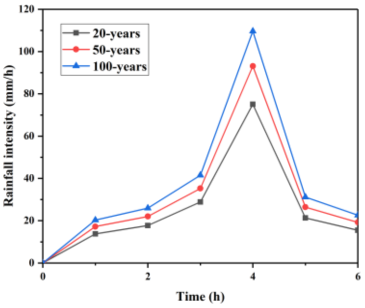


Figure 2 Designed rainfall.

The AMeDAS tool was used to design rainfall for 20-year, 50-year, and 100-year return periods as inputs to the model (Figure 2). The duration of rainfall was 6 hours, and the total running time of the model was 18 hours.

3. Results

Figure 3 shows surface inundation with and without runoff control devices. There was little difference in surface inundation at the 6th hour. But at the 12th hour (6 hours after the rain had ended), there was a significant difference in surface inundation.

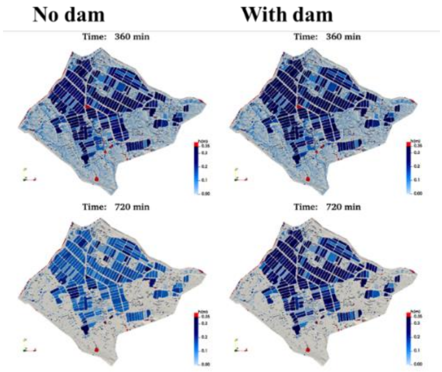


Figure 3 Surface inundation

The results of outlet discharge indicate that the runoff control devices can reduce flow discharge (Figure 4). Under different return periods rainfall, the outlet discharge can be reduced by 85.86,128.27,112.42 m^3/min (equivalent to 7.2, 10.75 and 9.43mm/h) at most. Compared with no control devices, they were reduced by 59.75%, 69.92% and 65.10% respectively. However, the runoff control effect of paddy dam is not obvious before the rainfall peak, and the reduction effect is gradually prominent after the rainfall peak. At about 960 minutes (16th hour), the discharge of without control devices becomes smaller than with controls devices. This may be caused by changes in the water level in the paddy field.

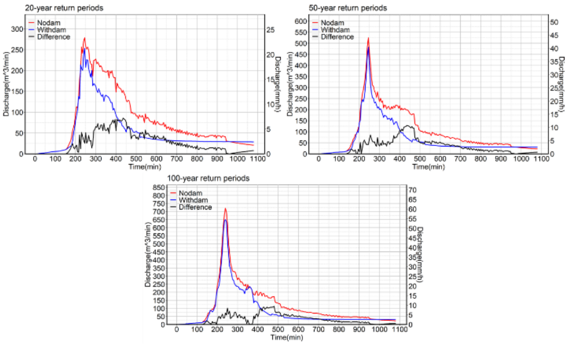


Figure 4 Outlet discharge

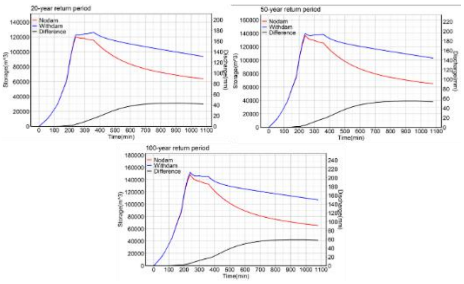


Figure 5 Paddy storage

The dynamic change of paddy water storage is shown in Figure 5. Similar to the outlet discharge curve in Figure 4, there is no significant difference in water storage capacity between those with and without runoff control devices before the peak rainfall. After the rain peak, the difference gradually becomes larger and finally reaches a stable value (43 mm, 54 mm and 59 mm respectively). At the end of the simulation, the average water depth of paddy fields without runoff control devices in the three return periods was around 100mm, indicating that drainage of most paddy fields units had been completed. However, the average water depth with the control device is greater than 100mm, indicating that the drainage has not yet finished. It can be inferred that paddy field dam can prolong the drainage time of paddy field.

4. Summary

Based on the theory of hydrodynamics, we developed a detailed paddy flood simulation model. Then, the effects of paddy field dams on paddy discharge and inundation were simulated. The results show that paddy field dams can effectively slow down the drainage process, reduce the drainage discharge, and increase the water storage of paddy fields. Paddy field dams can reduce discharge by nearly 70% in the case of a 50-year return period design rainfall event, increase paddy field water storage capacity by more than 30%. These results confirmed that the flood control measure is functioning effectively, as far as the study area is concerned