Mathematical simulation for optimal gate operation of a main drainage canal in a flat low-lying agricultural area

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1. Introduction During flood events, the drainage system in flat low-lying paddy-cultivated areas should be absolutely required two functions. The first function is to minimize the inundation damages to crop yield during the events avoiding the local concentration of inundation. The second function is to store the water volume for irrigation purpose after the events. Therefore, it is necessary to establish an appropriate operation of drainage structures during flood events. From this point of view, this paper presents a mathematical model of drainage system in an flat low-lying paddy-cultivated area for calculating the flood inundation and optimizing the operation of gates in a main drainage canal by using a continuous tank model, field measurement of canal water levels and numerical modeling of gate operation based on operators' experiences, and the optimal gate operation that meets fully both the flood drainage and the irrigation requirements are investigated.

2. Study area Chiyoda basin is located in Saga Prefecture in Kyushu Island, Japan, and lies next to the tidal compartment of Chikugo River to which the excess water in the basin is drained away. Chiyoda basin has a total basin area of about 1,100 ha and is a typical flat low-lying paddy-cultivated area. The excess water during flood events is removed by the pumped drainage and the check gate at the downstream end as shown in **Fig.1**.

3. Methodologies Considering the characteristics of the basin and the purpose of this study, a continuous tank model was adopted, because of its simplicity and high performance. In order to construct the tank model, the data such as topographic map, existing condition of the drainage basin and rainfall time series were firstly collected. Secondly, the paddy fields, the secondary drainage canals, the main drainage canal were divided into paddy tanks and river tanks shown in **Fig.1**. Interfaces between the paddy tanks and the river tanks are drainage structures: 21 outlets from paddy fields to drainage canals or rivers, 8 sluice gates from the secondary canals to the main canals, 6 main check gates located in the main canal, and 1 pump and 1 check gate located at the downstream end. Equation (1) is a basis equation. $dV_{(i)}/dt = Q_{\mathrm{in}(i)} - Q_{\mathrm{out}(i)} \cdots$ (1). Where $V_{(i)}$, $Q_{\mathrm{in}\,(i)}$ and $Q_{\mathrm{out}\,(i)}$ are a water volume, an inflow to tank No.*i* and an outflow from tank No.*i*. This model is numerically solved to determine the water level in the paddy tanks and the river tanks, and the flow discharges at every connection. Check gates play a very important role in Chiyoda drainage system, because during the rainfall event, the gates should be controlled in order to minimize the damages for crop yield and store irrigation water. After checking the accuracy of the model, the algorithm of optimal gate operation was investigated by trial and error method. By referring the operators' experiences, it was assumed in the simulation model that the water levels at the upstream and the downstream of the gate were checked every two–hour interval and, if necessary, closing or opening operation of the gate was executed with a gate moving speed of 0.1 m per 10 s. Three water levels of WL_1, WL_2 and WL_3 play an important role for gate operation. The water level WL_1 which is an initial water level at the upstream of check gate, meets the requirement for irrigation. Because the WL_1 is designed based on the irrigation requirements, it should be kept no changing.The water level WL_2 is a water level at the upstream of check gate, at which the gate operation starts. The water level WL_3 is a water level at the downstream of check gate at which the gate is closed in order to prevent flood concentration in the downstream. The water levels of WL_2 and WL_3 were optimally searched by changing WL_2 and WL_3 from a maximum to a minimum level: $WL_2 = WL_{2(0)} + x$ and $WL_3 = WL_{3(0)} - x$ where $WL_{2(0)}$ and $WL_{3(0)}$ are the reference water levels, and x = 0.1, 0.2, 0.3, 0.4, 0.5 m. The reference water level for each

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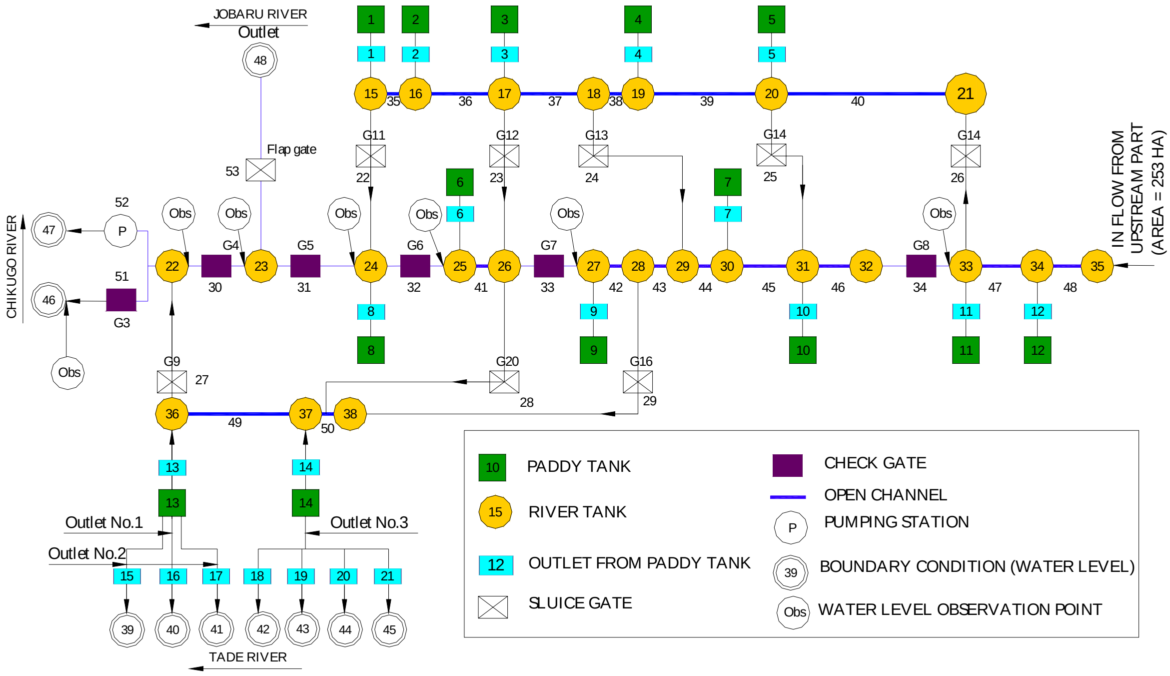

Fig.1 The Chiyoda basin model.

check gate was determined by considering the actual gate operation. The optimal operation, which was one of 25 combinations of five WL_2 and five WL_3, was selected after analyzing and evaluating the simulation results.

4. Results and discussion Using the actual rainfall event, the accuracy of the proposed model was evaluated by comparing the calculated results with observed water levels. The variation of water levels in River tanks 22, 23, 24, 25, 27, and 33 (**Fig.2**) show that the observed and simulated data are in a good agreement. Secondly, using a stochastic rainfall time series, the optimal option of gate operation was investigated based on the analysis of the simulated results such as the maximum water depth, the inundation time, and the coefficient C_v of variance of excess water depth over the paddy tanks. The results indicated that normally the inundation time and inundation area decreased when the gate started to operate as soon as possible and closed as late as possible, while the values of C_v were not so different among the 25 combinations. In Chiyoda basin, comparing with C_v, the inundation time and the inundation area are much more important. The optimal option of gate operation is recommended as the combination of the minimum WL_2 and the maximum WL_3.

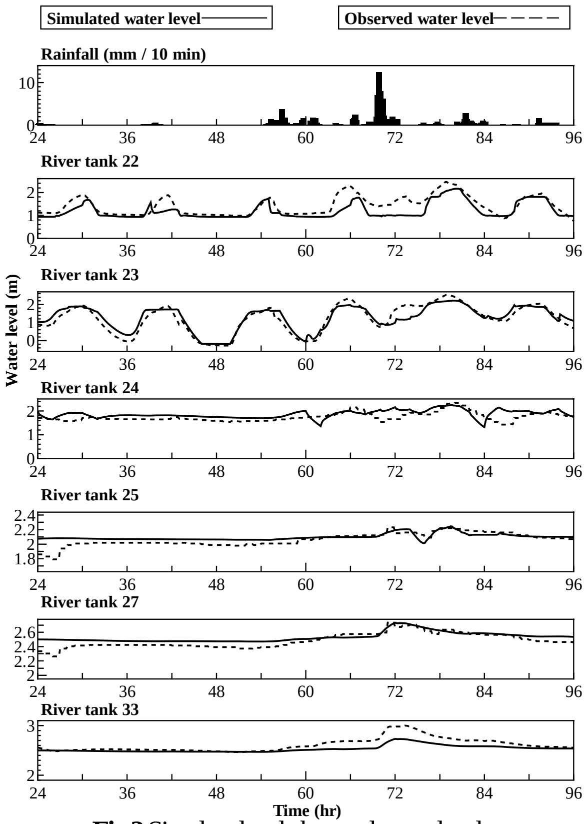

Fig.2 Simulated and observed water levels.

5. Conclusion The tank model was a very simple and useful tool to simulate the water flow in flat low-lying agricultural areas. In Chiyoda basin, it was applied to search for the optimal gate operation in the main drainage canal and one optimal option of gate was proposed. This optimization will help the managers, operators and the farmers overcome the difficult issues that they are facing.

References: Hiramatsu K, Shikasho S, Kurosawa K, Mori M (2004) Drainage and Inundation Analysis in a Flat low-lying Paddy-cultivated area of the Red River Delta of Vietnam, *Journal of Faculty of Agriculture Kyushu University* **49**(2), pp.383-399.