Nitrogen and phosphorus runoff modeling in a flat low-lying paddy cultivated area

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1. Introduction The main environmental issue in flat low-lying areas is total nitrogen (TN) and total phosphorus (TP) load management because TN and TP, which loaded from chemical fertilizer input in paddy fields and other areas, degrade surface water as a result of anthropogenic eutrophication. Therefore, it is necessary to carry out the analysis of the TN and TP runoff in order to elucidate the pollutant fluxes and to evaluate pollutant removal from target areas to the downstream areas. From this point of view, this paper presents a mathematical model for calculating the TN and TP runoff in flat low-lying paddy cultivated areas during an irrigation period. First, the water flow was simulated by a continuous tank model and the accuracy of the model was then evaluated by comparing the simulated water levels with observed ones. Second, the TN and TP runoff were simulated based on the TN and TP loads that were determined by observed data in paddy fields.

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 The models for water flow and nutrient runoff in flat low-lying paddy-cultivated areas are constructed based on the purposes of analysis and the characteristics of the basin. Considering the characteristics and the purpose of this study, a continuous tank model was adopted, because it is simple 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 basin was analyzed and the paddy field areas were divided into 15 tanks. The secondary drainage canal was divided into 10 river tanks. The main drainage canal was divided into 14 river tanks. 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 drainage canal to the main drainage canal, 6 main check gates located in the main drainage canal, and 1 pump and 1 check gate located at the downstream end. Equation (1) is a basic equation for calculating the water flow.

$$\frac{dV_{(i)}}{dt} = Q_{\mathrm{in}(i)} - Q_{\mathrm{out}(i)} \cdots\cdots \quad (1)$$

Where: $V_{(i)}$, $Q_{\mathrm{in}\,(i)}$ and $Q_{\mathrm{out}\,(i)}$ are a water volume in tank No.*i*, an inflow to tank No.*i* and an outflow from tank No.*i*.

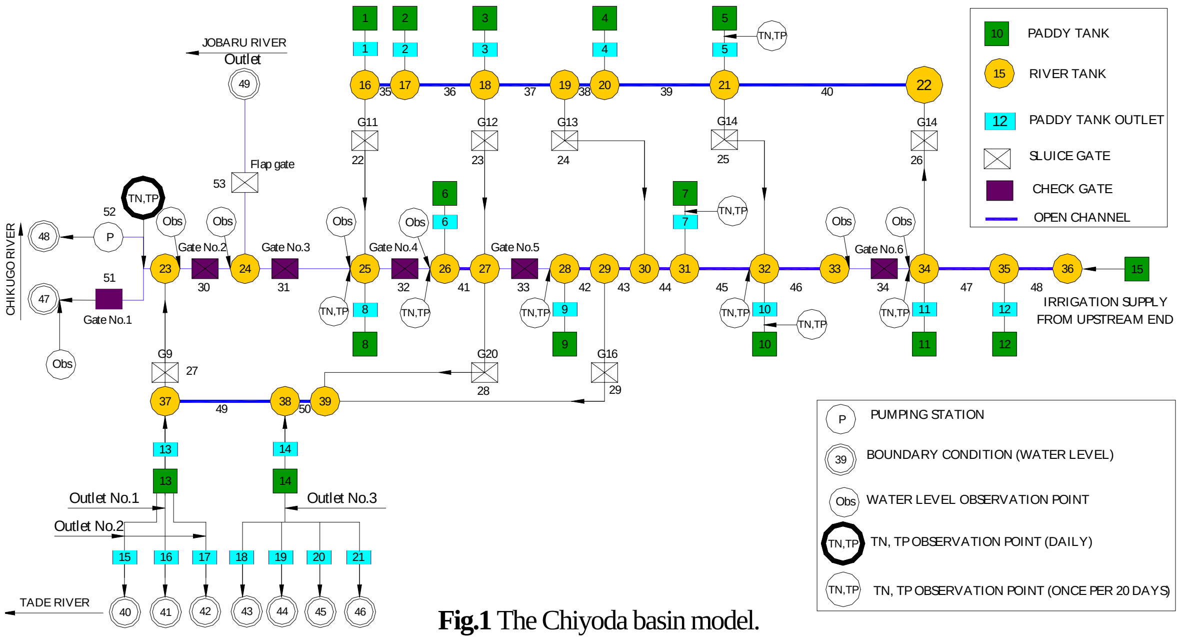

Fig.1 The Chiyoda basin model.

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Keyword: Irrigation period, chemical fertilizer, total nitrogen, total phosphorus, tank model

Equation (2) and (3) are the basic equations for calculating TN and TP runoff.

$$\frac{dLTN_{(i)}}{dt} = TN_{\text{in}(i)} - TN_{\text{out}(i)} \qquad (2)$$

$$\frac{dLTP_{(i)}}{dt} = TP_{\text{in}(i)} - TP_{\text{out}(i)} \qquad (3)$$

In equations (2) and (3), $LTN_{(i)}$, $LTP_{(i)}$;$TN_{\text{in}(i)}$, $TP_{\text{in}(i)}$; $TN_{\text{out}(i)}$, $TP_{\text{out}(i)}$ are total loads of TN and TP in tank No.*i*; TN and TP load rates to tank No.*i*; TN and TP release rates from tank No.*i*, respectively. This model is numerically solved to determine the water level in the paddy tanks and the river tanks, the flow discharges at every connection, and TN and TP runoff. These equations were solved by using the Runge-Kutta-Gill method.

4. Results and discussion Firstly, the accuracy of the proposed model was evaluated by comparing the calculated results using the actual rainfall event with observed water levels. The variation of water levels in River tanks 23, 24, 25, 26, 33, and 34 (**Fig.2**) show that the observed and simulated data are in a good agreement. Second, the TN and TP runoff during an irrigation period was simulated based on the TN and TP loads that were determined by observed data in paddy fields. For TN runoff, the simulated results and observed data were in good agreement whereas for TP runoff, the simulated results were higher than the observed data. This phenomenon could be explained by the reason that the total effluent load of TP would not be conveyed by the water flow. Some was settled inside of the interface between the paddy tanks and river tanks. If the settled TP within the paddy tank was calculated as 6%, then the simulated results and the observed data were in good agreement (**Fig.3**).

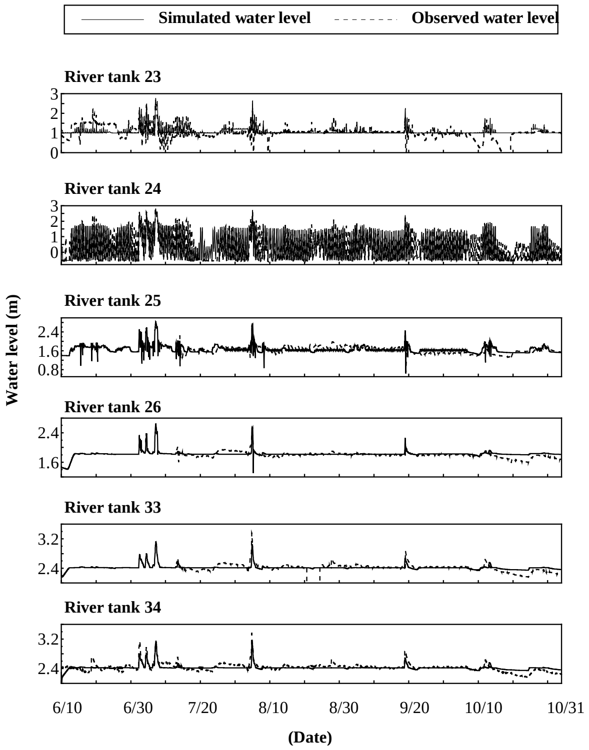

Fig.2 Comparison of simulated and observed water levels in a main drainage canal.

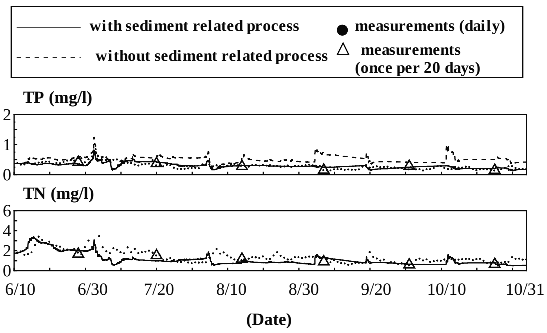

Fig.3 Comparison of simulated and observed TN and TP concentrations at the downstream end of main drainage canal.

5. Conclusion In this study, the water flow, and TN and TP runoff were simulated using a continuous tank model. For TN runoff, the simulated results and observed data are in good agreement; for TP runoff, the simulated results are higher than the observed data. However, if the settled TP within the paddy tank was calculated as 6%, then the simulated results and the observed data are in good agreement. It was concluded that TN runoff from paddy field to the drainage canal system was not affected much by the sediment related process, whereas for TP runoff, this process should be considered. The pollutant load from Chiyoda basin to Chikugo River was estimated by utilizing the TN and TP concentrations at the outlet of the main drainage. These results could provide farmers and managers with a useful tool for controlling the water distribution in an irrigation period and the TN and TP loads in the downstream area as well as Chikugo River.

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.