Scenario analyses for the emergency solution to protect Hanoi Capital from flood disaster of the Red River

Sai Hong Anh*, Toshinori Tabata**, Kazuaki Hiramatsu**, Masayoshi Harada**

1. Introduction Hanoi is the second largest city in Vietnam and it was located within the Red River Delta's boundaries as shown in **Fig.1**, which has been heavily affected by climate change. The environmental change such as urbanization and the climate change in Hanoi Capital has caused a worse effect to flooding. They caused damage to homes, possessions and people. Especially, the flood in 1971 was one of the ten worst flood disasters of the 20th century. Besides, the Red River is the largest river in the north of Vietnam and runs through the Hanoi Capital. The Red River dike system was built and an emergency solution was performed in order to protect Hanoi from flood disasters. In the solution, floodwater from the Red River is discharged through Van Coc Gate as well as the overflow point located on the bank of the Red River into Van Coc Lake located at 30 km far from the center of Hanoi as shown in **Fig.1**. The Van Coc Lake is utilized as a regulating reservoir and the flood water drains to the downstream through the Day Weir. However, an optimal scenario for operating procedure of the emergency solution, which is based on comprehensive evaluation about the flood risk level from the Red River to the residential areas located outside the protected areas of the Red River dike system, has not been adequately addressed yet. In this study, a two-dimensional depth-integrated hydro-dynamic model was constructed to simulate setup scenarios and find out the optimal one for the emergency solution.

2. Materials and methods A two-dimensional depth-integrated model was applied herein to simulate the floodwater in the area. The shallow water equations used in this study are as follows.

Continuity equation:

$$\frac{\partial \eta}{\partial t}+\frac{\partial}{\partial x}\{U(h+\eta)\}+\frac{\partial}{\partial y}\{V(h+\eta)\}=0 \qquad (1)$$

Momentum equations in the x and y directions:

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}=fV-g\frac{\partial \eta}{\partial x}+v_h\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial^2 y}\right)-\frac{gn^2U\sqrt{U^2+V^2}}{(h+\eta)^{4/3}} \qquad (2)$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}=-fU-g\frac{\partial \eta}{\partial y}+v_h\left(\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial^2 y}\right)-\frac{gn^2V\sqrt{U^2+V^2}}{(h+\eta)^{4/3}} \qquad (3)$$

Where U and V are the depth-averaged horizontal velocity components in the x and y directions; η is the level; t is the time; h is the water depth; f is the Coriolis parameters; g is the gravitational acceleration; n is the Manning's coefficient of roughness; and v_h is the coefficient of the eddy viscosity (m^2/s) calculated by Smagorinsky model. The research area was a part of the Red River from Son Tay to Hung Yen and the outside of the protected areas of the Red River dike system (the river area inside the dike system) and the Van Coc Lake area. The observed water level of the catastrophic flood in 1971 used for upstream boundary conditions at the Son Tay Station. Unknown outflow boundary conditions at Thuong Cat, Hung Yen and the Day Weir were treated by the uniform flow assumption. A leap-frog finite difference method was applied for the numerical solution. The wet-and-dry scheme was applied to

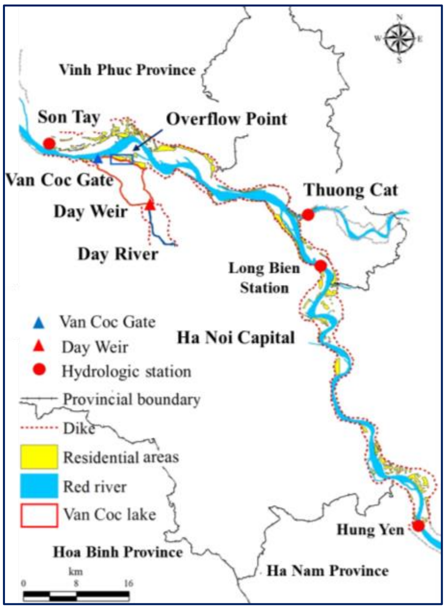

Fig.1 The research area.

*Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University ** Faculty of Agriculture, Kyushu University
Keywords: Two-dimensional depth-averaged model, numerical simulation, flood risk level, Van Coc Lake

represent the phenomena of inundation. In order to identify the optimal scenario, 11 scenarios were setup. **Table 1** shows all scenarios for operating procedure of the Van Coc Gate, the Day Weir and various opening sections of the overflow point with 13.0 m of bottom level.

3. Results and discussion The model was firstly validated with the observed data at Long Bien Station from 16th September to 27th September, 2014. As shown in **Fig.2**, the computed water level has good agreement with the observed water level with 0.85 of Nash–Sutcliffe model efficiency (NS). The optimal scenario was determined to minimize the flood risk level to the residential areas and to optimize the inflow discharge at the Van Coc Gate and the overflow point, and outflow discharge at the Day Weir for ensuring the safety of the operating system. Firstly, as an important indicator, the maximum water depth in front of the Day Weir must be lower than 4.9 m that is the maximum weir height, because the Day Weir was built 70 years ago and degraded, and the overload must be avoided. **Table 1** shows the maximum water depth in front of the Day Weir in 11 simulated scenarios. The maximum water depth increased from 4.16 m in the 2nd scenario to 4.86 m in the 6th scenario before exceeding 4.9 m in the remaining scenarios. Although the maximum water depth increased from the 2nd to 6th scenarios, they were still smaller than 4.9 m. In contrast, the maximum water depth in the 7th to 11th scenarios were higher than 4.9 m. Besides, the simulated maximum water levels at the Long Bien Station are shown in **Table 1**. The biggest value was 12.82 m at the 1st scenario which was the non-operating scenario. In the 2nd scenario, Van Coc Gate and Day Weir were opened and the maximum water level decreased sharply to 12,64 m. In the next three scenarios, the maximum water level showed a downward trend from 12.57 m in the 3rd scenario to 12.53 m in the 5th scenario. In the remaining scenarios, the width of the overflow point was rose from 1,000 m in the 6th scenario to 2,600 in the 11th scenario, but the maximum water level at Long Bien Station did not decrease with roundly 12.51 m, which were due to the maximum discharge capacity at the Day Weir. These results indicated that the 6th scenario was selected as an optimal scenario in emergency situation to protect Hanoi Capital from flood disaster of the Red River. In the 6th scenario, the maximum water level at Long Bien Station dropped 0.30 m compared to the non-operating scenario, but in the outside of the protected areas of the Red River dike system, most of the residential areas were inundated.

Table 1 All scenarios for operating procedure of the Van Coc Gate, the Day Weir and various opening sections of the overflow point and the results of simulation.

Scenario	Van Coc Gate	Day Weir	Overflow Point - width (m)	Water Depth at Day Weir (m)	Water Level at Long Bien (m)
1st	Close	Close	Close		12.82
2nd	Open	Open	Close	4.16	12.64
3rd	Open	Open	450	4.65	12.57
4th	Open	Open	650	4.71	12.55
5th	Open	Open	850	4.83	12.53
6th	Open	Open	1,000	4.86	12.52
7th	Open	Open	1,200	4.92	12.52
8th	Open	Open	1,400	4.95	12.52
9th	Open	Open	1,800	4.97	12.51
10th	Open	Open	2,200	4.97	12.51
11th	Open	Open	2,600	4.98	12.51

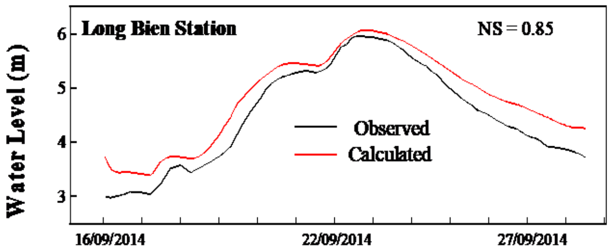

Fig. 2 Comparison of calculated and observed water level.

4. Conclusion The optimal operation of Van Coc Lake for minimizing the flood risk level in Hanoi Capital was determined by on the scenario analyses based on the numerical simulations using a two-dimensional hydrodynamic model. The results indicated that the residential areas still had vulnerability in floodwater that policy makers should consider protection measures in developing risk-reduction strategies. The authors appreciate the funding support of JSPS KAKENHI under Grant Number 17K15347 and 18H03968.