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CALCULATED SCENARIOS FOR UPGRADING THE NGU HUYEN KHE IRRITATION SYSTEM IN THE CONDITION OF 1% RAINFALL INUNDATION

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Abstract

Ngu Huyen Khe Irrigation System (NIS) is the main irrigation route for 5 districts Me Linh, Dong Anh, Gia Lam, Yen Phong and Tien Son. It plays an important role in draining and irrigating water for 18,404 Ha of rice fields. In 1% rainfall in 2008, NIS revealed its weak points, causing the inundation of thousands of hectares of rice fields and two hundred billions of VND loss. The main are reasons related to dike safety and lack of drainage pumping capacity. Therefore, this paper proposes and calculates some NIS scenarios to upgrade NIS to be able to drain 1% rainfall inundation. The scenarios are not only conducive to irrigation and drainage, but also to water storage, ecological and environmental rehabilitation.

Keywords: Ngu Huyen Khe Irrigation System; 1D hydraulics model Imech_1D; inundation in 2008.

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1. Introduction

NIS is the main irrigation axis for 5 districts of Me Linh, Dong Anh, Gia Lam, Yen Phong and Tien Son. This system has a task of draining and irrigating water for 18,404 ha of rice fields along Ha Noi - Vinh Phuc - Bac Ninh provinces. During the heavy rain period from 31 October to 07 November 2008, although NIS was fully operating, 3,000 ha of paddy rice area was inundated. The total loss is about 200 billion VND. Therefore, it is necessary to upgrade the NIS to meet the demand of draining 1% rainfall that equals to the 2008 inundation.

To succeed in draining 1% rainfall in NIS, it is important to build scenarios of dredging the riverbed, reinforcing the embankment and building more pump stations along the river. Reinforcing the embankment is not only to mitigate flooding in the rainy season but also help irrigate the fields by changing NIS to be a containing lake in the dry season.

Imech_1D model was developed by the Vietnam Institute of Mechanics basing on Saint - Venant equation. It has passed all 11 test cases that all hydraulic labs in Europe using to test hydraulic models. Up to now, the model has used in flood simulation and calibration for Red River Basin, Perfume River Basin, etc. The model plays an important role in flood forecasting and reservoirs regulating in Da and Se San River Systems.

The aim of this study is building draining scenarios for NIS as 1% rainfalls happen. After that, we use Imech_1d to calculate and verify to see which scenarios are appropriate.

2. Imech_1D introduction

For a general network, there may exist a flow in river network, flow in- or out- storage cells. So there are three types of equations: partial differential equations for a single river branch, ordinary differential equations for storage cells and equations for hydraulic structures. Apart from these, it is needed to add junction conditions in some location of the network to keep the flow continuity.

Equations for a single river branch:

The free surface flow in a single branch of a river network can be described by the so-called Saint-Venant equations [1 - 3] under the assumption of hydrostatic pressure and uniform distribution of the velocity along the vertical axis.

In practice, the flow in the main channel and flood plain are quite different by different frictions. So the following types of equations are often used:

$$\frac{\partial A_s}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (2.1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A_f}\right) + gA_f \frac{\partial Z}{\partial x} + gA_f \frac{Q|Q|}{K^2} = 0 \qquad (2.2)$$

Where

Z Water elevation

Q Discharge

A_s and A_f - wet cross sectional areas for the main and total flow.

K Conveyance

t time

x space coordinate

Equations for storage cells: This is the continuity equation for storage cells

$$\frac{dV}{dt} = \sum Q \qquad (2.3)$$

where

V is the water volume

Q is in- and out- going discharges.

The equation for hydraulic structures and junction conditions: The flow must be conserved so at confluences or tributaries the sum of all discharges must be zero. At hydraulic structures flow rate is defined by the empirical formula:

$$Q = f(Z_{tl}, Z_{hl}, a) \qquad (2.1)$$

Where

Z_{tl}, Z_{hl} are the upstream and downstream water levels

a is characteristic parameter of structures.

A structure may be modeled by one of two types: a spillway and a sluice. The discharge, going through a spillway is calculated by [4]

$$\frac{\partial A_s}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (2.1)$$

$$Q = mb\sqrt{2g}(Z_{tl} - Z_0)^{\frac{3}{2}} \quad \text{for non- submerged flow} \qquad (2.5)$$

$$Q = \phi\, b\sqrt{2g}(Z_{hl} - Z_0)\sqrt{Z_{tl} - Z_{hl}} \quad \text{for submerged flow} \qquad (2.6)$$

The discharge through sluices can be determined as follows:

$$Q = \mu\omega\sqrt{2g}\sqrt{Z_{tl} - Z_o} \quad \text{for non- submerged flow} \qquad (2.7)$$

$$Q = \mu_2\,\omega\sqrt{2g}\sqrt{Z_{tl} - Z_{hl}} \quad \text{for submerged flow} \qquad (2.8)$$

Where:

m, φ, μ, μ_2 are empirical coefficients for the structure;

b is the width of the spillway;

ω is the wet area of the sluice

Finally, the initial and boundary conditions must be added.

3. Study area

NIS is located in the North of Ha Noi next to Duong and Cau rivers. It includes:

- Ngu Huyen Khe river (NHK) with two tributaries, the main branch from Long Tuu Sluice to Dang Xa Drainage, the other from Co Loa Sluice to the main branch.

- Van Tri Lake connects to NHK by Co Loa self-flowing Sluice with three gates in 8m wide and bottom elevation of +3,2m. Table 1 shows the relationship between Q, Z and the Sluice's open degree.

- Long Tuu Sluice: connects Duong and NHK rivers. It is an irrigating construction that opens in dry season allowing water flow from Duong into NHK and closes in the rainy season.

- Dang Xa Sluice connects NHK and Cau rivers. It is the only way that help to release water from NHK into Cau river. It includes 5 gates, three central ones have its size of 2.87 m x 2.87 m each, the others have 1.90 m x 2.30 m.

- Dang Xa Drainage station is used to pump water from NHK into Cau river in the rainy season to keep water level under +6.7 m at Dang Xa Drainage avoiding dyke break. It has 34 pumps with the capacity of 3,400 m3/h of each pump.

- Other drainage pump stations: used to drain water from the rice fields into the main flow of NHK.

4. Operating drainage rule for NIS

There are rules for operating NIS as follow:

- Drainage must be ensured dike safety.

- Pump stations that drain for rice fields: Drainage pumping must stop when the water level at Dang Xa Drainage iss over +6.70 m.

- Dang Xa pump station: Operation when the following conditions are met

+ Dang Xa Sluice is closed.

+ The water level in NHK and Cau River raise up quickly (> 2cm / h).

+ Bad weather forecasts in the coming days (high rainfall, flood in Cau river...).

+ Stopping the pump when: One of the above conditions no longer exists or the water level in Cau River has fallen below +6.7 m and is continuing to fall.

5. Model Setup

a) Calculating diagram for NIS:

NIS as described above is shown in Fig. 1. Its topography is divided into two areas: the upper part of Me Linh District, Dong Anh Province with the elevation of +6.50 to +11.0 m. The lower one of the Yen Phong and Tien Son districts, Bac Ninh province has an elevation from +2.2 m +7.5 m.

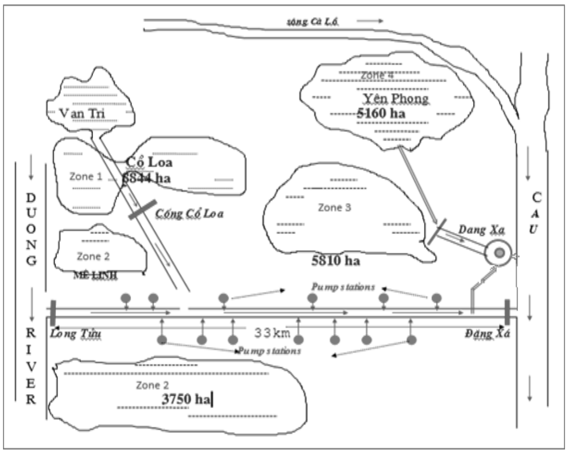

Figure 1: NIS diagram

b) Input data for storage cells: is rainfall data and V-Z relation of storage cells (Fig. 2) .

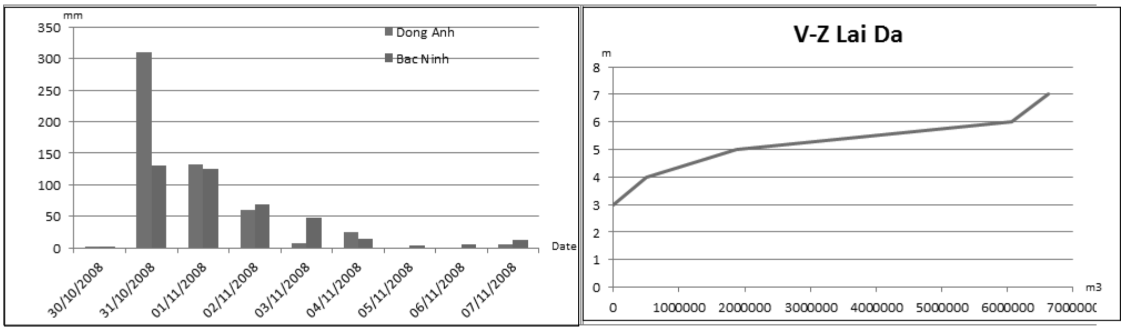

Figure 2: Rainfall data and V - Z relation

c) Input data for the river:

There are 69 cross-sections with a total length of over 40 km in NHK river. All those cross-sections were processed and used in Imech_1D model. Fig. 3 is some typical cross-sections.

Boundaries data: two flow and one stage boundaries are used. In drainage scenario, Long Tuu Sluice is always closed so the flow boundary from Long Tuu Sluice is zero. Flow boundary from Co Loa Sluice is calculated each time step. The stage boundary is the water level at Cau river next to Dang Xa Drainage.

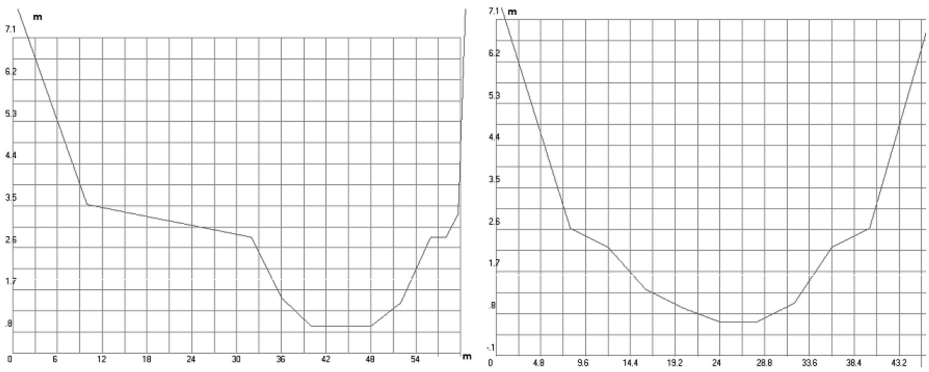

Figure 3: Cross - sections in NHK

d) Pump - hours data:

Time of using Pump station in 2008 inundation is shown in Fig. 4. Those stations could not be operated at full capacity because of dike safety reason.

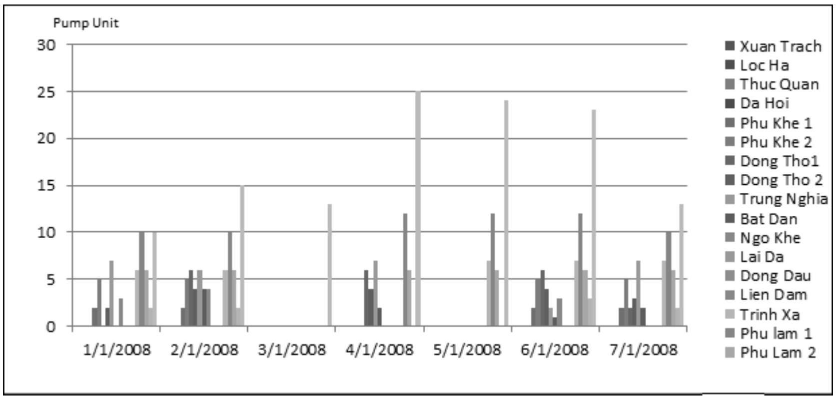

Figure 4: Time of using Pump station in 2008

e) Co Loa Sluice:

Is a self-flowing Sluice with three gates in 8 m wide and bottom elevation of 3,2 m. The relation between Q, Z and the Sluice's open degree is shown in Table 1.

Table 1. The relation between Q, Z and its open degree

a(m) / **Q**(m^3/s) / **ΔZ**(m)	0.1	0.3	0.5	0.7	0.9	1.0	1.2	1.5
0.1	0.86	2.59	4.32	6.04	7.77	8.63	10.4	12.9
0.2	1.22	3.66	6.10	8.55	11.0	12.2	14.7	18.3
0.3	1.50	4.49	7.68	10.5	13.5	15.0	17.9	22.4
0.4	1.73	5.18	8.63	12.1	15.5	17.3	20.7	25.9
0.5	1.93	5.79	9.65	13.5	17.4	19.3	23.2	29.0
0.6	2.11	6.34	10.6	14.8	19.0	21.1	25.4	31.7
0.7	2.28	6.85	11.4	16.0	20.6	22.8	27.4	34.3
0.8	2.44	7.33	12.2	17.1	22.0	24.4	29.3	36.6
0.9	2.59	7.77	12.9	18.1	23.3	25.9	31.1	38.8
1.0	2.73	8.19	13.7	19.1	24.6	27.3	32.8	41.0

6. 2008 simulation result

In water level simulations, NHK performs well at the following locations: Long Tuu, Trinh Xa and Dang Xa Drainage (Fig. 2). To estimate the result, the Nash-Sutcliffe (NSE) index is used (show in Table 3). The NSE is a statistical parameter that determines the relative value of the residual variance versus the variance of the observations, calculated as follows:

$$NSE = 1 - \frac{\sum_{i=1}^{N}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{N}(Y_i^{obs} - Y^{mean})^2}$$

Where:

NSE: Nash-Sutcliffe index,

Y_i^{obs} : Observed value at time i,

Y_i^{sim} : Calculated value at time i;

Y^{mean}: Average observed value;

Nash - Sutcliffe's characteristics:

- Measure the suitable between simulated data and observed data at 1: 1 ratio.

- Value: $-\infty \rightarrow 1$.

- The basis for evaluating the accuracy of the model according to the above two indicators is summarized by [4] from the previous studies and is presented in Table below:

Table 2. The results of simulating the water level

Accuracy	NSE
Very good	0.75 < NSE ≤ 1.00
Good	0.65 < NSE ≤ 0.75
Average	0.50 < NSE ≤ 0.65
Under average	NSE ≤ 0.50

Table 3. The Nash-Sutcliffe (NSE) index

Location	NSE
Long Tuu	0.82
Trinh Xa	0.87
Dang Xa	0.98

The result of inundation in rice fields is shown in table 3. In this table the deepest inundation is +1.33 m at Thac Qua. The biggest area inundation is 617.912 ha at Trinh Xa 1, Tam Son, Phu Lam 1 and Phu Lam 2. The longest time of inundation is 7.3 days at Xuan

Canh (Tab. 3). Rice typically dies after three to four days of inundation so it is important to drain water out of rice field within three days maximum. That is the aim of this paper, building scenarios and calculating to reduce the time of inundation incase of another 1% rainfall occurrence.

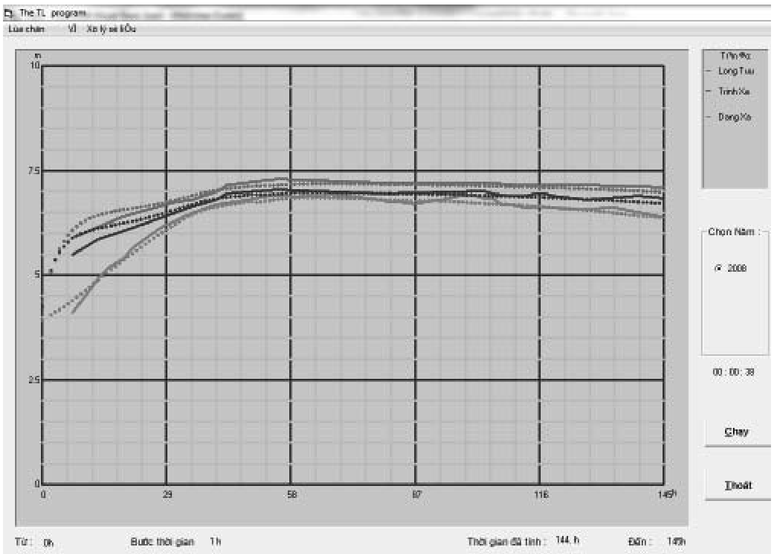

Figure 5: Comparison of calculated and observed water level at Long Tuu, Trinh Xa and Dang Xa

Table 4. Inundation of rice fields

No	Zones	Depth (m)	Flooded Area (Ha)	Flooded Times (Day)
1	Lai Da + Loc Ha	0.62	135.354	6.048
2	Xuan Canh	0.28	153.536	7.307
3	Dong Dau	0.21	87.948	3.665
4	Thac Qua	0.33	168.069	4.377
5	Nghia Vu + Lien Dam	1.03	145.442	3.987
6	Da Hoi	0.71	24.140	2.515
7	Ngoi Bet + Phu Khe + Huong Mac + Cau To	0.40	233.440	4.863
8	Trinh Xa1 + Tam Son + Phu Lam12	0.16	617.912	4.100
9	Dong Tho	1.28	89.012	6.181
10	Trung Nghia	0.87	67.425	3.122
11	Bat Dan	0.16	72.712	3.593
12	Ngo Khe	0.59	32.037	3.337
13	Trinh Xa 2	0.24	300.000	3.125

In this inundation, the pump stations could not drain all the water out of rice fields because of lack of capacity and high water level in NHK. So, the main problem is how to reduce the water level in NHK.

7. Upgrading NIS project to deal with 1% rainfall inundation

In the 2008 flood, drainage stations did not work at full capacity because the water level at Dang Xa was over +6.70 m. So, the intention of upgrading NIS is to focus the following scenarios:

a) Scenario 1:

Build +8.0 m - +8.2 m dike so the water level at Dang Xa Drainage could raise up to +7m but still ensure dike safety. That will allow all the drainage pumps to operate at full capacity. Table 5 shows the depth and inundated area result after drainage for 24h, 48h, 72h. After 72h, the water level at Lai Da - Loc Ha still at +0.31 m, Nghia Vu - Lien Dam at +0.28 m (Tab. 5). So it is necessary to set up more pump stations these places (Tab. 6).

Table 5. The depth and inundated area result after drainage for 24h, 48h, 72h

No	24h		48h		72h	
	Depth (m)	**Inundated Area (Ha)**	**Depth (m)**	**Inundated Area (Ha)**	**Depth (m)**	**Inundated Area (Ha)**
1	0.52	121.684	0.41	106.647	0.31	92.977
2	0.24	141.188	0.20	128.840	0.16	116.492
3	0.15	62.820	0.09	37.692		
4	0.26	132.418	0.18	91.674	0.10	50.930
5	0.84	108.276	0.57	73.473	0.28	36.092
6	0.43	14.620	0.14	4.760		
7	0.28	163.408	0.16	93.376		
8	0.10	483.020				
9	0.24	76.296	0.19	60.401	0.14	44.506
10	0.59	45.725	0.31	24.025	0.04	3.100
11	0.12	68.584	0.07	63.424		
12	0.41	22.263	0.24	13.032	0.06	3.258
13	0.16	200.000	0.08	100.000		

Table 6. Pump stations need to be set up

No	Zones	Remain Pump Station	Capacity (m^3/h)	New Pump Station	Total Capacity (m^3/h)
1	Lai Da + Loc Ha	8	1,000	4	12,000
5	Nghia Vu + Lien Dam	8	1,900	2	19,000

b) Scenario 2:

Keep the dike unchanged, all the drainage pumps operate at full capacity. However, the calculated water level at Dang Xa is still over +6.70 m and Lai Da - Loc Ha, Nghia Vu - Lien Dam is still inundated. Because the water level at Cau river is high, so the upgrade of Dang Xa Sluice is not effective in this case. So, the solution is to set up more pump stations at Dang Xa to enhance the capacity from 115,600 m^3/h to 211,200 m^3/h. And setting up more drainage pump station at Lai Da - Loc Ha and Nghia Vu - Lien Dam as Tab. 6. The calculating result shows that the inundation at the above zones is ended after 72h of draining (Tab. 7) and the water level along the river is low enough to ensure dike safety (Fig. 6). However, the high water level in the river (over +6.5 m) lasted for 24h can put dike at places as Xuan Canh, Thac Qua (on the left) and Lai Da, Loc Ha, Dong Dau, Trinh Xa (on the right) into danger.

Table 7. The depth and inundation at Lai Da - Loc Ha and Nghia Vu - Lien Dam zones after drainage for 24h, 48h, 72h

No	24h		48h		72h	
	Depth (m)	**Inundated Area (Ha)**	**Depth (m)**	**Inundated Area (Ha)**	**Depth (m)**	**Inundated Area (Ha)**
1	0.46	113.482	0.31	92.977	0.15	71.105
5	0.76	97.964	0.42	54.138	0.07	9.023

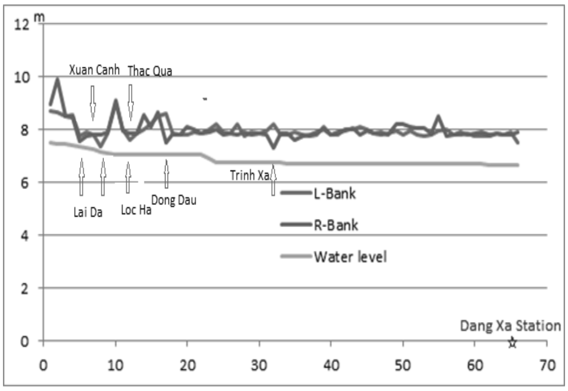

Figure 6: The water level along the NHK river

8. Conclusion

This paper introduces the methodology and results of setting up the 1D hydraulic model, simulating 2008 water level in NHK as well as building scenarios for the inundated problem in NIS. Setting up the model, bases on Imech_1D, that the model was built by the Institute of Mechanics - Vietnam Academy of Science and Technology, and the data from Northern Duong Irrigation Company. The simulating results at Long Tuu, Trinh Xa and Dang Xa have obtained high accuracy, NSE from 8.82 to 0.98 that estimated well in NSE scale.

In the first scenario to solve the inundation of 1% rainfall, the max of water level at Dang Xa is +6.89 m meeting the condition of keeping the water level at Dang Xa under +7.0 m that allows all drainage pump stations working at full capacity to solve the inundation within three days. Moreover, this scenario allows changing NHK into a lake helping enhance the environment and irrigation in the dry season.

In the second, the max of water level at Dang Xa is +6.59 m also meeting the condition of keeping water level at Dang Xa under +6.7 m and allows all drainage pump stations working at full capacity to solve the inundation within three days. The time that water level is over +6.5 m is about 24h and dike safety is still in danger at some places as Xuan Canh, Thac Qua on the left and Lai Da, Loc Ha, Dong Dau,Trinh Xa on the right (Fig. 6). Then in this scenario, upgrading dike embankment at these above places is also necessary.

The paper has suggested solutions for the problem of 1% rainfall inundation in NIS but still need to combine with the hydrology model for more accuracy.

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