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HOANG THI NGUYET MINH

STUDY ON THE SCIENTIFIC BASIS AND SOLUTION FOR FLOOD DRAINAGE IN PHAN – CA LO RIVER

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ABSTRACT

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Supervisors:

1. **Assoc.Prof. Dr. La Thanh Ha**
2. **Assoc.Prof. Dr. Hoang Minh Tuyen**

Opponant No 1: Assoc.Prof. Dr. Ngo Le Long

Thuy loi University

Opponant No 2: Assoc.Prof. Dr. Nguyen Thanh Son

VNU University of Science

Opponant No 3: Dr. Nguyen Kien Dung

National Hydro – Meteorological service

The thesis will be submitted to Institute scientific council held at Vietnam Institute of Meteorology, Hydrology and climate change

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INTRODUCTION

1. Reason for choosing the dissertation topic

Phan - Ca Lo (PCL) River is a tributary of the Cau River, flowing through the Vinh Phuc Province and Hanoi City. According to many hydrologists, PCL is the typical river among Vietnam's river systems because: 1) It takes historic vestiges of the first flood diversion river of the country; 2) It is one of the rivers having the highest meandering; 3) Although the PCL is not a big river, it still flows through three specific topographical characteristics: mountainous, midland and plain terrain; 4) The urbanization in the PCL river basin is highly rated in the country; and 5) It has a complex irrigation and drainage area.

In the early years of the 20th century (1918-1919), in order to protect Hanoi City from possible big floods in the Red River system, the PCL River was used as a flood diversion. However, the flood diversion function was inefficient and also caused inundation, leading to the filing of the flood diversion gate and subsequent disconnection with the Red River. Accordingly, the PCL River has made a closed basin with the only outlet contributing to the Cau River.

In recent years, natural disasters have occurred with increasing frequency and intensity, which causes extremely serious inundation in the region and the whole PCL river basin. The PCL River basin is located in the key economic zone of the Northern region; therefore, the comprehensive flood drainage in the whole basin becomes urgent than ever to ensure the sustainable economic and social growth in the basin.

In this context, the PhD thesis ***"Study on the scientific basis and solution for flood drainage in Phan – Ca Lo River"*** was selected in order to solve the problem of flood drainage comprehensively and sustainably in the PCL River.

2. Objectives and methodology of the thesis

Research objectives of the thesis are:

- Defining a scientific and practical basis to clarify the characteristics of the

PCL River basin, then analyzing the causes of the formation and development of flooding;

- Proposing the solution to flood drainage in the PCL River toward sustainable socioeconomic development and environmental protection of the river basin.

Research Methodology: field trip surveying; statistical analysis; hydrological and hydraulic modelling combined with GIS; experts and community consultation; system analysis.

3. Objects and scope of thesis research

The object of the thesis research was the flood drainage in the PCL River Basin, corresponding to specific conditions of various solutions. The scope of research is the whole PCL River Basin with a total basin area of 1229 km^2.

4. New contributions of thesis

1) Clarify the characteristics of the PCL River Basin and human impacts on the formation and development of flooding in the basin, subsequently establish a scientific basis for selecting and proposing appropriate solutions to drainage;

2) Propose the feasible drainage procedures and control points in order to operate the structures' system of flood drainage constructions in the basin, take it as a basis for planning of flood drainage in the PCL River.

5. Structure of thesis

In addition to the introduction and conclusion, the thesis is divided into four chapters: Chapter 1: Overview of studies related to the flood drainage worldwide and in Vietnam. Chapter 2: Causes' analysis of flooding and the assessment of drainage capacity of the PCL River. Chapter 3: Establishment of the scientific basis for proposing drainage solutions to the PCL River. Chapter 4: Solutions for drainage in the PCL River.

Chapter 1. OVERVIEW OF STUDIES RELATED TO THE FLOOD DRAINAGE IN THE WORLD AND VIETNAM

1.1. The flood drainage studies in the world

In recent years, flooding is increasing in both frequency and intensity, triggering off serious damages to many countries in the world. Historical records have shown many extreme floods in some countries such as the flood in China in 2008, causing 3000 deaths, 21 billion loss; the flood on the Yangtze River in 2010, causing 4150 deaths; the flood in Thailand in October, 1995 on the Chao Phraya River basin, causing 60,000 inundated hectares, 11.858 million baht loss; especially the historical flood in 2011, causing billions of dollar loss; in Bangladesh, the flood in 1998 caused 738 deaths, a total of 1.0 billion dollar loss; in the Netherlands, the flood in 1995 caused hundreds of millions of dollar loss.

Flood control in the world is changing towards an integrated management approach, which aims to include all activities of relevant fields to minimize the effects of flooding. Based on this point of view, flood control is considered before the flooding, during flooding and after flooding.

The structural and nonstructural measures have been applied in many countries over the world. Depending on the specific conditions of each region, measures will be selected to maximize the efficiency. Objective of flood control is to limit both the socioeconomic and human damage to a minimum value. Thus, it should not utilize only a single solution; in the contrary, it must be combined with other solutions. At the same time, depending on the specific natural conditions and socioeconomics, and technological development of each country, appropriate solutions will be chosen for each river basin.

1.2 The flood drainage study in Vietnam

Current research on flood drainage in Vietnam focuses on the cause of flooding formation and development on the river; it impacts on the socio-economic and flood drainage solutions. There are studies being done about flooding on the Red River system, the Thai Binh River, the Mekong River and other major rivers in the

Central region, especially the biggest focus is on the Red-Thai Binh river systems.

1.3. Research on inundation and flood drainage in Phan – Ca Lo river basin

Lots of researches have been carried out with the efforts to find a solution to prevent and remedy the damage caused by flooding in the basin, but there has not been a radical solution for the whole area from upstream to downstream and the estuarine which contributes water to Cau River. The causes of the limitations are:

- There is no research coordination among local areas: Vinh Phuc Province studied in the upper area while Hanoi did in the downstream area. On the other hand, two districts of Hanoi, Soc Son and Dong Anh are oriented to develop as eco-tourism zones, so solving flood problem are not concerned.

- The previous studies have not addressed the coordinated operation of the available construction system in the basin. The drainage plan has been just indicative, which was implemented based on the operational capability of the drainage system and upgraded existing drainage systems.

- On the other hand, although the river flow regime is complex and the flooding is frequent, the PCL river is only a small flow through a provincial region, not having influence into the surrounding basins. Hence, the studies of the basin are limited.

1.4. Research orientation of the thesis

- Analyzing the reasons for flood and inundation in the basin;

- Assessing flooding in the river basin, especially the historic flood in 2008 with the records on the inundated time span, inundation area, flooding scope to make a research solution for flooding problems in the basin;

- Setting up and selecting calculated options based on the current status and the cause of the flooding, the binding conditions combined with the actual situation that has been made to minimize flooding in the basin.

- Selecting and applying mathematical modeling tools to calculate the appropriate flood basin. Applying calculation on different schemes, based on computational analysis results to assess the effectiveness of the plan, then

proposing specific solutions for basin drainage

- Recommending operation procedures of drainage system, consisting of headworks, pump stations, regulator sewer, drainage channels regarding flood in 1978.

1.5. Conclusion of chapter I

Chapter 1 re-assesses flood status, the existing studies on the PCL River basin, and the measures for flood drainage in the world and in Vietnam, which are the basis for the next chapter to select appropriate and effective scientific solutions to flooding drainage on Phan - Ca Lo River basin.

CHAPTER 2. ANALYZING THE CAUSE OF FLOODING AND DRAINAGE CAPACITY ASSESSMENT OF PHAN – CA LO RIVER

2.1. Introduction of Phan – Ca Lo river basin

Phan - Ca Lo River Basin has a total area of 1229 km^2, consisting of 348 km^2 of Phan river basin and 881 km^2 of Ca Lo River basin. The basin covers a large area of Vinh Phuc province (including Binh Xuyen, Tam Duong, Vinh Tuong, Yen Lac district and Vinh Yen city) with the area of 733 km^2 and a part of the Hanoi (including Me Linh town, Dong Anh and Soc Son district) with the area of 496 km^2.

2.2. Current status of drainage system

1) The traditional drainage headworks for the whole basin are operated naturally, the main drainage orientation is Ca Lo river and the drainage direction is to Cau river.

2) The interior drainage constructions in Phan – Ca Lo have been built. However, all can deal with drainage mission in annually flooded agricultural land.

2.3. Analyze causes inundation and flooding in river basins

There are many causes of flooding in river basins, the 5 main reasons are as follows: 1) Topography, 2) Flood characteristics, 3) High meandering number of the river, 4) Influence of river backwater from Cau River, 5) Current drainage ability

2.4. Methods of solving flooding problem

Phan - Ca Lo river basin is a small area, including four tributaries with complex topography: mountainous terrain, midland and plains. To solve the problem of flood drainage, it should be incorporated both hydrology, hydraulic models in 1D, 2D. According to the purpose of the thesis MIKE software was chosen to be made flooding maps in the basin.

Hydrological calculations

Applied the GIS technology tools, Phan - Ca Lo river basin is divided into 12 sub-basins. It is then done the calibration and validation at Phu Cuong station as the basis for calculating the volume of rainfall in other river basin: calibration year: 1966, 1968, 1969, 1971, 1972; validation year: flood season in 1973, 1975.

Hydraulic calculations

Based on the documents on topography, cross-sections of the river and river network in the study area, the network is digitized in MIKE11 model with 3960 digitized points, 418 cross-sections that are presented in Figure 2.11.

- Upper boundary: The flow process of the upstream stations on Phan river in An Ha; Cau Ton river at Goc Gao bridge, Tranh river at Lam Po bridge, Ba Hanh River at bridge on Provincial Highway 310, on Cau bridge at the Gia Bay river gauging station;

- Minutes on - Import record store: process flow (Q ~ t) of the 12 sub-basins; lower boundary: The water level process (H ~ t) at Pha Lai stations; calibration boundary: Manh Tan and Phuc Luong station.

Calculation results after calibration (from June 1st, 2006 to Sep 31st, 2006) and validation (from June 1st, 2008 to Sep 31st, 2008) at two stations Manh Tan and Luong Phuc is pretty good. Measured flooding curve and calculated one have synchronization with each other in shape and peak values, in which the correlation coefficient of 0.9 and error peak value in the range of 0.01 to 0.06, and the objective function NASH is in permissible limit (≥ 0.8).

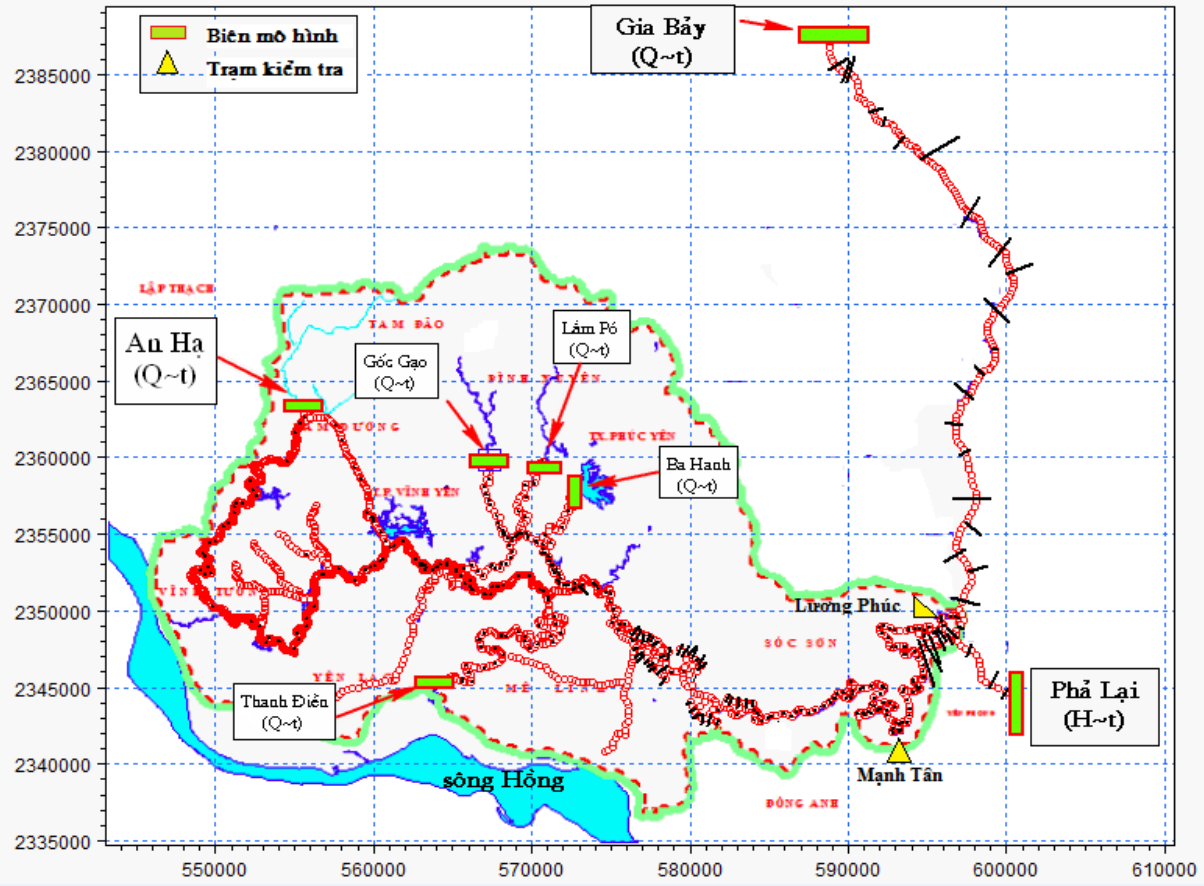

Figure 2.1. The boundary of the hydraulic model of Phan - Ca Lo river

Result of the current flooding in 2008

The calculation results in Table 2.1 and Figure 2.2 show that the inundation area in the river basin is corresponding to mainly at the depth of over 1m (245.394 km^2). The ability to drain the inundation area after 4 days at all levels of inundation depths remains over 20 km^2. Calculation results are entirely consistent with statistic data of the flooding situation in the province in the 2008 floods.

Table 2.1. Inundation area accord to the inundation level of the flood event in the end of October, 2008

Inundation level, m	**Inundation area, km^2**
<0.5	85.266
0.5-1.0	113.454
>1.0	245.394

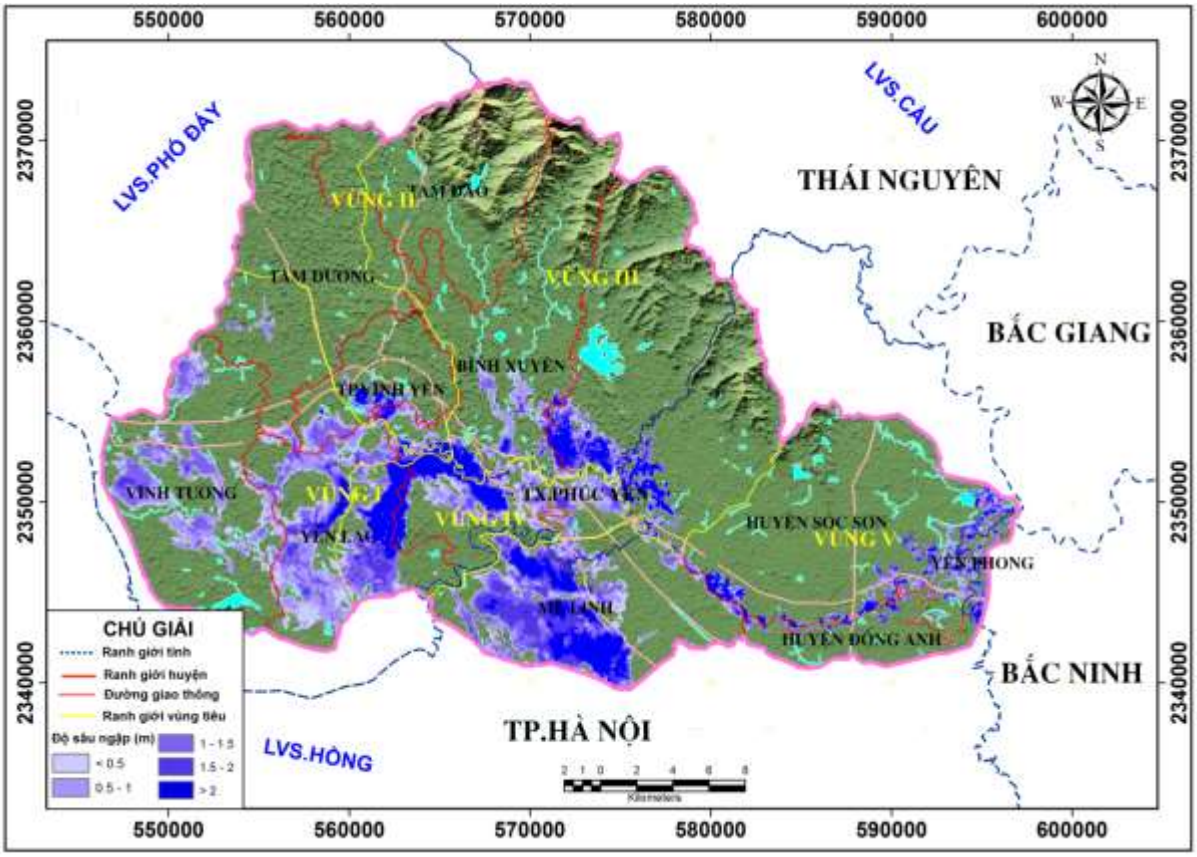

Figure 2.2. Flooding map in PCL river basin in October, 2008

2.5. Conclusion of chapter 2

In chapter 2, the thesis gives the overview of the study river basin. On the basis of analyzing the flood status in river basins, it then analyzes and clarifies the causes of flooding in the basin, and proposes specific solutions. The thesis uses modeling tools to simulate flooding situation in 2008 and to test the parameters as well as the feasibility of the model that will be applied in the following chapters.

Chapter 3. ESTABLISHING A SCIENTIFIC BASIS FOR PROPOSING DRAINAGE SOLUTION TO PHAN – CA LO RIVER

3.1. Basis for proposing drainage solutions to Phan – Ca Lo river basin

General principles: 1) Consider Basin Phan - Ca Lo as the unified system; 2) Inundation drainage solutions and flood drainage systems are performed simultaneously and support each other; 3) Consider the relationship between

flood on the field and in the river; 4) Inundation drainage solutions and flood drainage systems must be consistent with the typical characteristics of the basin.

3.2. Zoning flood drainage area in Phan - Ca Lo River basin

a) Zoning flood drainage area:

Phan – Ca Lo River basin is zoned into 5 drainage areas (Figure 3.1), comprising:

Zone 1: The western boundary is the dike of Day river,the south by the Red River dyke,the east by the canal in Ben Tre to Heron Lake; covering an area of 236.3 km^2; drained of river bed is Phan river from the Thuy Yen (Sp02) drain regulator to the Dam Vac (SP30).

Zone 2: Western boundary is the river dike of Day river, Ben Tre channel, the east is watershed of Cau - Ton River basin, the south is watershed of Ca Lo River is classified cross of Cau Ton – Tranh river and the area of 111.2 km^2; a bed drainage channel through the Ben Tre and Dam Vac River into Phan.

Zone 3: tributary basins of Tam Dao in Ca Lo river basins include Cau Ton river, Tranh Dong river, Ba Hanh river and Dong Do river; an area of 307.4 km^2; river bed is the Ca Lo River tributaries.

Zone 4: The northern boundary is zone II and III, the West was the zone I, south of the dyke of the Red River, southwest limited by the dike of Ca Lo river to Xuan Phuong bridge, the area of 77.6 km^2; the drainage bed is Ca Lo river.

Zone 5: The boundary to the west is limited by the zone III, IV, the north delimited by natural distributary river with Cau river, the south of the river drainage channels of Ngu Huyen Khue river (Dong Anh district, Gia Lam District) and Ca Lo river; total drainage area is 496 km^2; the bed rivers with main flow from Ca Lo river to Cau River.

b) Design drainage capacity criteria

Based on the national standard of irrigation works on primary design regulations QCVN 04-05: 2012 / MARD, including: Level I Design; design drainage frequency P = 10%. Design rainfall is 10%: the thesis deals with T = 3 days rainy period based on rainfall data in gauging stations of Tam Dao and

Vinh Yen; rainfall density reaches peak at the middle period, matching with10% infield flood and 10% river flood.

+ The rainfall data in 35 years (1970-2005) at two stations in Tam Dao, Vinh Yen shows the maximum three-day rainfall with 10% design in Vinh Yen station is approximately 380 mm with X_{1978} = 371.6 mm;

+ The calculation rainfall period matchs with Δt = 1 hour with typical hourly rainfall is 07 to 09 of October 1978.

- The design stage boundary: Cau River stage at the Gia Bay gauging station $H_{max10\,\%}$ = +9.06 m.

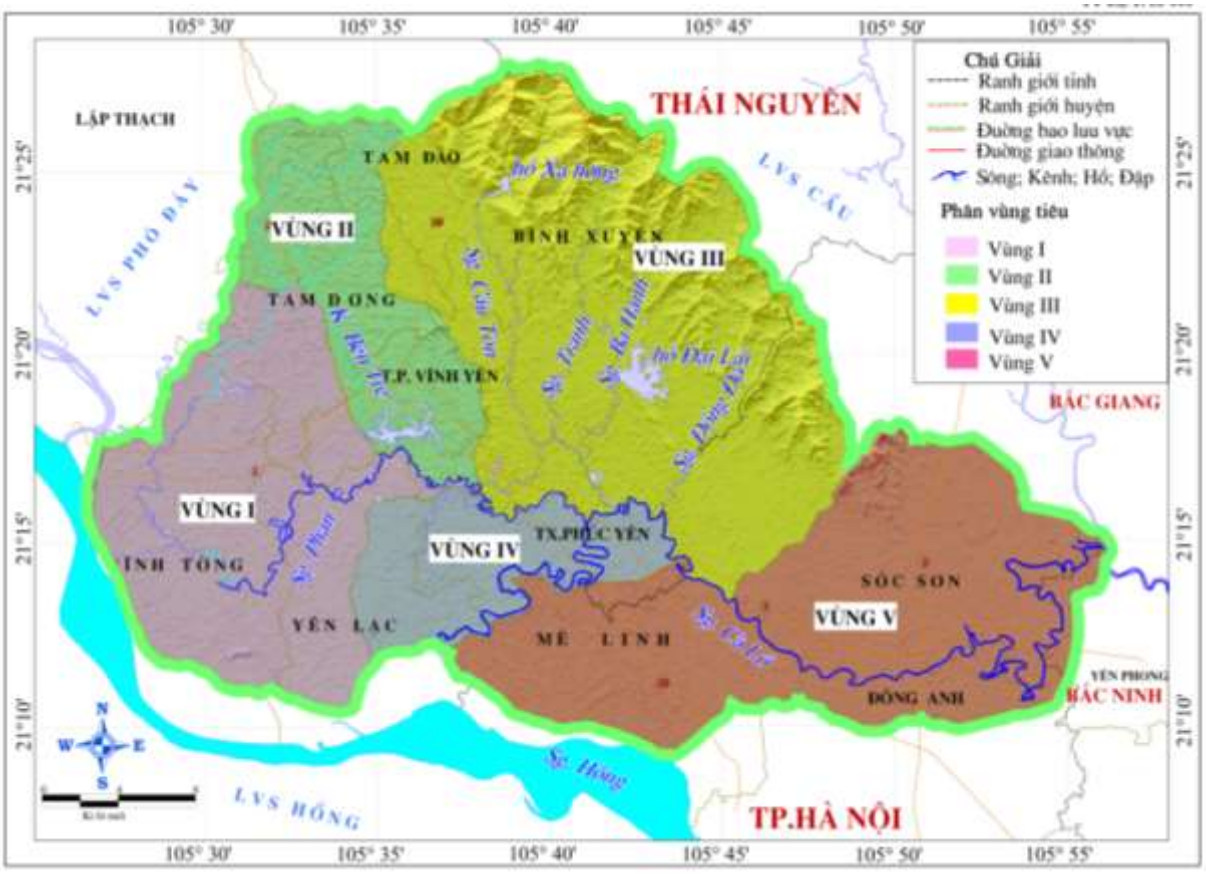

Figure 3.1. Drainage areas of Phan – Ca Lo River basin

3.3. Drainage solutions

Drainage problems of Phan – Ca Lo River basin: 3-day rainfall, 5-day drainage capacity; total drainage capacity is 80% total drainage requirement. Possible drainage solutions are shown in Table 3.2.

Table 3.1. Calculation solutions

No.	Scenario	Condition
1	Baseline	Current status of structure
2	Solution 1 (PA1)	Stream removal at Ca Lo downstream
3	Solution 2 (PA2)	PA1+ Upgradation of the river bed in some segments
4	Solution 3 (PA3)	PA2+ Drainage pumping in Nguyet Duc
5	Solution 4 (PA4)	PA3+ Drainage pumping in Ngu Kien

3.4. Hydraulic calculation

3.4.1. Baseline scenario (PAHT)

The calculation results of the current flooding show river stage maintain beyond + 8.46 m, the needed drainage volume is 115.90 x 10^6 m^3, the largest is in zone V with 36.6 x 10^6 m^3 on Ca Lo River downstream and Me Linh town. Flooded area and the total volume of inundation of flood occurred in October 1978 are presented in Table 3.2, flood map of Phan - Ca Lo River is Figure 3.2.

Table 3.2. Maximum flood area and drainage volume

Depth (m)	**Area (km^2)**					**Total**
	Zone I	**Zone II**	**Zone III**	**Zone IV**	**Zone V**	
<0.5	5,22	1,43	19,05	9,27	12,4	**47,37**
0.5-1.0	6,83	1,68	25,97	10,77	17,78	**63,03**
>1.0	19,38	4,23	23,41	28,81	60,5	**136,33**
Total flood area (km^2)	31,43	7,34	68,43	48,85	90,68	246,73
Total needed drainage volume (10^6m^3)	***19,63***	***3,57***	***34,36***	***21,74***	***36,6***	***115,9***

Zone III, despite of the small catchment area, the flood water volume is 2x10^6 m^3. In terms of drainage capacity, due to steep terrain, drainage capacity is faster than the Zone V; after 3 days, inundations at all levels are less than 1 km^2.

Zone IV has the needed drainage volume of 21.74 x10^6 m^3, concentrating on a part of Yen Lac District and area closed to Ca Lo River (Vinh Phuc

Province); this area has the low and unstable drainage capacity.

Zone I has the needed drainage volume is 19.63 x10^6 m^3; stage always maintains beyond +9,6 m, causing inundation in Vinh Tuong District and part of Yen Lac District, the drainage capacity is low, the flood area after 5-day drainage is 0,32 km^2.

Zone II has the needed drainage volume of 3.57 x10^6 m^3, concentrating mainly on Vinh Yen City. However, the current structures in this area cannot meet the drainage requirement, causing low drainage capacity.

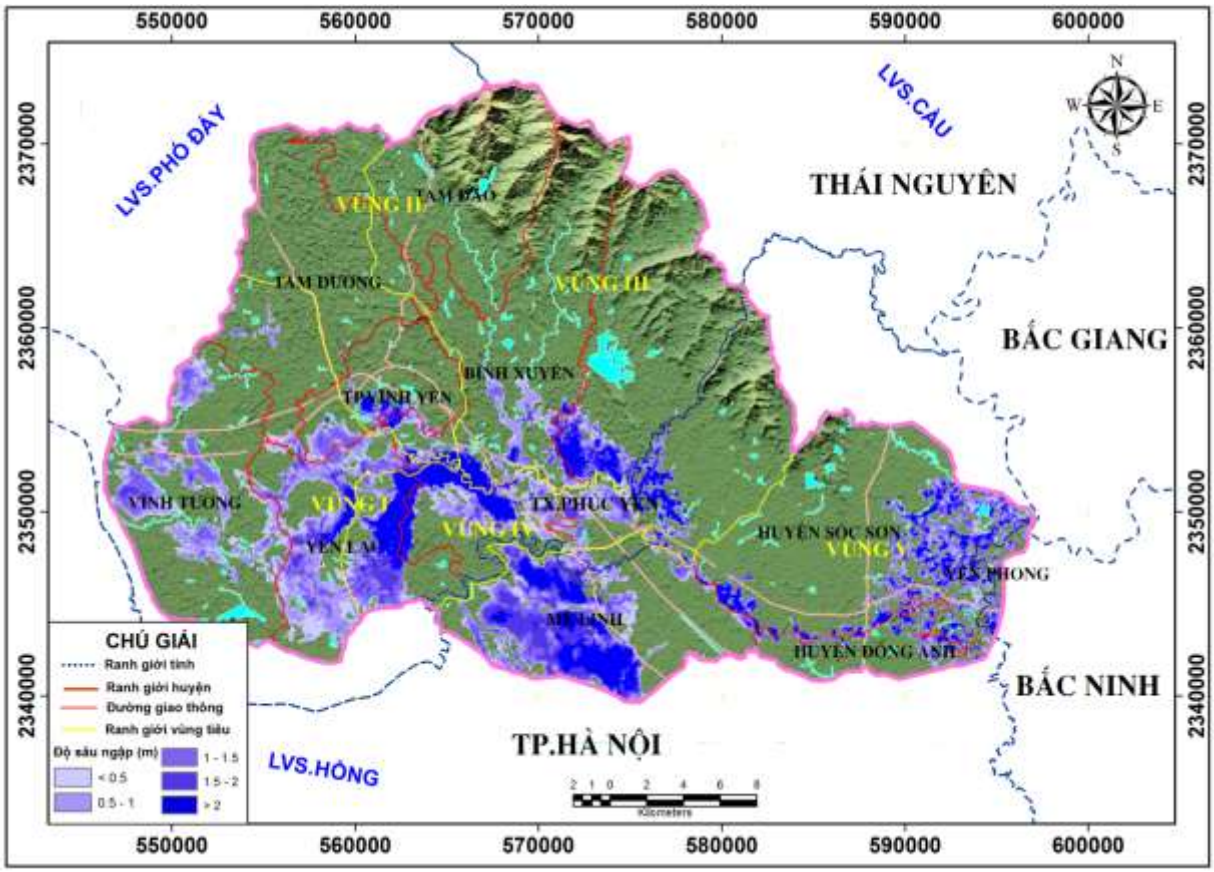

Figure 3.2. Flood map of Phan – Ca Lo River basin, baseline scenario

3.4.2. Solution 1 – Stream removal at Ca Lo downstream

The thesis proposes 4 stream diversion cases *removing stream to slowly straighten* downstream segment linking Cau River.

Case 1: Remove stream from Xuan Thu PC (located in Xuan Duong Village) to Kim Lu Thuong (located in Kim Lu Thuong Village, Kim Lu Commune; *Case 2:* Remove stream from Xuan Thu PC (located in Xuan Duong Village) to Dien Loc temple (located in Dien Loc Village, Tam Giang Commune); *Case 3:* Similar stream removal with case 1 with additional removal

of curve linking Dien Loc temple and Xuan Tao located in Dien Loc Village, Tam Giang Commune; *Case 4:* Removing curve from Xuan Thu PC (located in Xuan Duong Village) to Dien Loc temple and from Dien Loc temple to Xuan Tao (located in Dien Loc Village, Kim Lu Commune).

Table 3.3. Affect assessment of stream removal to river length and flood area

Comparison characteristics	**Before removal**	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Area under direct impact of flood (ha)	3529	3046	2857	2551	2357
Flood area affect (ha)		↓ 483	↓ 672	↓ 978	↓ 1172
River length (km)	26,2	14,75	11,68	7,69	4,62
River length affect (km)		↓ 11,45	↓ 14,52	↓ 18,51	↓ 21,58

Bảng 3.4. Diện tích ngập lớn nhất và hiệu quả tiêu thoát, PA1-TH4

Characteristics		Flood area affect **(km^2)**					
		I	**II**	**III**	**IV**	**V**	**Total**
Flood depth (m)	<0,5	4,82	1,41	19,14	8,96	9	43,33
	0,5-1	6,51	1,7	25,93	10,61	13,33	58,08
	>1	18,78	4,12	23,21	28,02	46,59	120,7
	Total	30,11	7,23	68,28	47,59	68,92	222,11
Flood drainage volume	10^6 m^3	0,85	0,05	0,08	0,59	20,58	22,14
	Compared to baseline (%)	4,3	1,5	0,2	2,7	56,2	19,1

The calculation results show that, in general, water levels on the river in most of the cases are decreasing. In regards to land use efficiency, the case 4 is selected because of most efficiency (Table 3.3).

Based on flood mapping and flood retention time, it can be seen inundated area has decreased significantly in the Ca Lo River downstream, especially in the area where Ca Lo River flows into the Cau river. However, in Yen Lac district (region IV), the downstream of tributaries (region III), Vinh Tuong district in the right side of Phan River (region I), Vinh Yen city are widespread flooded.

3.4.3. Option 2 – Improve the river bed in some middle sections of the river

It is implemented dredging measures of: River Phan, from cross section SP08 to SP35 with a total length of 48 km, an average dredging depth of 0.7 m; dead-end Ca Lo river with a length of 10 km, an average dredging depth of 1m; cross road of Cau Ton -Tranh - Ba Hanh river with a total length of 26.7 km and an average dredging depth of 1m.

Hydraulic calculation results: Although the mainstream of Ca Lo river is affected by the widen stream from the upstream, the water levels decrease from 2 cm to 15 cm at most point more than block option.

Results calculated on the flooding area level is the depth and amount of drainage is presented in Table 3.5.

Table 3.5. The largest inundated area and drainage efficiency - PA2

Characteristics		Flood area affect **(km^2)**					
		I	**II**	**III**	**IV**	**V**	**Total**
Flood depth (m)	<0,5	4,96	1,3	17,83	8,29	11,37	43,75
	0,5-1	5,85	1,56	14,51	10,61	20,02	52,55
	>1	16,9	3,56	7,4	21,25	36,9	86,01
	Total	27,71	6,42	39,74	40,15	68,29	182,31
Flood drainage volume	10^6 m^3	1,2	0,1	14,3	3,7	28,7	48,1
	Compared to baseline (%)	**6,3**	**3,4**	**41,7**	**17,0**	**78,5**	**41,5**
	Compared to solution 1 (%)	**2,0**	**1,9**	**41,5**	**14,3**	**22,2**	**22,4**

In regards to drainage capacity, option 2 is 41.5% more effective than the current state and 22.4% more effective than option 1. In the region III, V, drainage is most effective; in the region III of option 1 there is almost no drainage while it is drainaged more 41.7% than the current state. Region V has been 78.5% drained, drainage volume is mainly on Me Linh area due to pumping station to the Red River at the pumping station Nguyet Duc; the remaining areas are drainaged as follows: Region I: 6.3%, Region II: 3.4%, Region IV: 14.3%.

3.4.4. Option 3 – Drainage pumping station at Nguyet Duc

In this method, the target of gravity drainage will be applied to the region III and V in the direction toward Cau River at Phuc Loc Phuong. The rest of the river basin will be drainaged by dynamic methods in the direction toward Red River at Nguyet Duc pumping station. Calculation results of inundation area and drainage efficiency are shown in Table 3.6.

Table 3.6. Calculation results of the largest flooded area and effective drainage

Characteristics		Flood area affect **(km^2)**					
		I	**II**	**III**	**IV**	**V**	**Total**
Flood depth (m)	<0,5	4,43	1,05	9,23	2,67	3,07	20,45
	0,5-1	5,51	1,01	10,28	3,37	4,96	25,13
	>1	15,83	2,85	4,38	13,55	9,55	46,16
	Total	25,77	4,91	23,89	19,59	17,58	91,74
Flood drainage volume	10^6 m^3	3,52	0,31	22,71	14,49	28,89	69,92
	Compared to baseline (%)	**17,9**	**8,7**	**66,1**	**66,6**	**78,9**	**60,3**
	Compared to solution 2 (%)	**11,6**	**5,3**	**24,4**	**49,7**	**0,4**	**18,8**

The calculation results in option 3 shows the option that the drainage construction by dynamic methods has reduced the flood peak; especially in region IV where it is used drainage dynamics directly to the Red River. Besides, the addition of culverts in tributaries, also regulate and enhance drainage for region III. However, the amount of drainage in this option is 60.3% compared to the total quantity of water drainage requirements. In fact, based on inundation maps and calculation results it can be seen that some areas still affected by flooding.

3.4.5. Option 4 – Adding drainage pump at Ngu Kien

In option 4, based on all conditions of option 3, the regulation culvert is set up on Cau Ton river at the point A82 for the whold region III to be drained by gravity to Cau river; Ngu Kien pumping station with a flow of 100 m^3/s and the channel leading from Vũ Di bridge to Ngu Kien pumping station; then drainage pump is set up from Bac Binh Xuyen to Nam Viem with capacity of 20 m^3/s.

The drainage capacity of option 4 is 83% (96.18 million m^3) more than

current state, in which region III in downstream where tributaries enter Ca Lo river and is the flooding low-lying terrain with long retention period, the amount of drained flooding is nearly 98.7 %, 32.7% better than option 3; it is 89.0% in downstream of Ca Lo river, 10% better than option 3 (Table 3.7, Figure 3.3).

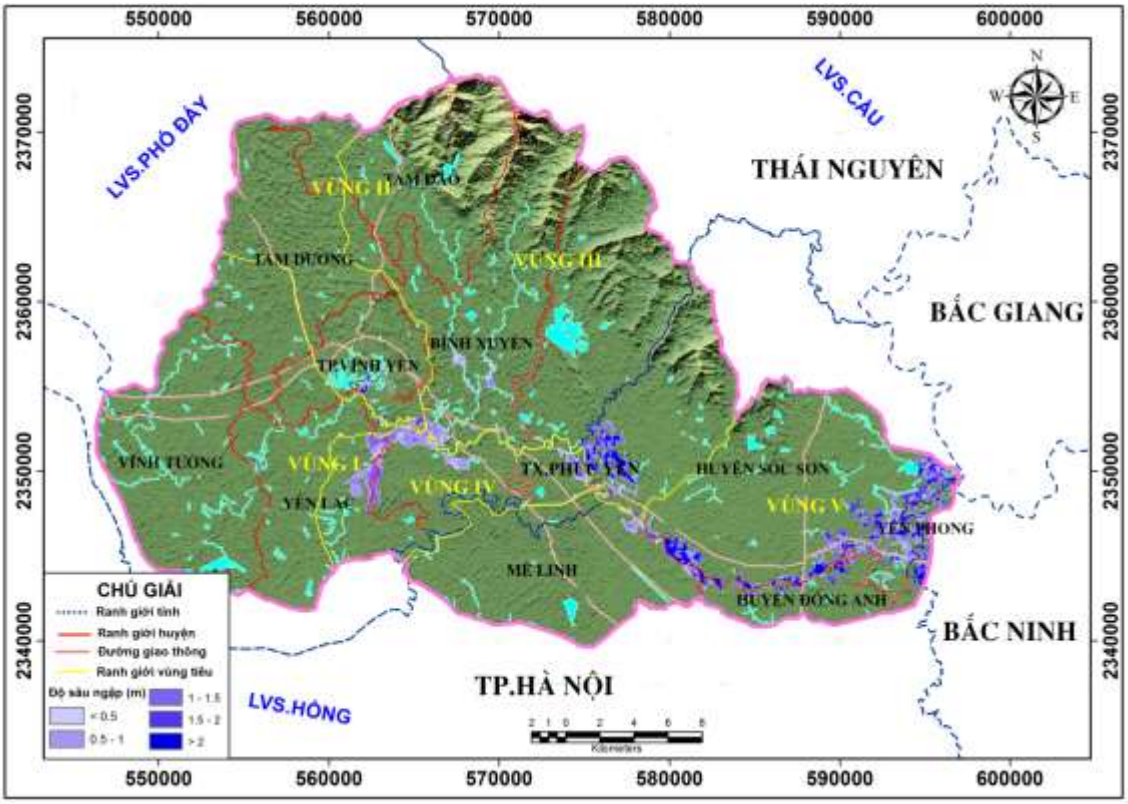

Figure 3.3. Flooding map in Phan - Ca Lo River Basin, PA4

Table 3.7. Flooded area and the largest amount of drained water required under PA4 option

Characteristics		Flood area affect **(km^2)**					
		I	**II**	**III**	**IV**	**V**	**Total**
Flood depth (m)	<0,5	3,23	0,33	0,26	2,02	1,32	7,16
	0,5-1	4,92	0,22	0,29	4,78	1,56	11,77
	>1	9,78	0,53	0,3	2,31	3,35	16,27
	Total	17,93	1,08	0,85	9,11	6,23	35,2
Flood drainage volume	10^6 m^3	9,49	3,01	33,93	17,18	32,58	96,18
	Compared to baseline (%)	48,3	84,2	98,7	79,0	89,0	83,0
	Compared to solution 3 (%)	30,4	75,5	32,7	12,4	10,1	22,7

3.4.6. Comments on option results

With the aim of 80% drainage in the basin, 4 drainage options are proposed, each option are selected based on various tests, and they closely related to each other. The measures of one option are applied the initial conditions of the later one, therefore, the drainage efficency of the later one is greater than the previous plan.

Figure 3.8. Comparing the results of the drainage option in the river basin

Characteristic		Current state	**Calculation option**			
			PA1	PA2	PA3	PA4
Maximum discharge (m^3/s)		561,7	542,2	489	430	310
Compared to current state	m^3/s		-19,5	-72,7	-131,7	-251,7
	%		-3%	-13%	-23%	-45%

In regards to the maximum discharge due to reasonable drainage measures, flow of the river is circulated so it tend to decrease from current state to option 4, particularly the maximum discharge of current state is 561.7 m^3/s while it is 310 m^3/s in option 4 (Table 3.8).

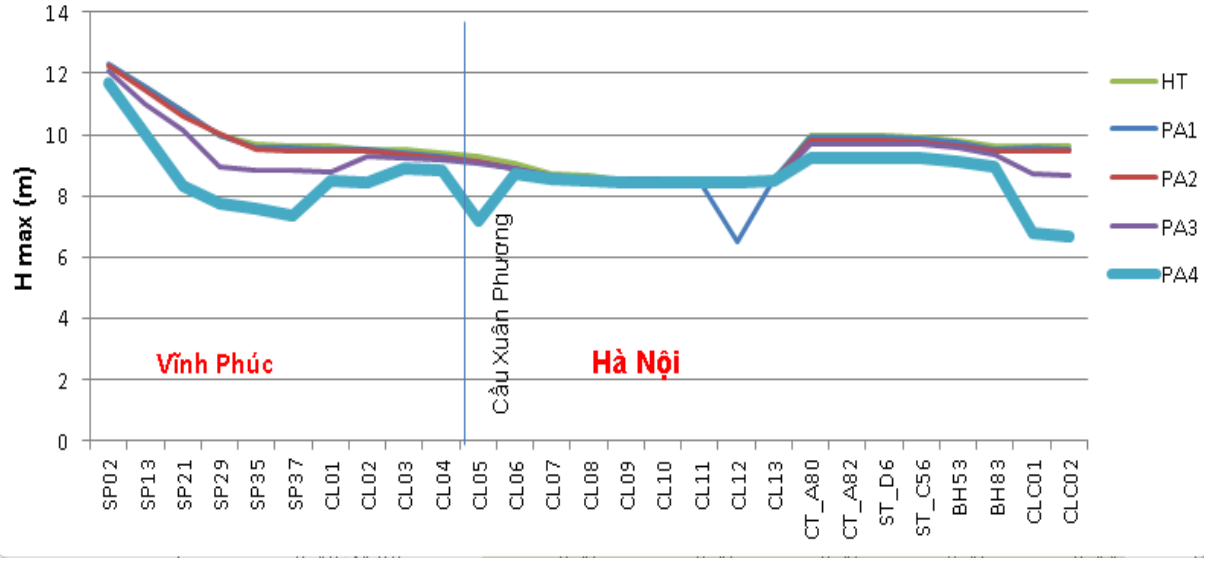

Figure 3.4. Comparing the maximum water levels at some points in Phan - Ca Lo river system between the current state and options.

The change in water level and discharge at some points showed levels of mitigation option is less than the current state and the option 4 is the best among different options.

3.5. Conclusion of chapter 3

The study river basin is divided into 5 drainage region. The thesis proposes 4 calculation options with different tests, analysis and efficiency assessment of each drainage area, and on the whole Phan - Ca Lo river basin. Based on the calculation results of changes in water level, flooded area, retention time, the quantities of drainage water are associated with drainage requirement of each option. On this basis, four options are selected and the calculated results of the total quantity of water drainage reach 83%, it meets the requirement of draining 80% of flooding in Phan - Ca Lo river basin.

Chapter 4. PROPOSED SOLUTIONS FOR FLOOD DRAINAGE IN PHAN – CA LO RIVER

4.1. Basis and diagram of proposed solutions

Only 62% of drainage area can be drained under the condition of 1978 historical flood with 3-day rainfall of 250mm. If 3-day rainfall remains in the range of 250 - 300 mm on a wide scale, 35 to 40 thousand ha can be flooded. The diagram for proposing a solution is presented in Figure 4.1.

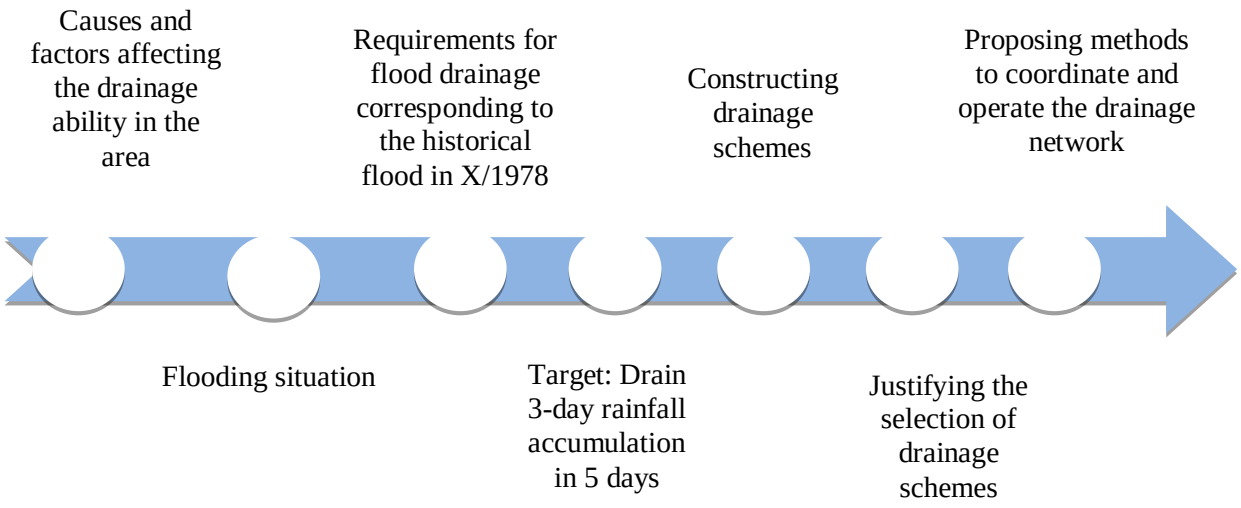

Figure 4.1. Diagram of proposing solutions for flood drainage in the PCL river basin

4.2. Drainage solutions for specific areas and entire system

Structural measures for specific drainage areas are listed in Table 4.1.

Table 4.1. Selected structural measures

Drainage area	**Structural measures**
Area I	Phan river: Dredging 48 km from (SP08) to (SP35), average dredging depth = 0.7 m.
	- Pumping station at Ngu Kien, Vinh Tuong: pumping rate Q_B = 100 m^3/s.
	- Under dike culvert: culvert discharge Q_C = 100 m^3/s.
	- Tailrace behind Ngu Kien pumping station: Q_K = 100 m^3/s, length = 3.0 km.
	- Main channel of Ngu Kien station: Q_K = 30 m^3/s, length = 5.0 km.
Area II,III	The river junction between Cau Ton -Tranh - Ba Hanh: Dredging and improving 28 km from (D0) to (B83), average bottom width = 30 m.
	- Pumping station for drainage area III at Nam Viem.
	- Designed pumping rate Q_B = 20 m^3/s.
	- Under dike culvert on Ca Lo river: Q_C = 20 m^3/s, culvert's size B x H = 6 x 2,5 m, length = 20 m.
	- Regulating culvert at the river junction between Cau Ton – Tranh: culvert discharge Q_C = 50 m^3/s.
	- Regulating culvert on Phan river at Binh Duong -Vinh Tuong: culvert discharge Q_C = 60 m^3/s.
Area IV	Ca Lo Cut river: Dredging 10 km, average dredging depth = 1.0 m.
	- Regulating culvert at river junction between Ca Lo - Ca Lo Cut: culvert discharge Q_C = 60 m^3/s.
	- Pumping station at Nguyet Duc, Yen Lac: pumping rate Q_B = 100 m^3/s.
	- Under dike culvert: culvert discharge Q_C = 100 m^3/s.
	- Tailrace behind Nguyet Duc pumping station: Q_K = 100 m^3/s, length = 3.0 km.
Area V	Divert Ca Lo river segment in the downstream at Dong Anh and Soc Son districts (begin at Xuan Thu commune, Dong Anh district; end at Xuan Tao commune, Soc Son district).

4.3. Proposing flood control system

In the event of a flood with a frequency response of 10% (the same historical flood in 1978), based on measures of overall and flood drainage basin regions (Section 4.1). Meanwhile, the drainage system (headworks, canals, pumping stations, ..) require coordination mechanism to bring high efficiency and station is required to drain 83% amount of flooding.

This study proposed 6 flood control points in 5 specific drainage area, which are listed in Table 4.2.

Table 4.2. Control and monitoring points in PCL river basin

Area	Locations of control points	Tasks	Ký hiệu
1	Vu Di culvert, Te Lo commune, Yen Lac district	Control H for area I, monitoring H_{flood} for Phan river upstream area	**KS1**
2	Lac Y culvert, Hoi Hop, Vinh Yen city	Control H for area II, monitoring H_{flood} for Ca Lo river at Dam Vac	**KS2**
3	Tranh bridge (old), Tam Hop commune, Binh Xuyen district	Control H for area III, monitoring H_{flood} for Cau Ton and Tranh rivers	**KS3**
4	Thinh Ky culvert, Tien Chau commune, Me Linh district	Control H for area IV, monitoring H_{flood} for Ca Lo Cut river	**KS4**
5	Xuan Phuong bridge, Nam Viem commune, Me Linh district	Control H for area V, monitoring H_{flood} for Ca Lo river at the boundary between Vinh Phuc and Ha Noi	**KS51**
	Gia Tan bridge, Soc Son district, Ha Noi	Control H for area V	**KS52**

4.4. Proposing coordination mechanisms and operation for drainage system

Warning time:

Warning time before starting pumping operation is determined by observing the water level at control points passing “control level” with fluctuating level of +10 cm/h.

Pumping regulation:

Based on the discharges of specific drainage areas, when the water level at control points reach "trigger level", Ngu Kien pumping station starts operating; when water level at control points 1, 2, 3 pass "control level", Ngu Kien station must be operated at 5-pump mode. The level III flood stages at control points 1, 2, 3 are used as trigger levels for pumping operation.

The target of Ngu Kien station is to reduce water level at control points 1, 2, 3 to below +7.82 m, +7.24 m, +7.16 m repectively; the target of Nguyet Duc station, incorporate with the operation of culverts in drainage areas 2 and 3, is to keep water level at control point 4 lesser than +6.94 m.

The regulations for operating drainage network are determined based on the flooding event in 1978 with rainfall distribution pattern of October 1978. Based on the changes in water level – discharge in the river system and at 6 control points, appropriate pumping operation and regulation were set out. Diagram of drainage system operation in this dissertation is presented in Figure 4.2.

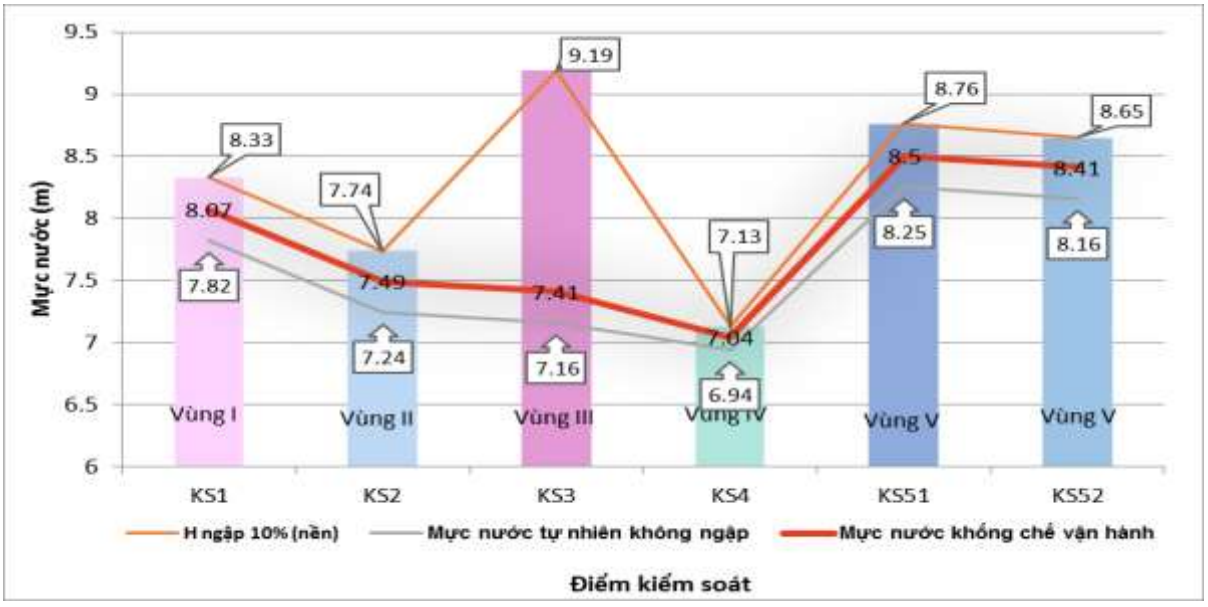

Figure 4.2. Operational targets of drainage network on PCL basin

Drainage network operation (Figure 4.3)

When the water level at control points 1, 2, 3 start to increase, water level at control points 4 and 5 fluctuate in the range of ± 25 cm around the level of +8.25 m and +8.16 m in 2 hours, Ngu Kien station must be operated at full capacity of 100 m^3/s and Nguyet Duc station must be prepared to start.

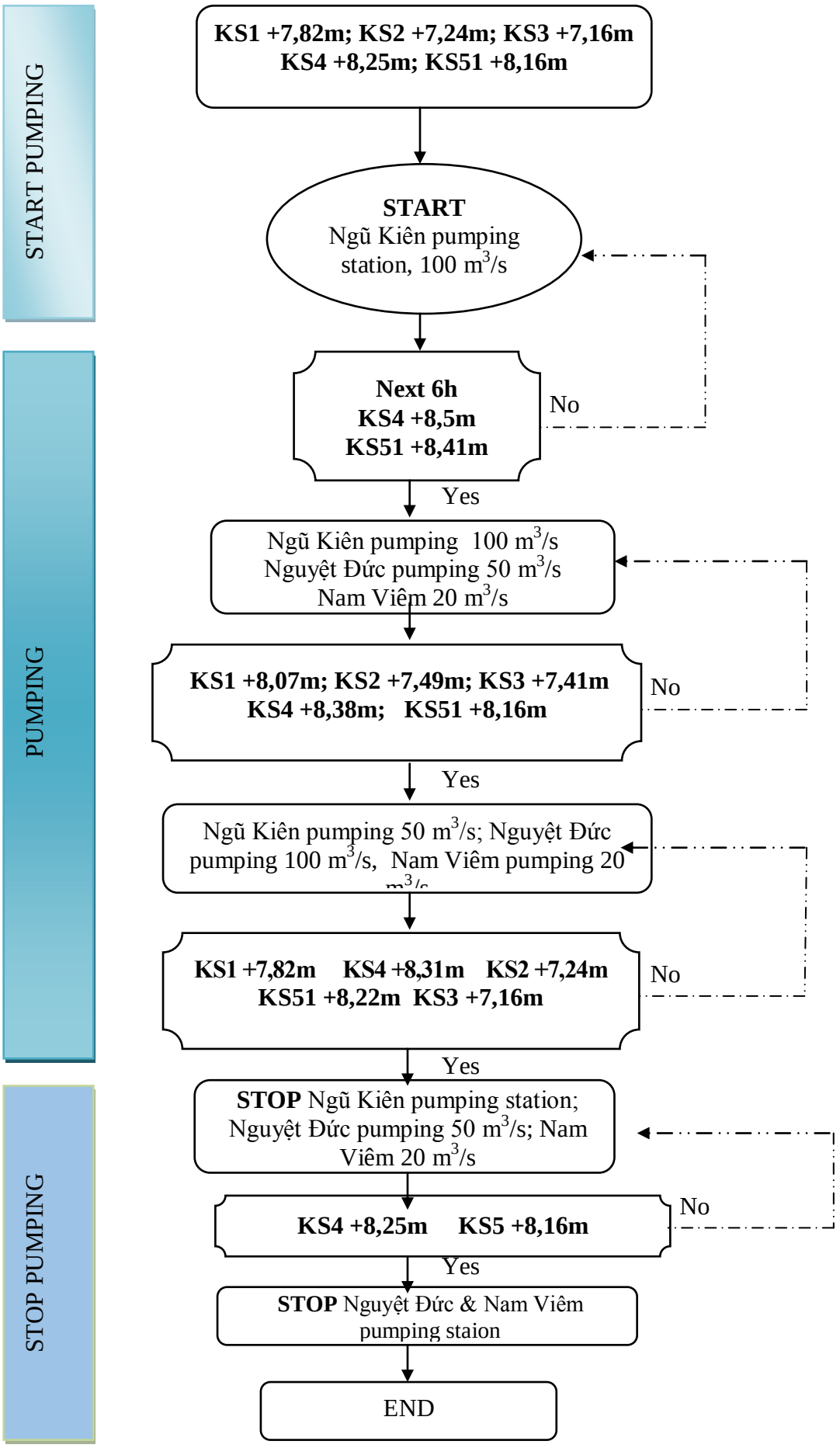

Figure 4.3. Diagram of flood drainage operation in PCL basin

In the next 6 hours, when water level at control points 4, 5 pass +8.25 m, +8.16 m and và continue to pass the level of +8.5 m và +8.4 m repectively, start pumping at Nguyet Duc station with the rate of 100 m^3/s (5 pumps).

When water level at control points 4, 5 reduce to +8.38 m and +8.16 m, and +8.07 m, +7.49 m, +7.41 m at 1, 2, 3 control points, reduce Ngu Kien station pumping rate to 50 m^3/s, maintain the pumping rate of Nguyet Duc station at 100 m^3/s.

Ngu Kien station stops pumping when water level at control points 1, 2, 3 reduce to below +7.82 m, +7.24 m, +7.16 m repectively.

Nguyet Duc station reduces pumping rate to 50 m^3/s when water level at control points 1, 2, 3, 4, 5 reduce to +7.82 m, +7.24 m, +7.16 m, +8.31 m, +8.22 m and stops pumping when water level at control points 4, 5 reduce to +8.25 m and +8.16 m.

The puping operation in 3 days should not be longer than 18 hours/station in total, and 8 hours/station under full capacity operating condition. This regulation is besed on economic and technical requirements in accordance to the management situation in the basin.

4.5. Chapter 4 conclusions

On the basis of selected drainage schemes in chapter 3, the dissertation has successfully proposed flood drainage measures for Phan – Ca Lo river and 5 specific drainage areas under flooding condition corresponding to flood event in 1978. The measures include structural and non-structural measures as follow:

- Structural measures: This dissertation has calculated the specifications of improved works (diverting and dredging), upgraded structures (regulating culverts), and new constructions (Ngu Kien and Nguyet Duc pumping stations);

- Non-structural measures:

+ Proposing the control system of 6 control points for 5 drainage areas, serving the monitoring of water level, the management and operation of drainage network in Phan Ca Lo river basin;

+ Based on the drainage requirements, combined with 4 selected drainage schemes, this dissertation has proposed regulations for drainage operation: Tracking changes in water level at 6 control points, then selecting the method of operation for the structure system. The proposed mechanism of operation includes: Identifying warning time, pumping time, pumping restrictions,

coordinated operation of the drainage system for specific drainage areas and the entire PCL river basin

CONCLUSIONS AND RECOMMENDATIONS

1. Main contents of dissertation

1) Overview of the current drainage situation; causes of flooding and solutions for flood drainage in the world and in Vietnam; simultaneously analyze of the causes of flooding in the basin as well as priod related researches.

2) Propose an effective and feasible drainage solution for Phan - Ca Lo river basin. The dissertation proposes operation for Ngu Kien, Nguyet Duc pumping stations and 2 regulating culverts, which are capable to drain 83% of the 1978 flood.

3) Propose operational procedures for flood drainage in the case of historical flood in 1978 as the basis for planning the overall flood protection for Phan- Ca Lo river.

4) Propose a system of control points for flood warning and forecasting, which serves as an important basis for coordination of flood drainage in the basin.

2. Development direction and recommendations

a. Development direction:

- Research and evaluate the effectiveness of economic and social environment;

- The local authorities should discuss with the community to achieve high consensus on the plans of diverting, reallocating and building new drainage works.

- Planning protection corridor for drainage works and water resources to ensure the socio-economic security along the river, as well as to serve the flood drainage effectively.

b. Reccomendations:

1. Supplement the meteo-hydrological monitoring network, construct at least 3 new gauges in areas III, IV and V; restore the hydrological station at Phu Cuong.

2. Regularly allocate funds to operate water resources monitoring network at the above locations and at 5 control points to gather information and data serving the flood warning and forecasting for operating the drainage system in the PCL river basin.

LIST OF AUTHOR'S PUBLICATIONS RELATED TO THESIS

[1] Hoang Thi Nguyet Minh, *Some Issues on Status of Food Drainage in the Phan – Ca Lo River basin*, Scientific and Technical Hydro – Meteorology Journal, No. 585, Sep/2009, pp. 34 – 39.

[2] Hoang Thi Nguyet Minh, *Rainfall runoff simulation in the Phan – Ca Lo River basin*, Scientific and Technical Hydro – Meteorology Journal, No. 587, Nov - 2009, pp. 28 – 35.

[3] Hoang Thi Nguyet Minh, *Zoning Water Drainge for Phan – Ca Lo River basin*, Scientific and Technical Hydro – Meteorology Journal, No. 623, Nov - 2012, pp. 22 – 26.

[4] Hoang Thi Nguyet Minh, *Applying mathematic models to compute urban flow for Vinh Yen city*, Scientific and Technical Hydro – Meteorology Journal, No. 625, Jan - 2009, pp. 21 – 25.