第 49 卷 第 4 期 湖南大学学报（自然科学版） Vol. 49 No. 4
2022 年 4 月 Journal of Hunan University (Natural Sciences） April 2022

Open Access Article https://doi.org/10.55463/issn.1674-2974.49.4.33

Determining the Rational Dimension of Thoa River to Ensure Drainage during the Crop Period Considering Climate Changes

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Abstract: The major Thoa river is located in Mo-Duc and Duc-Pho districts. It originates from the Ve river to the My-A estuary. Aiming to protect crops of the hollow region of the Thoa river system, many canals and hydraulic works were built for irrigation and drainage, preventing saline intrusion from Bau-Sung to My-A estuary. However, this hollow region is often experienced inundation during the crop period because of heavy rain, especially under climate change conditions, a flood that results from water depression caused by a narrow river, bendy reaches, and strongly tidal influence downstream: My-A estuary. On the other hand, flooding overflow from other places: Ve river, other valleys, waterlogging, concentrates in this region. So, it is very difficult to drainage. In this paper, the authors find the effective schema of the Thoa river system for drainage during the crop period. Then they apply the HEC-RAS model to find out the specific and reasonable dimensions of the cross-section of the major Thoa river to drain during the crop period for protection of the crops of the hollow regions of the Thoa river system under the influence of climate change.

Keywords: Thoa river system, drainage, hollow regions, flood, crop protection, climate change.

在考虑气候变化的情况下确定托阿河的合理尺寸以确保作物期间的排水

摘要：主要的托阿河位于莫杜克和德普区。它起源于维河到妙河口。为了保护托阿河流系统中空地区的农作物，修建了许多运河和水利工程用于灌溉和排水，防止从包松到妙河口的盐水侵入。然而，由于大雨，这个中空区域在作物期间经常被淹没，特别是在气候变化条件下，由于河流狭窄、河段弯曲和下游强烈潮汐影响造成的水洼导致洪水：妙河口.另一方面，洪水从其他地方溢出：维河，其他山谷，内涝，集中在这个地区。因此，排水非常困难。在本文中，作者找到了在丰收期使用托阿河流系统进行排水的有效方案。然后，他们应用水文工程中心/河流分析系统模型，找出在丰收期排水的主要托阿河流断面的具体合理尺寸，以保护托阿河流系统空心地区的农作物。在气候变化的影响下。

关键词：托阿河流系统、排水系统、空心地区、洪水、作物保护、气候变化.

1. Introduction

Thoa river system is originally a canal system from Ve river to My-A estuary, used for irrigation and drainage Mo-Duc (south of Ve river) and Duc-Pho (north of Tra-Cau stream) fields in Quang Ngai prefecture. It is located from $14^0 50'$ to $15^0 00'$ North latitudes and from $108^0 52'$ to $109^0 00'$ East longitude [1].

Nowadays, it becomes a reach of the Ve river, with a catchment area of 157 km^2 and a major river length of nearly 34 km from the Ve river to My-A estuary. Along the Thoa river, on the right, there are numerous tributaries: Ben stream, Phuoc-Dien stream, Ba-Hung stream, Nuoc-Man stream, Tra-Cau stream (Fig. 1, 2, 3) [1].

For irrigation and drainage in the region, many

Received: February 25, 2022 / Revised: March 21, 2022 / Accepted: March 23, 2022 / Published: April 30, 2022

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hydraulic structures are constructed on the Thoa river system for multi-purpose: Rising water levels and saline prevention. However, there are many hollow regions in the Thoa river system basin. Strong tides influence its downstream. Water from the Ve river flows into the Thoa river system as a big water source at its upstream river. On the other hand, along the major Thoa river, there are many small stream junctions, so waterlogging mostly occurs in heavy rains in dry and early or late rainy seasons.

Besides, the narrow cross-section, sediment deposition, torture of the river, and vegetations in the Thoa river cause a remarkable reduction in drainage discharge [1–13].

In this paper, the authors calculate the flow in the actual state of the Thoa river system to determine its discharge and water level along the major Thoa river corresponding to heavy rain in dry seasons, early or late rainy seasons during climate change conditions [1, 2, 14-17]. Depending on these results, the authors look for a solution to waterlogging and flooding mitigation to protect crops of the hollow region of the Thoa river basin. They also seek a suitable scenario and solution for drainage plan and locating hydraulic structures on the Thoa river system for designing the dimension of the major Thoa river.

2. Characteristics of Hydrometeorology

In the Thoa river basin, the rainy season occurs from September to December (occupying 75 ÷ 80%) of the year's total rainfall. Approximately (45 ÷ 60) % of this amount is concentrated in September and October.

Table 1 Flood occurrence period of the year

No	Classification	Time occurrence
1	Flood in the dry season	From May to June
2	Flood in the early rainy season	Late of August to 15 September
3	Flood in the rainy season	From September 20 to December 15
4	Flood in the late rainy season	From December 16 to late January of next year

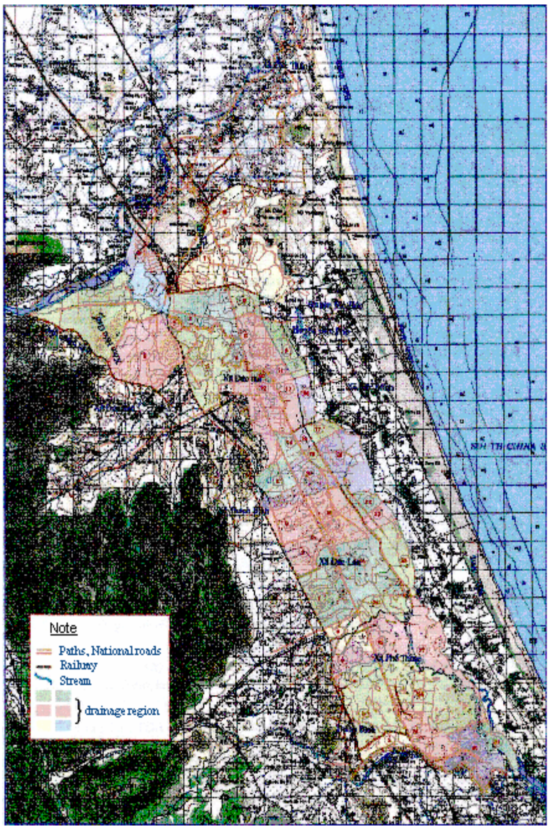


Fig. 1 Map of mark off into drainage regions of Thoa river system

The dry season lasts annually from January to August; the rain in the dry season occurs from May to June. There is little rainfall in the Thoa river basin in Quang-Ngai province; the mean annual rainfall is less than 2000 mm. The historically maximum daily rainfall in Quang-Ngai province, Mo-Duc, and Duc- Pho district is 525 mm, 373 mm, and 299 mm. The continuously rainy days often last less than 4 days; the discontinuous ones from 10 to 41 days in the Mo-Duc district and from 10 to 37.3 days in the Duc-Pho district [1, 2, 11-13].

Table 2 Crop rotation plan in the interest site

Crop time	Crop of Winter - Spring	Crop of Summer - Autumn
Start time of crop	25 Nov ÷ 15 Dec	Late May
Time of harvest	25 Mar ÷ 15 Apr	Early September

Table 3 Results Qmax (m3/s) of peak discharge of small streams in Thoa river basin with frequency correspondent to p = 10% or p = 20%

Stream basin	Crop of Winter - Spring		Crop of Summer - Autumn		Crop of Summer - Autumn		Crop of Summer - Autumn	
	10%	20%	10%	20%	10%	20%	10%	20%
Phuoc-Dien	156	127.8	15.2	11.1	32.9	26.0	27.4	22.2
Ben	215	176.2	20.9	15.3	45.3	35.8	37.8	30.6
Ba-Hung	307	251.6	29.8	21.8	64.7	51.2	54	43.7
Nuoc-Man	186	152.4	18.1	13.2	39.2	31.0	32.7	26.5

Table 4 Maximum water level (metre) in An-Chi (Ben-Thoc) station with corresponding frequency p = 10%, 20%

Stream basin	Crop of Winter - Spring		Crop of Summer - Autumn		Crop of Summer - Autumn		Crop of Summer - Autumn	
	10%	20%	10%	20%	10%	20%	10%	20%
Phuoc-Dien	156	127.8	15.2	11.1	32.9	26.0	27.4	22.2
Ben	215	176.2	20.9	15.3	45.3	35.8	37.8	30.6
Ba-Hung	307	251.6	29.8	21.8	64.7	51.2	54	43.7
Nuoc-Man	186	152.4	18.1	13.2	39.2	31.0	32.7	26.5

2.1. Climate Change Scenarios

According to the Ministry of Natural Resources and Environment [17], the climate change scenario corresponding to the most unfavorable scenario for drainage in the study area is the high scenario RCP 8.5.

Table 5 The variation of temperature and monthly rainfall in the RCP 8.5 scenario during the 2016 – 2035 period (Climate change scenarios [17])

Factor/Season	Winter (12÷2)	Spring (3÷5)	Summer (6÷8)	Autumn (9÷11)
Rainfall (%)	5.8	-5.4	18.4	23.5
Temperature	0.8	0.8	0.9	0.8

2.2. Computational Drainage from Rainfall

The data used for calculation was obtained from Mo-Duc hydro-meteorological station from 1977 to 2011 [1, 2]. Applying data analysis and statistics, we have:

- Almost maximum short-interval rainfall is embedded in maximum long-interval rainfall (i.e., maximum 1-day-duration rainfall is embedded in that of 3-day-duration, and in turn, that of 3-day-duration is embedded in 5-day-duration). That is true for all three periods: the dry season, the early rainy season, and the late one;
- The total amount of rainfall during 7 days increases very little in comparison with that of 5 days; therefore, Hung et al. [1] propose using the rainfall during 5 days to calculate the drainage in the Thoa river basin;
- The field investigation approach reveals the particular drainage subregions along the two banks of the Thoa river from the junction CauDap – Song Thoa to My-A estuary, showing a distance of 1 km wide approximately. Hence, the rainfall in one day in that area completely runs off to the Thoa river on that day (Fig. 1).

So, in this one subregion, the authors account for a 1-day-duration rainfall for calculation.

Table 6 Maximum rainfall (mm) of many stages according to frequency 10% and 20% - Not consider climate change conditions

Period of time	P = 10%			P = 20%		
	Flood in summer	Early flood in the rainy season	Late flood in the rainy season	Flood in summer	Early flood in the rainy season	Late flood in the rainy season
1 day (X1 max)	101.9	170	135.7	66.0	114	83.8
3 days (X3 max)	196.0	296.0	223	101	175	136
5 days (X5 max)	205.0	325.0	261	112	195	158

Table 7 Maximum rainfall (mm) of many stages according to frequency 10% and 20% - Consider climate change conditions

Period of time	P = 10%			P = 20%		
	Flood in summer	Early flood in the rainy season	Late flood in the rainy season	Flood in summer	Early flood in the rainy season	Late flood in the rainy season
1 day (X1 max)	96.4	201.3	167.6	62.4	135.0	103.5
3 days (X3 max)	185.4	350.5	275.4	95.5	207.2	168.0
5 days (X5 max)	193.9	384.8	322.3	106.0	230.9	195.1

2.3. Measure Flooding Drainage at the Interest Site

Using the field investigation method in combination with topography's survey of the Thoa river basin, inheriting the available results; this subject suggests a diagram for drainage and proposes two general measures for draining the flood for the hollow region of the Thoa river:

Scenario 1: Enlargement (by dredging), training Thoa river (straightening), constructing flood control dike, and widening the major canal of Thoa river system from junction Thoa river – Bau Sung to My-A estuary; in this scenario, the flood discharge only flows into the canal.

Scenario 2: Enlargement (by dredging), training Thoa river (straightening), and widening the main canal of Thoa river system from junction Thoa river system to My-A estuary; the flood flow can occur overland in the hollow region of Thoa river.

2.4. Applying HEC-RAS Software for Calculating Flood Flow–Drainage for the Hollow Region along the Main Thoa River

HEC-RAS is a free software for US Army solving one-dimensional & quasi-two-dimensional Saint-Venant equations, flooding plains as reservoirs that connect to the river by hydraulic structures [18].

2.5. The Governing Equations

Continuing equation:

$$\frac{\partial A}{\partial t}+\frac{\partial S}{\partial t}+\frac{\partial Q}{\partial x}-q_l=0 \quad (1)$$

Momentum equation

$$\frac{\partial Q}{\partial t}+\frac{\partial (VQ)}{\partial x}+gA\left(\frac{\partial H}{\partial x}+S_f\right)=0 \quad (2)$$

where x is longitudinal coordinate, H is water level, t is time, Q is discharged, A is an area of the main cross-section, S is an area of the flood plain, q_l is lateral discharge per unit length, g is an acceleration of gravity, S_f is a frictional slope, v is velocity.

2.6. Boundary Conditions

a. Internal boundary (at a junction):

* Continuing on discharge:

$$\sum_{i=1}^{l} S_{gi}Q_i=0 \quad (3)$$

Total discharge Q_i at junction equal zero; S_{gi} = 1, if inflow; and S_{gi} = -1 if outflow.

* Continuing on the water surface:

HK = HC (4)

The water level of all cross-sections at the junction is assumed to equal HK = HC.

b. Upstream boundary conditions:

Giving discharge or water level Q(t), H(t), or relation between discharge and water level Q(H).

c. Downstream boundary conditions:

Giving H(t) for boundaries that connect with estuary (Stage hydrograph).

2.7. Initial Conditions

Discharge and water level Q, H at all cross-sections of reachs are considered.

2.8. Reasonable Documents for Designing

In accordance with TCXD Vietnam 285:2002, the dimension of drainage project of the hollow region of the Thoa river system–with the plain is about 5000 ha (in the range 2000 ÷ 10000 ha), so this work is ranked III, frequency of drainage is p = 10%;

However, for convenience in comparative scenarios, the authors have also chosen the drainage frequency as p=20% [1].

In this document, one can see:

• Map of full Thoa river basin, scale: 1/25.000;

• Document on hydraulic structures in the Thoa river system;

• Document on cross-section, profile-section of Thoa river system;

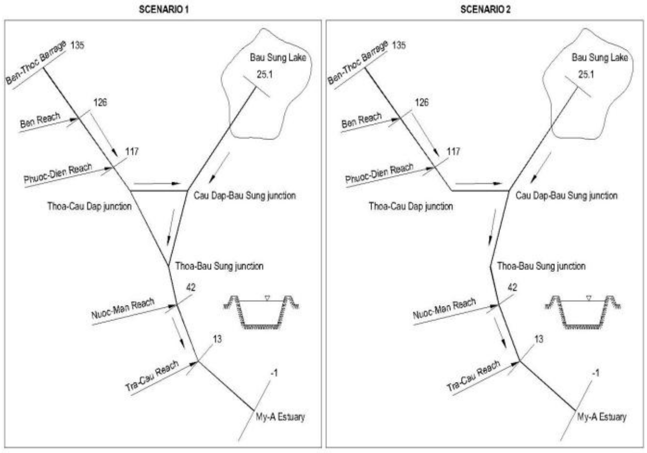
• Data on hydrometeorology.

2.9. Schemata on the Thoa River System

Schema on stretching hydraulics symbolizes the Thoa river system. There are 2 schemata for comparison: Schema 1 and Schema 2 (Fig. 2).

Schema 1 (Fig. 2a): Schema on computational hydraulics with the actual state of Thoa river system having reach: Thoa- Cau Dap junction and Thoa-Bau Sung junction.

Schema 2 (Fig. 2b): Schema on computational hydraulics with the actual state but without reach: Thoa-CauDap junction and Thoa-BauSung junction.



(a) (b)

Fig. 2 (a) Schema 1 on stretching hydraulics symbolizes the Thoa river system; (b) Schema 2 on stretching hydraulics symbolizes the Thoa river system

According to [1], schema 2 has more advantages than schema 1; so in this paper. The authors choose schema 2 for calculations.

2.10. Case Study

2.10.1. Computation of Actual State Flow of Flood in December 1999

Purpose: For model calibration.

The authors choose the late flood that happened in December 1999 had a rainfall of approximately 10% to calibrate the model.

Boundary conditions: Upstream boundary conditions:

Ben Thoc gate gives stage H(t), and Bau Sung gives discharge Q(t).

Downstream boundary conditions: Give H(t) at My-A estuary (Fig. 3).

Many tributary flows Q(t) contribute to the major Thoa river: Ben stream, Phuoc-Dien stream, Ba-Hung stream, Nuoc-Man stream, Tra-Cau stream (Fig. 4).

Boundary conditions corresponding to the frequency of 10% and 20% are given in fig. 5-6.

Many tributaries Q(t) contribute to the main Thoa river of flood in the dry season corresponding with frequency p = 10%, 20%, given in Fig. 7-11.Results of water surface profile along the Thoa river of actual state from Ben-Thoc gate to My-A estuary correspond with flood's frequency 10%, 20% as in Fig. 11.

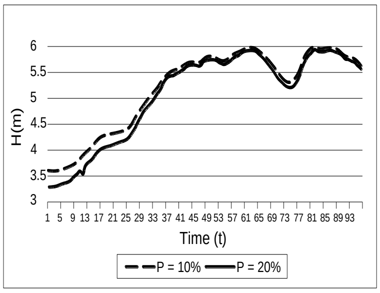


Fig. 3 Water level hydrographs H(t) at Ben-Thoc gate of flood in dry season corresponding with frequency p = 10%, 20%

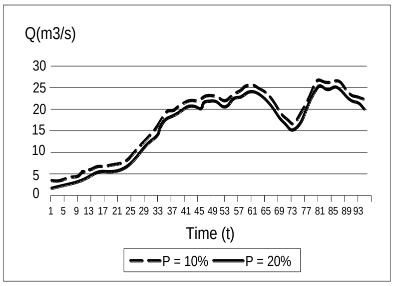


Fig. 4 Flood discharge hydrographs Q(t) at Bau-Sung of flood in dry season corresponding with frequency p = 10%, 20%

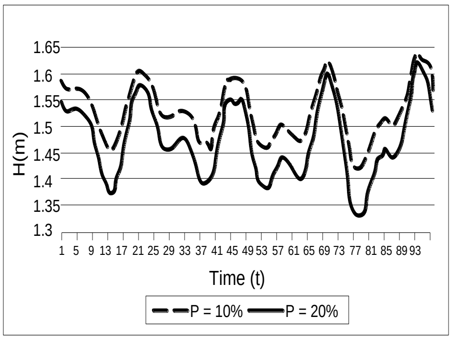


Fig. 5 Tidal water level hydrographs H(t) at My-A estuary of flood in dry season corresponding with frequency p = 10%, 20%

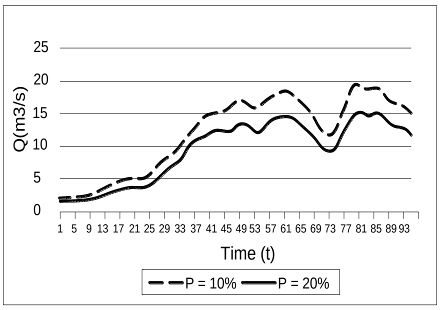


Fig. 6 Flood discharge hydrographs Q(t) of Ben stream in the dry season which joins the Thoa river corresponding with frequency p = 10%, 20%

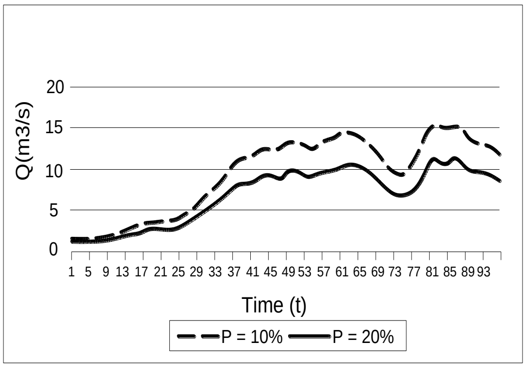


Fig. 7 Flood discharge hydrographs Q(t) of Phuoc-Dien stream in the dry season, which joins the Thoa river corresponding with frequency p = 10%, 20%

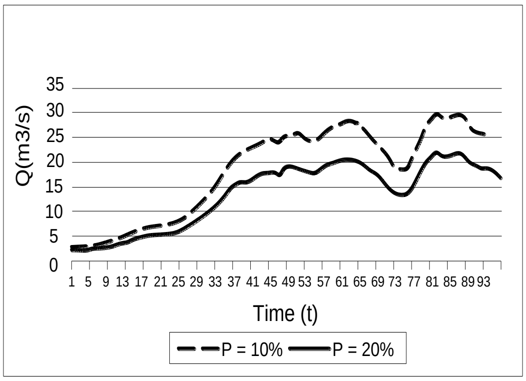


Fig. 8 Flood discharge Q(t) hydrographs of Ba-Hung stream in the dry season, which joins the Thoa river corresponding with the frequency p = 10%, 20%

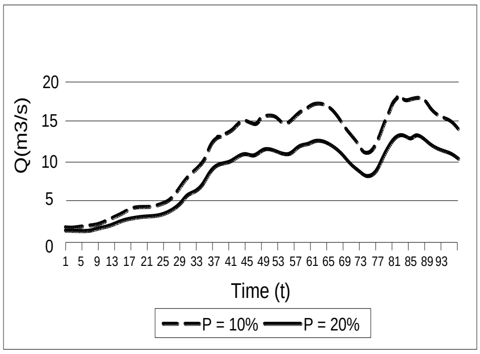


Fig. 9 Discharge hydrographs Q(t) of Nuoc-Man stream in the dry season, which joins the Thoa river corresponding with frequency p = 10%, 20%

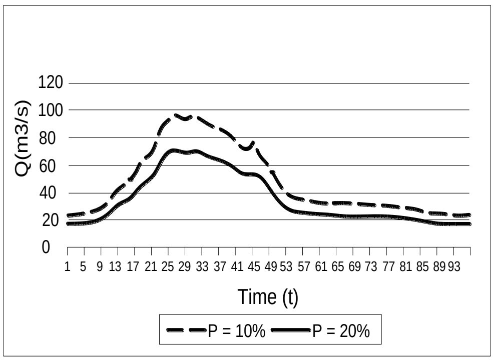


Fig. 10 Discharge hydrographs Q(t) of Tra-Cau stream in the dry season, which joins the Thoa river corresponding with frequency p = 10%, 20%

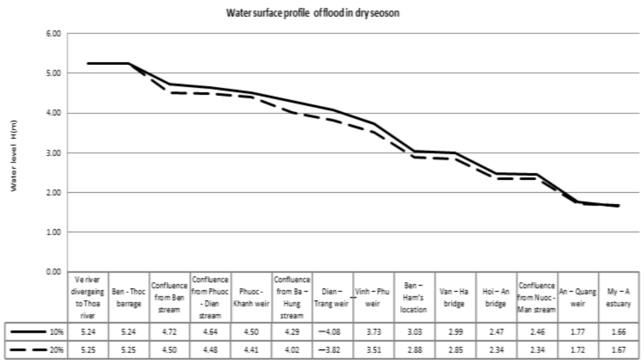


Fig. 11 Water surface profile's results H(t) of flood in the dry season which correspond with flood frequency p = 10% and 20%; case of study: Actual state of Thoa river system

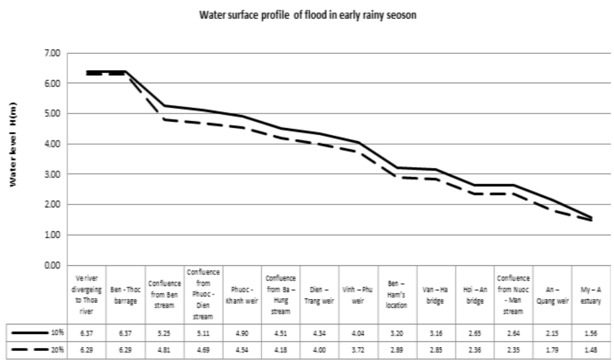


Fig. 12 Water surface profile's results H(t) of flood in the early rainy season, which corresponds with flood frequency p = 10% and 20%, case of study: Actual state of Thoa river system

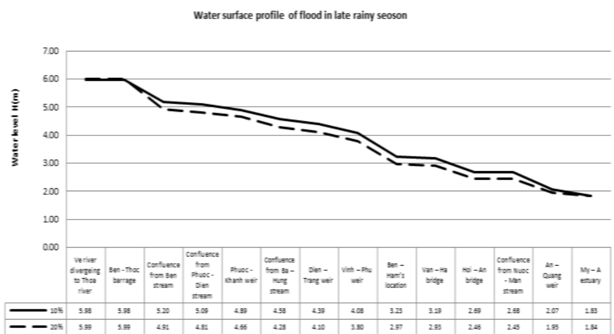


Fig. 13 Water surface profile's results H(t) of flood in the late rainy season, which corresponds with flood frequency p = 10% and 20%, case study: Actual state of Thoa river system

2.11. Scenarios on Dredging, Training, and Widening the Major Thoa River System

There are two study cases:

Case Study 1: Non-drop or non-cascade on major Thoa river;

Case Study 2: Drop or cascade on major Thoa river.

The longitudinal profile of the major Thoa river topography has not changed suddenly, so the authors only study case 1: Non-drop or non-cascade on the major Thoa river.

Authors only determine the dimension of the major Thoa river: From junction Thoa - CauDap to My-A estuary

Late flood in the rainy season has maximum flooding area, flooding depth, and flooding time, so the authors choose this one for designing the major Thoa river [1, 2].

For selecting the optimal scenario for the enlarged design of the major Thoa river; there are two scenarios to be chosen:

- Enlargement of the major Thoa river-bed and combination with embankment;
- Enlargement of the major Thoa river-bed and permission on flooding plain.

2.11.1. Enlargement of the Major Thoa River-Bed and Combination with Embankment, Scenario 1 (PA1)

With the scenario, The Thoa river-bed is expanded for flood flowing only in the major Thoa river, and the maximum water level is not as high as the code of embankments.

Strengths: The rice field is not flooding, so it is not needed to calculate the relationship between the drainage time and the bearable flooding possibility of rice.

Weak points: Increasing the width of the Thoa river-bed, so decreasing the land of rice fields; Increasing the cost of embankments and bridges, culverts, and loss of silts.

Table 8 Brief recap of cross-section's results of major Thoa river, scenario PA1, p = 10%

No	Cross section's name	Bed width of major Thoa river B(m)	Depth H(m)	Side slope (m)	Code of Thoa river-bed Z(m)	Note
1	6	34	4.39	3	-0.37	Junction Cau Dap-Bau Sung
2	5	36	3.75	3	-0.5	Junction Thoa river -Bau Sung
3	4	32	3.69	3	-0.55	
4	3	33	2.81	3	-0.69	Junction Ba Hung stream–Thoa river
5	2	42	2.78	3	-1.2	Junction Nuoc Man stream–Thoa river

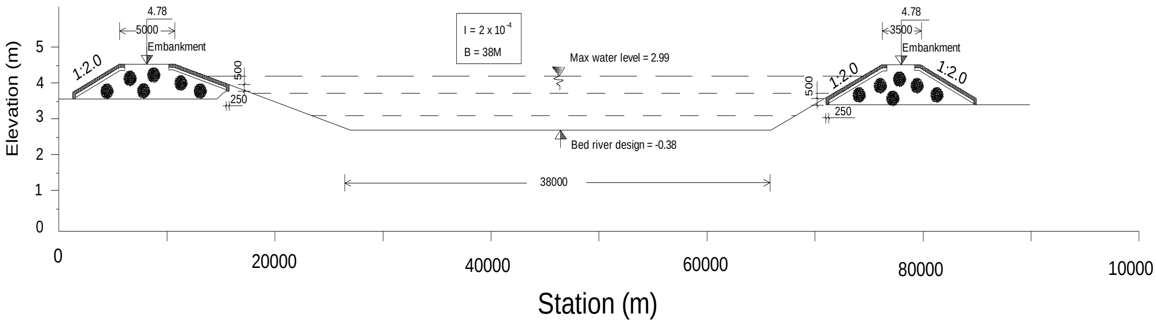


Fig. 14 Cross-section of major Thoa river – scenario PA1

2.11.2. Enlargement of the Major Thoa River-Bed and Permission of Flooding-Plain, Scenario 2 (PA2)

Strengths: Non-embankment, so decreasing the cost of embankments and bridges, of enlarged dig of the cross-section of major Thoa river and increasing rice fields; having a supplementary source of silt for rice fields.

Weak points: Rice fields are flooding, so it is needed to calculate the relationship between the drainage time and the bearable flooding possibility of rice.

In general, the bearable possibility of flooding rice is as follows:

- Flooding 1 day: Not exceeded 350 mm.
- Flooding 3 days: Not exceeded 250 mm.
- Flooding 5 days: Not exceeded 200 mm.
- Flooding 7 days: Not exceeded 150 mm.

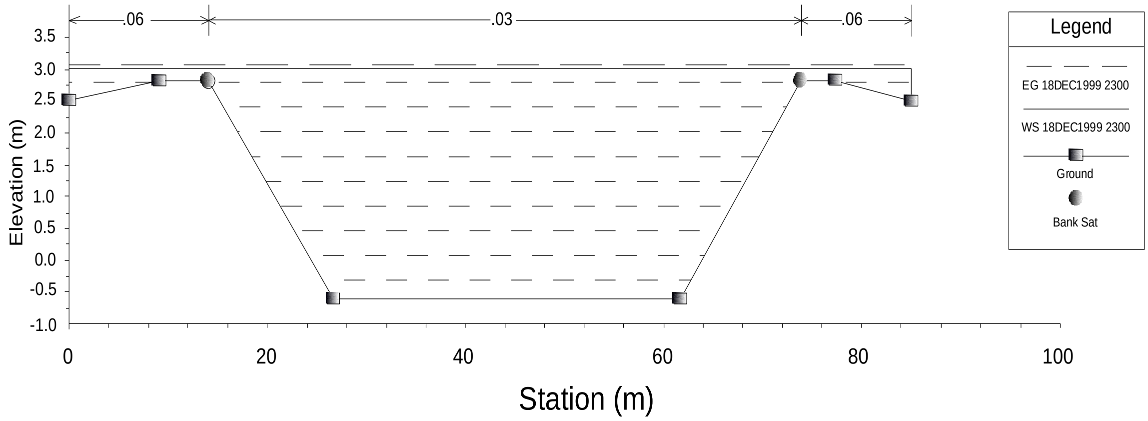


Fig. 15 Flood discharge hydrographs Q(t) of Phuoc-Dien stream in the dry season, which joins the Thoa river corresponding with frequency p = 10%, 20%

Table 9 Brief recap of cross-section's results of major Thoa river, scenario PA2, p = 10%

No	Cross section's name	Bed width of major Thoa river B(m)	Depth H(m)	Side slope (m)	Code of Thoa river-bed Z(m)	Note
1	6	32	4.55	3	-0.37	Junction Cau Dap-Bau Sung
2	5	34	3.97	3	-0.5	Junction Thoa river-Bau Sung
3	4	31	3.91	3	-0.55	
4	3	30	3.23	3	-0.69	Junction Ba Hung stream–Thoa river
5	2	35	3.2	3	-1.2	Junction Nuoc Man stream–Thoa river
6	1	31	1.76	3	-1.37	Junction Tra Cau stream–Thoa river
7	0.5	46	1.68	2.5	-1.49	Downstream of Thoa river-My A estuary
8	6	32	4.55	3	-0.37	

2.12. Results of Dimension of Major Thoa River Corresponding with Frequency $P_{10\%}$, Considering Climate Change until 2035

Scenario 1: The average water depth increases from 2 cm to 18 cm depending on the cross-section; compared to the case without considering climate change;

Scenario 2: The average water depth increases from 3 cm to 20 cm depending on the cross-section, compared to the case without considering the average climate change.

Table 10 Relief table on comparison of designed computational results of the major Thoa river cross-section with two scenarios PA1, PA2, frequencies P = 10%

No	Cross section's name	Bed width of major Thoa river (m), $P_{10\%}$		Width's difference ΔB (m) $P_{10\%}$
		PA1 (B_1)	PA2 (B_2)	ΔB= B2 –B1
1	6	34	32	2
2	5	36	34	2
3	4	32	31	1
4	3	33	30	3
5	2	42	35	7
6	1	32	31	1
7	0.5	47	46	1
8	0	52	50	2

2.13. Remarks

Scenario PA1 has a water surface of the major Thoa river much more than that of scenario PA2, so the water depth in the drainage canal is large, requiring filling and reinforcing the dyke. As a result, the construction cost would be enormous (Table 10).

With Scenario PA2, due to flooding over the riverbanks, the flow depth of the floodplain is small and lasts for a short time, so it does not affect the plants considerably; so the cost of hydraulic structures of scenario PA2 will be smaller than PA1.

So, we suggest choosing the scenario PA2 for designing the major Thoa river.

Table 9 illustrates the design calculation results of the major Thoa river.

3. Conclusions and Recommendations

3.1. Conclusions

Authors have applied HEC-RAS software to calculate the flood in the hollow region of the Thoa river basin and choose the efficiency schema (Schema 2, Fig. 3) for the Thoa river system.

Authors have selected the effective scenario PA2 on dredging, training, and widening the major Thoa river for drainage during the crop period following frequency $P_{10\%}$, $P_{20\%}$;

Designating the cross-section of the major Thoa river for scenario PA2 which permits the enlargement of the major Thoa river-bed and permission of flooding plain (Fig. 15, Table 9)

The climate change until 2035 (RCP 8.5 scenario) has been calculated and considered in the basin, which indicates that it is more reasonable to design a dredging section of the major Thoa river as scenario PA2. The increase in the cross-section of the major Thoa river has been calculated and given in Table 10.

3.2. Recommendations

The survey and measurement of water level and discharge of the Thoa river system are insufficient for calibrating the model in all case studies. On the other hand, the authors do not have conditions to survey all severe combinations for causing the flood damage of the hollow region of Thoa river catchment (i.e., Big discharge of Ve river, heavy rainfall of Thoa river system catchment, high tidal water level). Thus, for safety, authors have hypotheses that all severe combinations of the above factors simultaneously occurred.

The severe combinations here have a rare probability, so this scenario is perfectly satisfied.

During the next period, it is necessary to be surveyed and measure the water level and discharge along the Thoa river system to design the Thoa river system more exactly in detail.

For flooding drainage of flood in the dry season, as well as early and late one in the rainy season, barrage Ben-Thoc is the most important hydraulic structure to hinder the Ve river's flood which over-flows to the hollow region of Thoa river catchment; so, this barrage is the first prior hydraulic structure needed to improve or to construct a brand-new one;

For more efficient drainage of the hollow region of the Thoa river catchment, it is important to dredge and straighten the Thoa river system;

After carrying the project out, it is indispensable to dredge regularly to keep constant the designed cross-section of the main Thoa river;

In the local sub-hollow regions of the hollow region of the Thoa river system that one cannot drain flooding by gravity, it is vital to research a drainage scenario by pumping or converting crop plants structure for appropriate and sustainable development.

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