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Coastal and Marine Engineering and Management
CoMEM

THE MEKONG DELTAIC COAST: PAST, PRESENT AND FUTURE MORPHOLOGY

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Preface

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I also would like to thanks to the CoMEM girls Madelon, Inge and especially Mariette for always being there and helping me.

Finally I would like to thank my family and friends and especially my boyfriend Truong Hong Son for all of the time we've been through together.

Summary

This study focuses on the sustainable development of the Mekong Delta Viet Nam in two regions including: the Mekong Delta Estuaries and the Mekong Delta Coast.

The MD Estuaries play an important role in flood relief, water transportation, water management and land reclamation; however they are also the root of serious problems such as salinity intrusion, tide propagation. The most important result found for the Mekong Delta Estuaries in this study is the empirical relationship between the tidal prism and the river cross-section:

$$A_c = 10^{-3} \langle P_{ebb} \rangle^{0.86} = 5.39 \langle Q \rangle^{0.86}$$

Based on this equation, the MD Estuaries evolution in the future can be estimated. According to the future development plan, discharge sluices will be constructed at three main branches of Tien River to prevent salinity intrusion. The two open branches of Tien River will therefore deepen by more than 10 meters. Thus, mangroves along the river bank of these two branches should be strengthened in order to prevent river bank erosion.

Due to the need of land for agriculture and other economic sectors, sea dikes are always built close to the mangroves forest. Along the Southern Coast of Viet Nam there are many places where mangrove degradations and coastline erosions are observed on a large scale when sea dikes are built too close to the mangroves forests. However there are no investigations to estimate the required distance from the sea dike to the outer edge of the mangroves forest to ensure the normal development of mangroves. Based on the coastline evolution from 1965 to 2002, the relationship between mangrove forests width and the rate of coastline erosion or sedimentation was created for the East Coast of Viet Nam. According to this relationship, the critical value of 300 to 400 meters of mangroves width is found necessary for the stability of the East Coast. It means that to ensure the sustainable development of the coastline, the distance from the outer edge of mangrove forests to the constructed sea dikes must be at least 300 to 400 meters. Results from the SWAN wave model also show that mangroves have a significant effect only at cross-shore widths greater than 300 to 400 m and that an increase in width beyond 1000 m does not make much of difference.

Table of Contents

Non-technical summary i
Table of Contents ii
Figures iv
Tables vi
Terminology vii
1. Introduction 1
  1.1. Purpose and scope of the study 1
  1.2. Research objectives and research questions 2
  1.3. Methodology 3
2. System characteristics 4
  2.1. Natural characteristics and hydrological characteristics of the MD 4
    2.1.1. Topography and the River system 4
    2.1.2. Climatic 5
    2.1.2. Wind, wave and storm 6
    2.1.3. Tidal characteristics 8
    2.1.4. Sediment 9
  2.2. Human interventions 11
    2.2.1. Status of constructions at MD 11
    2.2.2. Dams construction in the upper stream of Mekong River and its influence 15
  2.3. Coastal classification 17
3. Mekong Delta Estuaries 20
  3.1. Framework 20
  3.2. Input data 21
    3.2.1 River cross-section 21
    3.2.2. River discharge 21
  3.3. Empirical relationship 22
    3.3.1. First approach 22
    3.3.2. Second approach 23
    3.3.3. Result and evaluation 24
  3.4. Impact of closing down river branches 27

3.5. River bank erosion 29

4. Mekong Delta Coast 34

4.1. Mangroves degradation in relation to the distance from the sea dike to the outer edge of the mangroves forest. 35

4.1.1. Coastal evolution 35

4.1.2. Relationship of mangroves forest width and coastline evolution 40

4.2. Wave attenuation in relation to mangroves width along the East Coast 46

4.2.1. SWAN model 46

4.2.2. Mangroves characteristic 47

4.2.3. Soc Trang case study 50

4.2.4. Result and evaluation 53

4.3. Applying mangroves in sustainable development for protecting the coastline 57

5. Conclusions and recommendations 61

5.1. Conclusions 61

5.1.1. Mekong Delta Estuaries 61

5.1.2. Mekong Delta Coast 62

5.2. Recommendations 62

6. ANNEX 64

Annex 2.1. Natural characteristic maps 65

Annex 2.2. Wave data 67

Annex 2.3. Flooding and Salinity intrusion in Mekong Delta Viet Nam 71

Annex 3.1. River discharge 76

Annex 3.2. Example of river cross-section calculation for Ham Luong branch 92

Annex 3.3. Empirical relationship between tidal prism & river cross-section calculation 96

Annex 3.4. Calculate the impact of closing down three main branches 99

Annex 3.5. Erosion and accretion status of the Mekong River in 2002 101

Annex 4.1: Mangroves in Vietnam: species, status, roles and influencing factors. 106

Annex 4.2: Previous research of MD evolution 111

Annex 4.3: SWAN input parameters 113

Annex 4.4. Sample of SWAN input file 115

Bibliography 116

Figures

Figure 1.1: Location of the Mekong River Delta. 1
Figure 2.1: The Mekong River in Viet Nam and its branches (Nguyen Anh Duc 2008) 5
Figure 2.2: Wind rose at Bach Ho station (Hoang Van Huan 2006). 6
Figure 2.3: Monthly offshore wave parameters at Bach Ho station (Hoang Van Huan 2006). . 7
Figure 2.4: Tidal levels at Vung Tau station from 2007 to 2009 (SIWRR 2010b). 9
Figure 2.5: Sediment distribution from 1987 to 2002 at downstream of the Mekong River (Mekong committee) 9
Figure 2.6: Sediment characteristic 10
Figure 2.7: Location of existing construction of the MDV (SIWRR 2010a) 12
Figure 2.8: Water works development plan for the Mekong Delta (Deltares 2011) 14
Figure 2.9: Map showing China's cascade dams 15
Figure 2.10: Temporal changes in mean monthly sediment concentration at Tan Chau, Can Tho, and My Thuan station. 16
Figure 2.11: Sediment concentration variation along the Lower MR (Lu and Siew 2005). 16
Figure 2.12: Coastal morphology classification map of the Mekong River Delta 19
Figure 3.1: Flow discharges at Tan Chau and Chau Doc from 1/1996 to 12/2000 (Le Anh Tuan et al. 2007). 22
Figure 3.2: Empirical relationship of river cross-section and tidal prism for 5 branches of Tien River-first approach 24
Figure 3.3: Empirical relationship of river cross-section and tidal prism for 5 branches of Tien River-second approach 25
Figure 3.4: Empirical relationship of river cross-section and tidal prism for 7 branches of Tien River and Hau River – second approach 25
Figure 3.5: River depth increase after closing down branches 28
Figure 3.6: Maximum discharge at upstream and downstream of the MR in flood season and dry season 31
Figure 3.7: Erosion and deposition map of Dinh An branch in 2002 (SIWRR 2005b) 32
Figure 3.8: Cross-section at Dinh An branch 33
Figure 4.1: Mangrove forests at Cu Lao Duong and Go Cong (Google Earth 2012) 35
Figure 4.2: Coastline change from Vung Tau to Ben Tre (SIWRR 2005a) 37
Figure 4.3: Coastline change from Tra Vinh to Soc Trang (SIWRR 2005a). 38
Figure 4.4: Coastline change from Bac Lieu to Ca Mau (SIWRR 2005a) 38
Figure 4.5: Coastline change at Ca Mau (SIWRR 2005a) 39
Figure 4.6: Coastline change from Rach Gia to Ha Tien, Kien Giang province (SIWRR 2005a)40
Figure 4.7: The relationship between mangroves width and coastline evolution along the East Coast of the MDR 44
Figure 4.8: Failure case in planting mangroves along the River bank (Bob Ursem) 45

Figure 4.9: Mangrove tree height schematization followed in SWAN 40.55MOD (Burger 2005). 47
Figure 4.10: Natural succession of mangrove vegetation at Ca Mau Cape (Phan Nguyen Hong and Hoang Thi San 1993) 48
Figure 4.11: Mangrove root systems 49
Figure 4.12: Interpolated 1-D Bathymetry..........50
Figure 4.13: 1-D Wind profile..........52
Figure 4.14: Transmitted wave height offshore to wave height nearshore 53
Figure 4.15: Wave height attenuation due to bottom friction and vegetation dissipation 54
Figure 4.16: Wave attenuation as the function of Mangroves width; Offshore conditions: wave height 3m, wave period 7.9 s; Species Rhizophora..........55
Figure 4.17: Wave attenuation as the function of Mangroves width; Offshore conditions: wave height 7.2 m, wave period 9.7 s; Species Rhizophora 55
Figure 4.18: Wave attenuation as the function of Mangroves width; Offshore conditions: wave height 3m, wave period 7.9 s; Average Mangroves density 56
Figure 4.19: Relationship of mangroves to human intervention (sea dike) and coastal issues (coastal erosion and flooding) 57
Figure 4.20: Applying mangroves in coastline protection 59
Figure 6.1: Topographic elevation map of the Mekong Delta (Deltares 2011). 65
Figure 6.2: The distribution of annual rainfall (Quyet 2009). 66
Figure 6.3: Storm history of Vietnam (SIWRR 2010a). 66
Figure 6.4: Location of wave station along the East Coast (SIWRR 2010a) 69
Figure 6.5: Significant wave height measurement at near-shore stations (SIWRR 2010a).....69
Figure 6.6: Wave rose at near-shore stations (SIWRR 2010a)..........70
Figure 6.7: Three major water resource zones of the Mekong Delta (Le Anh Tuan et al. 2007). 71
Figure 6.8: Flood-prone and brackish areas in the Mekong Delta (Pham Cong Huu 2011). ...72
Figure 6.9: Salinity intrusion isolines in some dry years (Deltares 2011). 74
Figure 6.10: Maximum salinity intrusion from Jan to April due to sea level rise and climate change in the next 40 years (To Quang Toan et al. 2011) 75
Figure 6.11: River discharge observed at five branches of Tien River from 15/09/2009 to 30/09/2009 76
Figure 6.12: Erosion and deposition map of Tran De branch in 2002 (SIWRR 2005b)..........104
Figure 6.13: Erosion and deposition map of Ham Luong branch in 2002 (SIWRR 2005b) 105
Figure 6.14: Erosion and deposition map of Tieu branch in 2002 (SIWRR 2005b)..........105
Figure 6.15: Mangroves disappear during the period from 1953-1995 (Minh et al. 2011) ..108
Figure 6.16: Environment sedimentary map of the Mekong River Delta..........111
Figure 6.17: Wave forecasting nomograms (Shore Protection Manual 1984)..........114
Figure 6.18: Sample of SWAN input file..........115

Tables

Table 2.1: Wind direction along the Southern Coastline (SIWRR 2010a) 6
Table 2.2: Maximum storm surge level along the Southern Coast of Viet Nam 8
Table 3.1: Cross-section for each branch of the Mekong River (SIWRR 2010a) 21
Table 3.2: River discharge characteristic for different braches of Tien River from 15/09/2009 to 30/09/2009 (SIWRR 2010a) 23
Table 3.3: Tidal prism calculated-first approach 23
Table 3.4: Tidal prism calculated -second approach 24
Table 3.5: Location of river discharge measurement station in the first approach 26
Table 3.6: Compare the empirical equation found for the Mekong Delta Estuaries and that of US entrances 27
Table 3.7: River depth change due to new discharge sluices construction 28
Table 3.8: Maximum and average river discharge at upstream and downstream of the MR in flood and dry season 30
Table 3.9: Situation of erosion and deposition at Dinh An branch in 2002 (SIWRR 2005b) 31
Table 4.1: Chosen location and cross-section for mangroves width measurement 42
Table 4.2: Distance from the sea dike to the outer edge of mangrove forests and coastline evolution rate 42
Table 4.3: Selected parameters for S.alba and Rhizophora (Narayan 2009) 50
Table 4.4: Input vegetation parameters: different height and diameter for three layers 52
Table 4.5: Input vegetation parameters: density variation for three layers 52
Table 6.1: Frequency of wave height by intervals and months at Bach Ho station 67
Table 6.2: Wave height and wave period of maximum significant wave 67
Table 6.3: Frequency of wave direction in 8 directions and months at Bach Ho station 67
Table 6.4: Example of average river depth and river width calculation for one branch (Ham Luong branch) 92
Table 6.5: Erosion and accretion status of difference branches of Tien and Hau River, observed in 2002 (SIWRR 2005b) 101
Table 6.6: Some mangrove species in Viet Nam 106
Table 6.7: Factors influence the development of mangroves in Viet Nam 109
Table 6.8: Representative wave height calculation 113

Terminology

ADCP	Acoustic Doppler Current Profilers	
MDR	Mekong Delta River	
MD	Mekong Delta	
MDV	Mekong Delta Viet Nam	
MARD	Ministry of Agriculture and Rural Development	
MR	Mekong River	
MRC	Mekong River Commission	
NEDECO	Netherlands Engineering Consultants	
MONRE	Ministry of Natural Resources and Environment	
SSC	Suspended sediment concentration	
SIWRR	Southern Institute of Water Resources Research	
RP	Return period	
A	River cross-section	$[m^2]$
B	River width	[m]
b_v	vegetation diameter	[m]
c	Tidal (Wave) velocity	[m/s]
C_D	Drag coefficient	
h	water depth	[m]
H	Wave height	[m]
H_{rep}	Representative Wave height	[m]
k	Wave number	
L	Tidal (Wave) length	[m]
N	Number of vegetation stands per unit area	
P	Spring tidal prism	$[m^3]$
P_{ebb}	Ebb tidal prism	$[m^3]$
$\langle P \rangle$	Average tidal prism	$[m^3]$
Q_r	River discharge	$[m^3/s]$

<Q>	Average discharge	[m^3/s]
R.	Rhizophora	
S.	Sonneratia	
S	Cross-shore sediment transport rate	
T	Tidal (Wave) Period	[s]
u	horizontal water particle velocity	[m/s]
U_{10}	wind velocity at 10 meters elevation	[m/s]
U_A	wind speed factor	
W_{in}/ W_{out}	Water volume go in or go out the river	[m^3]
σ	Wave frequency	
ε_v	Time averaged rate of energy dissipation per unit area	

1. Introduction

1.1. Purpose and scope of the study

Purpose and scope of the study

The Mekong Deltaic Coast is historically rich in sediment with an overall sedimentation of both sand, fines and mud, creating a coastline of both mangrove and non-mangrove sections. Presently, sedimentation still prevails, but due to natural and human induced causes erosion exists and it is anticipated that erosion will increase in the future. The Government of Viet Nam has developed many plans to prepare the Mekong Delta for future sustainable development. What seems to lack is a proper integration of these plans into an integrated, long term MD development plan. The coast should not only have the function to protect the delta from external force such as waves, currents and typhoons, but it should also provide access to the hinterland. This report will focus on these issues.

Study area

The Mekong River originates from many sources and is shared by six countries: China, Myanmar, Laos, Thailand, Cambodia and Viet Nam (Le Anh Tuan et al. 2007).

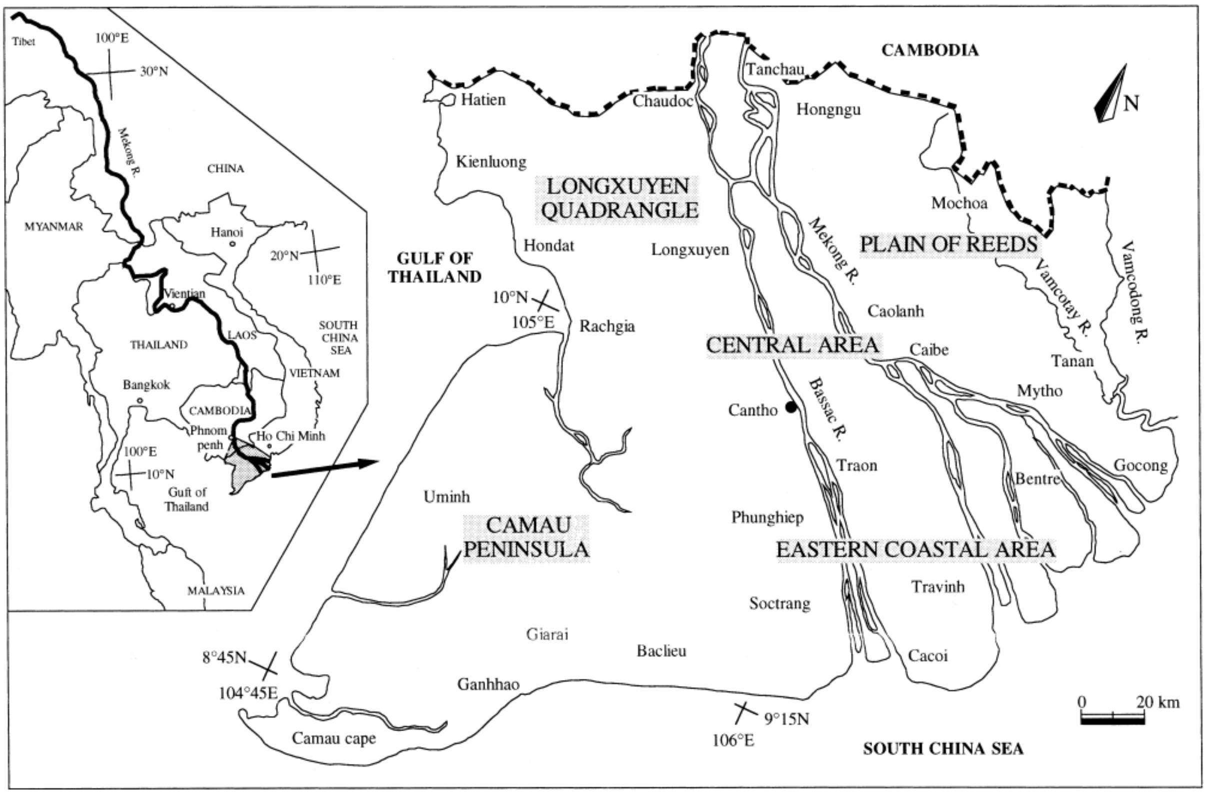


Figure 1.1: Location of the Mekong River Delta.
Inset shows location of the Mekong River and Mekong River Delta in Southeast Asia (Nguyen Van Lap et al. 2000)

The Mekong Delta begins at Phnom Penh where the river divides into its two main distributaries, the Mekong (Tien River) and the Bassac (Hau River) (MRC 2005a).The Tien then divides into six main channels and the Hau into three channels to form the “Nine Dragons” of the outer delta in Viet Nam. The lower Mekong basin, which starts from Phnom Penh to Viet Nam beach, is a single entity. For two-third the Mekong delta is situated in southern Viet Nam and for one third in Cambodia (Bucx et al. 2010).

The Mekong Delta in Viet Nam is the most downstream part of the lower Mekong basin which has an area of 3.9 million hectares in the total 5.5 million hectares of the Mekong basin. The Mekong Delta of Viet Nam is defined by:

(a) Viet Nam-Cambodia border in the North;

(b) Pacific ocean / South China Sea to the East (the so-called East sea),

(c) Gulf of Thailand in the West (the so-called West sea), and

(d) Vam Co Dong River and Ho Chi Minh City in the North-West

1.2. Research objectives and research questions

Research objectives

Estuary evolution under the influence of natural and human intervention will be discussed in the MD estuary section (chapter 3). Mekong Delta estuaries play an important role for waterway transport, connecting the Sea and the hinterland. Therefore for the future development plan it is necessary to know the relationship between the tidal prism and the river cross-section. According to the future development plan of the Vietnamese government, in order to prevent salinity intrusion and river bank erosion, it is planned to build new discharge sluices at three main branches of the Tien River and the embankments along the river banks. These constructions will bring many benefits for people living in the Mekong Delta however their adverse impacts also need to be carefully considered. All of these problems will therefore be discussed in chapter 3.

Meanwhile the main goal for the MD coast research is to identify the situation of the mangroves in the MDV that may inform future planning and decision-making in more effective prevention and mitigation of land use. Information of coastal evolution and human intervention is then necessary to evaluate mangrove forest development. A classification of coastal morphology therefore will also be provided as a framework for the assessment. Although there are already many studies about mangroves degradation along the Southern Coast of Viet Nam none of them consider the adverse impact of sea dikes to the mangrove forest. The degradation of mangroves since sea dikes were built too close to the mangroves forest and the relationship between wave attenuation and mangroves width will be two main concerns in this section. From that, the implementation of sustainable measures to ensure the protection of the deltaic coastal system against flooding and erosion will be addressed. These issues are discussed in chapter 4.

Research questions

For the MD estuary:

- What is the impact of human intervention on estuary evolution?
- What is the empirical relationship of tidal prism and river cross-section? Based on that relationship, the impact of closing down three main branches of Tien River according to future development plan for MDV would be analyzed.
- What are the reasons for river bank erosion and some solutions suggestion?

For the MD coast:

- What is the critical width of mangroves forest to maintain the sustainable development of the beach?
- What is the relationship between wave attenuation and mangrove forest width?
- What is the solution for the sustainable development of MD coast in the future?

1.3. Methodology

- Synthesize existing hydrological data, status maps, coastal morphology and river bank morphology reports and technical documents through a detailed literature review;
- Analyze coastal and estuary evolution in relation to natural conditions and human interventions.
- Application of the SWAN model to research the relationship of wave attenuation and mangroves width.

2. System characteristics

The hydrodynamic and morphodynamic processes play an important role in Delta evolution. Therefore, in order to have a comprehensive coastal morphology picture of the Mekong Delta Viet Nam from the past to the future, this chapter will have three main parts. The first two parts provide the general information needed to come to a classification of coastal morphology in the third part.

The first part will describe all of the coastal and estuaries characteristics which include wind, wave climate, tidal climate, topography, sediment supply, sediment budget etc. The natural data for example wind, waves, sediments, etc, are mostly provided by SIWRR, the measurement station along the coast and inside the river branches; the other data comes from previous researches in this area.

Human intervention in the Delta itself and in the upstream of Mekong River will be presented in the second part.

Finally, in part three the MDV will be classified into a specific coastal morphology type.

The system characteristics and the coastal morphology developed in this chapter provide the basis knowledge for the next two chapters.

2.1. Natural characteristics and hydrological characteristics of the MD

2.1.1. Topography and the River system

The Mekong Delta is rather flat with an elevation from 0.8 to 1.2 m above MSL (MRC 2005b). The highest terrain (from 2.0 to 4.0 m above sea level) can be found near the Cambodian border; lower levels closer to the central plains, from 1.0 to 1.5 m high, and level of only 0.3 to 0.7 m in the tidal and coastal areas. Topography map of MD can be found in Annex 2.1.

The Mekong River has two main branch systems of importance. The Tien River branches into six tributaries and the Hau River which branches into three tributaries. However the Bat Xac mouth, located between Tran De branch and Dinh An branch is now completely silted up and has disappeared and only eight branches remain today. These branches can be seen in Figure 2.1.

When the Hau River approaches the sea at Soc Trang province, it splits into two branches: Tran De and Dinh An. The Tien River is the northern branch of the river system. At Vinh Long, the Tien separates into three river branches: Co Chien, Ham Luong and My Tho. At a distance of 30 km from the East Sea, the Co Chien river again splits into two estuary branches, Co Chien and Cung Hau. The My Tho branch again splits into 3 more separate branches the Tieu, Dai and Ba Lai branch. However, the Ba Lai branch was entirely silted up and the river nearly completely disappeared. The river flow from Ba Lai branch is too small to carry away the sediment from the Dai branch, thus these sediments settle at Ba Lai mouth causing sedimentation of the Ba Lai branch.

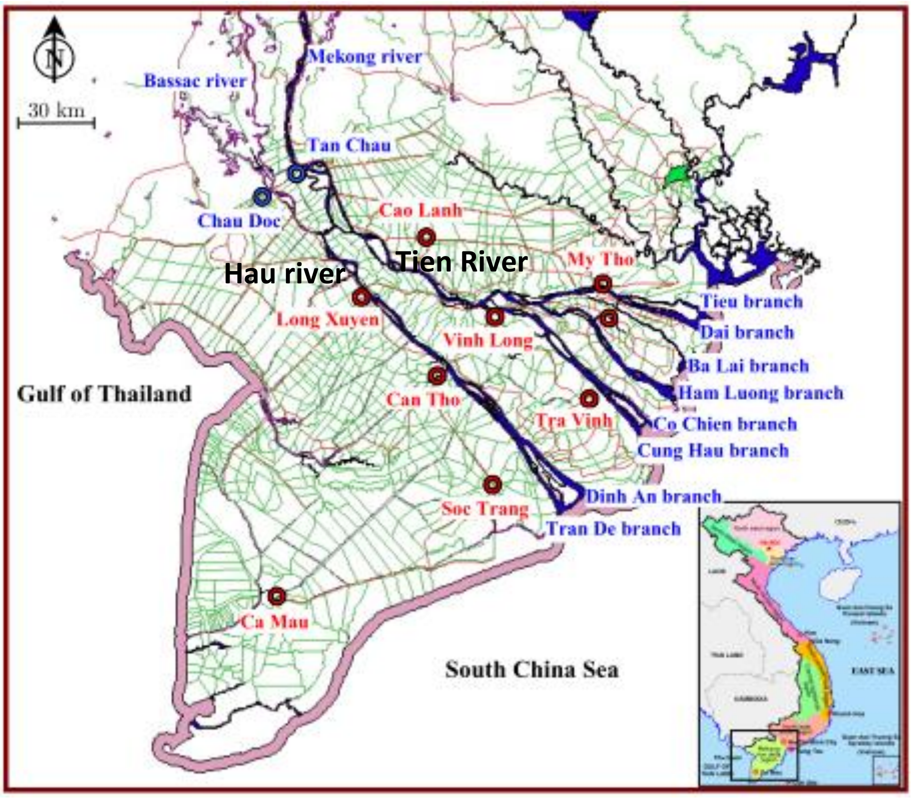


Figure 2.1: The Mekong River in Viet Nam and its branches (Nguyen Anh Duc 2008)

Therefore, this report will only consider seven branches including: Tieu branch, Dai branch, Ham Luong branch, Co Chien branch, Cung Hau branch, Dinh An branch and Tran De branch.

2.1.2. Climatic

The Mekong Delta, located in a tropical monsoon region, is hot year-round and has a seasonal distribution of dry-wet months depending on the monsoon: the North-East monsoon dominates the dry season, creating dry heat and little rain from November to April; while the South-West monsoon climate is characterized by local, humidity and rainfall, lasting from May to October.

The highest average rainfall comes from the western region (2000-2400mm); the lowest rainfall was observed at the central plains with averages of 1200-1600 mm (Deltares 2011). However the amount of rain is also unevenly distributed over the year, in which 90% of annual rainfall occurs during the rainy months and 10% during the dry months. In general, the distribution of rainfall in the MD is uneven both in space and in time and the MD can be divided into 3 main regions following this distribution:

- Along the East Sea: the rainy season coming late and finishing early, resulting in a small amount of precipitation.

- Along the West Sea: the rainy season coming early and finishing late, resulting in mean annual rainfall of about 2000 mm/year; the precipitation is about 70-80% larger than that of the first region (East Sea).
- Ca Mau Peninsula: intermediate rainfall characteristic of both above mentioned regions (East Sea and West Sea).

The distribution of annual rainfall is presented in Annex 2.1.

2.1.2. Wind, wave and storm

2.1.2.1. Wind climate

Wind in the MD is subject to the seasonal monsoons and determine the direction of the wind as seen in the table 2.1. In winter the north east monsoon is dominating and blowing from north east to south west; in summer the south west monsoon is dominating and blowing from south west to north east.

Table 2.1: Wind direction along the Southern Coastline (SIWRR 2010a)

Direction	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
West Sea	←	↖	↖	↖	↖	→	→	→	↗	↙	←	↙
	E	SE	SE	SE	SE	W	W	W	SW	NE	E	ENE
East Sea	↙	↙	←	↖	↖	↗	↗	↗	↗	↘	↙	↙
	NE	NE	E	SE	SE	SW	SW	SW	SW	NW	ENE	NE

Wind in the East Sea

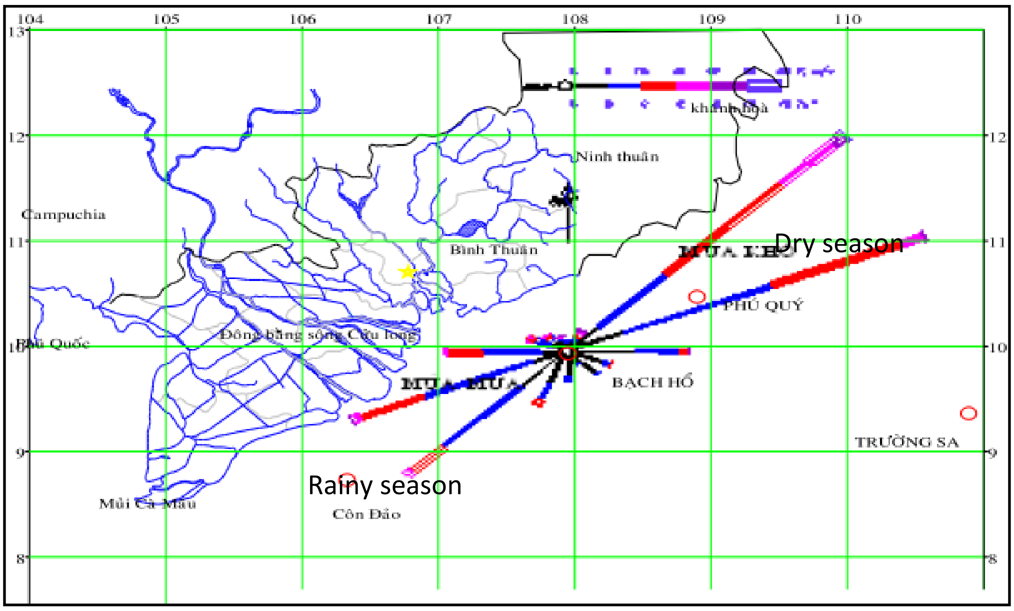


Figure 2.2: Wind rose at Bach Ho station (Hoang Van Huan 2006).

Offshore winds at the East Sea are measured at Bach Ho station (Figure 2.2). The winds in the north-east of the Mekong Delta are prevalent during the dry season (December to April) and in the south-west during the rainy season (May to October).

Near shore wind in low-pressure periods and storms can reach 15 to 18 m/s (with a storm level 5 in 1997). However, the impact of near shore wind to wave field can be neglected since winds with high velocity only appear in a short time.

Wind in the West Sea

The annual average wind velocity in the West Sea is 2.7 m/s. The maximum wind velocity is 57 m/s blowing from the West.

- In the winter (November to April): the prevailing wind direction is from the South-East and the East. The average wind velocity in this season is 1.6÷2.8 m/s. The maximum wind velocity observed is 48 m/s.
- In the summer (May to October): the prevailing wind direction is from the South-West and the West. The average wind velocity recorded is 1.8÷4.5 m/s and the maximum wind velocity can reach 57 m/s.

2.1.2.2. Wave climate

Offshore waves data (Figure 2.3) at the East Sea are also observed at Bach Ho station.

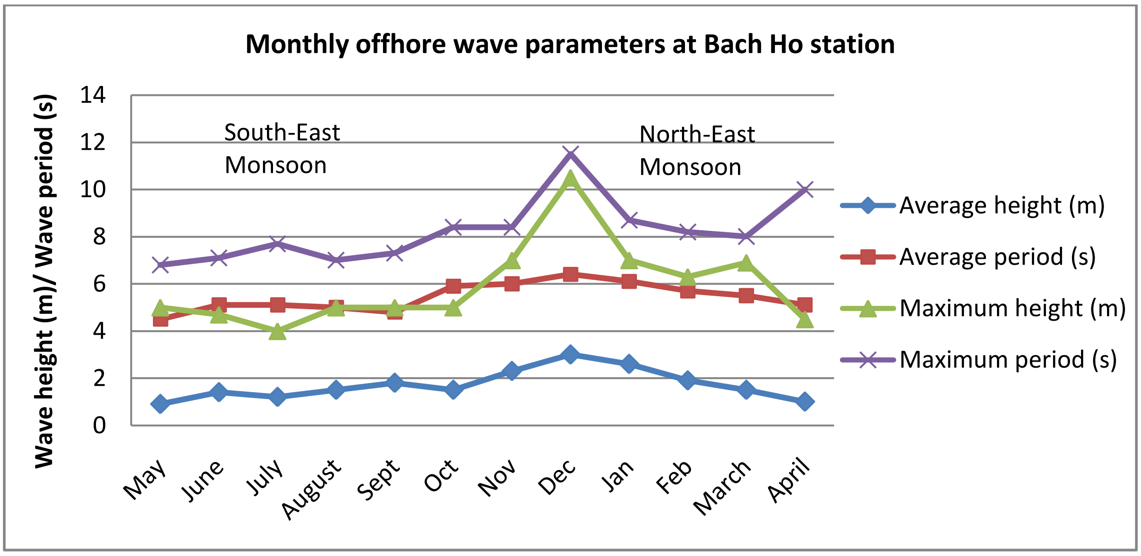


Figure 2.3: Monthly offshore wave parameters at Bach Ho station (Hoang Van Huan 2006).

From these data some conclusion can be drawn (Hoang Van Huan 2006):

- Waves in the Southern continental shelf are a combination of wind and swell with an average height of 1.6m, T= 5s. Based on observed data, in the NE monsoon time, the highest wave height and period are 10.5m and 11.5s respectively. In the southwest time, wave height is not bigger than 3m and Ts= 5-12s.

- In the SW wind time, inshore wave are weak except during storms and tropical depression times.

The information of offshore wave height and their frequencies observed at Bach Ho station is presented in Annex 2.2.

Recently, the near shore wave heights were also measured by SIWRR at six stations along the Southern Coast of Viet Nam. All the collected data of near shore wave height and wave direction is also presented in Annex 2.2.

2.1.2.3. Storm history

From 1951 to 2007 there have been 9 storms that had a direct influence on Southern part of Viet Nam (one in August, one in October, six in November and one in December). The Linda storm in 1997 (storm level 10) and the Durian storm in 2006 (storm level 9) were the two strongest and cause serious damage to people and infrastructure. The map of Viet Nam historic storm is presented in Annex 2.1. Storm distribution and maximum storm surge level along the Southern Coast of Viet Nam is presented in table 2.2.

Table 2.2: Maximum storm surge level along the Southern Coast of Viet Nam (Nguyen Tho Sao and Nguyen Minh Huan 2011)

Location	Number of storm	Frequence (%)	Max storm surge level (m)
Binh Thuan-Ben Tre	4	1.66	1.8
Ben Tre – Bac Lieu	3	1.24	2.0
Bac Lieu – Ca Mau	2	0.83	2.0

2.1.3. Tidal characteristics

A study of tidal regimes will contribute to control the depositional processes in this area.

2.1.3.1. Tides along the coast

The tidal characteristics differ in the 3 main regions of the MDV:

- The East Shore: 400km length starting from Vung Tau to Ca Mau Peninsula. Tides in the East Sea have a semi-diurnal characteristic daily unevens as there are two troughs and two peaks during a day, but their relative height varies over a fortnight. The tide here has a high amplitude (more than 2m at mean tide increase up to 4m at spring tide). As the tidal amplitude decreases towards Ca Mau Cape, the number of diurnal tidal days and the diurnal characteristic increase. There are four main tidal componants including M2, S2, K1, O1.
- The West Shore: 250 km length starting from Ca Mau to Ha Tien. In the Gulf of Thai Lan, the diurnal tide is dominated by an average amplitude of 0.8 to 1m and a maximum amplitude of about 1.2 m (SIWRR 2005b). Since the tide in the West Sea has a small amplitude and is only propagated in a small canal, it is not of much

importance. In general, the tidal influence area of the West Shore is considered mostly in Kien Giang province.

- Ca Mau Peninsula: Tides in the Ca Mau Peninsula have a mixed diurnal and semi-diurnal characteristic due to influences of both the West and the East Sea.

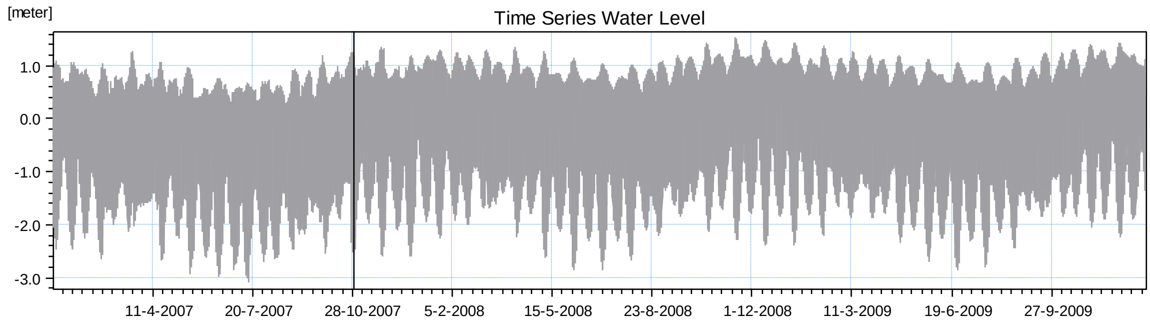


Figure 2.4: Tidal levels at Vung Tau station from 2007 to 2009 (SIWRR 2010b).

2.1.3.2. Tides propagation

The tidal amplitudes increase towards the river mouth and then reduce when propagating further inland. For instance, in the dry season the tidal amplitudes reduce from 3.75 m to 0.69 m when the tides propagate from Vung Tau (near the sea) to Tan Chau (about 225 km from the sea). Tidal amplitudes have a strong impact on the dry season. The tides travel to 350 km upstream from the river mouth which means that tidal influences can be observed as far as PhnomPenh.

2.1.4. Sediment

2.1.4.1. Sediment budget

The availability of sediment to maintain the landforms of the delta and their dimension is an important variable in the development of the MDV.

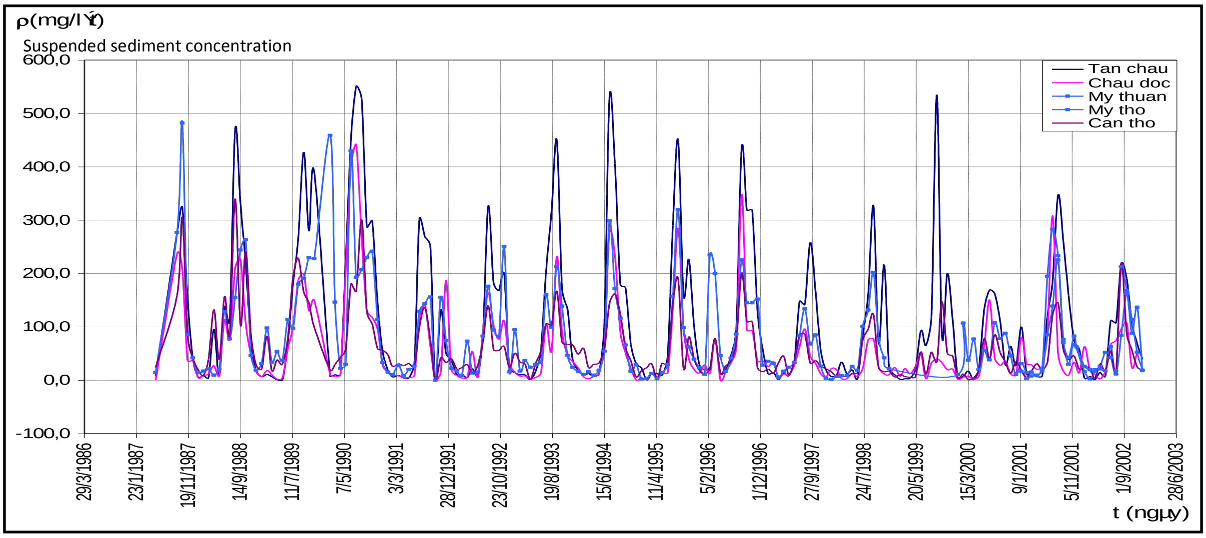


Figure 2.5: Sediment distribution from 1987 to 2002 at downstream of the Mekong River (Mekong committee)

Figure 2.5 shows the suspended sediment at different measurement station (Tan Chau, Chau Doc, My Thuan, My Thi and Can Tho station) along Tien and Hau River from 1988 to 2004 (Location of these stations can be found in Figure 2.1). Sediment transport in dry season will be more restricted than in the rainy season due to the strong reduction of sediment discharge. Therefore, the river sediment supply to the coastline mainly comes from the rainy season. According to Milliman and Syvitski (1992) every year there is about 80-160 million m^3 of sediment from Mekong River flowing into the sea.

2.1.4.2. Sediment deposition and sediment transport

The tendency of mean grain size variation clearly shows the dominance of fine sediments south-westwards and towards the western part of Ca Mau Peninsula. The median grain size is coarser than 90 µm in front of Tien River mouths and become finer to near the Ganh Hao River mouth. Around the Ganh Hao River mouth the median grain size varies around 30-90 µm and then becomes finer south-westwards and in the west part of Ca Mau Peninsula (Figure 2.6).This trend reflects the distance from the origin of the sediment supply to the location where it settles. Coarser sediment can mostly be found in front of Ganh Hao anh Tien River. According to Wentworth classification on the basis of sediment size, along the Southern Coast of Viet Nam could find fine sand, silt and mainly clay material.

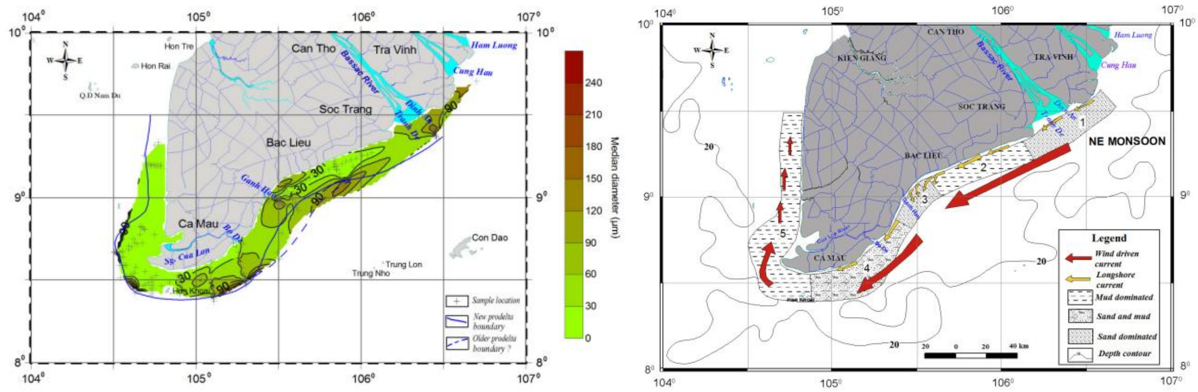


Figure 2.6: Sediment characteristic
(a) Distribution of median grain size; (b) Sediment deposition and sediment transport pathways under the influence of north east monsoon (Nguyen Trung Thanh 2009)

Generally, the terrigenous sediment from Mekong River is transported southwestwards by coastal currents driven by the Northeast monsoon in winter. The influence of the monsoon decreases south-westward to Ca Mau Peninsula. The longshore transport of sandy sediment develops mainly along the coast from the Tien River mouths to the Ganh Hao River mouth in tidal flat environment (Nguyen Trung Thanh 2009). In the dry season, the NE monsoon wind coming from the East Sea meet the SE monsoon wind coming from the West Sea at the Ca Mau Cape (wind direction table 2.1). The result is the wind driven current parallel with the coastline from Ca Mau peninsula to Kien Giang Province (Figure2.6). These currents provide favorable conditions for sediment transportation to the West Sea coastline. Meanwhile in the wet season, the West Sea wind driven current mainly blows from West to east while the SW wind prevails at the East Sea. Therefore Ca Mau peninsula plays as flow distribution point which divides the flow to two directions, one go to Kien Giang and one go to the East Sea.

2.2. Human interventions

2.2.1. Status of constructions at MD

2.2.1.1. Existing construction

Viet Nam has annually suffered natural disasters such as typhoons, tropical storms, floods, inundation, drought, salt penetration, landslides, for centuries. In which, the MD is considered to be an extremely vulnerable flooding region located at the downstream end of the Mekong River Basin. Some typical example can be seen in Annex 2.3 (flooding and salinity situation in MDV). Nowadays, in order to reduce flood disasters as well as other mentioned disaster structural flood, erosion and salinity control measures have been applied in most of the cities in the Southern of Viet Nam.

The history of sea dike development at the Southern Coast of Viet Nam can be summaried as follow (SIWRR 2005b):

- Before 1975: there is about 138 km small and discontinuously sea dike was constructed.
- From 1975 to 1998: the old sea dike was upgraded and there are more new sea dike were built such as 22 km sea dike at Go Cong, 34 km sea dike at Vinh Chau, Ben Tre, Tra Vinh, Ca Mau, Kien Giang.
- From 2000 to 2001: “New Sea dike plan for Southern Coastline” is provided.

There are no available maps for exact position of sea dikes for each of these periods. The final statement of sea dikes until now can be seen on Figure 2.7. There is about 250 km sea dikes along the West Sea from Ha Tien to the Southwest Ca Mau and more than 260 km sea dikes along the East Sea. Revetments were constructed along Go Cong coastline where the erosion rate recorded highest along the Southern Coast of Viet Nam.

In the MD agriculture is the major economic sector however due to the salinity intrusion the cultivable lands are restricted; reducing the production and then increasing poverty. Sea dikes not only can protect people from flooding but also reduce salinity intrusion, thus enhance the development of economy and the living standard of people.

However, there are also questionable about the adverse impacts of sea dikes to coastline evolution since coastal erosion become more complicated after sea dikes were constructed for example erosion was observed at the location of sedimentation before sea dikes were presented. The degradation of mangroves forest also happen in a large scale along Southern Coast at the same time with the appearance of sea dikes. These issues will be addressed in more detail in chapter 4.

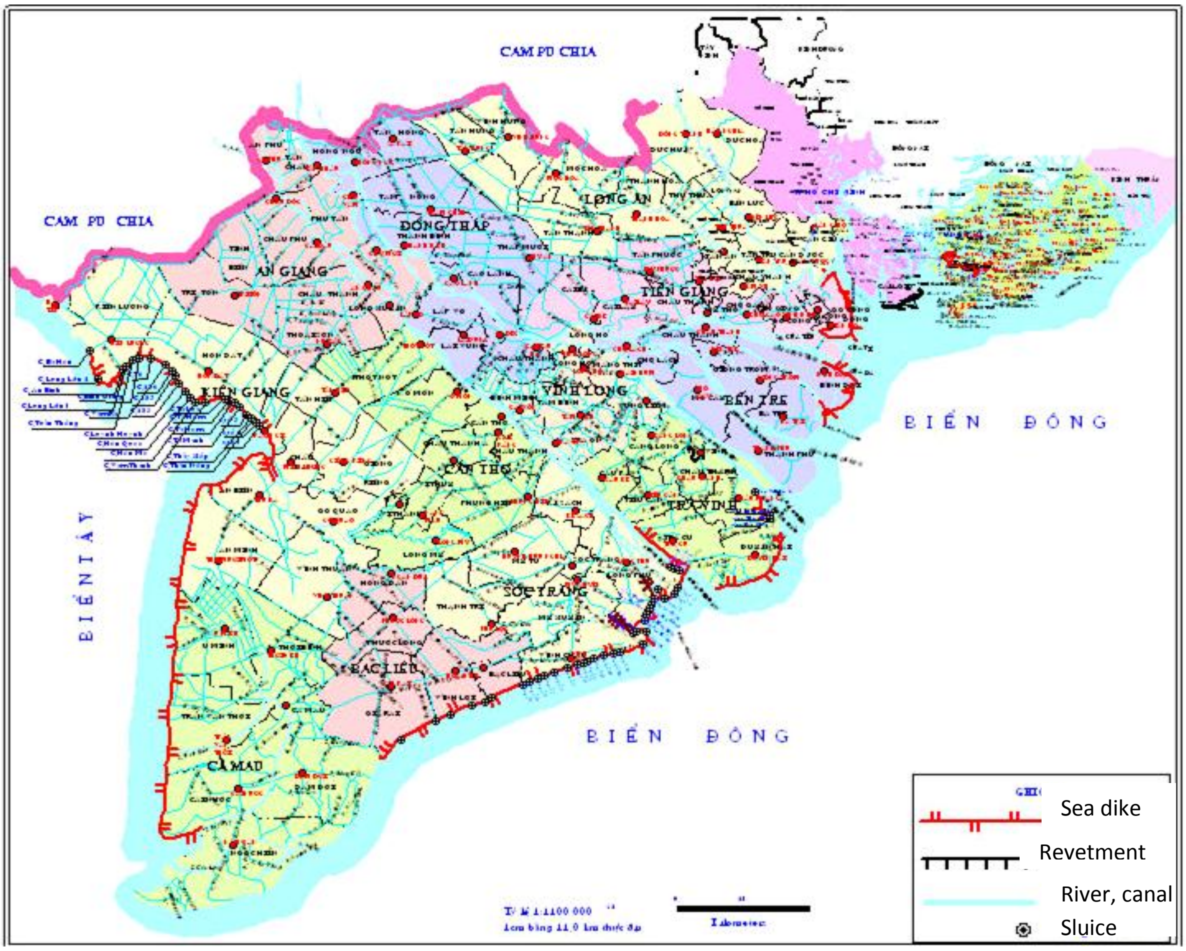


Figure 2.7: Location of existing construction of the MDV (SIWRR 2010a)

2.2.1.2. Future plan construction

In pursuit of the MDGs and in order to ensure agricultural livelihood and infrastructure in the flooding context of the MD, the Vietnamese government responded to flood catastrophes by issuing Decision 99TTg on February 09th, 1996 regarding long-term orientation in a 5-years plan from 1996 to 2000. The aim of this decree is to develop irrigation and infrastructure, transportation and construction in rural areas and to respond to the flood risks in the MD. In order to implement this decision, the Ministry of Agriculture and Rural Development (MARD) was assigned to set up and implement a program called Mekong Delta general flood control planning. In the year 2005 MARD executed a master plan study on integrated water resources planning for the delta, including analysis of local socio-economic developments and particularly looking for more effective crop patterns. The result of the investment was submitted for approval by the Prime Minister under the Decision No.84/2006/QC-TTg dated 19/04/2006. The Decision proposed a number of investment projects for the period 2006-2010 and 2011-2020 as well as solutions for the sub-regions.

A number of proactive measures and adaptation guidelines for in particular salinity intrusion was recommended as follow (Deltares 2011)

Completion of projects listed in decree 84/2006/QD-TTg and additional works proposed by the provincial authorities

Construction of sea dikes, associated works and coastal roads;

Construction of estuary dikes and culverts;

Construction of water diversion channels/pipes for coastal sub-areas;

Construction of flood control systems;

Development of urban drainage systems;

Upgrade the existing sea dike;

Building large sluice gates at river mouths: (i) The Cai Lon-Cai Be sluice, (ii) Vam Co sluice, (iii) Ham Luong sluice, (iv) Cung Hau sluice and (v) Co Chien sluice.

These constructions are necessary for the safety of people who living in the MD and also needed for the economy development of this area. However, the impacts of these constructions into the environment and the evolution of MD are not well researched. For instance the construction of estuary dikes and culverts could reduce the salinity intrusion and flooding however the estuary dikes will also increase the load into the weak river bank soil and causing more erosion.

Some of the adverse impact caused by these interactions would be discussed into more detail in the next chapters including:

- In chapter 3-River estuary: the adverse impact of building large sluice gates at river mouths.
- In chapter 4- Mekong Delta coast: the adverse impact of sea dikes construction and upgrade the existing sea dike.

The locations of new constructions can be seen in Figure 2.8.

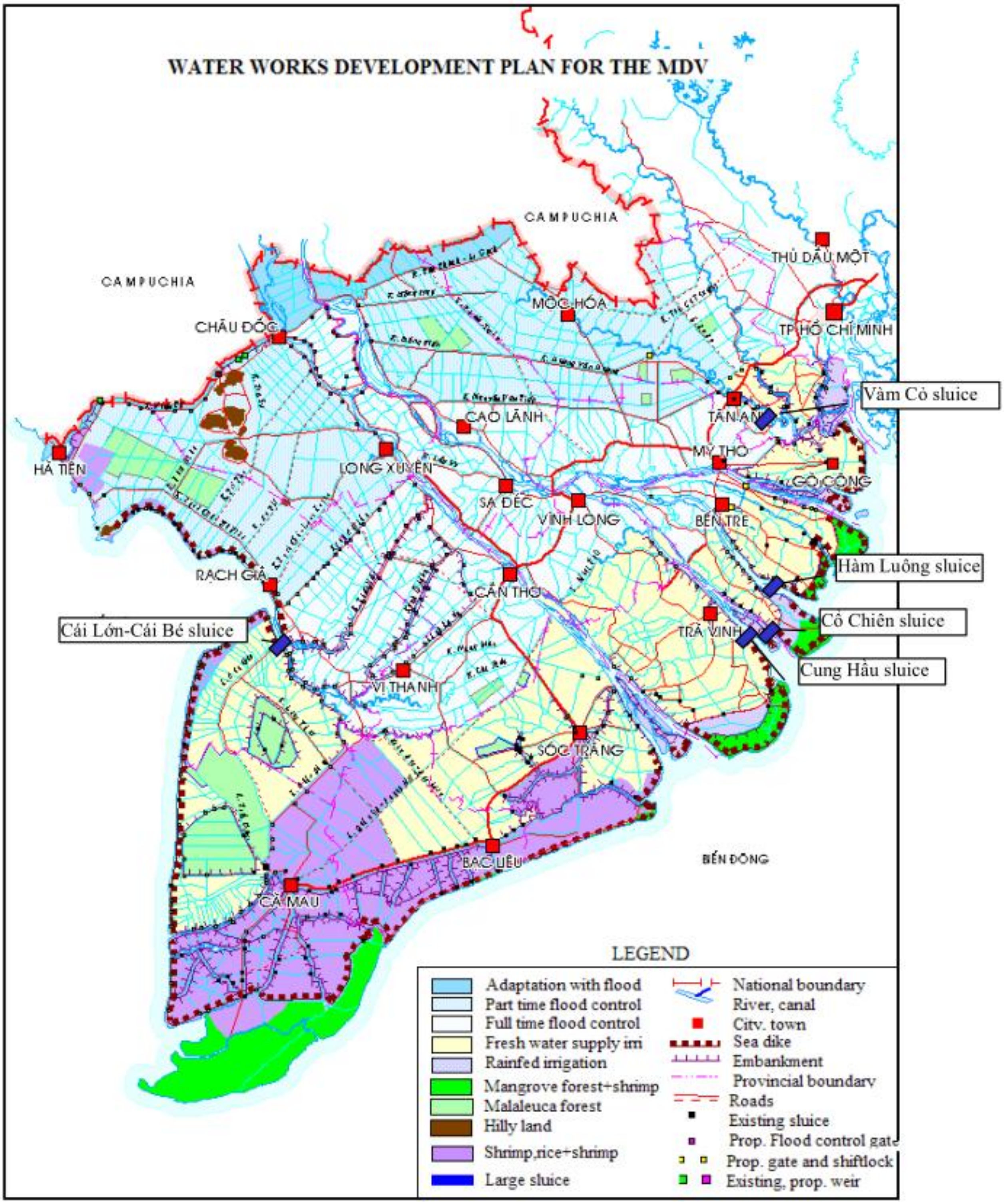


Figure 2.8: Water works development plan for the Mekong Delta (Deltares 2011)

2.2.2. Dams construction in the upper stream of Mekong River and its influence

2.2.2.1. Location of dam construction

One of the main concerns with dam construction in the Mekong is the influence on suspended sediment flux, because a change in sediment behaviour might be potentially detrimental to the health of the entire river ecosystem. The time and position of the dams constructed at the upper stream of the Mekong River can be seen on Figure 2.9.

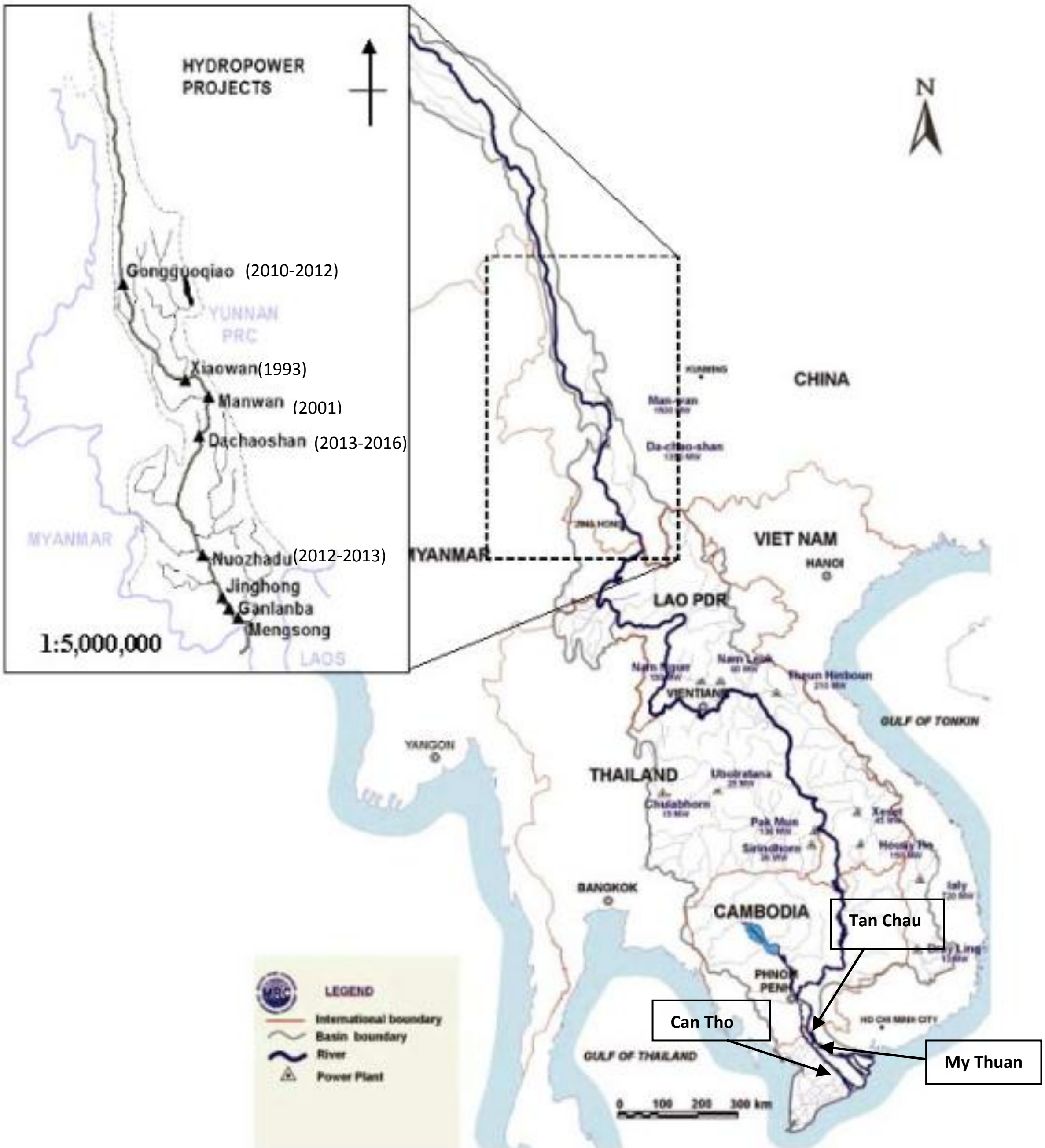


Figure 2.9: Map showing China's cascade dams and its commissioning years in Yunnan province (inset), with reference to the location of the dams and Tan Chau, Can Tho and My Thuan station in the Mekong River basin (background map) (Lu and Siew 2005)

2.2.2.2. Impact

A declining trend in mean monthly suspended sediment concentration was observed along the entire length of the Lower Mekong River since water quality measurement began in 1985 (Lu and Siew 2005). Stations furthest downstream such as Tan Chau, My Thuan in Viet Nam also experienced reductions as a consequence of dam closure (Figure 2.10)

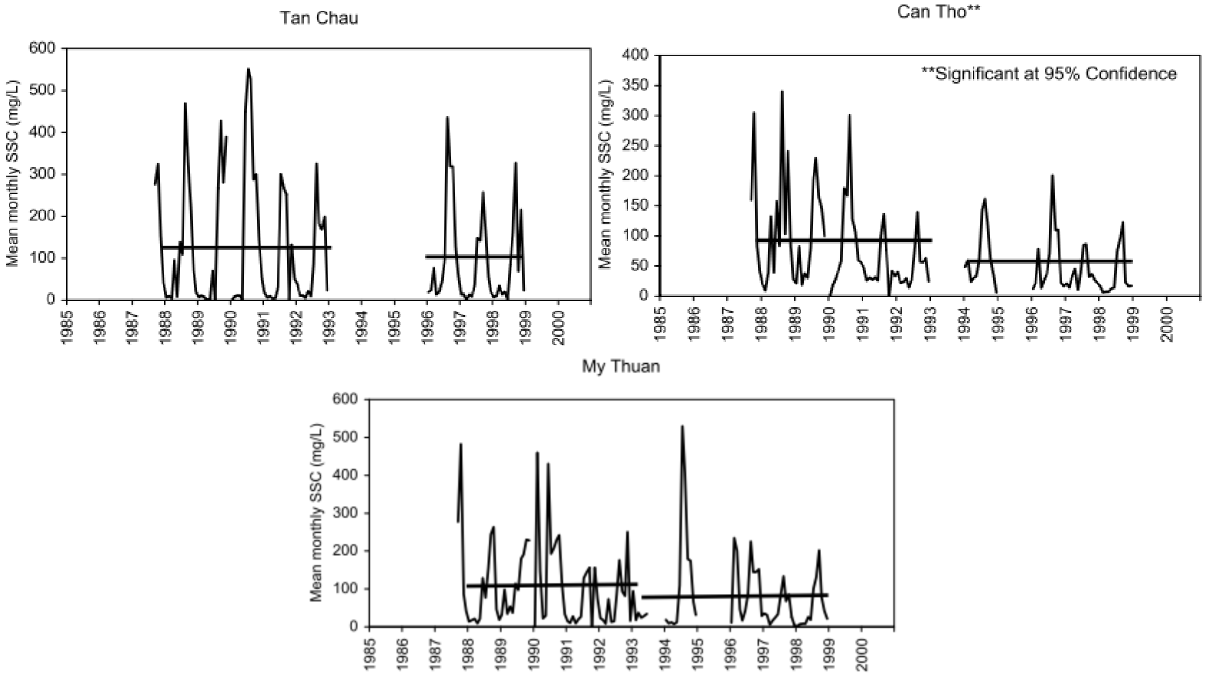


Figure 2.10: Temporal changes in mean monthly sediment concentration at Tan Chau, Can Tho, and My Thuan station. The horizontal lines represent the mean SSC in pre- and post-dam periods (Lu and Siew 2005).

Comparison of mean sediment fluxes in pre- (1962–1992) and post-dam (1993–2000) periods for each station shows the apparent effects of flow impoundment on sediment fluxes, and downstream persistence of these effects (Lu and Siew 2005).

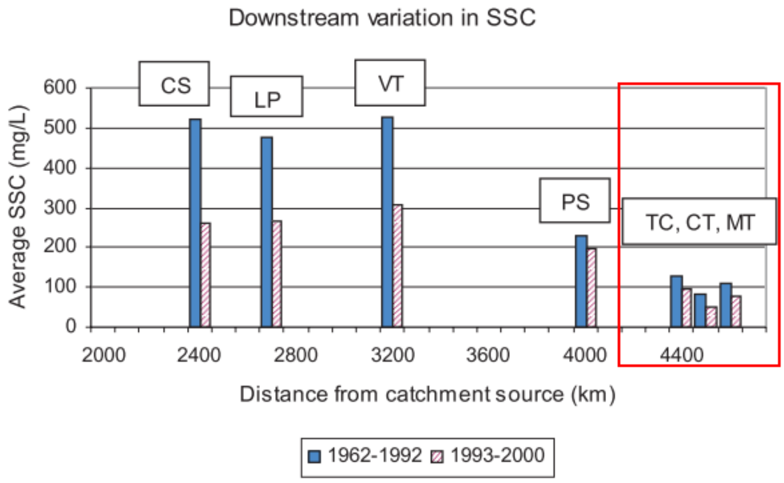


Figure 2.11: Sediment concentration variation along the Lower MR (Lu and Siew 2005).

2.3. Coastal classification

2.3.1. Classification schemes

A classification scheme can be a most useful tool for coastal resource management. It groups estuaries or coastal environments into classes which reflect a particular origin and the dominant hydraulic, sedimentological and ecological processes operating therein.

According to the coastal classification summary of Finkl (2004), a group of process-related elements in coastal classification was provided:

- Geotectonic systems (geodynamic processes): by Suess(1888) and consecutively by Inman and Nordstrom(1971), Cotton (1925), and Bridge (1992);
- Sea-level change (eustatic processes): by Johnson (1919);
- Marine modification and terrestrial inheritance: by Shepard (1973;)
- Coastal erosion (shoreline retreat) and deposition (shoreline advance): by Valentine (1952).

Besides, Finkl (2004) also provides a classification for special purpose for instance a classification of coastal dune morphology, a classification of Rocky coasts (Cliff and Platform), a classification of Beaches and Beach Geomorphology etc. In the case of classification of Beaches and Beach Geomorphology the beach can be divided into two main types:

- Wave dominated beach types (including reflective beach, intermediate beach and dissipative beach);
- Tide dominated beach types.

2.3.2. Apply for classification of MDV

Since the 1960s the Mekong River Delta has been studied by many geologists with interests in general geology, sedimentology, tectonism and geomorphology. There has been a proliferation of research in recent years concerned with the mapping of surficial sediments of the Mekong River Delta (Annex 4.2). These investigations are important for understanding the evolutionary history of the Holocene deposits. The main results of these investigations are the sedimentary map of the Mekong Delta (Nguyen Van Lap et al. 2000) and the Holocene evolution map of Mekong River Delta (Ta Thi Kim Oanh et al. 2002) indicating the evolution of the Mekong Delta from a tide-dominated to a tide and wave dominated delta as denoted in the triangular classification of deltaic depositional systems. In this section, the coastal classification map will be provided based on other previous researches, the natural characteristic of the system (refer to section 2.1) and the classification schemes presented in section 2.3.1.

Mekong Delta Coast is mainly shaped by terrestrial (river) deposition, thus the MD coast should be put in the “Coasts shaped primarily by non-marine agencies” category (Shepard, 1948). According to the worldwide distribution of coastal types as classified by Inman and Nordstrom (1971) eastern Asian shorelines are marginal sea coasts: techtonic stable coasts protected from the open ocean by island arcs at converging plate boundaries.

Mangrove marshes are distributed along the present coastline and usually behind the tidal flat. Mangrove dominated intertidal environments are quite extensive in the southern part of the Camau Peninsula and along the mainland margins of estuaries.

At the highest level of classification, the MD coast will be classified into 3 zones (Figure 2.12):

- Zone 1- River mouth: from Vung Tau Province to Soc Trang Province

This is an area of estuaries belonging to Mekong River system, semi-diurnal tide with high amplitude of 3 to 4 m. Flood tide in dry season can bring salinity water far inland. Near the estuaries, the alluvium accreted quickly due to reduce of water flow velocity, thereby creating bars within the estuaries. Tidal flats mainly occupy a great width of 2.0–5.0 km where sandy flats are dominant at the lower portion, but mixed flats (sandy and muddy) at the upper one.

- Zone 2- East Shore and Ca Mau Cape: from Soc Trang Province to Ca Mau cape

This is unstable area which is not directly affected by the flow pattern of the Mekong River. At Ca Mau Cape accreted land develops south-westward while along the East Sea from Ganh Hao estuary (refer to figure 2.6) to Ca Mau Cape the coast is strongly eroded. Sedimentation also occurs from Soc Trang to Ganh Hao estuary. The mixed tidal flat is well distributed from Ganh Hao to Ca Mau Cape while sandy tidal flat is found from Soc Trang to Ganh Hao (refer to figure 2.6).

The shoreline stream, which flows south-westward and meets with other shoreline streams flowing in the south-east direction from the Gulf of Thailand when they reach Ca Mau Cape, resulting in the expansion of Ca Mau Cape westward. Beside, when the high tide of the East Sea meets the high tide of the Gulf of Thailand, it causes “interferential tidal waves” rarely found elsewhere in the world (Phan Nguyen Hong and Hoang Thi San 1993). Under these conditions, the water literally stops flowing and alluvium is accumulated at a much higher rate than at any other places. High alluvium deposition, calm water conditions combine with high annual rainfall, semi diurnal tide and tropical climate making it easy for mangroves to develop.

- Zone 3- Gulf: from Ca Mau Cape to Ha Tien province

In the Gulf of Thailand, because the tidal regime and sediment supply are weaker than those of the East Sea, the coastal plain deposits are distributed through almost the whole area of the Ca Mau Peninsula, and are low elevation consisting of light gray silty clays, poor in organic matter and do not have any sand beach ridges (Nguyen Van Lap et al.

2000). Due to the narrow tide amplitude (0.8 to 1 m) salinity water cannot enter far inland as in the first zone even in dry season. This area also has high rainfall (above 2000 mm/yr), average temperature larger than $27^{0}C$, humidity larger than 83% which are favourable for mangroves growth. However, due to the deficiency of sediment supply mangroves cannot develop far and often form a marginal community along the coastline (Phan Nguyen Hong and Hoang Thi San 1993).

The coastal morphology map of the Mekong Delta is presented in Figure 2.12.

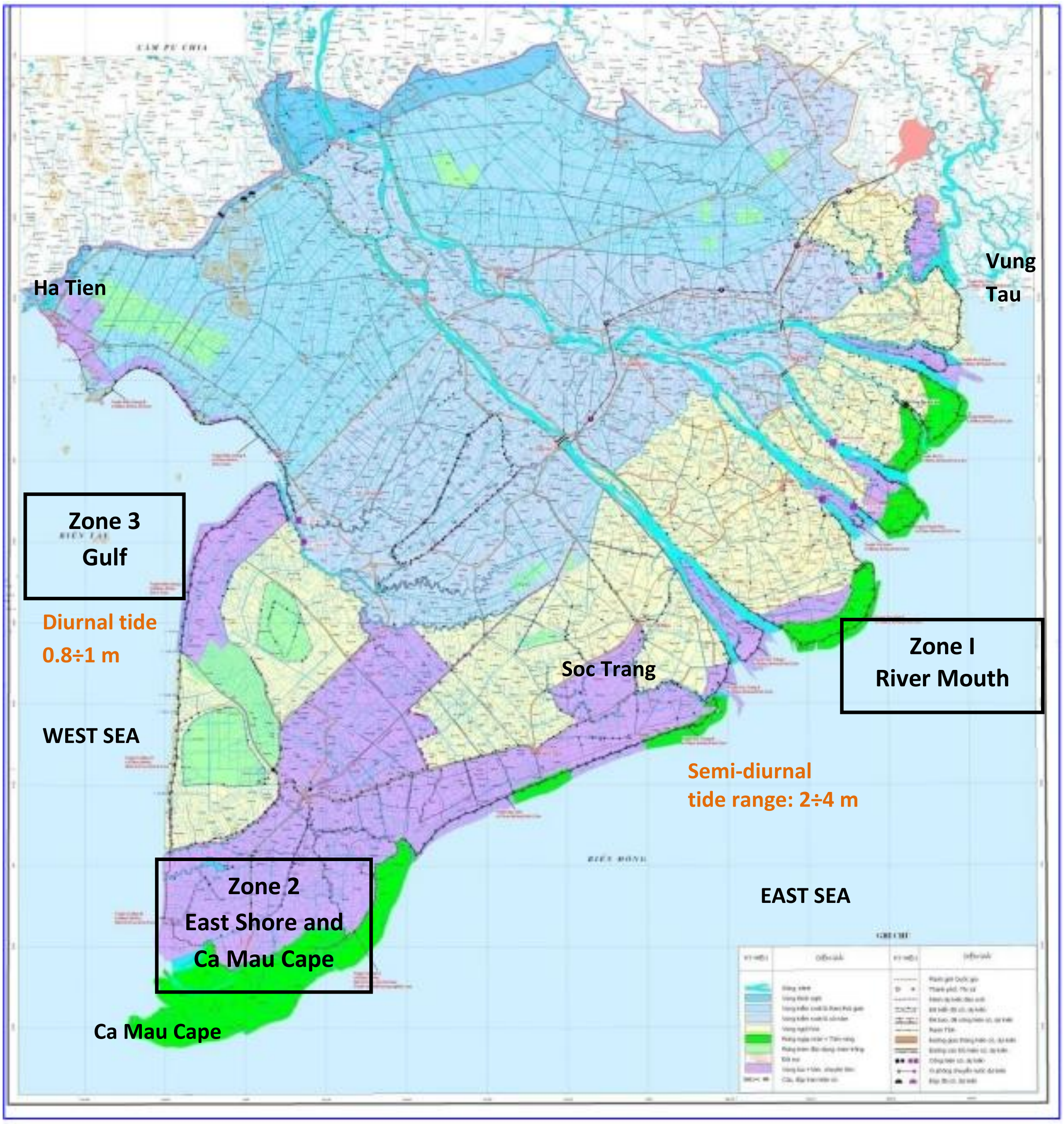


Figure 2.12: Coastal morphology classification map of the Mekong River Delta

3. Mekong Delta Estuaries

As mention earlier, the purpose of this section is finding the empirical relationship of the river cross-section and the tidal prism, and to use this relationship to predict the impact of closing down river branches in the future. Since the empirical relationship is created with uncertainties parameters, in particular river depth, the purpose is not to predict the evolution of the estuary in detail, but only to provide a qualitative impression of how the river depth can be changed in the future.

This empirical relationship will be created based on the framework of O'Brien equation.

3.1. Framework

The familiar relationship between tidal prism and inlet cross-section was first derived by O'Brien (1960):

$$A = a.P^{m} \tag{1}$$

Where: A is the cross-sectional area (relative to mean sea level) and P is the spring tidal prism. The coefficients a and m vary from entrance to entrance; however O'Brien (1969) showed that for 28 US entrances, $a=4.69\ 10^{-4}$ and $m=0.85$ are best-fit values applicable to all entrances when P is measured in cubic meters (m^3) and A in square meters (m^2) (Stive and Rakhorst 2008).

For a sinusoidal variation of the flow discharge at the tidal frequency, *P* is related to the mean discharge *<Q>* over flood or ebb flow duration by:

$$P = 1/2\ T <Q> \tag{2}$$

Where *T* is the tidal period. Combining equations 1 and 2 yields:

$$A = a\ (1/2\ T)^{m} <Q>^{m} = b<Q>^{m} \tag{3}$$

Where $b=a\ (1/2\ T)^{m}$

For semidiurnal tide T = 44700s and taking O'Brien value for A and m yields:

$$A=2.3<Q>^{0.85} \tag{4}$$

This equation is similar to equation found by Powell et al. (2006) tested for 66 Florida entrances:

$$A_r=1.51<Q_r>^{0.83} \tag{5}$$

A_r is the river cross-sectional area and Q_r is the river discharge. Equation 5, known as the regime equation, was empirically derived for several non-tidal rivers in the US by Blench (1961).The transition between river-dominated flow and tide-dominated flow depends on the ratio of $<Q>/Q_r$. The influence of the river on tidal flow becomes minor when $<Q>/<Q_r>=20$ (Stive and Rakhorst 2008). Although many small entrances in Florida are inundated by river outflows during spates, such events are relatively rare and, on an annual mean basis, the ratio $<Q>/<Q_r>$ at all entrances is well above 20 (Bruun 1978 cited Powell et al. 2006). This, in turn, provides the justification for dealing with delta volumes in terms of their dependence on the tidal prism, without invoking the influence of river discharge (Powell et al. 2006) .

3.2. Input data

3.2.1 River cross-section

For each branch, the average cross-section was calculated based on the river bathymetry. There are 6 to 9 cross-sections are taken into account depend on the length of the river and the available of the data. The data using for calculation are collected from the river bank erosion investigation of the Mekong River in 2002 provided by SIWRR. The example of river cross-section calculation for one branch is presented in Annex3.2. The result can be seen in table 3.1.

Table 3.1: Cross-section for each branch of the Mekong River (SIWRR 2010a)

Branch name	Mean width(m)	Mean depth(m)	Cross-section (m^2)
Tieu	1000	7	7000
Dai	2200	8	17000
Ham Luong	2200	9	20000
Co Chien	1500	10.5	15000
Cung Hau	1900	7	12500
Dinh An	2300	10	23000
Tran De	1700	8	14000

3.2.2. River discharge

Every year, the Mekong river transports 500 billion m^3 water to the sea with an average water discharge of 13.500 m^3/s (Quyet 2009). At the Tonlesap, the average water discharge increases to 16.644 m^3/s and is flowing into Viet Nam at Tan Chau and at Chau Doc (Quyet 2009). Most of the water will flow into the East Sea and only about 5% of the volume is flowing into the Gulf of Thai Lan and into other canals and chanels.

The River discharge at Tan Chau is 3-5 times larger than that of Chau Doc (Nguyen Anh Duc and Savenije 2006). This can be explained by the different rivers relief, and the water level recorded at Tan Chau always higher than that of Chau Doc. However, as Vam Nao River connects the Tien River and the Hau River and transfer about 40% of water from Tien River to Hau River during high flow, the volume of water at Hau River increases about 3 times and thanks to that there is an equal amout of water in these two rivers since this position to the sea. The flow discharges at Tan Chau and Chau Doc from 1996 to 2002 are presented in Figure 3.1.

There are two available sources of river discharge which can be used to calculate the relationship of the tidal prism and river cross-section (presented in Annex 3.3):

- The first source is the hourly river discharge of the Tien River collected in two weeks from 15/09/2009 to 30/09/2009 by ACDP machine (SIWRR 2010a).
- The second source is the monthly river discharge of the Tien and the Hau River collected from 1990 to 2002.

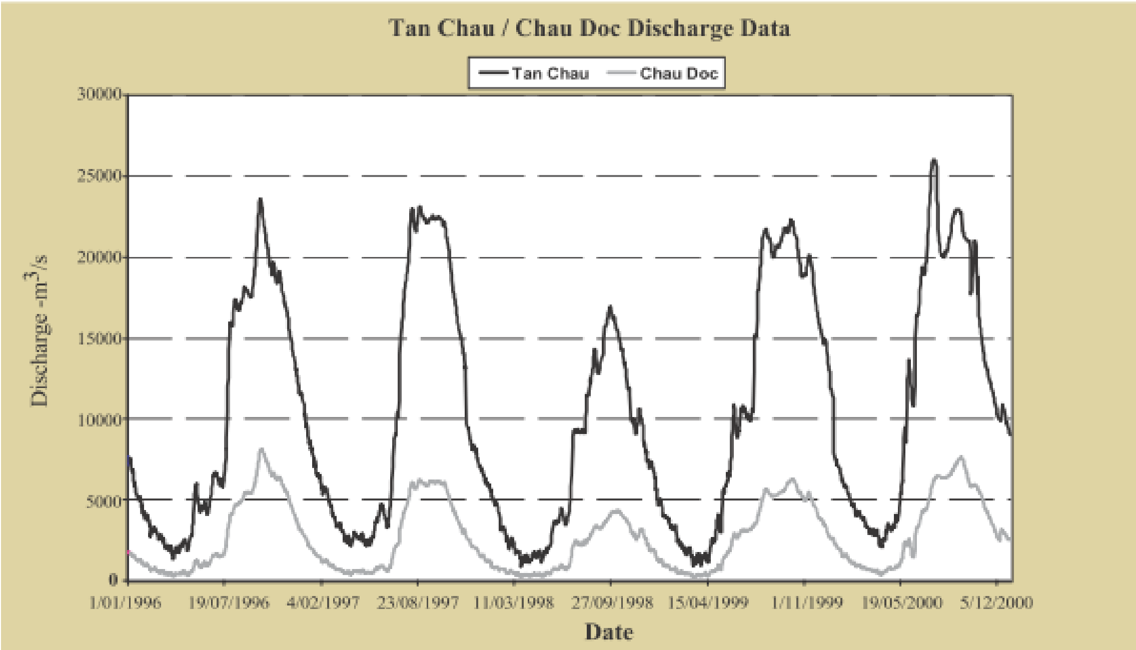


Figure 3.1: Flow discharges at Tan Chau and Chau Doc from 1/1996 to 12/2000 (Le Anh Tuan et al. 2007).

Therefore the empirical relationship will be calculated in two ways based on two different river discharge data. The most appropriate empirical relationship of tidal prism and river cross-section at Mekong estuaries will then be chosen from the result of these two approaches.

3.3. Empirical relationship

Since the ebb tidal is dominant at all seven branches of Mekong River, the empirical relationship will be created between ebb tidal prism and river cross-section. Three kind of ebb tidal prism are considered:

- Average ebb tidal prism($P_{ebb\text{-}average}$);
- Ebb tidal prism exceeded in 3 months/year($P_{ebb\text{-}3months}$);
- Ebb tidal prism exceeded in 1 month/year($P_{ebb\text{-}1month}$).

3.3.1. First approach

The ebb tidal prism will be calculated following these steps:

- Step 1: Calculate the average river discharge, the river discharge exceeded 3 months per year and river discharge exceeded 1 month per year for the 2 main tributaries of Mekong River: the Tien and the Hau River based on Figure 3.1.

- Step 2: Based on the data of river discharge collected for each branch of Tien River in 2 weeks from 15/09/2009 to 30/09/2009, calculate the distribution of river discharge from the Tien River to its branches (see table 3.2). Then use these ratios to calculate the average river discharge, the river discharge exceeded 3 months per year and the river discharge exceeded 1 month per year for each branch of Tien River, including: Tieu branch, Dai branch, Ham Luong branch, Co Chien branch and Cung Hau branch.
- Step 3: Calculate the ebb tidal discharge for each branch based on the discharge measured in 2 weeks for each branch
- Step 4: Estimate the ebb tidal prism correlated with each river discharge: average, 3 months exceeded, 1 month exceeded.
  Ebb Tidal Prism = 0.5T×(Average Ebb Tidal discharge + River discharge)

The detail of calculation can be seen in Annex 3.3. The result can be seen in table 3.3.

Table 3.2: River discharge characteristic for different braches of Tien River from 15/09/2009 to 30/09/2009 (SIWRR 2010a)

Branch name	$Q_{max-out}$ (m^3/s)	Q_{max-in} (m^3/s)	$Q_{average}$ (m^3/s)	Q/Q_{total} (%)		
				Q_{out}	Q_{in}	$Q_{average}$
Ham Luong	23034	-21673	3075	28.8	30.5	22.1
Co Chien	18666	-16457	4427	23.4	23.2	31.8
Cung Hau	11558	-9348	3048	14.5	13.2	22.1
Dai	17396	-15638	2397	21.8	22.0	17.2
Tieu	7628	-6651	843	9.5	9.4	6.1
Total	79903	-71009	13927	100	100	100

Table 3.3: Tidal prism calculated-first approach

Branch name	$P_{ebb-average}$ (10^6 m^3)	$P_{ebb-3monthsexceeded}$ ($10^6 m^3$)	$P_{ebb-1monthexceeded}$ ($10^6 m^3$)
Tieu	105	115	118
Dai	240	260	265
Ham Luong	345	375	380
Co Chien	250	290	300
Cung Hau	165	195	205

3.3.2. Second approach

The second data source provides the river discharge and volume of water going in and out for every month of year from 1996 to 2002 (7 years) for seven branches of Tien and Hau River (Annex 3.3).

The average ebb tidal prism can be calculated as:

Total water volume going out per day=Total water volumes going out in 7 years/ (7 years×12 months×30 days)

$P_{ebb\text{-}average}$=Total water volumes going out per days/2 (semi diurnal tide).
The same steps can also be followed to find out the ebb tidal prism exceeded in 3 months and ebb tidal prism exceeded in 1 month. The result can be seen in table 3.4.

Table 3.4: Tidal prism calculated -second approach

Branch name	$P_{ebb\text{-}average}$ ($10^6 m^3$)	$P_{ebb\text{-}3monthsexceeded}$ ($10^6 m^3$)	$P_{ebb\text{-}1monthexceeded}$ ($10^6 m^3$)
Tieu	82	98	104
Dai	125	149	158
Ham Luong	191	232	240
Co Chien	174	245	254
Cung Hau	192	267	277
Tran De	267	349	362
Dinh An	335	458	475

3.3.3. Result and evaluation

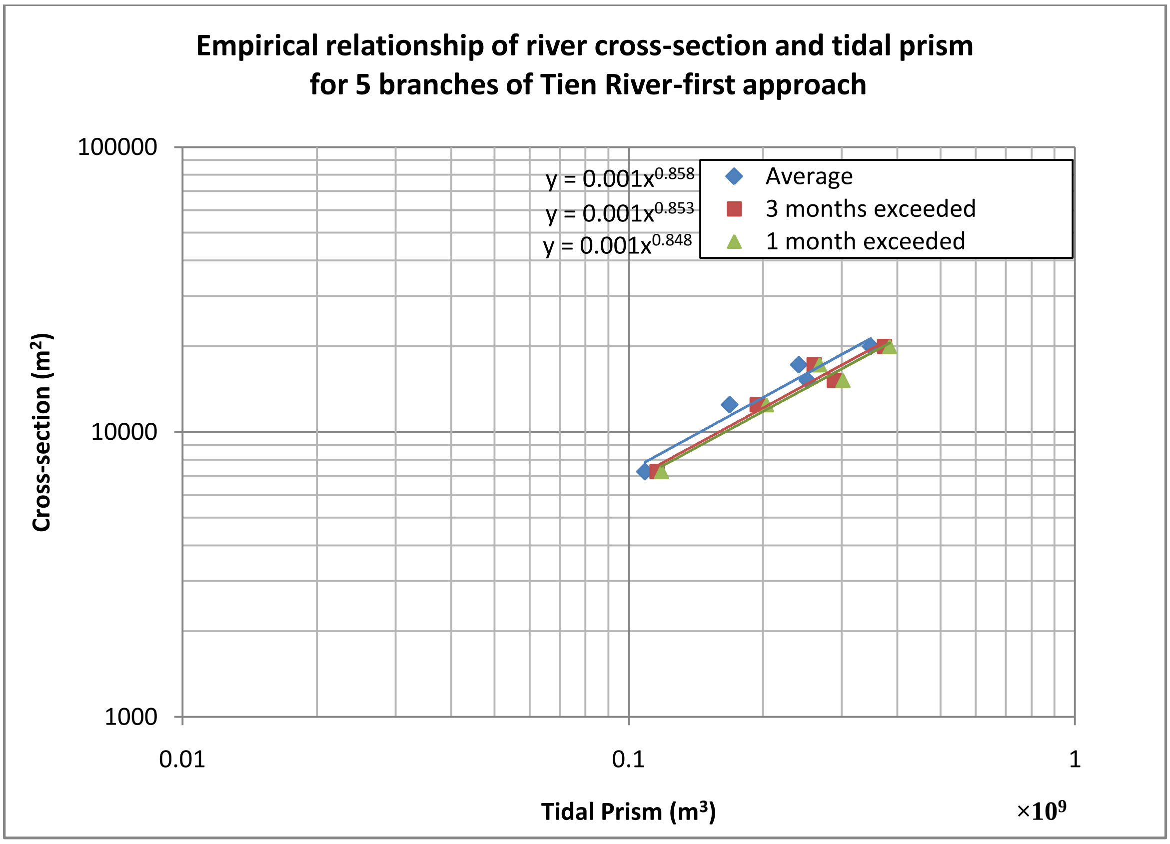


Figure 3.2: Empirical relationship of river cross-section and tidal prism for 5 branches of Tien River-first approach

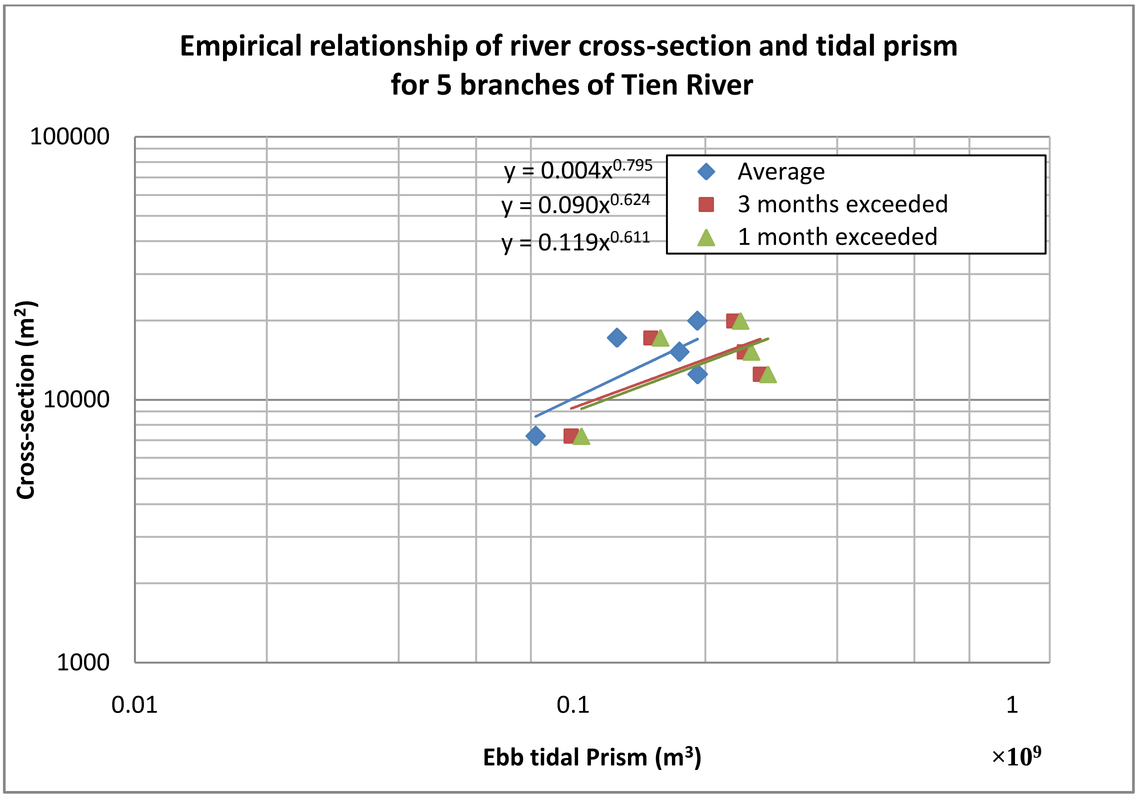


Figure 3.3: Empirical relationship of river cross-section and tidal prism for 5 branches of Tien River-second approach

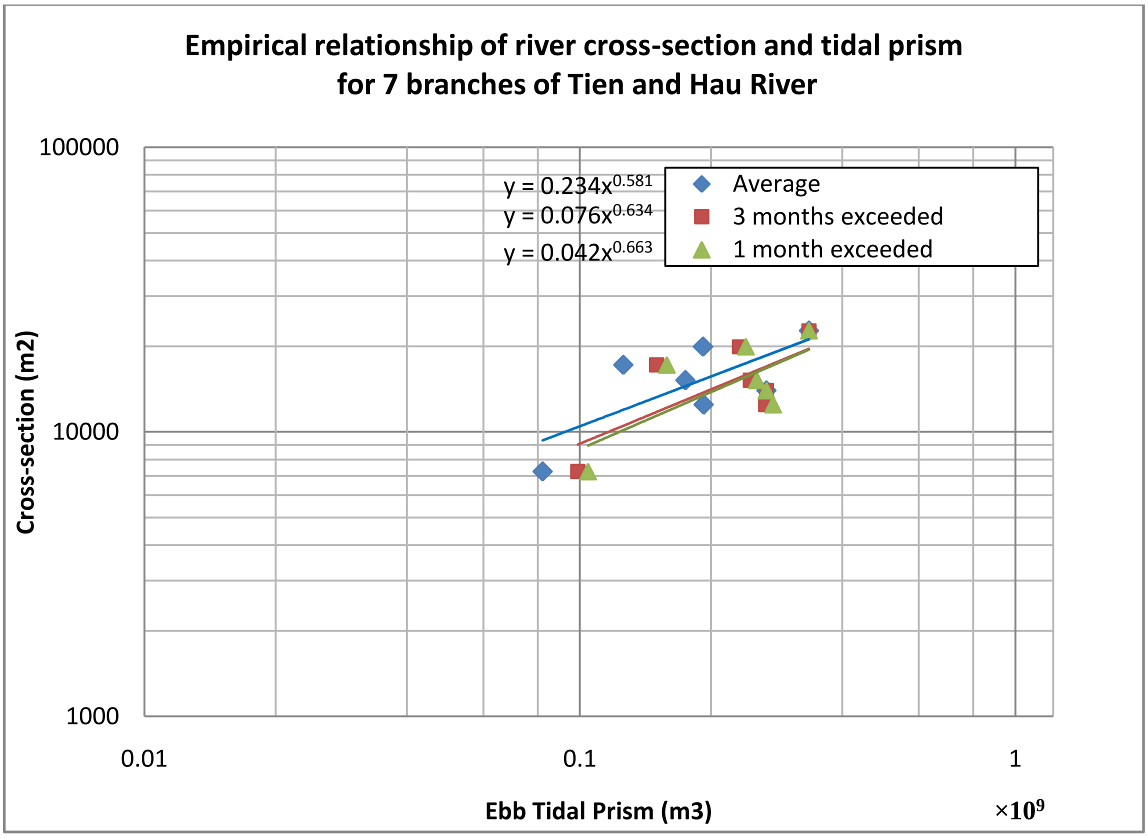


Figure 3.4: Empirical relationship of river cross-section and tidal prism for 7 branches of Tien River and Hau River – second approach

Based on the empirical relationship result (Figure 3.2 to Figure 3.4) it can be concluded that the first approach has the smaller deviation than the second approach which means the first approach provides the better empirical relationship line. The reason for that can be due to the location of the river discharge measurement since in the first approach the river discharge is measured near the river mouth (refer to table 3.5) which could provide the most accurate estimated tidal prism volume.

Table 3.5: Location of river discharge measurement station in the first approach

River branch	Location of river discharge measurement station in the first approach
Tieu	10°16'16.53"N,106°44'44.64"E 1 km from the river mouth
Dai	10°12'16.60"N, 106°42'55."E 4 km from the river mouth
Ham Luong	9°59'02.765"N,106°35'46.158"E 6 km from the river mouth
Cung Hau	9°53'38.44''N; 106°26'13.9''E 10 km from the river mouth
Co Chien	9°52'46.97"N; 106°30'43.47"E 5 km from the river mouth

Meanwhile in the second approach, the data is not directly collected near the river mouth because before 2002, river discharge data at the downstream of Mekong River are barely available since there are no station measurement near the river mouth therefore most of the data provided in the second approach is calculated based on the upstream stations data and some intermediary stations. Therefore, the data collected in the first approach is more reliable than in the second approach in order to estimate the ebb tidal prism near the river mouth. The empirical relationship created in the first approach will then be chosen.

However the tidal prism estimated in the first approach can be larger than in reality because the data based to calculate the tidal prism in the first approach were measured in the wet season from 15/09/2009 to 30/09/2009. The tidal prism and river discharge in September are always higher than in most of the other months. Therefore, the most appropriate river cross section and tidal prism relationship equation will be the one with the average tidal prism because the two other tidal prisms (three months exceeded and one month exceeded) will provide even higher tidal prisms in the prediction.

In conclusion the empirical relationship of tidal prism and river cross-section for the Mekong estuaries is:

$$A_c = 10^{-3} \langle P \rangle^{0.86} \qquad (6)$$

Combining equation (3) and equation (6) yields:

$$A_c = 5.39 \langle Q \rangle^{0.86} \qquad (7)$$

Table 3.6: Compare the empirical equation found for the Mekong Delta Estuaries and that of US entrances

Coefficient	US entrances		Mekong Estuaries (eq. 7)
	O'Brien (eq. 4)	Powell (eq. 5)	
b	2.3	1.51	5.39
m	0.85	0.83	0.86

The empirical equation found for the Mekong Delta Estuaries has the same order of magnitude (coefficient 'm') with other equations found for US entrances. The difference of coefficient 'b' can be explained due to the influence of river discharge. The Mekong Delta estuaries are strongly influenced by the river discharge while the US entrances (inlet barriers) are not.

3.4. Impact of closing down river branches

The Vietnamese government is planning to build discharge sluices at the three river branches: Ham Luong, Co Chien, Cung Hau in Tien River to prevent salinity intrusion (see Figure 2.8).

The length of the tidal influence can be estimated approximately 400 km (annex 3.4) which is longer than the distance from the river divide point to each of the river mouths (about 100 km). Therefore, when one of the branches is closed, it still can be filled by the tide coming from other branches or, in other word the other branches must carry out the tidal prism of the closed branch. This situation will lead to serious changes in river cross-sections of these two left branches.

Applying the empirical relation between the cross section of river branches and tidal prism and the distribution of river discharge over five branches of Tien River (table 3.2) could provide the approximation of cross-section change for the open branches when these other branches are shutting down. It is assumed that when the river cross-section change, only the river depth will change while the river width will remain stable.

Below, several cases will be considered are:

- Closing one branch;
- Closing two branches;
- Or closing all three branches.

Details of the calculation are presented in Annex 3.4. The result can be seen in table 3.7 and Figure 3.5.

Table 3.7: River depth change due to new discharge sluices construction

Branch name	Depth before closing (m)	Depth after closing (m)						
		1 branch			2 branches			3 branches
		Cung Hau	Co Chien	Ham Luong	C.Chien &C.Hau	HL & C.Hau	HL & C.Chien	HL,C.Chien, C.Hau
Tieu	7	8.5	9	10	11	12	14	19
Dai	8	8	9	10	11	12	14	20
HL	9	10	11		14			
C.Chien	10.5	14		16		19.5		
C.Hau	7		8	8			11.5	

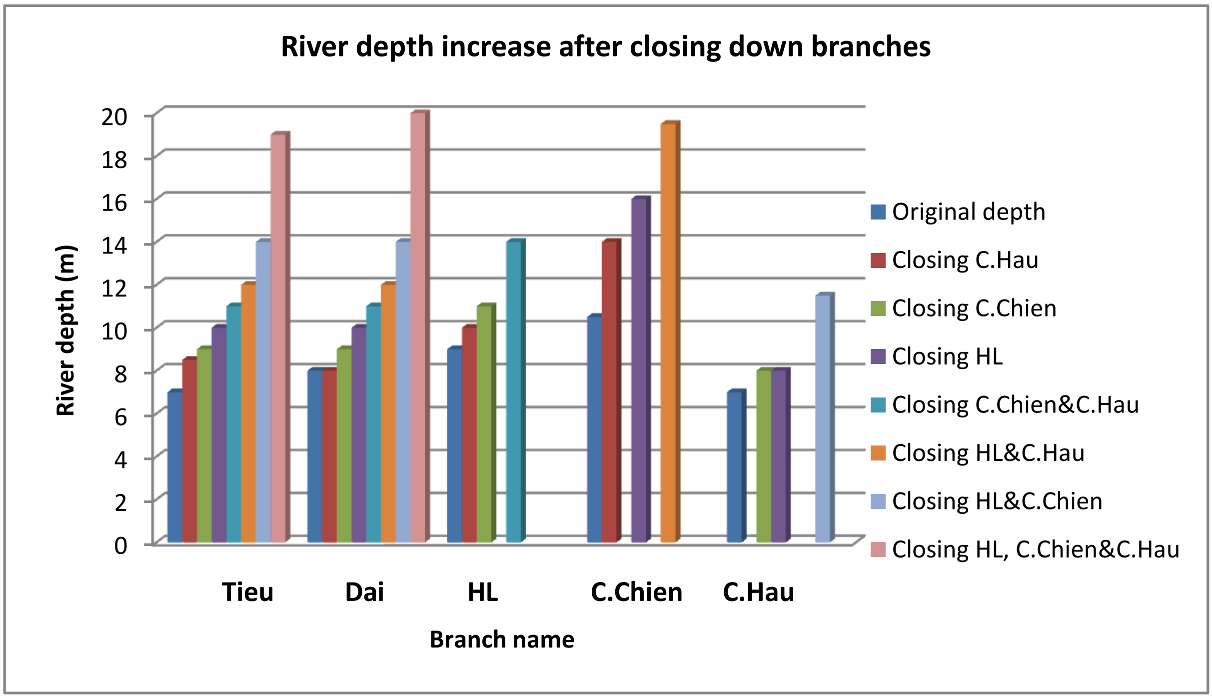


Figure 3.5: River depth increase after closing down branches

It can be clearly seen that, when one of three branches is closed, the river depth of other branches will be about 2 to 4 meters deeper. In these three branches, Ham Luong has the most influence on other branches when it is closed because of its large tidal prism. The situation will be at its worst when two or three branches are closed. If Ham Luong, Co Chien and Cung Hau are all shut down, Dai and Tieu branch will be deeper by more than 10 meters. Increasing the depth of the river will steepen the slope of the river bank and cause erosion at the river bank. Therefore, if one of the branches or all of them are closed as in the future development plan, action must be taken to protect the river bank and the mangrove forest along the river bank. There are number of "hard" solutions such as revetments, river groynes. The erosion of the river bank might be reduced however these methods will not have any benefit and sometimes they could even create adverse impact for mangroves. Therefore in this case a soft solution will bring more sustainable development for the MD estuary. Before closing down any branches the mangrove areas along other branches should be strengthened to ensure that in the future no erosion will occur.

3.5. River bank erosion

Because estuaries are situated on the border of land and sea, they are zones of rapidly fluctuating environmental conditions and are markedly influenced by catchment and oceanic processes as well as in-estuary uses (Hume and Herdendorf 1988). An estuary has characteristics of both river and sea. The sea and the river exchange their water, substances and sediments. The estuary is, therefore, a unique and complicated environment that is mainly influenced by tidal movements of the sea and the freshwater discharge of the river. In this section several reasons for river bank erosion will be discussed. Then the difference of the erosion between the upstream and downstream of the Mekong River will also be explained.

The main types of natural river erosion to be seen in the MD River are described below:

- Hydraulic, or fluvial, erosion: if the shear force of the water becomes higher than the shear force that can be mobilized between the soils particles, the soil particles will begin to move. At low forces the particles are only rearranged, but if the forces are strong enough they are lifted by the water and transported as long as the forces of the current are strong enough. When the forces of the current aren't strong enough to carry the particles they are deposited on the river bed. In addition to the shear forces between the particles themselves the stability, or erosion resistance, of the soil particles depends on their density, shape and grading, compactness of the bottom material and the angle of the bottom surface.
- River bend erosion: Secondary currents occur in the flows around bends. These flows transport coarse material to the convex side of the channel where deposits accumulate, while clearer water near the surface flows to the concave bank, causing sustained bank erosion.
- Wave erosion, erosion of river banks caused by water waves: These waves are most often caused by wind or ship traffic.

The erosions are different between upstream and downstream of the Mekong River. At the upstream, erosions are observed from May to September (wet season) while at the downstream erosions always happen from October to April (dry season).

In the flood season, the river discharge at the upstream is much larger than in dry season (according to Figure 3.1 river discharge at Tan Chau and Chau Doc in flood season is approximately 1.5 time larger than in dry season). However when the flow travels to the River mouth a huge amount of water discharge is divided into channels along the river and therefore the river discharge becomes smaller when it reaches the river mouth. The volume of the ebb flow at the river mouth is mainly coming from the tidal current going in and out of the river mouth.

Therefore when the flow reaches the River mouth, river discharge between the wet season and dry season is not so much different. Following the upstream river discharge (Figure 3.1) and monthly downstream river discharge of each River branch (annex 3.1) the difference of river discharge in the flood season and in the dry season of all branches in 2002 is calculated in the table 3.8.

Table 3.8: Maximum and average river discharge at upstream and downstream of the MR in flood and dry season

River branch	Flood season		Dry season		River discharge difference (m^3/s)	
	Maximum river discharge (m^3/s)	Average river discharge (m^3/s)	Maximum river discharge (m^3/s)	Average river discharge (m^3/s)	Maximum river discharge month	Average river discharge
Upstream						
Tan Chau	26000	13000	20000	9000	6000	4000
Chau Doc	7500	4500	5000	2500	2500	2000
Down stream						
Tran De	23000	19500	22000	19000	1000	500
Dinh An	28500	24000	27000	23000	1500	1000
Cung Hau	16500	14000	15000	13500	1000	500
Co Chien	15000	13000	14500	12500	500	500
Ham Luong	17500	15000	17000	14800	500	200
Dai	11200	9700	10300	9300	900	400
Tieu	7000	6000	6600	6000	400	0

Flood season: (May to October) the highest river discharge is observed at October.

Dry season: (November to April) the highest river discharge is observed at November.

Therefore, it could be said that at the upstream, erosions are the result of large water discharge combined with large precipitation causing exceeding water flow velocity (hydraulic or fluvial erosion).

Meanwhile at downstream the erosion can be the result of combining other factors such as wave, wind, tidal under the influence of Coriolis force since in the dry season wind and wave are much stronger than in flood season. According to the wind record, in dry season, the wind velocity can reach 10 to 15 m/s and sometimes even 20m/s at the river mouth and reduce to 9 m/s when blowing inside the river. The average velocity of the wind is about 4 to 6m/s.

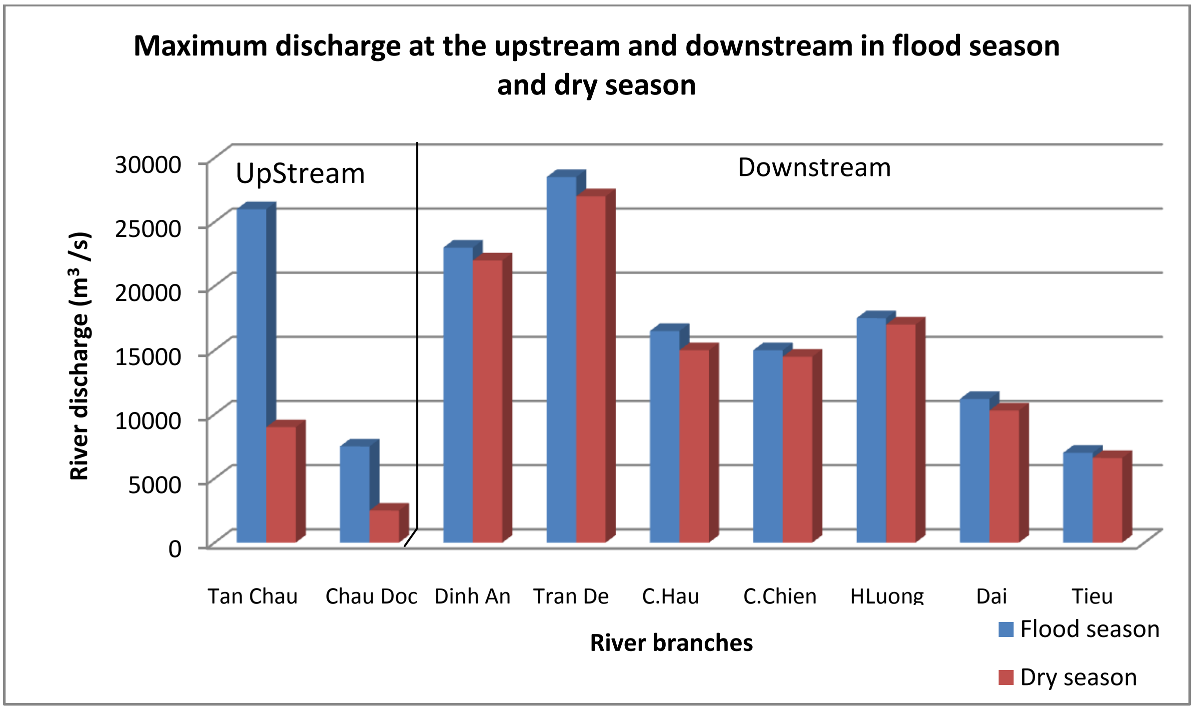


Figure 3.6: Maximum discharge at upstream and downstream of the MR in flood season and dry season

Besides, Observation also shows that near the river mouth, the left side (direction from the river to the sea) at all branches of Mekong River suffers more serious erosion than the right side. The situation of erosion and deposition at Dinh An branch (table 3.9 and figure 3.7) can be seen as an typical example.

Table 3.9: Situation of erosion and deposition at Dinh An branch in 2002 (SIWRR 2005b)

Bank	Section	Location	Length	Deposition/Erosion
Left bank	L1	Located at Luu Nghiep Anh village	4km	Erosion 2÷3m/yr
	L2	From Thanh Son village to Ham Giang village	5km	Erosion 3÷4m/yr
	L3	From Vam Lang Sac canal to the sea	7.6km	Quite flat, lots of mangroves
Right bank	R1	Located at An Thanh Nhi village	4km	Deposition in flood season, lots of mangroves, erosion from Nov to April
	R2	From An Thanh Nhi to Ben Ba river mouth	2km	Erosion 2÷3m/yr
	R3	From Ben Ba river to the sea	7.2km	Large alluvial flat, healthy mangroves development

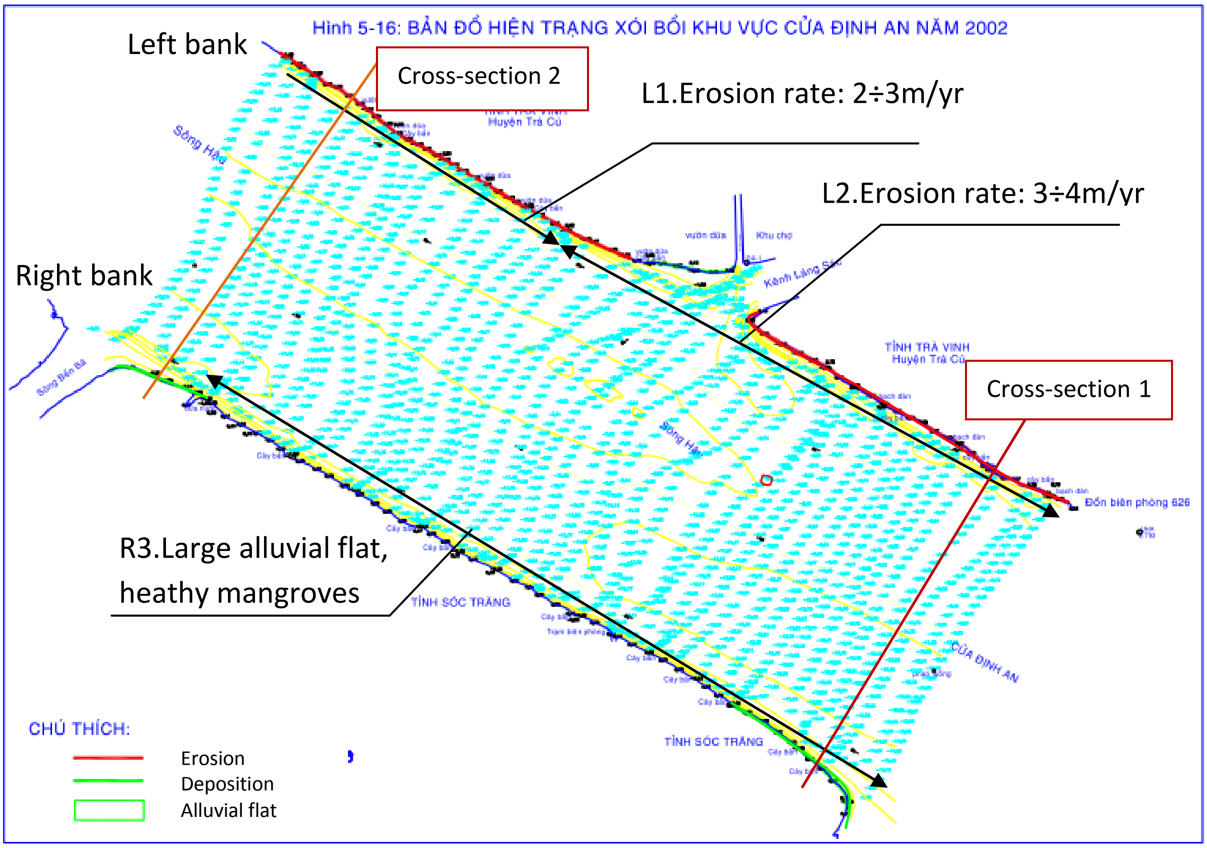
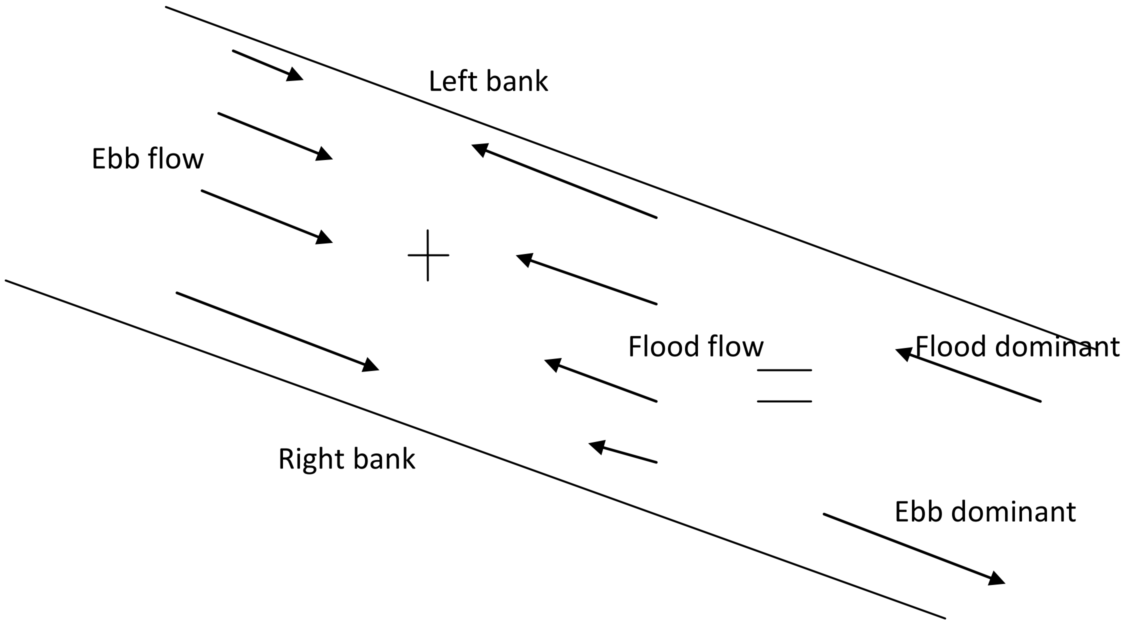


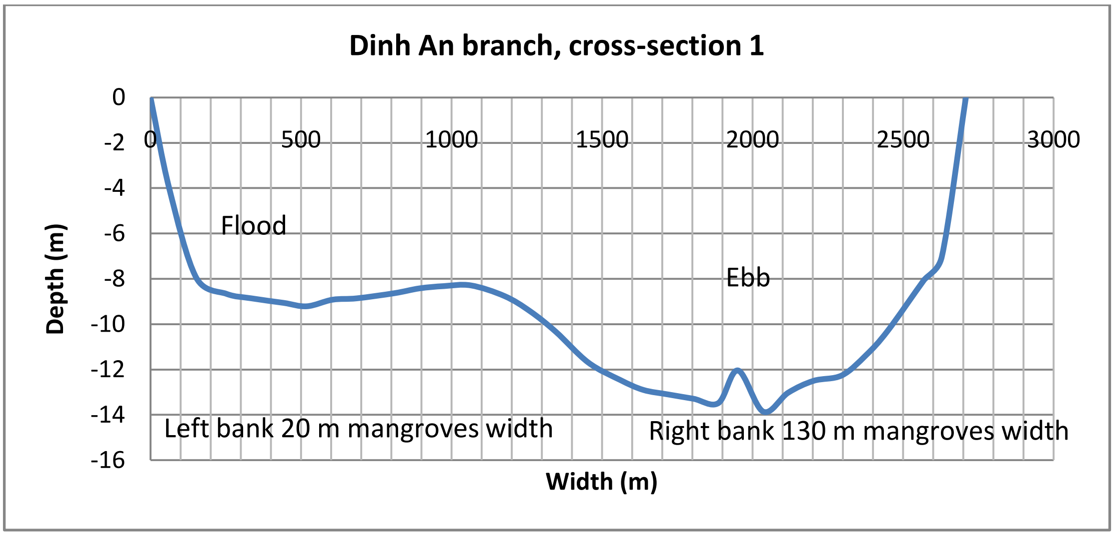
Figure 3.7: Erosion and deposition map of Dinh An branch in 2002 (SIWRR 2005b)

Since Viet Nam is above the equator, the Coriolis Effect will cause air and water current to deflect to the right. The water going in and out of the river under the influence of the Coriolis Effect will have the flow distribution as in the figure below:



Thus, under the influence of the Coriolis Effect the flood flow will dominate at the left side of the river bank while the ebb flow will dominate at the right side of the river bank.

Looking at Dinh An estuary cross-sections (cross-section 1 is located right after the river mouth and cross-section 2 is located at 6 km away from the river mouth) the right side of the river is deeper than the left side. Therefore the hypothesis of flooding flow dominated at the left side and ebb flow dominated at the right side of the river seems quite reasonable since the ebb flow is stronger than the flood flow so the ebb flow can create the deeper channel than the flood flow.



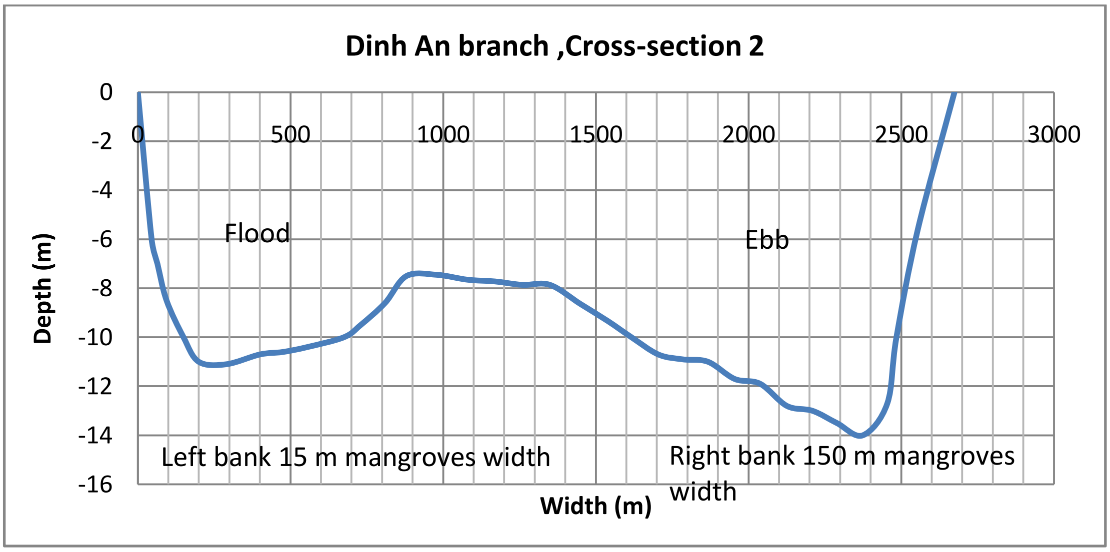


Figure 3.8: Cross-section at Dinh An branch

Therefore, the waves at the left side would be stronger than the waves at the right side since the flood dominance at the left side will strengthen the influence of the waves while at the right side the ebb dominance against and reduce the influence of the wave.

An overview of river bank erosion for other branch in 2002 can be found in Annex 3.5.

4. Mekong Delta Coast

Even though mangrove forests have the ability to protect both sea dike and coastline from attenuating waves during extreme events and reducing long term coastal erosion by trapping sediment along the Southern Coast of Viet Nam, there are many places where mangroves become more and more vulnerable. The status of mangrove forest development and their role for coastal protection in Viet Nam according to Ngo Dinh Que (2003); Ngo Ngoc Cat et al. (2005) and other authors is summarized in Annex 4.1. The reasons for mangrove degradation at the MD coast are provided by Phan Nguyen Hong and Hoang Thi San (1993); Minh et al. (2001); Christensen et al. (2008) including:

- The Viet Nam war (1962-1971);
- Clearance for shrimp aquaculture, agriculture land (1953-1995);
- Overexploitation of timber in the 1980s and early 1990s;
- Pollution;

However, there is one more important reason for mangrove degradation along the Southern Coast of Viet Nam, which has not received enough attention from the Vietnamese government and researchers, is that mangroves cannot regenerate if sea dikes are built too close to the mangrove forest. Along the Southern Coast, when sea dikes were built too close to the mangrove forest, for example at places such as Go Cong coastline (Figure 4.1) and Bac Lieu coastline where mangroves almost disappeared while at some other places, for example Cu Lao Duong (Figure 4.1), and Kinh Ba where mangroves have enough space for regeneration, they strongly developed and sedimentation was enhanced.

Therefore, this chapter will concentrate on the question of what is the suitable distance between sea dikes and the mangroves to ensure the normal development of mangrove forest or, in other words, to what extend does the sea dike cause an adverse effect to mangrove forests growths. The information of coastline evolutions is therefore necessary and will be presented in section 4.1.1 as background to provide answers to this question. The relationship of wave attenuation and mangroves width along the Southern coast of Vietnam will then be applied and generated by the SWAN model.

Figure 4.1: Mangrove forests at Cu Lao Duong and Go Cong (Google Earth 2012)

4.1. Mangroves degradation in relation to the distance from the sea dike to the outer edge of the mangroves forest.

4.1.1. Coastal evolution

Studies and reports of the Mekong Delta evolution (Annex 4.2) all conclude that: "During the highstand and regressions of relative sea level over the last 4550 yr BP, delta propagation has produced a great flat-plain of 62,520 km^2. This extremely fast propagation could be due to: (a) very high sediment supply depositing in the slight inclination of the receiving basin; (b) neotectonic movements and relative sea-level changes; (c) widespread mangrove forests playing an important role to enhance sediment accumulation."

The supply of sediment to the coast is periodic and closely related to river discharge, which is controlled by high precipitation during the wet summer monsoons and low precipitation during the dry winter monsoons. However the sediment transport is dominated by the north-eastern monsoon. The Southwest monsoon dominates from May to October, but it is much weaker compare to the Northeast Monsoon (Annex 2.3). Therefore in the summer, when sediment is discharged into the sea, it is likely to remain close to the shore of the river mouth until long shore currents, generated by the north-easterly winter monsoon, transport them southwest along the coast.

Dominant south-westward sediment transport is also indicated by the asymmetric geometry of beach ridges, and by the formation of the Ca Mau Peninsula at the south-western edge of the delta, which is composed of finer sediments than those near the river mouths (Tamura et al. 2010).

The results of surveys and assembling of reported data from the localities, together with the results of interpretation of maps and remote sensing data, show that before 1940 there was no erosion in the coastal and river mouth areas from Vung Tau to Ha Tien (Ngo Ngoc Cat et al. 2005).

In the period 1940 - 1950, coastal erosion did occur in the river mouth areas of the Southern region, but at a very low rate. Since 1960 coastal erosion has been rather common along most of the coastal zone of the provinces in the Southern plain.

Since 1995, coastal erosion in the Southern plain has been occurring in many areas, in a rather complicated manner, causing serious consequences.

The erosion of the coastline could be due to a combination of several factors including:

- Reduce sediment budget: it can be seen from Figure 2.11, that due to the construction of a new dam in the upstream of the Mekong River in 1993, the suspended sediment is reduced to about 20 % at Tan Chau and My Tho, and more than 30% at Can Tho.
- Wave and currents flow.
- Wind and storm conditions.
- Relative sea level rise: Data from tidal gauges along Viet Nam coasts show that sea level rise increased at the rate of about 3 mm/year during the period of 1993-2008 which is comparable with the global tendency (Pham Khoi Nguyen 2009)
- Degradation of mangroves: About 40 % of mangroves forest was destroyed in the Viet Nam war (1962-1971); mangrove forests continue to be destroyed for timber exploitation, aquaculture and shrimp farming. Water pollution due to shrimp farming and aquaculture, is also one of the reasons for mangroves degradation along the coast. One more reason for mangroves degradation which is not received enough attention of the government, is the impact of closed sea dikes.
- Human activities.

The coastal evolution map is presented in the figures below.

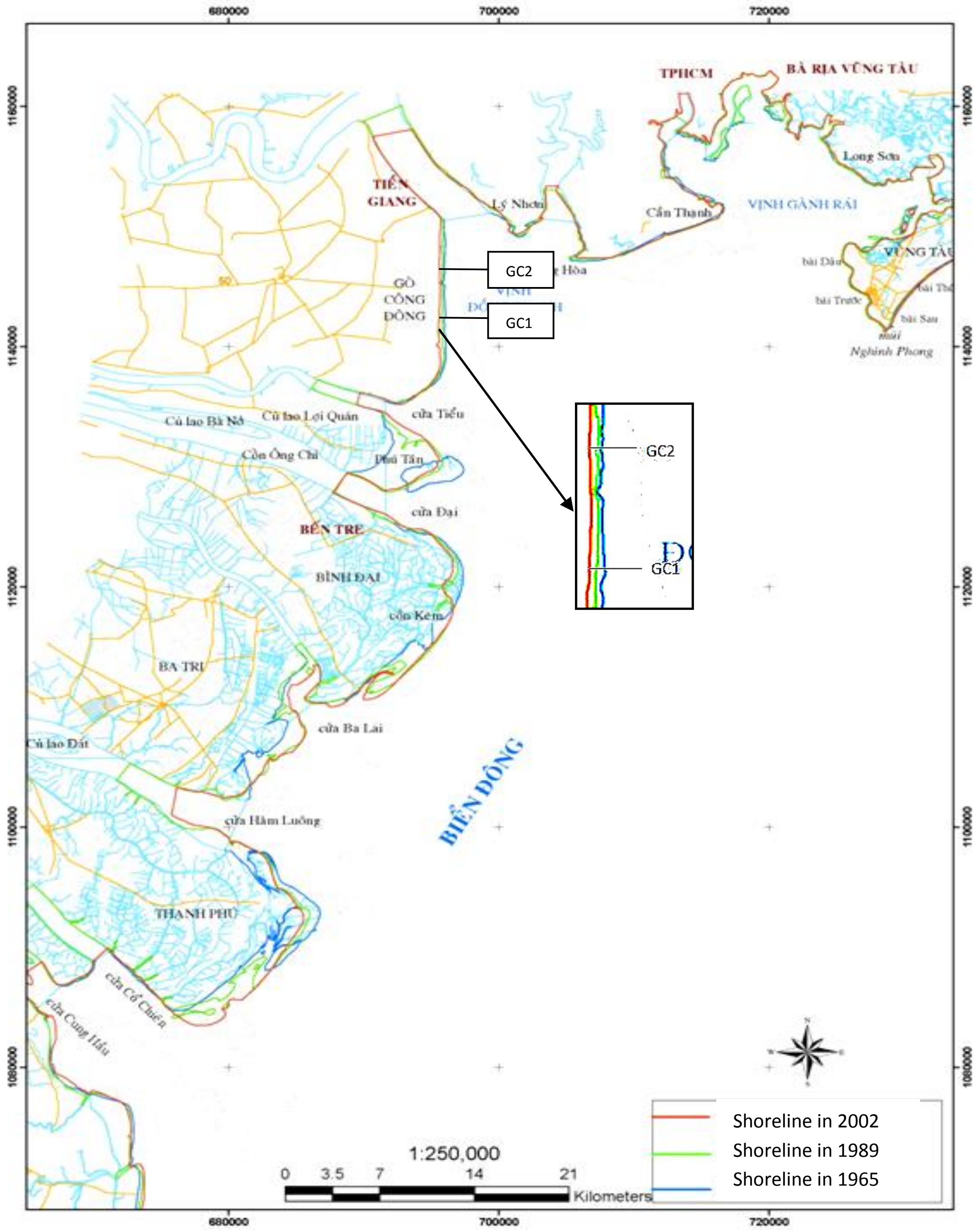


Figure 4.2: Coastline change from Vung Tau to Ben Tre (SIWRR 2005a)

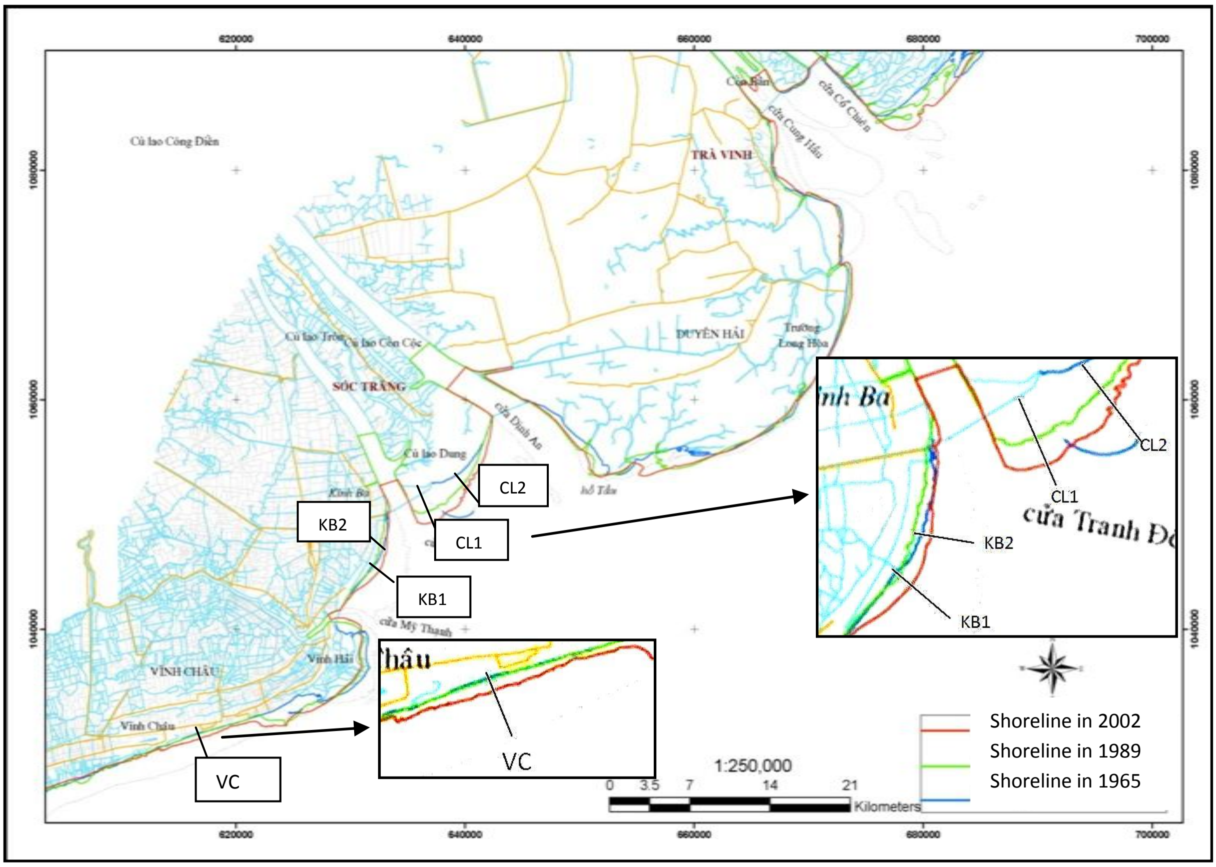


Figure 4.3: Coastline change from Tra Vinh to Soc Trang (SIWRR 2005a)

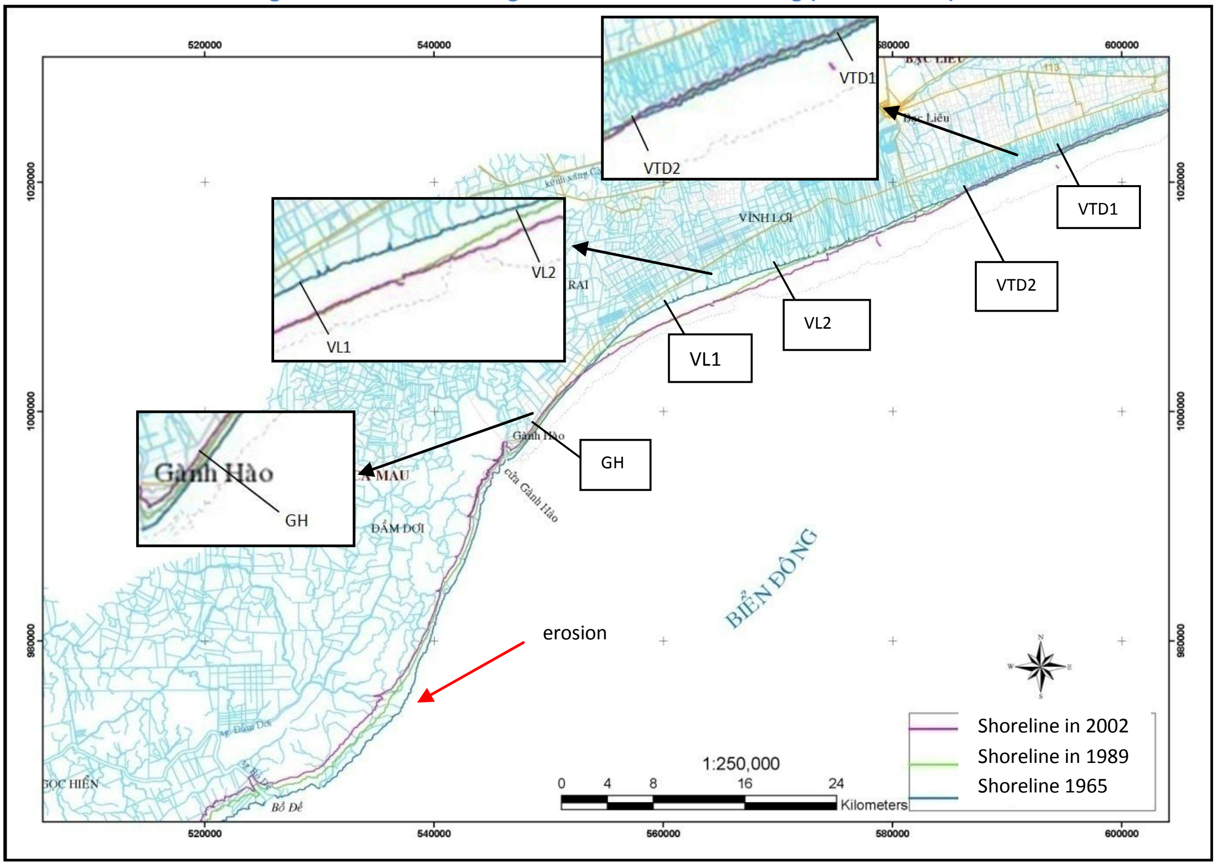


Figure 4.4: Coastline change from Bac Lieu to Ca Mau (SIWRR 2005a)

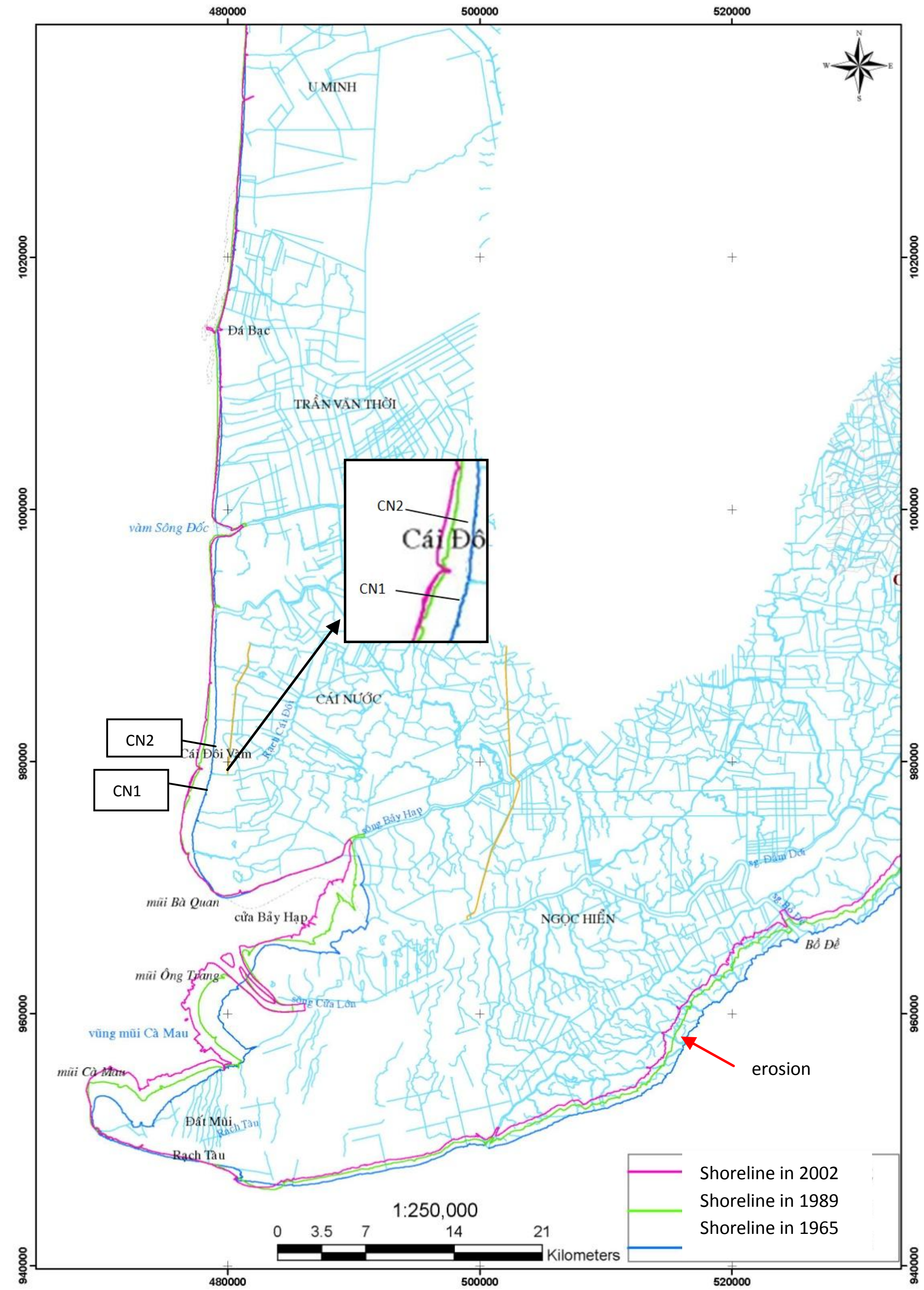


Figure 4.5: Coastline change at Ca Mau (SIWRR 2005a)

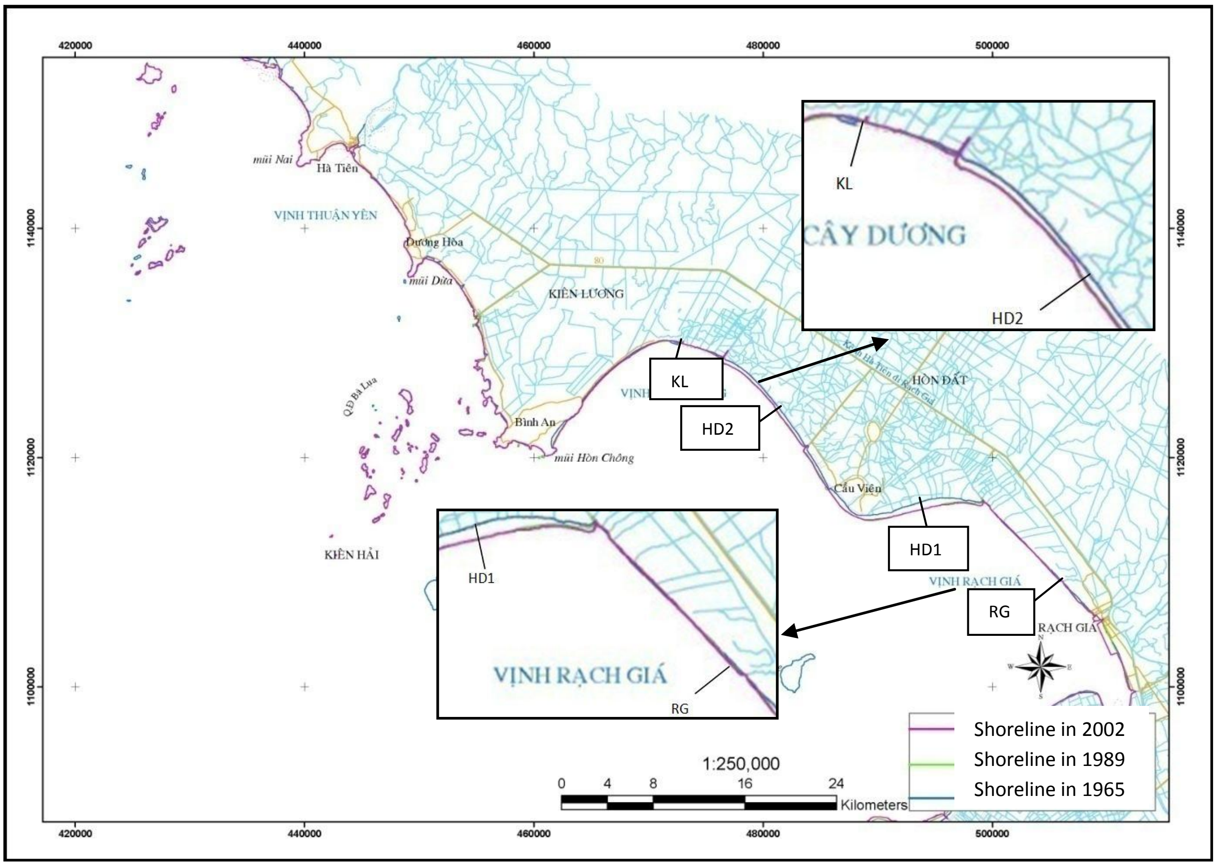


Figure 4.6: Coastline change from Rach Gia to Ha Tien, Kien Giang province (SIWRR 2005a)

4.1.2. Relationship of mangroves forest width and coastline evolution

Coastline erosion and mangroves degradation have a strong impact on each other. When the coast is starting to erode, the propagules will not have enough space to growth. If the erosion is getting more serious, even mature mangroves can erode away with the soil. Conversely, mangrove's roots capture sediment, therefore enhance sedimentation. Beside, mangroves also help to reduce wave height and wave energy.

As mentioned in section 4.1.1, erosions have become more common along the Southern Coast since 1960. This might be due to mangrove degradation in the Viet Nam war from 1962 to 1971. At this time, there were only 138 km discontinuous sea dikes. Then from 1975 to 1998 more sea dikes were constructed along the Southern Coast (see section 2.2.1). Observation also shows that since 1995, erosion happened in rather complicated and at a larger scale. Thus, it could be said that sea dikes have a certain impact on coastline erosion and therefore mangrove degradation. However, to what extend can the sea dike have an impact on mangrove degradation? To answer this question the following hypothesis will be made: "if a sea dike is built too close to the mangrove forest, the mangroves will be degraded". The distance from the sea dike to the outer edge of the mangrove forest can be considered as the width of the mangrove forest.

The impact of sea dike on mangroves degradation then can be described as the relationship between the width of mangrove forest and the rate of coastline erosion or sedimentation. The mangrove forest width can be measured with Google Earth. The measurement will be taken at different locations which suffer from erosion or and sedimentation along the Southern Coast. Ca Mau peninsula is not taken into account since at this location no sea dike was built in the past. There are **two steps** need to be taken in order to identify the relationship between mangroves width and coastline evolution which are:

1. Step 1: Locate the position of the sea dike along the Southern Coast and measure the distance from the sea dike to the outer edge of the mangrove forest (mangrove width) at the present time by Google Earth for each specific location.

The locations are chosen based on two criteria:

- where the sea dike can be clearly seen on Google Earth;
- And where a clear coastline evolution trend can be observed on the evolution maps.

Then, mangroves width will be measured by the Ruler tool of Google Earth.

The coastline evolution according to the evolution maps (figure 4.2 to figure 4.6) are observed in two periods:

First period: (24 years) from 1965 to 1989;

Second period: (13 years) from 1989 to 2002.

According to the scale classification of shores and shoreline variability (Stive et al. 2002), these evolutions belong to the middle term scale with the time scale from years to decades and the space scale from 1 to 5 km. Therefore, for each location where the measurement takes place the observed distance along the coastline will be chosen at about 2 km. Thus, several cross section will be chosen for each location; the cross-section will be chosen at the place where the rate of erosion or sedimentation is quite similar within 2 km length of observation.

There are 3 values of mangroves width will be measured for each 2 km shoreline including:

- The smallest value;
- The largest value;
- The control value: the major value of mangroves width observed within 2 km selected shoreline.

The chosen locations and cross-sections are presented in the table 4.1.

Table 4.1: Chosen location and cross-section for mangroves width measurement

Maps	Location	Cross-section
Figure 4.2	Go Cong	GC1, GC2
Figure 4.3	Cu Lao	CL1, CL2
	Kinh Ba	KB1, KB2
	Vinh Chau	VC
Figure 4.4	Vinh Trach Dong	VTD
	Vinh Loi	VL1, VL2
	Ganh Hao	GH
Figure 4.5	Cai Nuoc	CN1, CN2
Figure 4.6	Rach Gia	RG
	Hon Dat	HD1, HD2
	Kien Luong	KL

2. Step 2: Based on the evolution map (Figure 4.2 to Figure 4.6) calculate the rate of erosion and accretion at these locations chosen in step 1 for two periods (1965-1989) and (1989-2002). The results are shown in the table 4.2.

Table 4.2: Distance from the sea dike to the outer edge of mangrove forests and coastline evolution rate

Cross-section	**1965-1989**		**1989-2002**		**Mangroves width (m)**	
	Coastline change (m)	Rate of erosion /sedimentation (m/yr)	Coastline change (m)	Rate of erosion /sedimentation (m/yr)	Range	Control value
East Coast						
GC1	-350	-15	-300	-20	0	0
GC2	-250	-10	-350	-25	50÷150	130
CL1	1800	75	1000	80	1050÷1200	1100
CL2	900	40	650	50	800÷950	900
KB1			1000	80	900÷1200	1200
KB2	-350	15	550	40	700÷850	750
VC			550	40	450÷600	500
VTD1			-350	-25	50÷180	150
VTD2					200÷300	250
VL1	1600	65				800
VL2	700	30	600	45	600÷750	700
GH	-350	-15	-300	-20	150÷250	200
West Coast						
CN1	1500	60	300	20	300÷450	400
CN2	1000	40	550	40	850÷900	900
RG					200÷300	250
HD1	700	30			300÷450	450
HD2	350	15			300÷400	350
KL					50÷170	150

(red)	Erosion
(light blue)	Sedimentation
(grey)	No significant change over years

From table 4.2 some conclusions can be made:

Along the West Coast

There was not so many significant change observed along the West Coast. For example, there are no changes at Rach Gia and Kien Luong since 1965 and at Hon Dat, there were only small changes from 1965 to 1989 and no more change was observed from 1989 until 2002. At other places, slight sedimentation happened, however the accretion rate was reduced between the two periods of 1965-1989 and 1989-2002. In the future, if the sedimentation rate continues to decrease, erosion may happen.

At most of the places the distance from the sea dike to the outer edge of the mangroves is fluctuating from 300 meters to 500 meters. The largest distance from the sea dike to the outer edge of the mangroves is 900 meters found at Cai Nuoc. At Cai Nuoc, sedimentation is still prevails however the accretion rate is significantly reduced from 60 to 20 m/yr at CN1 cross-section where the mangrove forest width is only 450 meters.

Along the East Coast

In 1965 erosion happened in Go Cong and continued to happen until 2002 with a higher erosion rate during the period of 1989-2002 than during the period of 1965-1989. For instance the erosion rate estimated for GC2 cross-section from 1965 to 1989 of 10 m/yr, increased to 25 m/yr in the period between 1989 and 2002. Accretion was observed at a higher rate at the place where sedimentation happened in the past; for example, at CL1 cross-section the sedimentation rate increased from 75m/yr during the period from 1965 to 1989 to 80 m/yr in the period from 1989 to 2002.

Accretion is still the dominant trend along the East Coast except in places as Go Cong, Vinh Trach Dong and Ganh Hao.

It can be seen that the wider the distance from the sea dike to the outer edge of the mangrove forest, the higher the sedimentation rate that can be achieved. For instance with 1100 to 1200 m distance between the sea dike and the outer edge of mangroves the sedimentation rate can reach 80 m/yr (CL1 and KB1).

The relationship of mangroves width and East Sea coastline evolution is presented in Figure 4.7. This empirical relationship is based on the control value of the mangroves width and the evolution rate of the coastline in the period of (1989 to 2002). In figure 4.7, the vertical bar is 5 m/yr for every data points while the horizontal bar is drawn according to the range of the mangroves width (see table 4.2).

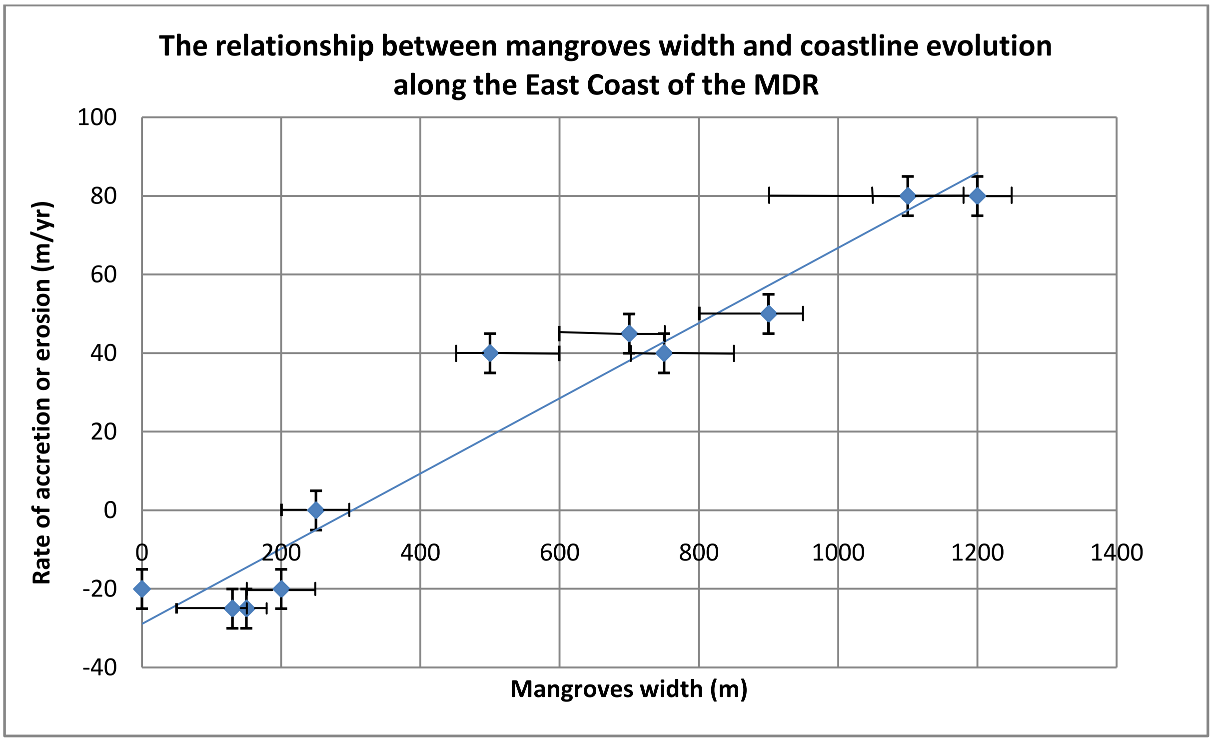


Figure 4.7: The relationship between mangroves width and coastline evolution along the East Coast of the MDR

It can be seen from Figure 4.7 that, the shoreline will remain stable with the protection of 300 to 400 m wide of mangrove forest. It is obvious that the larger mangrove forest width the higher sedimentation rate that can be achieved. For example the sedimentation rate of 80 m/yr can be achieved with a mangrove width of about 1000 to 1200m. However the coastline evolution also depends on many other factors such as: sediment supply, hydraulic conditions (wave, wind, current), bathymetry etc. Therefore, there is no unique critical mangroves width value that can be set for all shorelines. For instance, there will be a huge difference between the critical mangroves width of the East Coast and that of the West Coast. Even though the West Sea has smaller tidal amplitudes and smaller wave heights, the sediment supply in the West Sea is also weaker than in the East Sea. Therefore, no significant erosions are observed along the West Coast nor is there much sedimentation to be found even at the location where mangrove forest width is about 900 m.

However all along the East Coast, the natural characteristics are quite similar (see chapter 2) with larger tidal amplitudes, small wave heights, gentle slope and a larger sediment supply from the Mekong River system. Thus, the critical value of 300 to 400 m mangrove width can be used as a first estimation for coastal reclamation and mangrove forest restoration along the East Coast of Viet Nam. For example the distance from the sea dike to the outer edge of the mangrove forest should be at least 300 to 400 m to ensure the stability of the coast.

Creating the relationship between mangrove forest width and coastline evolution seems quite reasonable for the East Coast of the Mekong Delta Viet Nam since among other reasons (see section 4.1.1) waves during the Northeast monsoon is the major factor leading to coastline erosion and mangroves are very effective in reducing wave height and wave energy. In the next part (section 4.2) the critical value of mangroves width will be checked again for its ability of wave attenuation along the East Coast.

This kind of relationship could also be suggested for the West Coast (observation data are also shown in table 4.2). However it will not be created here because under the shortage of sediment supply, small wave heights and restricted tidal amplitudes, mangrove forest apparently do not have the same influence on coastline evolution as in the East Coast. As mention earlier in section 2.3, due to the deficiency of sediment supply, mangroves cannot develop far and often form a marginal community along the coastline. Moreover, the small tidal amplitude and small wave height at the West Sea does not threaten the stability of the coastline. If erosions happen, the only reason could be due to the starvation of sediment budget. For instance at CN2 cross-section, even though the mangroves width is 900m, accretion still happens but the accretion rate is considerably reduce from 55 m/yr in the period of 1965 to 1989 to 40 m/yr in the period of 1989 to 2002 (see table 4.2).

This empirical relationship should also not be created for the mangroves along the estuary since mangroves foundation can be washed away due to river bank erosion (see Figure 4.8). At one side of the river bank, sedimentation happens and mangroves develop while at the other side erosion happens and mangroves will be collapsed together with the foundation. This type of erosion is known as bend river erosion (see section 3.5).

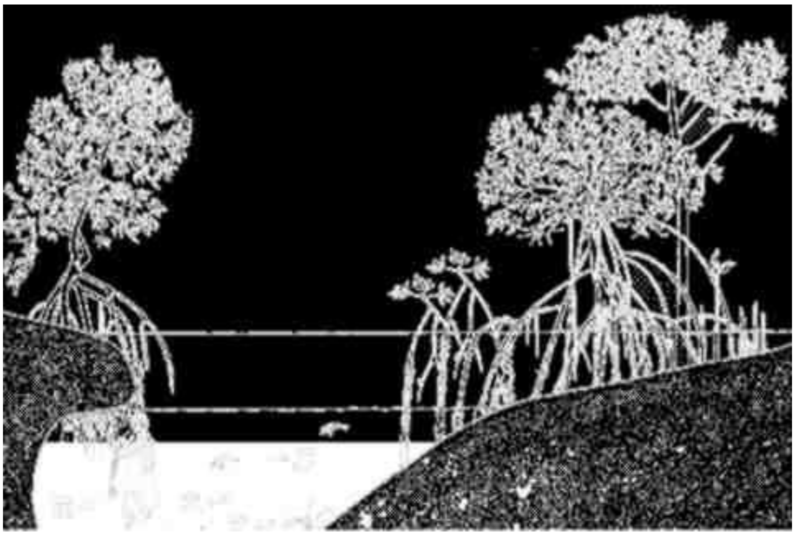


Figure 4.8: Failure case in planting mangroves along the River bank (Bob Ursem)

Therefore, in conclusion, the empirical relationship between mangroves forest width and the evolution rate of the coastline should only be created and used for the East Coast of the Mekong Delta Viet Nam. The critical mangroves width for the East Coast is about 300 to 400 m. The new sea dike constructed according to the future development plan of Vietnamese Government (see section 2.2.1) along the East Coast should be located at least 300 to 400 meters from the outer edged of the existing mangroves.

4.2. Wave attenuation in relation to mangroves width along the East Coast

There have been many studies and experiments in wave attenuation in mangroves forest (Ngo Dinh Que 2003; De Vos 2004; Meijer 2005 and Ngo Ngoc Cat et al. 2005). They all conclude that mangrove forests are very effective for wave height and wave energy reduction.

In the previous part, the critical width of mangrove forest at a stable coastline in the East Sea is found to be equal to 300 to 400 meters. In this section SWAN 1D is used to calculate the wave attenuation behind the mangrove forest for different mangroves width. The critical value for mangrove forest width will then be tested in terms of wave height attenuation.

Since the slope of the MD coastal zone is quite similar (about 10^{-3}) one location where mangroves are strongly developed will be chosen to evaluate the effectiveness of mangrove forest in wave attenuation. As along Soc Trang coast especially near Dinh An and Tran De branch, a large mangroves width (from 500 to more than 1000 m) and a high sedimentations rate (from 40 to 80 m/yr) were observed (see section 4.1), it is decided to choose this location for modelling.

4.2.1. SWAN model

4.2.1.1. SWAN basic

SWAN is a third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. The model is based on the wave action balance equation with sources and sinks. In this study, the following physics will be accounted by SWAN 1D:

- Wave generation by wind.
- White capping, bottom friction and depth-induced breaking.
- Dissipation due to vegetation.

4.2.1.2. Vegetation dissipation in SWAN

The SWAN model assumes the mangrove vegetation to consist of cylindrical units. The important factors in such a case are the diameter and density of each cylinder. Most mangrove trees exhibit a structure with three distinct layers: roots, stem and canopy, with regard to the projected surface (Figure 4.9). This schematization is however quite simple and therefore the vegetation parameters related to hydraulic loss is not fully described. Researches on vegetation parameters and hydraulic process within mangrove forest are ongoing. The newest result comes from Husrin et al. (2012) which provide an estimation of drag and initial coefficient a function of Reynolds number for the parameterized mangrove models with stiff structure. In this study, for the purpose of simplicity, drag coefficient will be assumed to be 1.

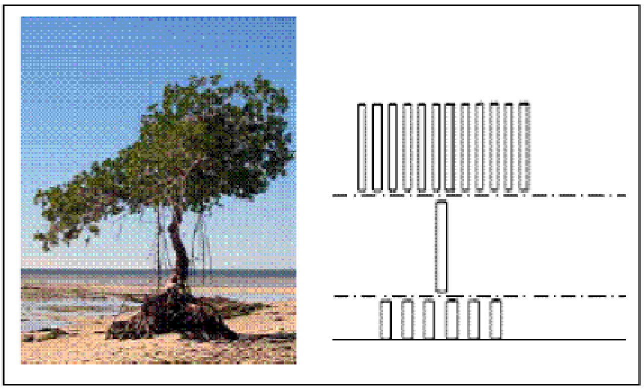


Figure 4.9: Mangrove tree height schematization followed in SWAN 40.55MOD (Burger 2005).

Morison's equation is using in SWAN to calculate wave attenuation in cylinders. The energy dissipation expression used in this model, given in equation 8, is the one by Dalrymple et al. (1984) which forms the basis of the empirical model developed by Mendez & Losada (2004).

$$\varepsilon_v = \frac{2}{3\pi}\rho C_D b_v N \left(\frac{gk}{2\sigma}\right)^3 \frac{sinh^3 k\alpha h + 3sinhk\alpha h}{3kcosh^3 kh} H^3 \tag{8}$$

Where:

ε_v is the time-averaged rate of energy dissipation per unit area;

C_D, b_v and N are the vegetation drag coefficient, diameter and spatial density;

k is the average wave number;

σ is the average wave frequency;

h is the water depth (m);

H is the wave height at that point (m).

4.2.2. Mangroves characteristic

4.2.2.1. Mangroves species in Mekong Delta Viet Nam

Sixty nine mangrove species were found in the Southern Coast of Viet Nam. The mangroves and other coastal vegetation were found to consist mainly of Sonneratia alba, S.ovata, Ceriops tagal, Rhizophora apiculata, R. Mucronata, Bruguiera cylindrica, B. Parviflora, Avicennia alba, A. Officinalis and Nypa fruiticans. The Southern Coast has favourable condistions, especially rainfall and alluvium, for the growth and distribution of mangrove trees. Therefore, mangrove species are quite diverse in this area:

- Pioneer stage: Avicennia alba and Sonneratia alba are pioneer species along the coast. Like other pioneer species, they play the role of maintaning alluvium which gradually makes the land higher and suitable for the trees and seeds of other later species.

- Transitional, intermediate stage: A community of Avicennia alba-Rhizophora follows the pioneer stage. Propagules of Rhizophora apiculata are rapidly developed due to the protection of A.alba from waves and water flow. After 4 to 5 years Rhizophora surpasses A.Alba and the pioneer species is eliminated in due course of time. Higher inland, a mixed community of R.apiculata-C.decandra is developed.
- Final stage: Once the land becomes highly elevated so that it is flooded only by spring tide, the former community is replaced by a new one. Thus, multi-species communities consisting of L.racemosa, B.parviflora, Excoecaria agallocha and a few associated mangrove species, such as Thespesia populnea, Cerbera manghas, Hibiscus tiliaceus, etc., can be found.

Generally Rhizophora sp., Sonneratia and Avicennia are present in the lower part of the intertidal zone; the upper part are typically colonized by the back mangrove trees, Avicennia sp. and Bruguiera sp. M.

An example of the natural succession of mangrove vegetation at Ca Mau Cape is presented in Figure 4.10.

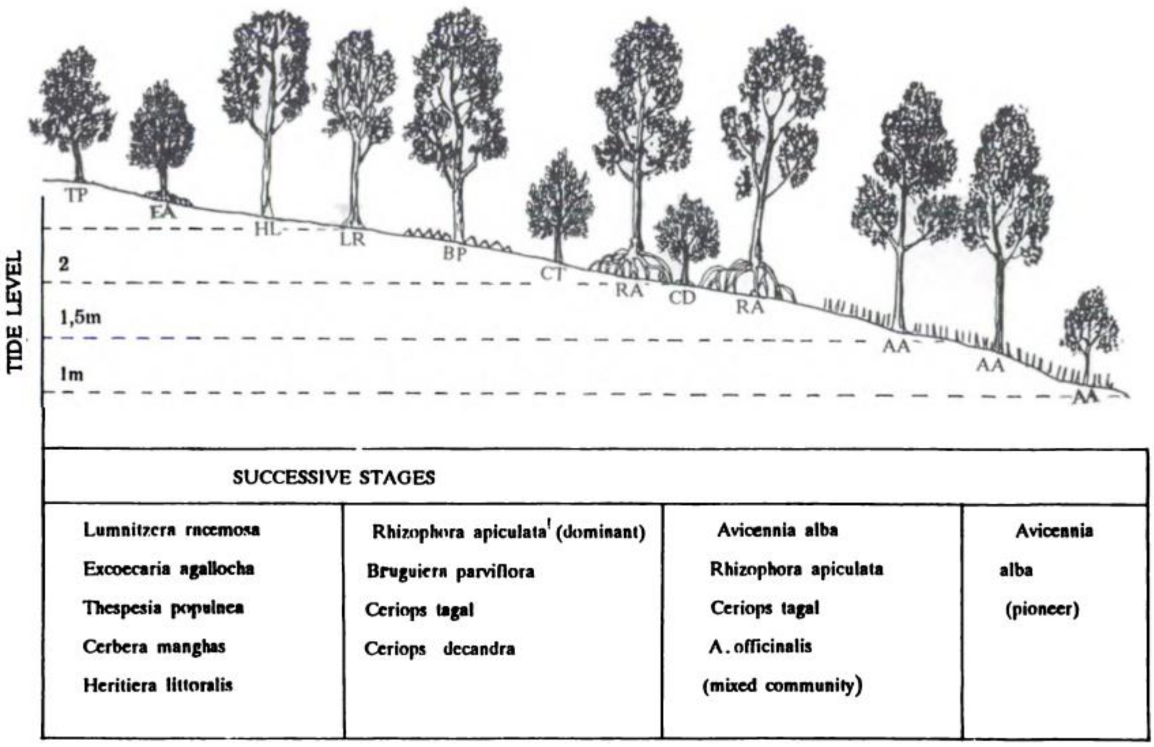


Figure 4.10: Natural succession of mangrove vegetation at Ca Mau Cape (Phan Nguyen Hong and Hoang Thi San 1993)

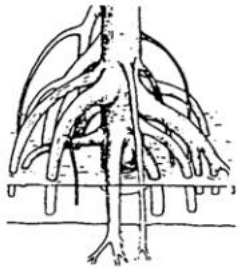
4.2.2.2. Selected parameters for mangroves (height, density and drag coefficient)

Due to the lack of time and available information about mangroves characteristics (height, density, and drag coefficient caused by mangrove) it was decided to divide mangrove species in Mekong Delta coast into two families Rhizophora and Sonneratia alba since the characteristics of these two species are fully described by Narayan (2009) for mangroves in India.

The application of Narayan's description seems reasonable since:

- There are similarities between the mangrove species in Mekong Delta Viet Nam and those in India (including A.alba, S.alba and Rhizophora).
- Mangroves are easily distinguished by their root systems which are highly adapted to their specific habitat (Figure 4.11). Rhizophora is typical for prop root system (stilt roots) that arise from its trunk and its lower branches. Meanwhile Avicennia and Sonneratia are known by their Pneumatophores which are erect lateral branches of the horizontal cable roots, which are themselves growing underground (De Vos 2004).

(a) Stilt root



(b) Pneumatophores root

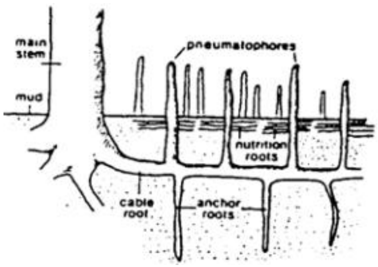


Figure 4.11: Mangrove root systems
(a) Stilt roots- Rhizophora and (b) Pneumatophores roots- Avicennia and Sonneratia

The selected parameters are shown in Table 4.3 for the species Sonneratia alba and Rhizophora mucronata, as selected by Narayan (2009).

Table 4.3: Selected parameters for S.alba and Rhizophora (Narayan 2009)

Parameter	S. alba		Rhizophora	
	Value Range	Control Value	Value Range	Control Value
Stem Diameter (DBH)	0.2 - 0.5 m	0.3 m	0.15 - 0.4 m	0.25 m
Root Diameter	0 - 0.04 m	0.02 m	0.05 - 0.1 m	0.075 m
Canopy Diameter	0.02 - 1 m	0.5 m	0.02 - 1 m	0.5 m
Stem Density	0.5 - 1.7 m^{-2}	0.7 m^{-2}	0.5 - 1.7 m^{-2}	0.7 m^{-2}
Root Density	4 - 100 m^{-2}	50 m^{-2}	1 - 130 m^{-2}	60 m^{-2}
Canopy Density	1 - 100 m^{-2}	100 m^{-2}	1 - 100 m^{-2}	100 m^{-2}
Stem Height	3 - 15 m	6 m	5 - 8 m	6 m
Root Height	0.3 - 0.8 m	0.5 m	0 - 1 m	0.8 m
Canopy Height	0.2 - 3 m	2 m	0.2 - 3 m	2 m

4.2.3. Soc Trang case study

4.2.4.1. Bathymetry

The 1-D cross-shore bathymetry was estimated using low spatial scale hydrographic maps from the Map Room of the TU Delft. During the process it was assumed that the depth contours run parallel to the section of coast being studied and are more or less monotonic in nature. The interpolated bathymetry is shown in Figure 4.12.

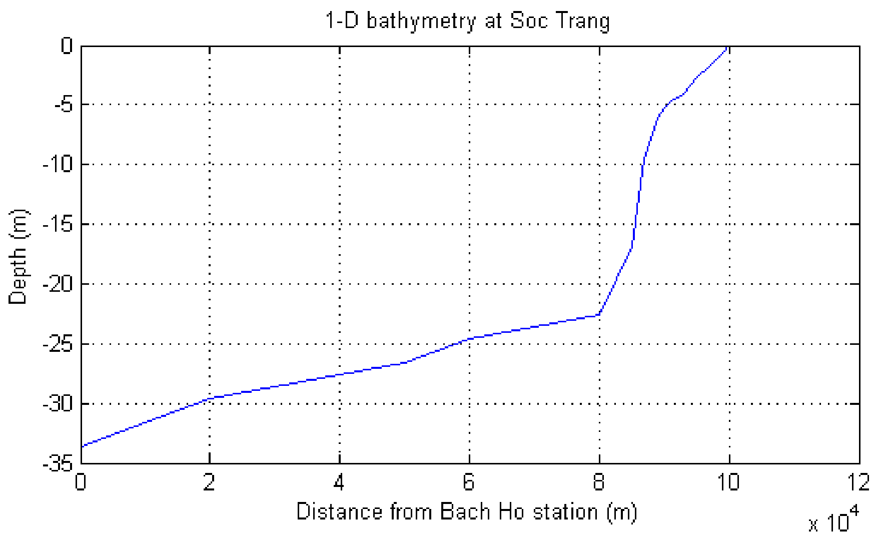


Figure 4.12: Interpolated 1-D Bathymetry

4.2.4.2. Hydraulic parameters

1. Wave

Waves offshore data are collected at Bach Ho station (see section 2.1.2 and annex 2.2). There are two wave height values that will be considered including: the most representative wave height and the highest wave height in storms with RP 100 years. For simplicity, it is assumed that the wave direction is perpendicular to the coastline in both cases.

The representative wave height

The cross-shore sediment transport rate S is proportional to the odd moment $\langle u|u^2|\rangle$ (Bosboom and Stive 2011).

Where:

u is the horizontal water particle velocity (m/s);

$$u = \frac{\omega H}{2kh}\cos(kx - \sigma t) \quad (9)$$

H is the wave height (m);

σ is the wave frequency;

k is the wave number;

$|u^2|$ refers to the concentration, reflecting to the sediment load is stirred by waves;

Therefore, the cross-shore sediment transport rate is proportional to H^2. Thus, the most representative wave height H_{rep} which has the major influence on the erosion of the coastline can be found based on the assumption that "the product of the representative wave height square multiple with the corresponding frequency (H^2_{rep} ×Frequency) is highest". The most representative wave height is therefore found equal 3 m (see table 6.8, annex 4.3).

The highest wave height

According to data collected at Bach Ho station, the storm with RP 100 years has the maximum significant wave height of 7.2 m and, wave period of 9.7 s (table 6.2). The highest wave height in the 100 years RP storm is taken into account in order to evaluate the effectiveness of mangroves in wave height attenuation in storm conditions.

2. Wind and water level

The wind and the water level in the normal conditions and in the storm conditions are presented below:

- Case 1: Normal conditions with the most representative wave height
  - Wave height H = 3 m;
  - Wave period T = 7.9 s;
  - Wind velocity at 10 m elevation U_{10} = 14 m/s;
  - Water level = Spring tide = 1.6 m (see figure 2.4).
- Case 2: Storm conditions with the return period 100 years :
  - Wave height H = 7.2 (m)
  - Wave period T = 9.7 (s)
  - Wind velocity at 10 m elevation U_{10} = 30 m/s;
  - Storm surge level = 2 m (see table 2.3);
  - Water level = Spring tide + Storm surge = 1.6+2=3.6 m.

The wind has the same direction as the wave. The corresponding wind velocity at 10 m elevation is estimated based on the wave forecasting graphs (Annex 4.3). Since the effect of the wind to the wave field is reduced when the waves come near shore, the wind profile is assumed as in the figure 4.13.

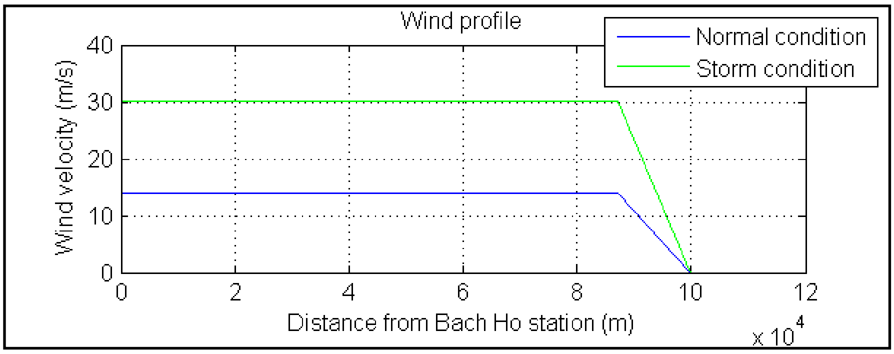


Figure 4.13: 1-D Wind profile

4.2.4.3. Vegetation parameters

The nine vegetation parameters – three for each of the three layers that had to be estimated or measured based on the requirements of the SWAN 40.85MOD model are the diameters, densities and heights of the roots , stem and canopy. These values can be estimated from table 4.3 by taking the control value for the diameter and the height of mangroves. Different scenarios (table 4.5) of mangroves density will be provided in order to evaluate the effectiveness of wave attenuation by mangroves forest. There are no variations of vegetation height is taken into account since the water depth is quite small compared with the mangroves height.

Table 4.4: Input vegetation parameters: different height and diameter for three layers

Parameter	S.alba	Rhizophora
Stem Diameter (DBH)	0.3 m	0.25 m
Root Diameter	0.02 m	0.075 m
Canopy Diameter	0.5 m	0.5 m
Stem Height	6 m	6 m
Root Height	0.5 m	0.8 m
Canopy Height	2 m	2 m

Table 4.5: Input vegetation parameters: density variation for three layers

Parameter	S. alba			Rhizophora		
	Sparse	Average	Dense	Sparse	Average	Dense
Stem density	0.5 m^{-2}	0.7 m^{-2}	1.7 m^{-2}	0.5 m^{-2}	0.7 m^{-2}	1.7 m^{-2}
Root density	25 m^{-2}	50 m^{-2}	100 m^{-2}	30 m^{-2}	60 m^{-2}	130 m^{-2}
Canopy density	50 m^{-2}	100 m^{-2}	100 m^{-2}	50 m^{-2}	100 m^{-2}	100 m^{-2}

Three different scenarios for various mangrove densities are:

- Dense scenarios: the density value is equal to the highest density value from the value range.

- Average scenario: the density value is equal to the control value of the density.
- Sparse scenario: the stem density value is equal to the lowest stem density value while the root and the canopy density are estimated from the above two scenarios.

Mangrove trees only live in the upper tidal zone (approximately from the MSL up to High Water (spring) as they need regular fresh air (Schiereck and Booij 1995). Due to the absence of data and with the aim of simplifying the generic analyses, the distribution of S.alba and Rhizophora will be considered in three cases:

- Rhizophora is uniformly distributed in the cross-section direction.
- S.alba is uniformly distributed in the cross-section direction.
- Rhizophora and S.alba are both presented.

4.2.4. Result and evaluation

4.2.4.1. Result

Under the effect of wind growth, white capping, wave breaking and bottom friction, the transmitted wave height offshore to wave height near-shore without the influence of vegetation dissipation can be seen in Figure 4.14. Due to the influence of wind growth, the wave height increases from 7 meters to above 8 meters and from 3 meters to above 4 meters before breaking in case of storm wave and representative wave height respectively.

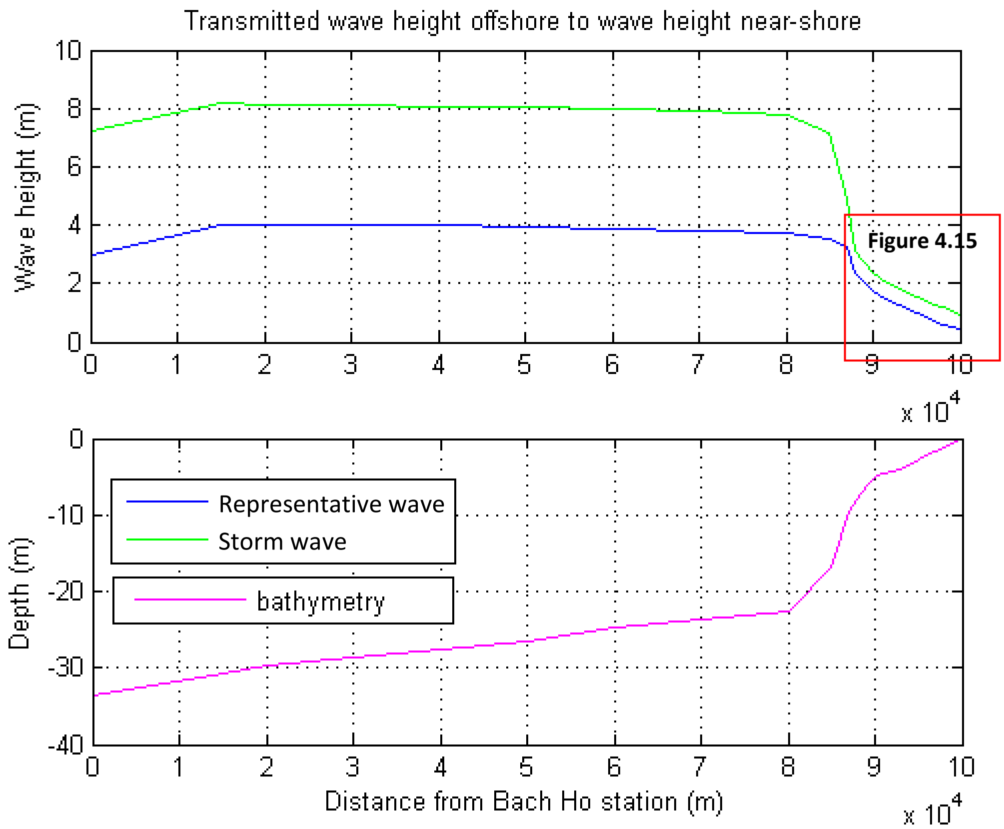


Figure 4.14: Transmitted wave height offshore to wave height nearshore

A close look of wave height near-shore under the effect of bottom friction and vegetation dissipation is presented in Figure 4.15 in case of representative wave height,; mangrove species are Rhizophora. It can be seen from Figure 4.15 that Soc Trang has a very gentle slope and shallow bathymetry. Therefore the wave height is already quite small even before entering the mangroves forest (0.43 m wave height in normal conditions and 1 m wave height in storm conditions).

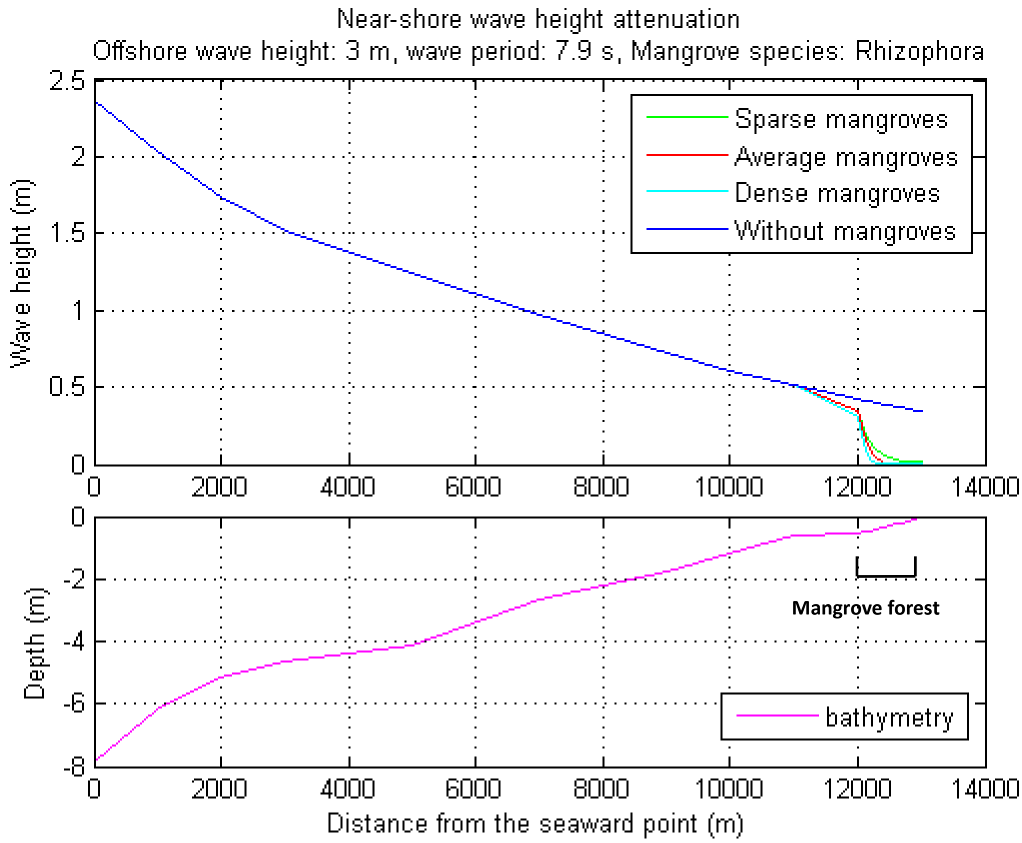


Figure 4.15: Wave height attenuation due to bottom friction and vegetation dissipation

The wave height attenuation in mangrove forests for varying mangroves density and varying mangrove species distribution are presented in Figure 4.16, Figure 4.17 and Figure 4.18:

1. Density variations

The result shows an expected overall increase in sharpness of wave attenuation from low density to high density as seen in Figure 4.16 and Figure 4.17.

Figure 4.16 showing the wave height attenuation in the normal case with the most representative wave height offshore while Figure 4.17 showing the wave height attenuation in the storm case with the return period 100 years. In both cases Rhizophora is uniformly distributed across-shore.

It can be concluded from both cases that the wave height is significantly reduced after passing through 200 to 400 meters of mangroves width. In case of average and dense mangroves density, the wave height is almost zero after passing through 400 meters and

200 meters width of mangroves respectively. In case of sparse mangroves, approximately 90% of wave height is reduced after passing through 400 meters of mangroves.

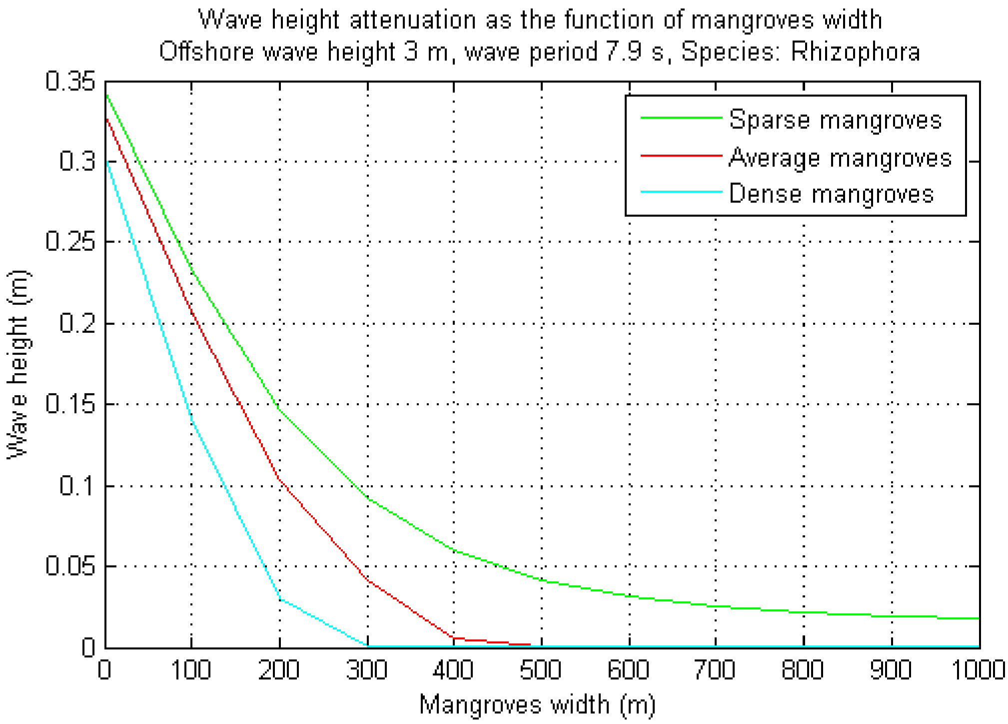


Figure 4.16: Wave attenuation as the function of Mangroves width; Offshore conditions: wave height 3m, wave period 7.9 s; Species Rhizophora

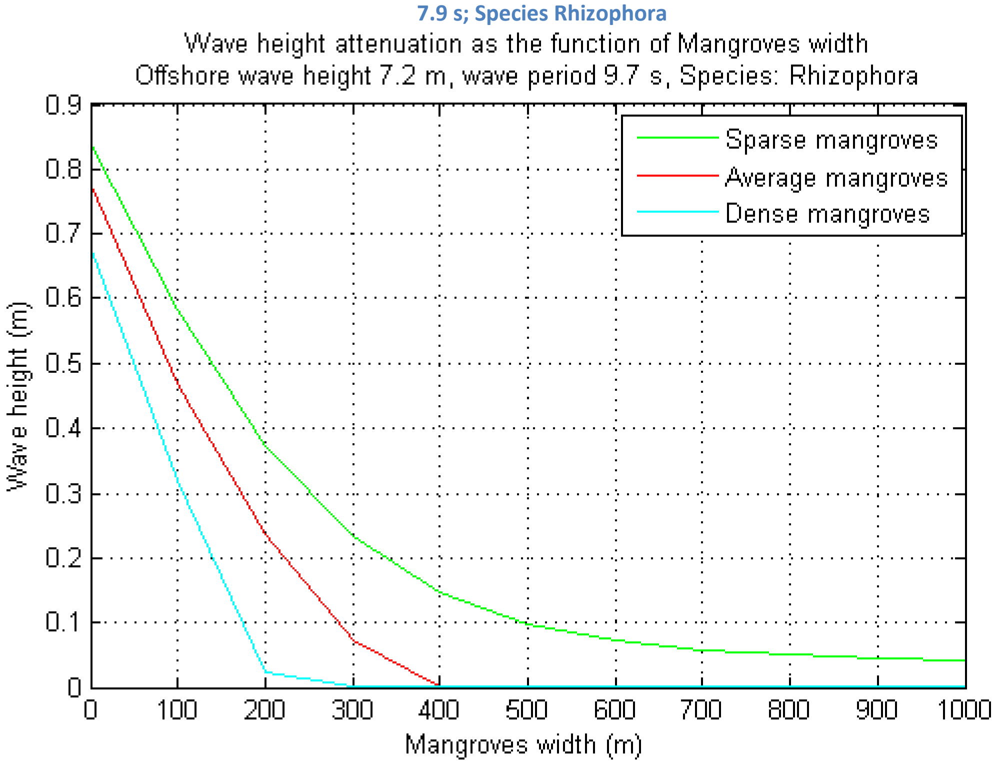


Figure 4.17: Wave attenuation as the function of Mangroves width; Offshore conditions: wave height 7.2 m, wave period 9.7 s; Species Rhizophora

2. Species variation

Since the Rhizophora species has the ability to reduce more wave height than S.alba species, the result showing in Figure 4.18 is quite reasonable. If S.alba is uniformly distributed across shore, the wave height will be significantly reduced after passing the 500 meters wide of mangrove forest while only a 300 to 400 meters width of Rhizophora mangroves is necessary for a significant reduction of wave height. Therefore it can be said that even with mixed mangrove species the wave height is still considerable reduced after passing through 400 meters as shown in Figure 4.18.

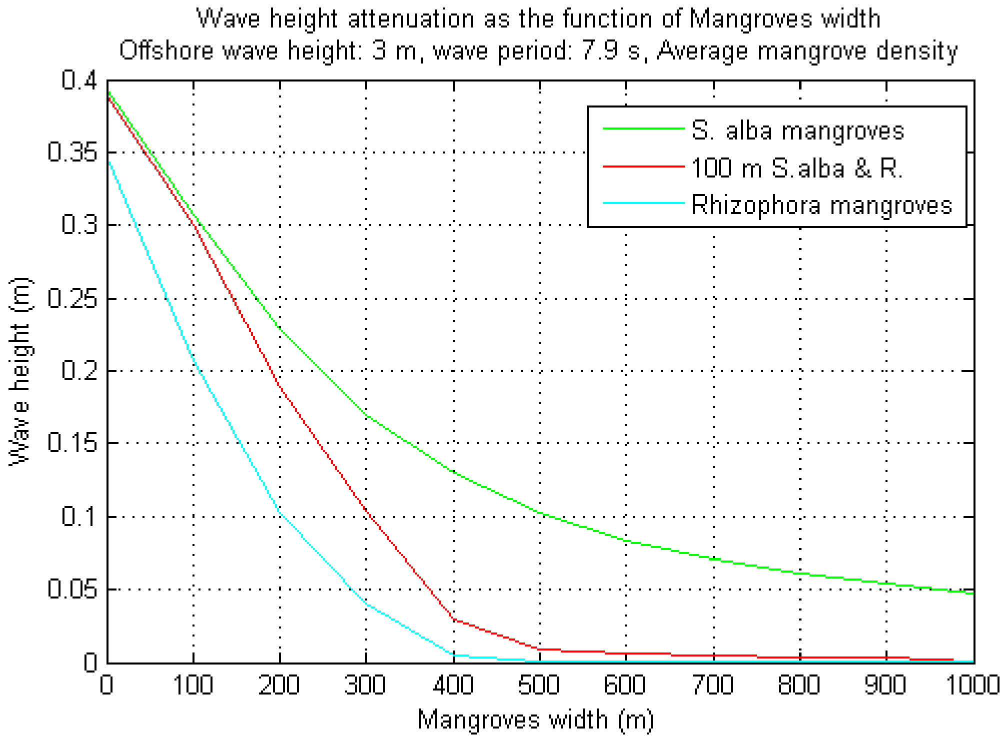


Figure 4.18: Wave attenuation as the function of Mangroves width; Offshore conditions: wave height 3m, wave period 7.9 s; Average Mangroves density

4.2.4.2. Uncertainties

Since calculation of wave height attenuation by SWAN is already tested and worked well in many studies (Meijer 2005; Narayan 2009) the purpose of using SWAN 1D in this study is only to evaluate the effectiveness of wave height attenuation with different mangroves width. It can be said that the result of SWAN 1D confirms the accuracy of the critical width of mangrove forest since the mangroves have a significant effect only at cross-shore widths greater than 300 to 400 m (critical value of mangroves width). However, there are several uncertainties during the calculation process which need to be considered:

- The drag coefficient is very important to determine the wave energy dissipation due to vegetation. The drag coefficient depends on the Reynolds number, density and diameter of vegetation and wave characteristic (Meijer 2005). However in this study due to the lack of time and information, the drag coefficient that is chosen equals 1, following Narayan (2009).

- Vegetation parameters are only estimated based on Narayan description. More realistic vegetation parameters can be achieved by field measurement.

4.3. Applying mangroves in sustainable development for protecting the coastline

The relationship between sea dike, mangroves and related coastal issues can be summarized in the flow chart below.

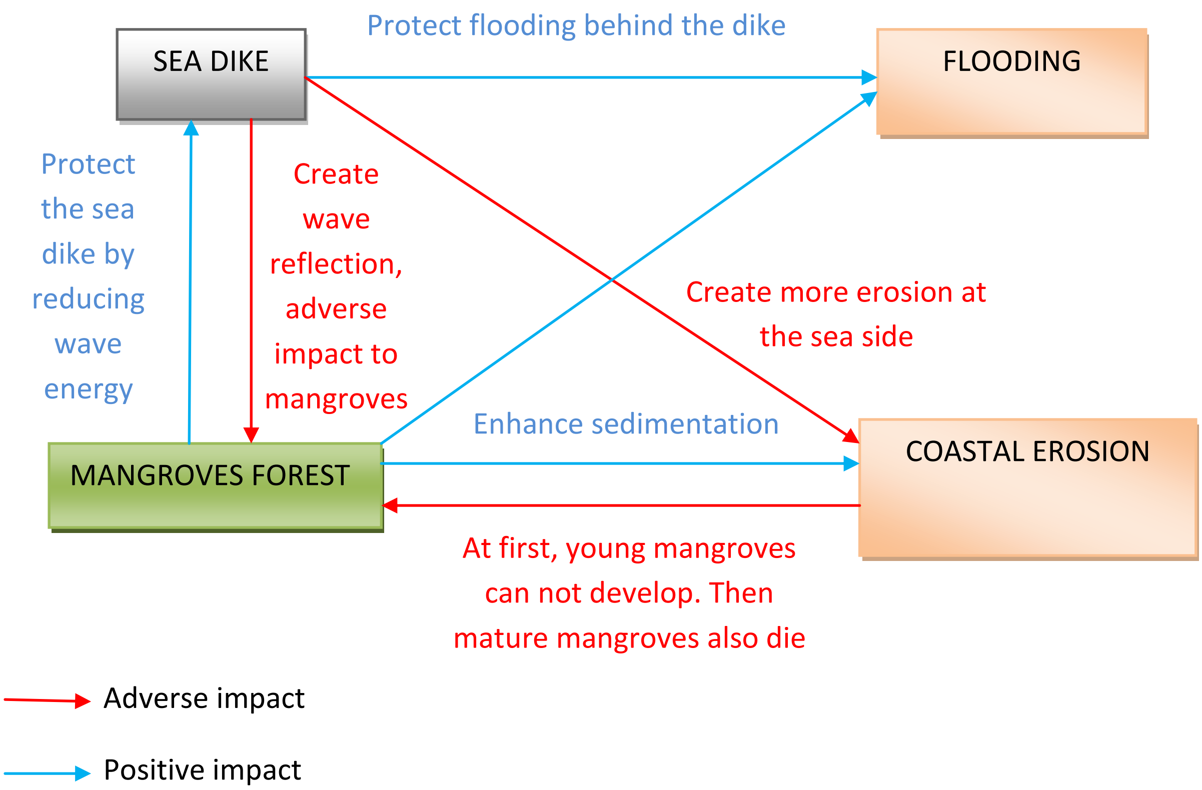


Figure 4.19: Relationship of mangroves to human intervention (sea dike) and coastal issues (coastal erosion and flooding)

Hard structure such as sea dikes are necessary for flooding protection. However, sea dikes are also one of the reasons for coastline erosion since the wave will take the sediment in front of the sea dike and deposit it offshore.

Clearly, erosion problems along the Southern coast of Viet Nam cannot be solved by 'hard methods' such as breakwaters, groynes etc. For example the building of a breakwater will create sedimentation at the up drift side, but will also create double erosion at the down drift side. Therefore, the answer for this problem must be found in a 'soft method' or in building with nature. Mangroves will be the best solution for this problem since they can enhance sedimentation and reduce wave energy. Besides, the southern delta coast with a low topography, with abundant alluvial deposits, half-day tides with high amplitudes, very few storms and a tropical climate provide favourable living conditions for mangroves.

Today, the Vietnamese government and the Vietnamese people do recognize the importance of mangrove forests as coastal protection, however recovery of destroyed mangroves forest and creating sedimentation at the eroded part of the coastline are not easy tasks. According to Dutch experience the following steps should be taken in order to apply mangroves in coastline protection:

Step 1: Creating sedimentation, preparing suitable conditions for mangroves development.

There are 2 vital conditions to achieve sedimentation:

- Sediment characteristic: A stable coastline must contain all sizes of sediments ranging from small to large sediments such as clay, sand, cobble etc. The median particle diameter D_{50} is a very important parameter to classify sediment grain size.
- Water velocity: Sediments need calm conditions to settle.

Bamboo grids can be used to reduce the water velocity to enhance sedimentation. The grain size of the sediment which can settle depend mostly on the gap between bamboos.

In the first stage, the gap between bamboos should not be too close to allow coarse sediment to settle, thus the sedimentation process can happen more quickly. Then, fine sediment will be allowed to stay when reducing the gap between bamboos.

A threshold of about **30 cm** of clay should be achieved since:

- Mangroves propagule has the length of 25 to 30 cm.
- The volume of air in the clay layer is important for the development of aerial roots of mangroves. The aerial roots of mangroves only develop in the conditions of lacking air in clay. From experience, 30 cm thickness of clay will provide a suitable environment for mangroves root system development.

The thickness of the clay should be kept at around 30 cm. The success of this step is important in order to achieve suitable conditions for the development of mangroves. The volume of sedimentation and the necessary gap between bamboos can be calculated based on the sediment characteristics (grain size, fall velocity etc.) and the hydrodynamic characteristics (wave, current etc.).

Step 2: Planting pioneers

Planting pioneers to prepare the way for other mangroves species.

Step 3: Creating mangroves forest

Within the mangroves forests, communities are often zoned parallel to the shoreline, with series of different species dominating distinct sections from shore to the landward limits. For instance after Rhizophora are planted and grow toward the sea, accretion takes place and at the inner part of this fringing forest, other species take over.

Therefore, when the pioneer stage develops, the intermediate/transitional species should continue to be planted to create a protection boundary for the beach, and then, final stage species should be planted in order to create a healthy mangrove forest community.

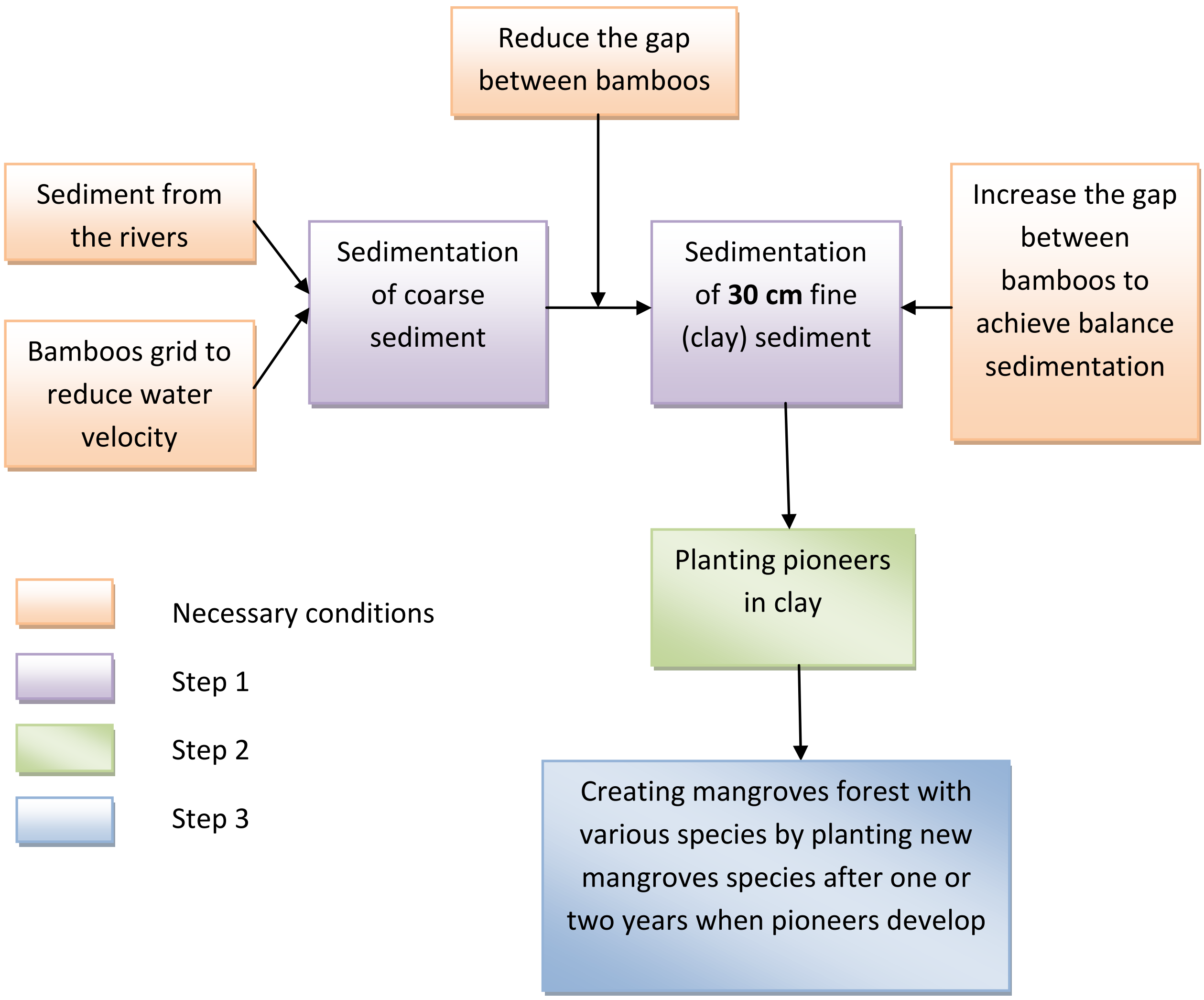


Figure 4.20: Applying mangroves in coastline protection

It is necessary for carefully choosing mangroves species for each stage. Avicennia alba has pencil aerial roots and stilt roots as pneumatophores, while Rhizophora apiculata, Ceriops tagal and Avicennia officinalis only produces stilt pneumatophores. So A. alba is less appropriate to use in barren conditions, because it can be directly destroyed in the very first typhoon or gale. Furthermore erect pencil like aerial roots only grow to the highest flood level and contribute only effective for silt or clay setting if there is a limited tidal difference.

These conditions only occur in the hinterland area of a mangrove forest. In conclusion these species is not useful for forest restoration projects. Therefore, an example of Ca Mau succession should not be used for mangroves restoration.

5. Conclusions and recommendations

5.1. Conclusions

5.1.1. Mekong Delta Estuaries

The Mekong Delta Estuaries are important waterways transport, connecting the sea and the hinterland but they are also the way of salinity intrusion. According to the future plan development, discharge sluices will be constructed at three main branches of Tien River including: Ham Luong, Co Chien and Cung Hau to prevent salinity intrusion. Closing down these three main branches might lead to serious consequences to estuaries evolution. These consequences can be estimated based on the empirical relationship of tidal prism and river cross-section.

The average river cross-sections near the river mouth for different branches of the Mekong River are calculated based on the bathymetry maps collected in 2002. The ebb tidal prisms at the Mekong Delta estuaries are calculated in three forms: average ebb tidal prism, ebb tidal prism exceeded 3 months per year and ebb tidal prism exceeded 1 month per year by two different approaches:

- The first approach using upstream river discharge collected at Tan Chau and Chau Doc from 01/1996 to 12/2000 and downstream river discharges collected at the river mouth from 15/09/2011 to 30/09/2011. The river discharge at the downstream are provided for every hour.
- The second approach using the monthly river discharges from 1990 to 2002 however the locations of the measurement stations are unknown.

It is concluded that the first approach provide more reasonable result than the second one. The difference of these two approaches is mainly due to the different river discharge data. As mentioned earlier, there are barely available river discharges data can be observed near the river mouth before 2002. Therefore the data collected in the first approach is more reliable than in the second approach for calculating tidal prism at the estuaries. Since in September the river discharge is higher than in the other months of year, it is decided to choose the empirical equation created by the average ebb tidal prisms and the average river cross-sections:

$$A_c = 10^{-3}\langle P\rangle^{0.86} = 5.39\langle Q\rangle^{0.86} \qquad (6)$$

The empirical relationship found for Mekong Delta Estuaries is quite comparable with other empirical relationship found for US Inlet by O'Brien and Powell since they have the same order of magnitude.

Closing down all three main branches can deepen the river depth of Tieu and Dai branch for more than 10 meters according to equation (6). Ham Luong will have the most influence to other river branches due to its large tidal prism. The erosion of the river bank will also increase together with the increase of the river depth.

It's also concluded that River bank erosion at the Mekong Estuaries is the result of many complicated factors such as river flow, wave, wind and tide. Beside, Coriolis Effect can also be one of the reasons which lead to more erosion at the left bank than at the right bank.

Revetments are mentioned in the future development plan as the solution for river bank erosion. However using mangroves for protecting the river bank can be consider as a better solution since planting mangroves are much cheaper and more effective (Observations show that along the river bank where mangroves develop healthily, no erosion happen).

5.1.2. Mekong Delta Coast

Since 1995, erosion becomes serious problem along the Southern Coast of Viet Nam. Erosions are observed in a larger scale, even at the locations where sedimentations are observed in the past. **Planting mangrove forest is so far the best solutions for coastal erosion in the Southern Coast of Viet Nam since the coast is rich in sediment supply from the Mekong River system.** Mangroves can reduce wave energy, trapping sediment and therefore enhance sedimentation. It is found that the coast will be stable with the mangroves width of approximately 300 to 400 meters. This result is estimated based on the empirical relationship of mangrove forest width and coastline evolution from 1965 to 2002.

300 to 400 meters also seems to be the best value range of mangroves forest width for wave height attenuation. Results from the SWAN wave model for the Soc Trang case study show the effectiveness of wave attenuations in a mangrove forest in both normal and storm conditions. After passing through 300 to 400 meters of mangroves width, the wave height is significantly reduced. In case of average and dense mangroves density, the wave height can even approach zero while in case of sparse mangroves 90 % of wave height can be reduced.

Since bathymetry along the East Coast is very gentle (about 10^{-3}), bottom friction also plays an important role in wave height attenuation.

5.2. Recommendations

The empirical relationship between tidal prism and river cross-section is only created for five branches of Tien River since there are no available data of Hau River can be collected. However, the empirical relationship for all seven branches of the Mekong River can be easily created in the same way if there are more data can be collected.

Actions must be taken to prevent river bank erosion if discharge sluices are constructed in the future. The most effective way is strengthen mangroves forest along the River bank.

The critical mangroves width of 300 to 400 meters is recommended for the East Coast of the Mekong Delta Viet Nam.

Due to the limit of time and available data, simplifying assumptions had to be made. It is recommended to extend the research for the following topics:

- More accurate vegetations parameters can be provided by field measurement.
- Drag coefficient should be tested in order to achieve the most appropriate value for different cases.
- Recently, cross-section from the coastline to about several km offshore is measured at some specific locations along the Southern Coast of Viet Nam. By using these data, more accurate bathymetry could be provided.

6. ANNEX

Annex 2.1. Natural characteristic maps

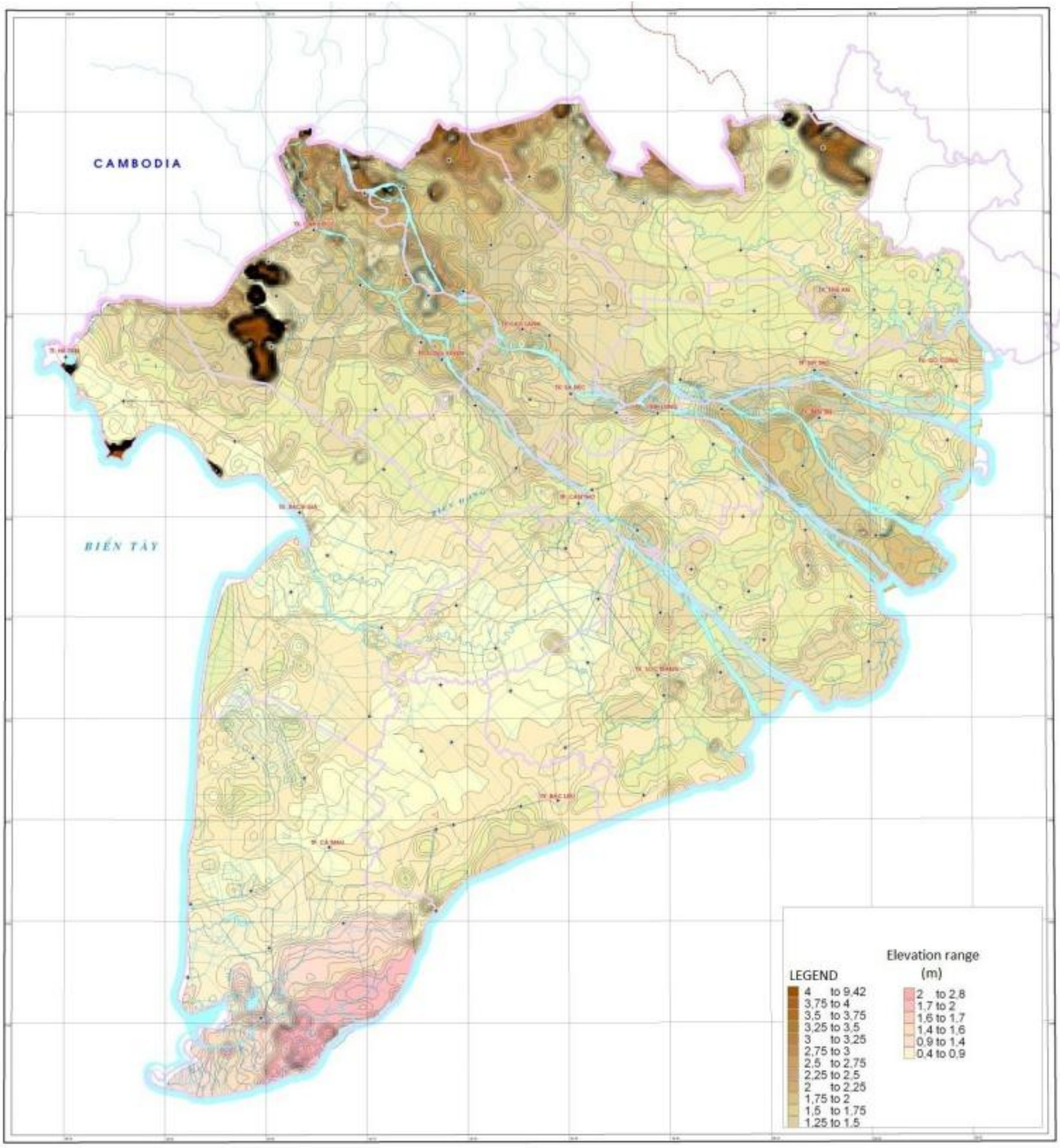


Figure 6.1: Topographic elevation map of the Mekong Delta (Deltares 2011).

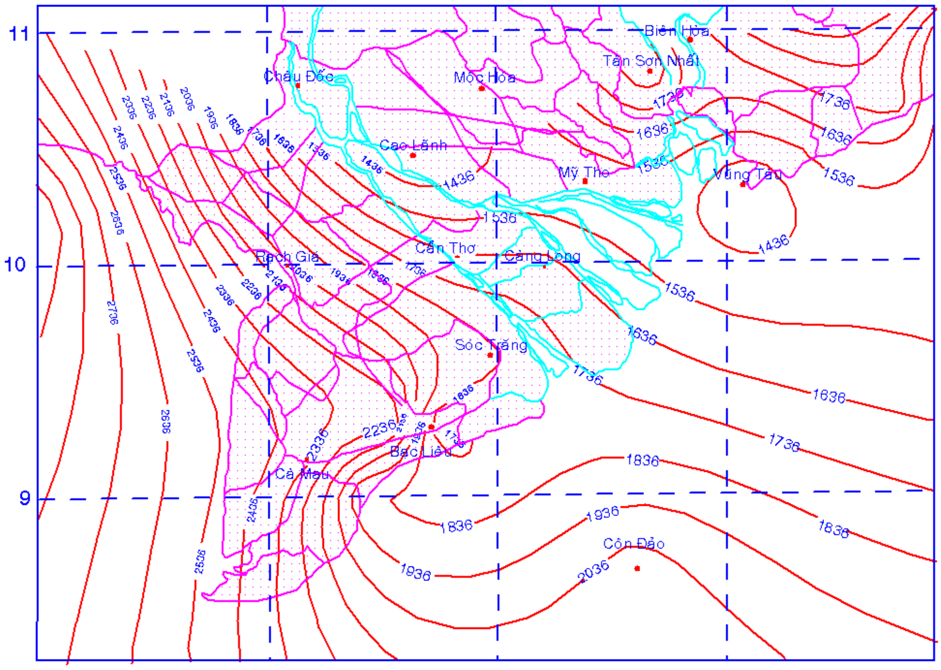


Figure 6.2: The distribution of annual rainfall (Quyet 2009).

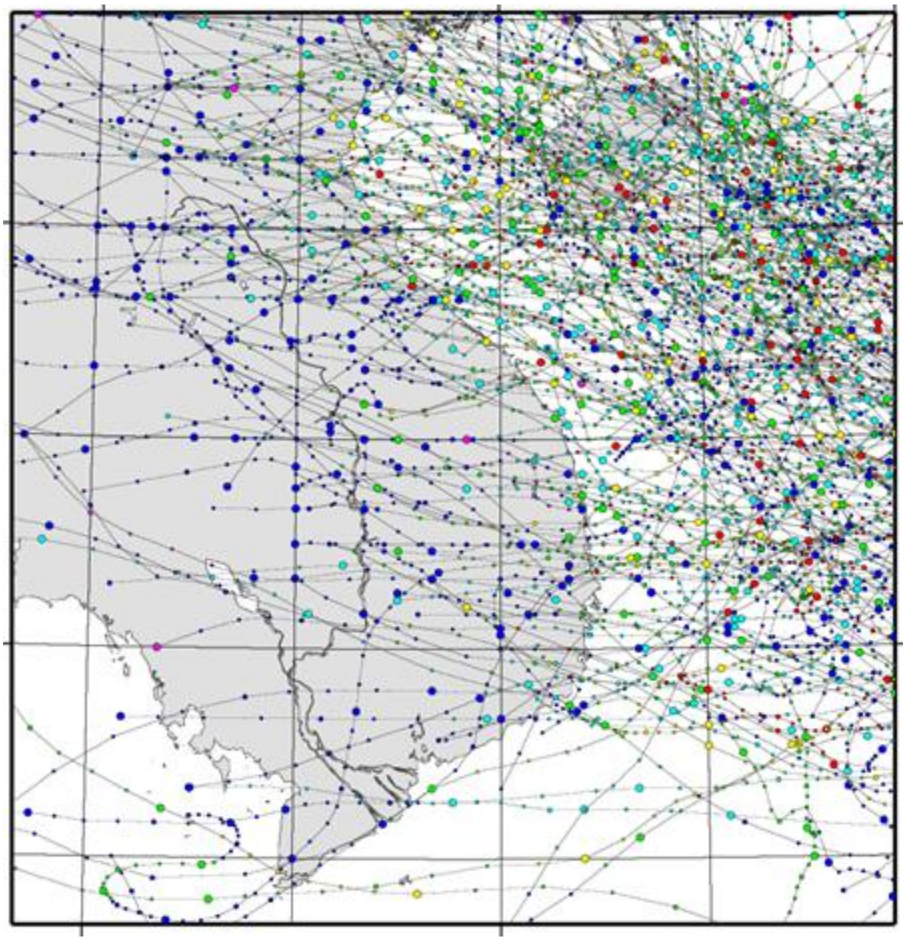


Figure 6.3: Storm history of Vietnam (SIWRR 2010a).

Annex 2.2. Wave data

2.2.1. Offshore wave (Hoang Van Huan 2006)

Table 6.1: Frequency of wave height by intervals and months at Bach Ho station

Height intervals	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
0-0.5	0.12	7.14	28.68	37.40	38.22	9.68	11.64	9.29	40.45	17.61	2.92	-
0.6-1.0	2.56	13.62	18.67	24.93	30.69	22.30	23.78	16.53	29.89	30.62	8.62	1.34
1.1-1.5	9.56	21.03	11.37	18.35	21.27	30.75	33.05	37.57	15.72	25.34	19.89	10.90
1.6-2.0	20.19	18.49	12.45	9.38	5.56	18.23	15.68	24.18	16.01	15.04	20.71	16.42
2.1-2.5	24.90	14.22	9.34	5.18	2.01	9.37	9.11	7.92	5.10	5.83	18.72	17.36
2.6-3.0	16.96	14.67	7.35	3.92	0.81	7.43	5.40	3.69	2.26	3.79	12.10	14.00
3.1-3.5	11.84	5.60	4.46	0.84	0.81	1.40	0.67	0.68	0.57	1.22	5.56	11.31
3.6-4.0	6.33	3.78	4.06	0	0.54	0.84	0.67	0.14	0	0.41	7.65	16.73
4.1-5.0	6.19	1.21	2.44	0	0	0	0	0	0	0.14	4.75	11.71
5.1-6.0	1.35	0	0.54	0	0	0	0	0	0	0	1.60	1.48
6.1-7.0	0	0	0.13	0	0	0	0	0	0	0	0.42	1.35
>7.0	0	0	0	0	0	0	0	0	0	0	0	0.40

Table 6.2: Wave height and wave period of maximum significant wave

Direction	100 years	50 years	25 years	10 years	1 year
NE	7.2 m 9.7s	6.4 m 9.5 s	5.5 m 9.2 s	4.5 m 8.7 s	3.5 m 8.1 s
E	6.2 m 9.4 s	5.4 m 9.1 s	5.0 m 8.9 s	3.8 m 8.5 s	3.0 m 7.9 s
SE	5.2 m 7.8s	4.1 m 7.5 s	3.3 m 7.2 s	2.8 m 6.9 s	2.3 m 6.2 s
S	3.3 m 7.3 s	3.1 m 7.1 s	2.9 m 7.0 s	2.5 m 6.7 s	1.8 m 5.6 s
SW	5.5 m 8.7 s	4.8 m 8.6 s	4.4 m 8.5 s	4.1 m 8.1 s	3.0 m 7.9 s

Table 6.3: Frequency of wave direction in 8 directions and months at Bach Ho station

Months	N	NE	E	SE	S	SW	W	NW
Jan	-	100.0	-	-	-	-	-	-
Feb	-	79.0	19.7	0.3	0.1	0.3	0.6	-
March	0.14	63.6	27.2	4.19	3.39	1.49	-	-
April	-	50.0	17.09	5.88	10.64	15.97	0.42	-
May	0.13	15.88	18.18	5.92	8.48	38.76	11.79	0.67
June	0.28	0.42	2.92	0.14	1.96	63.53	29.59	1.12
July	0.34	0.51	3.54	0.17	2.05	58.68	33.22	1.34
August	0.55	0.41	1.37	2.05	2.05	48.89	43.85	0.83
Sept	1.70	10.47	8.50	3.69	3.69	36.41	31.30	3.97
Oct	3.25	43.35	11.28	0.82	1.90	14.23	21.81	3.39
Nov	1.12	73.99	14.04	1.12	1.39	3.90	3.32	1.12
Dec	-	96.52	3.09	0.13	-	-	0.26	-

2.2.2. Near shore wave

According to the summary report produced by the Southern Institute of Water Resources Research (SIWRR 2010a), the wave parameters are measured in 6 stations along the East coast of MDV. The wave data including maximum wave height, average wave height, wave direction and wave period and wave frequency were observed every 15 minutes. All of the data were measured by ADCP (Acoustic Doppler Current Profilers) machine.

The measurement took places from 15/09/2009 to 30/09/2009. However, it must be notice that in September, the South-East Monsoon is dominated and the wave height is quite low compare with the wave height from October to April (Figure 2.3).

Station	Coordinates	Wave characteristic	Remarks
1	10°16'42.72"N 106°51'19.14"E	The maximum wave observed in storm conditions was approximately 1m, South-East direction with the average period of 5.08s. The major wave direction in the measurement period come from North-Western (more than 15%).	Average water depth: 6-7 m This location is known for serious coastal erosion, threat to Go Cong sea dike and destruction of the mangrove area.
2	10°11'45.30"N 106°50'48.18"E	Major wave direction come from South-Eastern (more than 25%) and then East and South-Western. In general, wave height is small (wave height of 0.3 m account for about 70 % of wave observation). Wave height from 0.5 to 0.9m account for 9 % and only 1 % wave height is larger than 0.9m.	Average water depth: 4-5m Accretion happens very fast at this location, create new land and move landward.
3	10° 1'53.37"N 106°47'25.62"E	The wave come mainly from South-East direction	Average water depth: 4-5 m Accretion, topography interrupt by small canal, small bank
4	9°58'9.42"N 106°42'45.78"E	The maximum wave height is about 0.55 m, mainly come from South and South-East direction	Average water depth: 7-8 m
5	9°48'8.900"N 106°42'54.000"E	The maximum wave height observed in measurement period is nearly 1m, coming from Southwest direction. The average value of maximum wave height is quite small, about 0.3m.	Average water depth: 3.8 m 6km away from the coastal line
6	9°37'22.02"N 106°33'39.52"E	The wave comes mainly from East, East-Northest and South-Southeast direction.	Average water depth: 1-1.5 m

Station	Average wave height	Maximum wave height	Main direction
1	0.6 m	1 m	N-W &S-E
2	0.55 m	1.2 m	N &SS-E
3	0.45 m	0.9 m	S-E
4	0.3 m	0.55 m	S & S-E
5	0.4 m	1 m	S-W
6	0.55 m	0.8 m	E, N-E &S-E

Figure 6.4: Location of wave station along the East Coast (SIWRR 2010a)

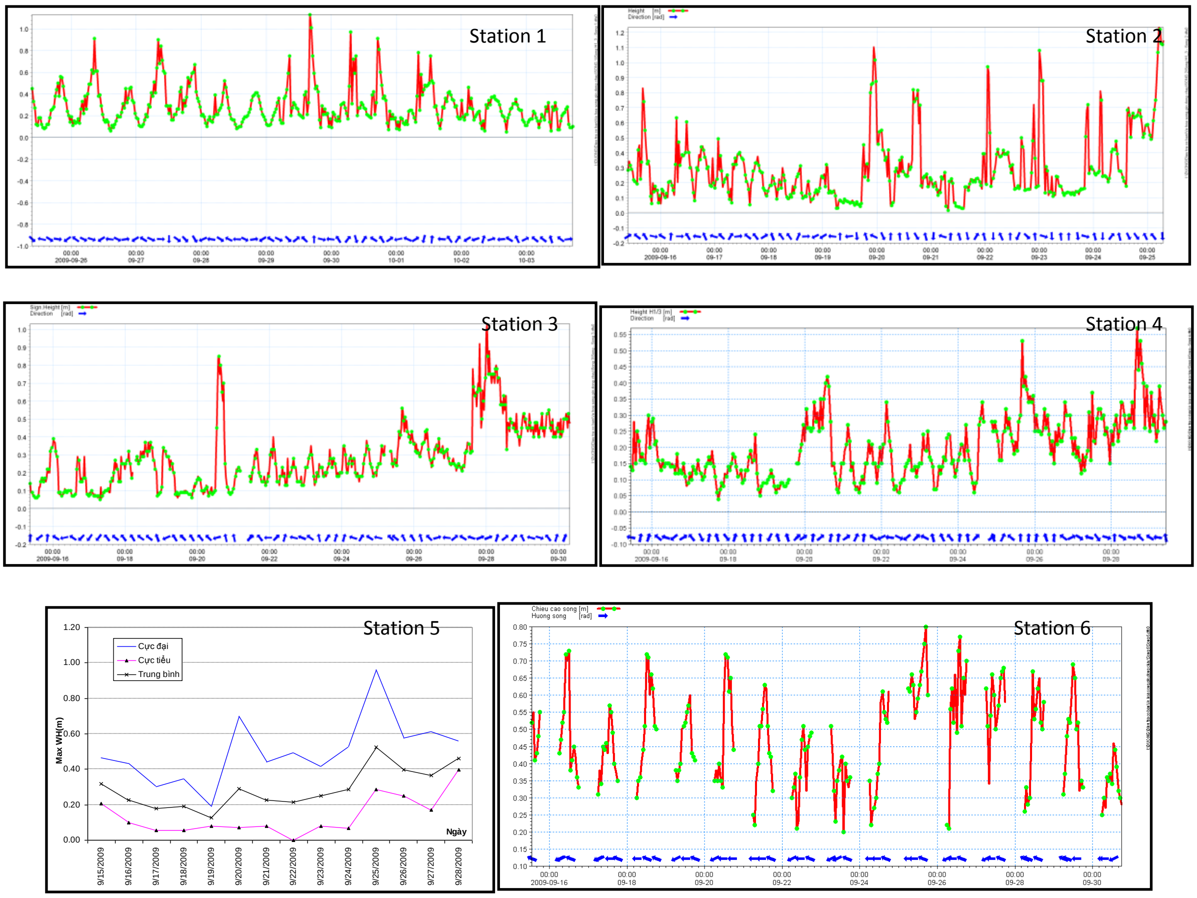


Figure 6.5: Significant wave height measurement at near-shore stations (SIWRR 2010a)

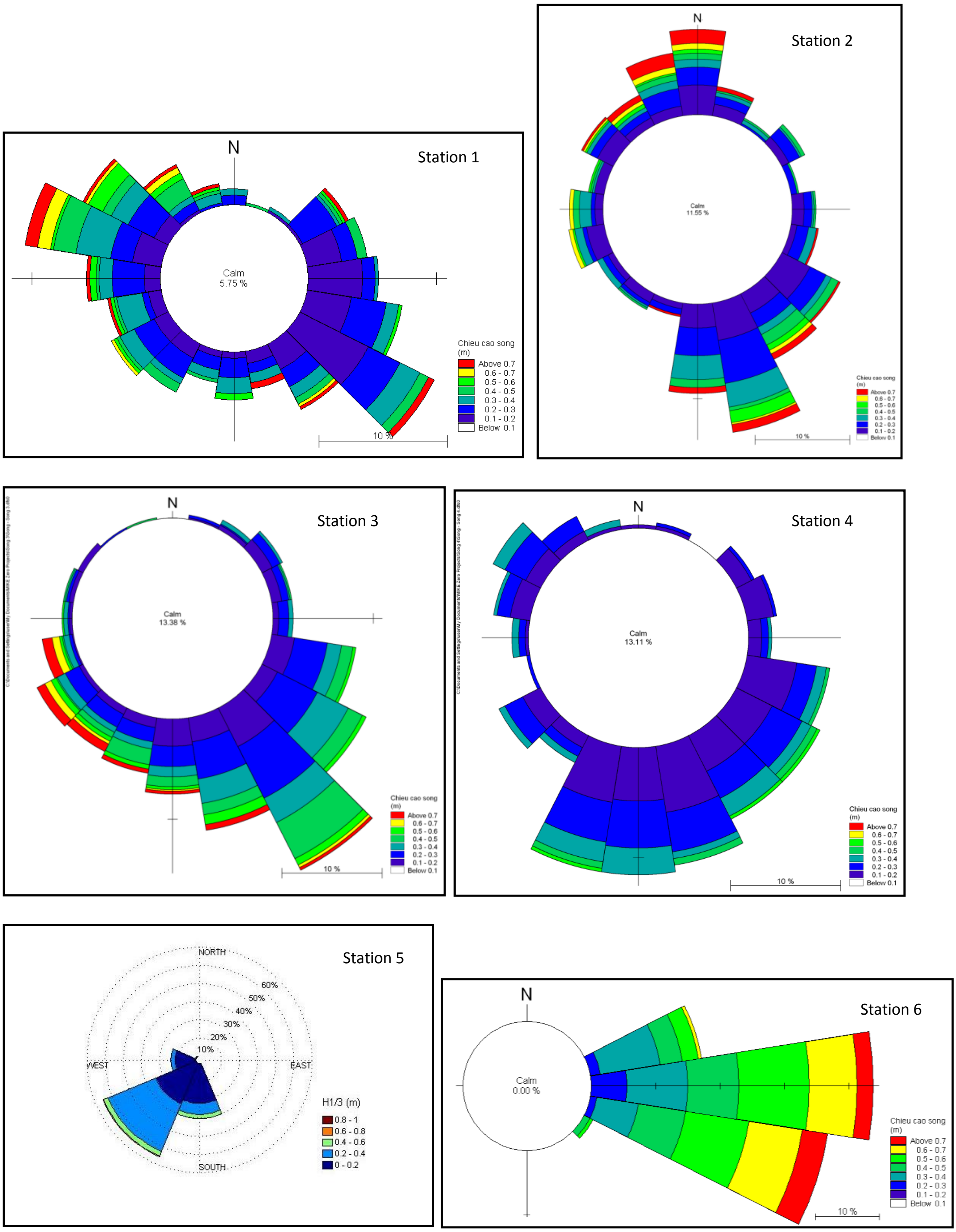


Figure 6.6: Wave rose at near-shore stations (SIWRR 2010a)

Annex 2.3. Flooding and Salinity intrusion in Mekong Delta Viet Nam

The natural characteristic of MD bring not only positive but also adverse impacts such as flooding, salinity intrusion and erosion.

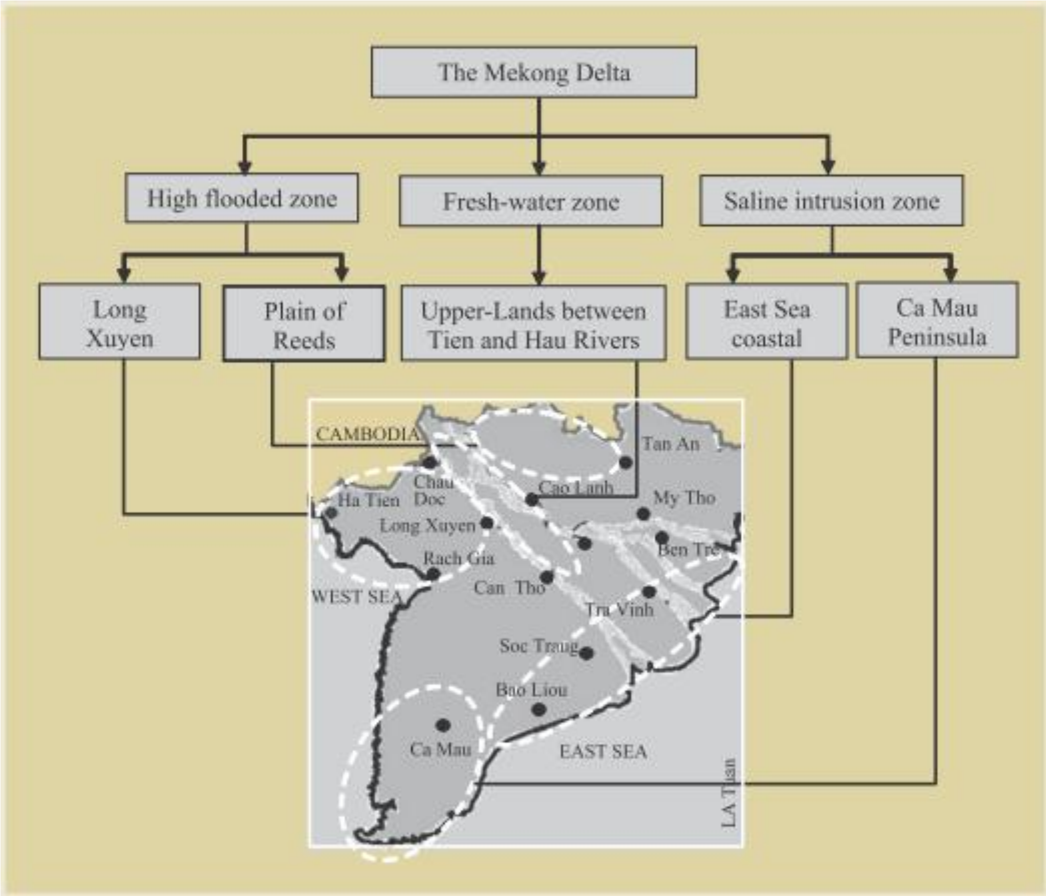


Figure 6.7: Three major water resource zones of the Mekong Delta (Le Anh Tuan et al. 2007).

1. Flooding

State of flooding

In the Mekong Delta, annual floods are always a part of the life of nature and people. Due to its location in the most downstream part of the basin, the Mekong Delta receives the total volume of floodwaters from upstream.

Each year, from July to December, a large part of the delta is inundated from both the overflow from the Mekong River and local rainfall. In the dry season, the low discharge of the Mekong River combines together with the lower groundwater table leading to serious shortages of fresh water for rice cultivation and domestic drinking water.

Certainly, the flood of 2000 was the worst experienced in terms of social and economic damage, mainly in rural poor-farmers groups living in low land settlements.

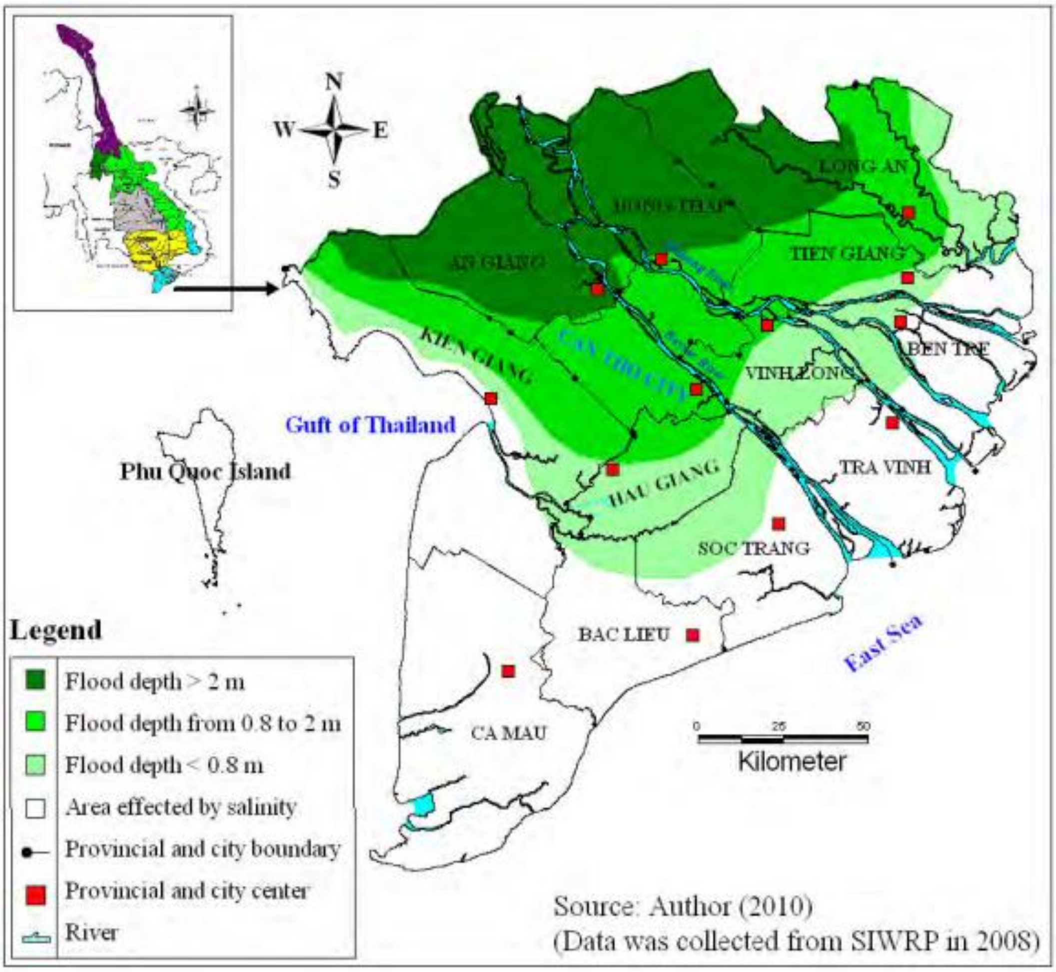


Figure 6.8: Flood-prone and brackish areas in the Mekong Delta (Pham Cong Huu 2011).

Relation of flooding and MD evolution

Direct impact on MD evolution

- Bank erosion: Many villages in 70 sites along the Tien and Hau Rivers face severe bank erosion due to floods, especially in Dong Thap and An Giang provinces (Le Anh Tuan et al. 2007).
- Sedimentation: Sedimentation in the Mekong delta is 7- 8 times higher than for the Red River (the North of Viet Nam), estimated at 160 million ton/year (Milliman and Syvistky 1992) resulting in an inherently dynamic channel system. Sedimentation due to floods makes river channel changes which cause hazards and challenges for navigation in the Hau River mouth.

Indirect impact on MD evolution

- There are large numbers of constructions such as sea dikes, embankment etc. was built and will be built to prevent and control flooding which might lead to major change of coastal morphology.

2. Salinity intrusion

State of salinity intrusion

Salinity intrusion is a complex process depending on the magnitude of the floods, the ability to supply fresh water from upstream during the dry season, summer-autumn paddy production status and timing of the rainy season. The highest salinities always found in dry season, then the flood waters from upstream will push the salt back to the estuaries. Therefore, with a small flood the salt intrusion may reaches far upstream while a large flood can push the salt intrusion outwards

Closer to the East Sea, the river width gradually expands and its flow velocity decreases progressively. Saline water from the East Sea and the Gulf of Thailand flows into the mainstream and the canal network covers a wide area in the coastal zone that is largest at high tide. The saline affected area expands throughout the Mekong Delta in two main zones (Le Anh Tuan et al. 2007):

- The Eastern coastal zone running from Vam Co River through the Hau River, with an affected total area of 780,000 hectares; and
- The Ca Mau peninsula with 1.26 million hectares that constitute one-third to a half of the total cultivable land of the delta. Ca Mau peninsula is considered as the most extremely serious and complex salt water intrusion in MD of Viet Nam since this area is bordered on two side by the East Sea and the West Sea respectively (Deltares 2011). Two different tidal regimes affect the river flow in the canal system and restrict the transfer of fresh water from the Hau river towards the deeper interior fields.

Salinity penetrates inland through various branches of the Mekong and canals over 20 to 65 km from the shore (Nguyen Hieu Trung 2006). The most extreme salinity intrusion happens in 1993, 1998 and 2005. And this situation is predicted to be worst in the next 40 years due to sea level rise and climate change. To Quang Toan (2011) provide evaluation of salinity for different scenarios with the based scenarios is: “Sea level rise 30cm + Rainfall pattern change (Climate change) + Based year land use”. Salinity intrusion for this scenario can be seen in Figure 6.10

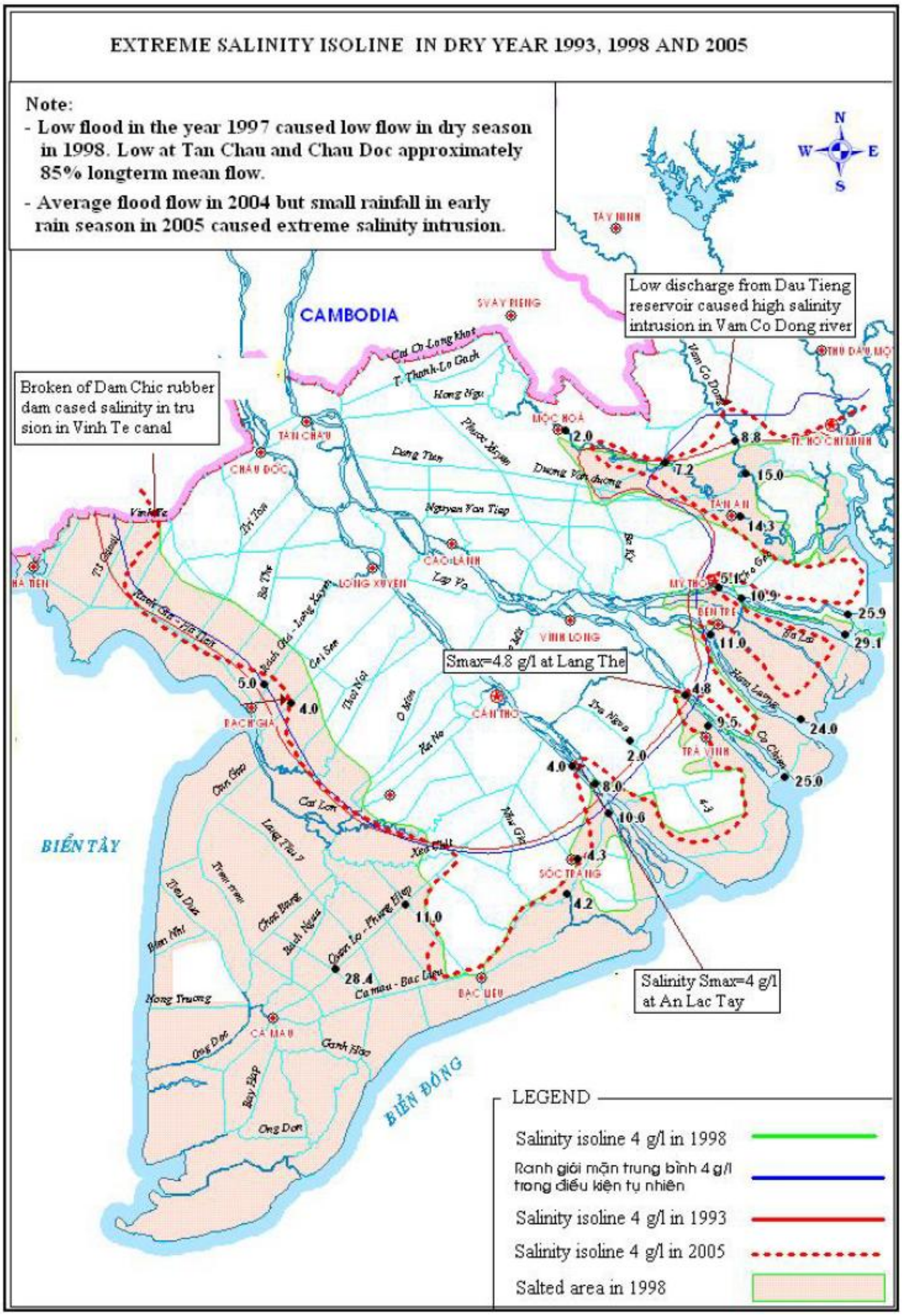


Figure 6.9: Salinity intrusion isolines in some dry years (Deltares 2011).

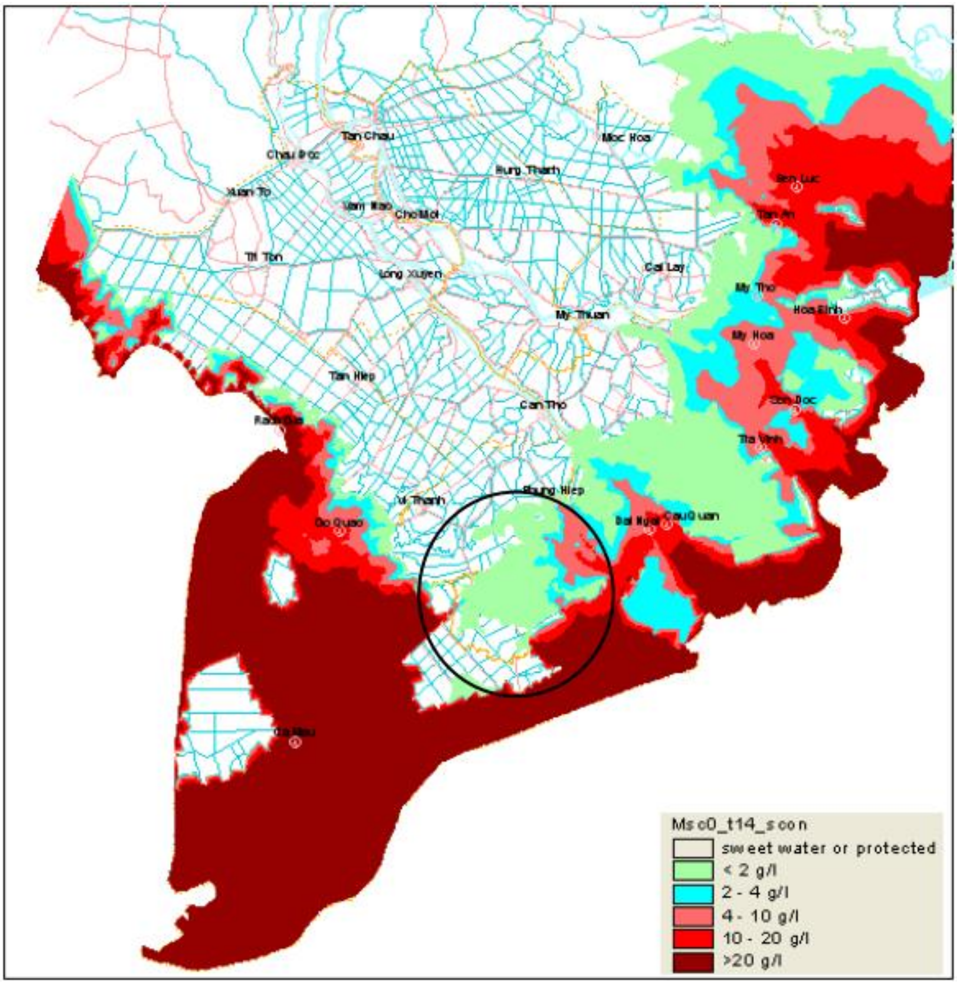


Figure 6.10: Maximum salinity intrusion from Jan to April due to sea level rise and climate change in the next 40 years (To Quang Toan et al. 2011)

Relation of salinity intrusion to MD evolution

Direct impact on MD evolution

- Positive impact to maintenance several morphology systems: Coastal areas are home to mangroves and saline intrusion maintains these and other ecosystems, such as tidal mudflat habitats, estuaries, small offshore islands, large coastal brackish and saline lagoons, large areas of salt pans and aquaculture ponds (Molle and Dao The Tuan 2001).

Indirect impact on MD evolution

- The same as indirect impact from flooding. Lots of construction was built and plan to be built in the future will have great influence on the morphology of MD.

Annex 3.1. River discharge

1. Source 1: Hourly river discharge (observation from 15/09/2009 to 30/09/2009) (SIWRR 2010a).

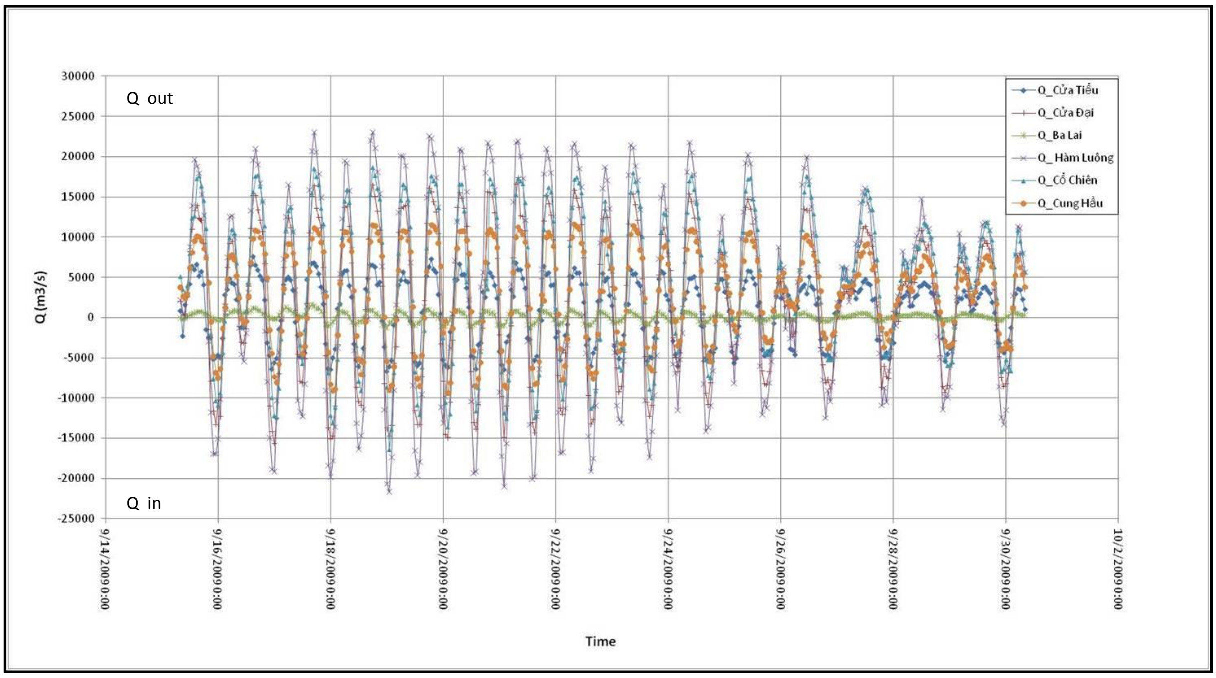


Figure 6.11: River discharge observed at five branches of Tien River from 15/09/2009 to 30/09/2009

River branch	Characteristic
Tieu branch	River discharge was observed at the location of 1 km upstream from the river mouth.
Dai branch	River discharge was observed at the location of 5 km upstream from the river mouth. Dai branch has quite large cross-section. The river flow is unstable, weak in the middle therefore create sand bar in the river, but very strong in both side of the sand bar with the maximum velocity from 2.3 m/s.
Ham Luong branch	Ham Luong branch has 71km length, starting from Cho Lach province go through Ben Tre village and reach the sea at An Thuan sea gate, Ben Tre province. There are many sand bar along the river length due to the complicated sediment and river discharge.
Co Chien branch	Co Chien river starts from My Thuan Bridge, flow along Vinh Long, Tra Vinh and Ben Tre province and then divide into two river mouth: Co Chien and Cung Hau river mouth.
Cung Hau branch	Cung Hau branch has the length of 25 km. Its quite straight and has the largest wide of 2500 m near the river mouth and smallest wide of 700 m near Tra Vinh village.

2. Source 2: Monthly river discharge (observed from 1996 to 2002)

1. Cung Hau branch

Year	Month	Qmax out (m3/s)	Qmax in (m3/s)	Q average (m3/s)	W out (10^9 m^3)	W in (10^9 m^3)
1996	1	13062	-13516.3	737.03	8.66	6.69
	2	12389.1	-13105.8	740.41	7.99	6.2
	3	11329.9	-12672.4	706.59	8.71	6.82
	4	11433.7	-12532	518.17	8.4	7.06
	5	11739.5	-12746.5	724.21	8.84	6.9
	6	12350.1	-12686.1	1085.01	9.02	6.21
	7	13682	-12701.5	1879.3	10.54	5.51
	8	14722.6	-11499	4290.22	14.67	3.18
	9	15265.3	-8840.7	5075.86	15.7	2.54
	10	15341.7	-8667	5703.22	17.3	2.02
	11	14914.8	-9488.2	4821.58	14.88	2.38
	12	14597.9	-15871.1	3270.81	12.56	3.8
1997	1	13204.3	-13619.5	516.64	8.72	7.33
	2	12751.5	-14140.4	570.19	8.04	6.66
	3	12057.1	-13223.8	642.58	8.9	7.18
	4	11530.1	-16784.8	683.04	8.69	6.92
	5	11508.6	-15371.2	800.08	9.15	7.01
	6	13953.3	-14112.7	823.29	8.38	6.24
	7	13689.9	-11833.3	2730.47	11.8	4.48
	8	14919.5	-9440.8	5279.62	16.15	2.01
	9	15713.9	-8840.2	5713.93	16.71	1.9
	10	15362.9	-9157.8	5298.9	16.57	2.37
	11	14762.6	-9934.5	3686.32	13.11	3.55
	12	13658.1	-11020.4	2363.44	11.11	4.78
1998	1	12896.7	-12804.4	698.89	8.8	6.93
	2	12014.3	-13155.4	644.9	7.88	6.32
	3	11588.9	-12890.1	552.19	8.96	7.48
	4	11286.2	-13488.8	432.32	8.24	7.12
	5	11503.6	-12815.1	379.66	8.2	7.18
	6	12026.7	-13977.8	712.5	8.36	6.51
	7	12806.4	-11498	2083.72	10.8	5.22
	8	12838.4	-11459.9	2572.8	11.74	4.85
	9	13512.2	-12241.4	3466.52	13.1	4.12
	10	14184	-11282.3	3077.46	13.06	4.81
	11	14133	-13126.2	2328.8	11.43	5.39
	12	14254.5	-12806.8	1718.69	10.48	5.88
1999	1	13168.1	-13176.5	560.89	8.61	7.11
	2	11809.7	-13118	421.67	7.42	6.4

	3	11571.6	-12883.1	344.3	8.44	7.51
	4	11589.7	-13876.6	327.61	8.13	7.28
	5	12454.4	-14799.4	864.97	9.28	6.96
	6	13279	-12095.1	2177.25	10.57	4.93
	7	13438.1	-13262	2822.32	11.89	4.34
	8	14485.7	-10376.7	4720.18	15.36	2.72
	9	15030	-9032	4884.17	15.34	2.68
	10	15071.2	-11887.3	4836.37	15.79	2.83
	11	14994.1	-10987.6	4127.38	13.88	3.18
	12	14572.3	-12344.5	2731.21	11.85	4.53
2000	1	13648.1	-13234.3	768.58	8.63	6.57
	2	12266.8	-12747.9	775.9	8.17	6.29
	3	11594	-12774	606.7	8.65	7.02
	4	11316.2	-12669.9	639.69	8.57	6.91
	5	11746.5	-13715.9	1063.61	9.45	6.6
	6	12953.5	-12861.8	2355.56	10.82	4.71
	7	14487.8	-13637.5	4502.66	14.73	2.67
	8	14843.4	-9147.3	5491.53	16.59	1.88
	9	15868.7	-9317.1	6266.9	17.8	1.56
	10	15590.6	-7579.8	6167.91	18.28	1.76
	11	15228.7	-8940.9	4678.78	14.65	2.52
	12	14524.5	-11282	3055.09	12.22	4.04
2001	1	13077.2	-14024.5	830.29	8.67	6.44
	2	12800.5	-14008	725.82	7.91	6.15
	3	11866.7	-12996.3	690.32	8.89	7.05
	4	11348.6	-13669	523.22	8.48	7.13
	5	11215.2	-12699.7	664.23	8.63	6.86
	6	12596.7	-12331.7	1948.87	10.2	5.15
	7	13926.4	-11188.2	3915.17	13.57	3.08
	8	15094.1	-10909.5	5083.26	15.82	2.2
	9	15643.6	-8803.1	6339.34	17.86	1.43
	10	15289.5	-8222.8	5838.79	17.45	1.81
	11	15484.8	-10263.5	4683.67	14.66	2.52
	12	14518.4	-9473	3199.37	12.29	3.72
2002	1	13509.2	-13206.9	925.19	8.85	6.37
	2	13030	-13522	914	8.05	5.83
	3	12308.7	-13350.2	747.15	9.25	7.25
	4	11554.8	-13431.2	537	8.51	7.12
	5	11670.1	-12446.7	623.68	8.5	6.83
	6	12399	-11578.3	1773.84	9.83	5.23
	7	13405.7	-9366.6	3845.78	13.21	2.91
	8	14224.1	-9473.8	5158.67	15.74	1.92

	9	15369.5	-8171.5	6318.51	17.61	1.23
	10	16309	-8095.5	5921.35	17.65	1.79
	11	15563	-9967.6	4334.27	14.15	2.92
	12	14506.4	-10264.4	3047.02	12.17	4.01

2. Co Chien branch

Year	Month	Qmaxout (m3/s)	Qmax in (m3/s)	Qav (m3/s)	W out (10^9 m^3)	W in (10^9 m^3)
1996	1	12364.8	-10953.1	960.94	7.77	5.2
	2	11354.7	-10581.2	956.19	7.11	4.8
	3	10522	-10241.6	932.76	7.8	5.3
	4	10645.3	-10151.2	746.4	7.48	5.54
	5	10986	-10381.5	943.6	7.94	5.41
	6	11621.7	-10390.3	1294.49	8.19	4.83
	7	12888.6	-10285.7	2055.47	9.66	4.16
	8	13658.4	-8909.7	4315.24	13.64	2.08
	9	14067.7	-6503	5015.23	14.55	1.55
	10	14124.4	-6248.8	5448.98	15.76	1.16
	11	13821.3	-7013	4646.99	13.52	1.48
	12	13520.5	-12544.8	3246.34	11.35	2.66
1997	1	12148	-11061.4	748.78	7.74	5.74
	2	11766.8	-11458.8	813	7.14	5.18
	3	11261.6	-10645.3	882.92	7.94	5.58
	4	10867.2	-13695.4	901.2	7.79	5.45
	5	10933	-12876.8	1012.75	8.26	5.55
	6	14638.5	-11592.3	1102.87	7.66	4.8
	7	13054.3	-9334.7	2846.29	10.9	3.28
	8	13940.3	-6988.8	5159.14	15.06	1.24
	9	14353.2	-6248.7	5539.01	15.44	1.08
	10	14004.1	-6606.4	5131.68	15.15	1.41
	11	13803.9	-7523.4	3649.37	11.89	2.43
	12	12839.6	-8516.5	2425.54	10.01	3.51
1998	1	12155.6	-10336	910.6	7.86	5.43
	2	11164.9	-10600.8	877.9	7.06	4.93
	3	10793	-10371.9	796.53	7.99	5.86
	4	10515.8	-11001.8	663.17	7.35	5.63
	5	10791.1	-10501.9	595.04	7.31	5.72
	6	11443.2	-11447.9	915.09	7.53	5.16
	7	12052.5	-9435.4	2227.55	9.87	3.9
	8	12102.9	-9176	2715.96	10.78	3.51
	9	12619.9	-9634.5	3549.35	12.06	2.86
	10	13017.1	-8612.7	3121.2	11.8	3.44
	11	13223.9	-10397.7	2418.19	10.29	4.03

	12	13423.4	-10229.6	1837.95	9.38	4.46
1999	1	12323.1	-10569.9	771.69	7.67	5.6
	2	11128	-10666.6	640.84	6.59	5.04
	3	10658.9	-10395.6	572.37	7.48	5.95
	4	10739.9	-11357.1	557.15	7.21	5.77
	5	11807.8	-12132.8	1054.76	8.31	5.49
	6	13431	-9589.4	2303.58	9.69	3.72
	7	12783.9	-10735	2938.73	11.03	3.16
	8	13862.1	-8077.8	4686.49	14.31	1.76
	9	13801.7	-6649.6	4828.86	14.18	1.67
	10	13827.8	-8893.8	4706	14.4	1.79
	11	14094.8	-8327.5	4022.28	12.56	2.13
	12	13658.5	-9685.5	2744.32	10.65	3.3
2000	1	12568.4	-10888.1	960.78	7.69	5.12
	2	11594.7	-10293.7	991.98	7.29	4.89
	3	10674.7	-10305.4	807.98	7.67	5.5
	4	10448.5	-10176.5	836.83	7.63	5.46
	5	11116.4	-11183.1	1229.64	8.49	5.19
	6	12122	-10377.6	2447.91	9.89	3.55
	7	13721.1	-10889.1	4420.02	13.66	1.82
	8	14100.3	-6626.9	5334.26	15.43	1.14
	9	14843.8	-6784.7	5970.18	16.35	0.87
	10	14270	-5251.1	5860.53	16.69	0.99
	11	13847.9	-6432.1	4483.26	13.23	1.61
	12	13704	-8703.1	3019.78	10.99	2.9
2001	1	12305.8	-11431.2	987.53	7.7	5.06
	2	12004.7	-11391.8	921.23	7.03	4.8
	3	11061.5	-10546.5	893.78	7.91	5.51
	4	10522	-11041.4	712.59	7.52	5.67
	5	10595.7	-10412.7	831.59	7.7	5.48
	6	11924.6	-10023.8	2057.1	9.29	3.96
	7	13225.2	-8931.7	3896.01	12.56	2.12
	8	14301.5	-8121.6	4945.27	14.64	1.4
	9	14520.9	-6306.6	6026.59	16.42	0.79
	10	13962.7	-5965.1	5540.72	15.85	1.01
	11	14462.1	-7751	4510.93	13.27	1.58
	12	13411	-7282.7	3161.79	11.07	2.6
2002	1	12750.2	-10719.9	1071.88	7.89	5.02
	2	12118	-10940.8	1088.38	7.16	4.53
	3	11511.5	-10945.9	947.91	8.24	5.7
	4	10664.9	-10867.8	733.74	7.55	5.65
	5	10946.8	-10184.8	781.32	7.55	5.46

	6	11626.8	-9310.1	1858.36	8.88	4.06
	7	12795	-7196.8	3816.05	12.24	2.02
	8	13404.1	-7053.2	5009.75	14.61	1.19
	9	14416.9	-5766.4	6020	16.26	0.66
	10	14803.4	-5713.7	5606.9	16.05	1.03
	11	14381.9	-7462.5	4185.24	12.78	1.93
	12	13515.5	-7905.9	3016.24	10.94	2.87

3. Dai branch

Year	Month	Qmax out (m3/s)	Qmax in (m3/s)	Qtb (m3/s)	W out (10^9 m^3)	W in (10^9 m^3)
1996	1	9358.6	-11352.4	702.66	7.05	5.17
	2	9664.1	-11571.7	474.39	6.29	5.14
	3	8014.4	-10806.2	275.76	6.42	5.68
	4	7787.4	-10768.9	199.87	6.24	5.73
	5	7390	-11148.7	299.7	6.2	5.4
	6	8194.7	-11000.3	352.21	6.23	5.32
	7	8755.2	-10504.7	1000.72	7.37	4.69
	8	9957.8	-10768.2	1504.13	8.6	4.57
	9	10199.3	-10553.6	1551	8.7	4.68
	10	10610.5	-10633.2	2095.87	9.93	4.32
	11	10247.6	-10279.7	1947.56	9.1	4.05
	12	10678.9	-10330.5	1454.05	8.41	4.52
1997	1	10111.3	-11337.2	906.8	7.69	5.27
	2	9672	-11365	800.05	6.86	4.92
	3	9248.6	-10904.6	421.3	6.91	5.78
	4	8257.6	-11635.8	243.3	6.57	5.94
	5	8058.6	-11311	137.38	6.57	6.21
	6	8396.5	-12113.3	360.95	6.54	5.61
	7	9101.6	-11532	953.31	7.55	4.99
	8	9684.1	-11082	1646.99	8.53	4.12
	9	10151.4	-11097.4	1866.97	9.17	4.33
	10	10481.7	-10567.8	1764.81	9.44	4.71
	11	9829.4	-11516.5	1379.89	8.3	4.73
	12	9952.9	-10684.8	964.7	7.74	5.15
1998	1	9489.3	-11913.1	479.77	6.9	5.62
	2	8784.1	-11468.5	420.38	6.1	5.08
	3	9172.3	-11230.8	256.66	6.92	6.24
	4	8130.1	-11388.1	261.63	6.43	5.75
	5	7921.1	-10893.3	297.65	6.43	5.64
	6	8156.2	-11275.2	331.86	6.15	5.29
	7	8847.1	-10356.7	833.43	7.22	4.98
	8	8595.3	-10757.7	972.4	7.67	5.06

	9	9187.8	-11316.7	1266	8.11	4.82
	10	10432.4	-10937.1	1245.94	8.55	5.22
	11	9758.1	-12514.6	1027.72	7.85	5.19
	12	10125.6	-11523.7	854.54	7.72	5.43
1999	1	9426.7	-10643.2	449.82	6.85	5.65
	2	8648.5	-11125.8	216.57	5.81	5.29
	3	8292.7	-10581.2	228.51	6.65	6.04
	4	8295.4	-11428.8	235.31	6.39	5.78
	5	8599.6	-11978.4	349.74	6.8	5.86
	6	8992.1	-10916.1	894.63	6.98	4.67
	7	8614.3	-11134.3	1040.46	7.47	4.68
	8	9509.7	-11257.8	1476.01	8.62	4.66
	9	9942.9	-10291.7	1699.31	8.86	4.45
	10	10540.5	-12235.2	1683.86	9.3	4.79
	11	10202.4	-10946.7	1639.29	8.56	4.31
	12	10830.3	-11205	1199.45	8.07	4.85
2000	1	9414.8	-11748.4	677	6.98	5.16
	2	8673.5	-10505.1	647.15	6.41	4.84
	3	8831.8	-10368.6	383.72	6.79	5.76
	4	8034.9	-10777.1	261.25	6.4	5.72
	5	8200	-11191.9	396.24	6.57	5.51
	6	8516.4	-10904.8	883.09	6.79	4.5
	7	9481.9	-10515.8	1530.51	8.25	4.15
	8	9497.2	-10688.9	1866.57	8.86	3.87
	9	9735.6	-10887.8	2133.15	9.41	3.88
	10	9970.1	-10334.2	2170.8	10	4.18
	11	10323.1	-11181.1	1783.67	8.88	4.26
	12	9788.5	-10457.6	1366.1	8.19	4.53
2001	1	9177	-11465	729.91	6.93	4.98
	2	9167.5	-11092.6	608.31	6.28	4.81
	3	8820.6	-10925.4	404.65	6.77	5.69
	4	8230	-11139.3	362.52	6.59	5.65
	5	8033.3	-11080.1	306.4	6.3	5.48
	6	7973.7	-11126.1	637.32	6.39	4.74
	7	8565.7	-10564.3	1330.19	7.7	4.14
	8	9257.6	-11600.1	1624	8.25	3.9
	9	9954.7	-10609.9	2096.55	9.29	3.85
	10	10008.4	-9573.4	2040.66	9.68	4.22
	11	10235.9	-10487.8	1649.68	8.6	4.33
	12	9582.1	-10210.1	1215.21	7.87	4.61
2002	1	10441.4	-11489.9	541.75	6.91	5.46
	2	9936.1	-11361.7	470.81	6.15	5.01

	3	9235.8	-11557.8	387.74	7.09	6.05
	4	8467.2	-11586.7	275.48	6.6	5.89
	5	8197	-11725.3	372.63	6.56	5.56
	6	8532.8	-10799.4	730.46	6.73	4.84
	7	8601.2	-9970.2	1289.77	7.53	4.08
	8	9191.4	-10452.6	1641.45	8.36	3.97
	9	9911.6	-9949.8	2018.17	8.9	3.67
	10	11241.9	-10900.9	2003.84	9.52	4.15
	11	10337.1	-11540.1	1575.96	8.48	4.4
	12	9894.5	-10946.7	1125.22	7.85	4.83

4. Tieu branch

Year	Month	Qmax out (m3/s)	Qmax in (m3/s)	Qtb (m3/s)	W out (10^9 m^3)	W in (10^9 m^3)
1996	1	5993.3	-7110	512.41	4.57	3.2
	2	6166.7	-7124.5	353.37	4.06	3.21
	3	5163.7	-6803.1	207.06	4.13	3.57
	4	4946.6	-6737.7	155.39	4	3.6
	5	4748.7	-6997.6	221.88	3.99	3.39
	6	5180.3	-6843.6	261.96	4.02	3.34
	7	5666.9	-6601.1	717.34	4.82	2.9
	8	6362.8	-6683.6	1080.04	5.66	2.77
	9	6541.5	-6356.2	1115.8	5.71	2.82
	10	6860.8	-6336.3	1504.44	6.57	2.54
	11	6589.4	-6390.4	1399.12	6.01	2.39
	12	6812.9	-6438.9	1049.92	5.53	2.72
1997	1	6467	-7094.2	658.99	5	3.24
	2	6209	-7129.4	584.22	4.44	3.03
	3	5925.6	-6847	312.47	4.46	3.62
	4	5276.7	-7199.4	186.08	4.22	3.74
	5	5222.4	-7106.8	113.92	4.21	3.91
	6	5406.6	-7578.9	269.46	4.21	3.52
	7	5871.3	-7205.4	689.14	4.93	3.09
	8	6175.9	-6925.4	1178.17	5.64	2.48
	9	6530.6	-6710.3	1338.11	6.05	2.58
	10	6769.8	-6327	1267.87	6.21	2.81
	11	6362.6	-7095.5	996.99	5.45	2.86
	12	6381.5	-6687.5	704.69	5.03	3.15
1998	1	6060.3	-7321.8	354.58	4.46	3.51
	2	5656.9	-7222.9	311.64	3.93	3.17
	3	5841	-6990	194.74	4.45	3.93
	4	5266.5	-7199.4	195.69	4.13	3.63
	5	5141.2	-6884.8	222.74	4.15	3.55

	6	5231.7	-7011	247.05	3.98	3.34
	7	5709.5	-6534.1	602.63	4.72	3.1
	8	5555.8	-6740.3	702.74	5.01	3.12
	9	5885.1	-6987.7	911.8	5.31	2.95
	10	6634.8	-6760	900.31	5.6	3.19
	11	6331.7	-7547	745.38	5.12	3.19
	12	6533.5	-7214.2	627.08	5.02	3.34
1999	1	6085.5	-6683.6	336.41	4.42	3.52
	2	5586.5	-6943.8	168.11	3.73	3.33
	3	5276.2	-6671.5	174.97	4.27	3.8
	4	5337.7	-7163	177.64	4.11	3.65
	5	5591.1	-7368.5	260.88	4.39	3.69
	6	5751.3	-6846.8	644.82	4.56	2.89
	7	5586.1	-6969.7	748.06	4.9	2.89
	8	6079.8	-6974.6	1060.5	5.66	2.82
	9	6444.3	-6392.9	1218.03	5.83	2.67
	10	6710.4	-7492.1	1212.78	6.12	2.87
	11	6490.4	-6787.7	1178.45	5.64	2.59
	12	6956.5	-7022.2	871.74	5.28	2.95
2000	1	6087.3	-7331.9	496.38	4.52	3.2
	2	5547.5	-6534.8	469.67	4.14	3.01
	3	5711.4	-6495.8	285.11	4.36	3.6
	4	5217.4	-6751.4	197.27	4.11	3.6
	5	5328.1	-7035.7	291.9	4.25	3.47
	6	5513.8	-6892.9	635.17	4.45	2.8
	7	6113.9	-6551.5	1097.28	5.45	2.51
	8	6171.6	-6580.9	1332.53	5.88	2.31
	9	6317	-6546.3	1524.19	6.24	2.29
	10	6453.8	-6262.4	1553.66	6.62	2.46
	11	6644.8	-6784.4	1281.36	5.86	2.54
	12	6298.7	-6514.7	985.21	5.38	2.74
2001	1	5936.4	-7199.8	529.2	4.51	3.09
	2	5919.4	-6937.6	444.83	4.07	2.99
	3	5733.8	-6787.4	297.93	4.36	3.56
	4	5281.6	-6968.6	267.95	4.25	3.55
	5	5215.3	-7007.1	227.87	4.07	3.46
	6	5153.1	-6987.6	460.55	4.17	2.97
	7	5571.6	-6647.3	953.35	5.08	2.53
	8	6024.5	-7071.5	1161.39	5.46	2.35
	9	6482.9	-6507.3	1498.72	6.16	2.28
	10	6466.1	-5878.1	1462.13	6.4	2.48
	11	6605.1	-6336.3	1185.05	5.67	2.6

	12	6184.4	-6338.5	878.45	5.16	2.81
2002	1	6607.7	-7183.4	401.6	4.47	3.39
	2	6312.6	-7139.7	349.39	3.97	3.13
	3	5909.6	-7239	285.58	4.55	3.79
	4	5454.4	-7290.9	208.17	4.24	3.7
	5	5276.2	-7310.3	272.15	4.24	3.51
	6	5509.5	-6723.9	528.8	4.39	3.02
	7	5547.3	-6294.7	925.42	4.97	2.49
	8	5939.5	-6500.6	1175.13	5.52	2.38
	9	6409.6	-6132.1	1440.48	5.9	2.17
	10	7163.5	-6585.2	1432.97	6.3	2.47
	11	6686.3	-7069.9	1131.14	5.58	2.65
	12	6346.3	-6776.8	817.91	5.14	2.95

5. Ham Luong branch

Year	Month	Qmax out (m3/s)	Qmax in (m3/s)	Qtb (m3/s)	W out (10^9 m³)	W in (10^9 m³)
1996	1	14877.9	-19064.9	81.71	9.94	9.72
	2	14374.1	-18289.7	161.56	9.27	8.88
	3	12964.7	-16954.6	217.53	10.14	9.56
	4	12925.7	-17401.8	119.49	9.98	9.67
	5	12976.5	-17056.2	225.81	10.28	9.68
	6	13693	-17215.1	424.43	10.26	9.16
	7	14740.9	-18170.7	692.98	11.2	9.34
	8	15735.7	-19826	1853.55	13.41	8.45
	9	16260.3	-17677.5	2376.64	14.03	7.87
	10	16504.1	-17446.6	2566.71	14.73	7.85
	11	15692.2	-18001.3	2066.48	13.01	7.66
	12	15962.6	-24297.6	1314.74	11.96	8.44
1997	1	15328.1	-19272.3	-115.7	10.24	10.55
	2	14830.9	-19900.9	-68.97	9.42	9.59
	3	14206	-18773.3	100.56	10.44	10.17
	4	13284.2	-22691.1	203.26	10.16	9.64
	5	13189.6	-19907.3	290.1	10.65	9.87
	6	13016.7	-18911.1	234.33	9.64	9.03
	7	14495.3	-18846.2	1188.41	11.85	8.67
	8	15727.2	-17899.7	2454.53	13.73	7.16
	9	16779.3	-17941.8	2682.88	14.38	7.43
	10	16440.2	-18133.2	2498.5	14.62	7.93
	11	15955.5	-17428.3	1634.01	12.37	8.14
	12	14963	-17034.4	965.57	11.35	8.77
1998	1	14401.7	-17652.6	167.13	10.27	9.82
	2	14034.7	-17906.9	111.26	9.23	8.96

	3	13929.2	-17635.7	131.43	10.65	10.3
	4	13126.4	-17981.3	41.39	9.83	9.72
	5	12803.4	-17034.2	-9.36	9.69	9.72
	6	13301.9	-18600.1	193.2	9.63	9.13
	7	13525.2	-16637.3	838.42	11.26	9.01
	8	13791.1	-17360	1054.71	11.93	9.1
	9	15110.5	-19226.8	1486.16	12.7	8.85
	10	15931.3	-18876.5	1308.92	12.85	9.35
	11	16005.8	-19934.1	950.94	11.81	9.35
	12	15901.2	-18778.5	603.9	11.26	9.65
1999	1	14994.8	-18342.7	66.1	10.15	9.97
	2	13498.6	-17381.4	37.12	8.82	8.73
	3	13091.5	-17262.5	12.14	10.15	10.12
	4	13725.8	-17660.1	-7.96	9.74	9.76
	5	14041.6	-20008	295.48	10.63	9.83
	6	14464.7	-17965.5	885.6	10.81	8.51
	7	14552.8	-19372	1221.34	11.84	8.57
	8	15142.4	-17500.6	2134.11	13.76	8.05
	9	15958.1	-17173.9	2148.31	13.69	8.12
	10	16392.6	-20698.3	2180.3	14.1	8.26
	11	16421.1	-19205.7	1758.48	12.54	7.98
	12	16571.6	-19176.3	1095.41	11.78	8.84
2000	1	16350.2	-19037	100.89	9.91	9.64
	2	13896.4	-18054.9	147.55	9.52	9.17
	3	13701.5	-17257.2	116.7	10.13	9.82
	4	13439.9	-17273.8	175.13	9.96	9.5
	5	13195.3	-18590.7	383.42	10.54	9.51
	6	13951.9	-18459.1	988.34	10.9	8.34
	7	15051.3	-20941	2029.93	13.02	7.59
	8	15322.3	-17983.6	2503.83	13.99	7.28
	9	16142.6	-19043.1	2930.23	14.65	7.05
	10	16384.6	-16821.8	2932.36	15.26	7.41
	11	16345.6	-17506.4	2095.75	12.89	7.46
	12	15568.1	-18627.4	1218.63	11.61	8.35
2001	1	14925	-19558.2	158.94	9.82	9.4
	2	14767.5	-19372.6	108.08	9.11	8.85
	3	14144.5	-17576.6	163.77	10.31	9.87
	4	12710.8	-18420.1	70.45	9.93	9.74
	5	12583.3	-17167	173.94	9.88	9.41
	6	13479.3	-17602.8	839.36	10.54	8.36
	7	14710.4	-18748.9	1730.34	12.34	7.71
	8	15872.2	-19607.3	2362.57	13.44	7.11

	9	16521	-18571.9	3032.12	14.62	6.76
	10	16220.3	-16798.3	2796.51	14.76	7.27
	11	16918.7	-19292.7	2157.01	13.01	7.42
	12	15494.3	-16144.5	1388.19	11.62	7.9
2002	1	15229.4	-18375.1	272.31	10.06	9.33
	2	14915	-18331.3	277.45	9.18	8.51
	3	14086.4	-18243.6	229.64	10.69	10.08
	4	13224.9	-18288.5	106.79	9.92	9.64
	5	13288.7	-17028.4	145.03	9.78	9.39
	6	13432.5	-17000.5	701.54	10.19	8.38
	7	13628.5	-16375	1694.75	11.88	7.34
	8	14815.3	-17639.8	2338.28	13.29	7.03
	9	16281.3	-17496.1	3041.47	14.21	6.33
	10	17287	-17687.2	2855.91	14.73	7.08
	11	16720.5	-18622.5	1974.8	12.72	7.6
	12	15694.5	-17637.4	1289.38	11.67	8.22

6. Dinh An branch

Year	Month	Qmax out (m3/s)	Qmax in (m3/s)	Qtb (m3/s)	W out (10^9 m³)	W in (10^9 m³)
1996	1	23000.3	-25624	2105.79	15.5	9.85
	2	21075	-25346	1972.74	14.13	9.36
	3	20147.6	-25016.1	1597.8	15.48	11.2
	4	20836.9	-25737	1327.36	15.24	11.8
	5	20757.6	-26314.3	1803.69	15.68	10.85
	6	21270.3	-28635.1	2231.08	16.36	10.57
	7	23137.6	-25290	3856.06	19.46	9.13
	8	25400.9	-22793.6	7852.18	26.25	5.22
	9	26398.2	-17758.6	8890.31	26.81	3.77
	10	27663.2	-19664.9	9710.02	29.52	3.51
	11	25997.8	-20990	8628.51	25.97	3.61
	12	26013.1	-18856	6436.53	22.03	4.79
1997	1	21815.3	-23105.9	2883.43	17.19	9.46
	2	21753.1	-25809.8	2625.47	15.13	8.78
	3	23727.9	-26073.8	1920.29	16.13	10.98
	4	19834.5	-31832	1506.54	15.22	11.31
	5	20059.7	-28583.2	1354.08	15.33	11.7
	6	19378.1	-28484.6	1910.96	15.55	10.59
	7	24473.4	-24917.3	5242.32	20.89	6.84
	8	25365.7	-19108.6	9114.23	27.95	3.54
	9	27051.5	-16496.9	9825.56	28.81	3.34
	10	26809.9	-18381.1	9068.89	28.5	4.21
	11	25580.2	-20903.5	6860.14	23.02	5.23

	12	25380.8	-20212.7	4738.52	19.45	6.76
1998	1	22419.5	-24546.2	1980.49	15.46	10.16
	2	21643.3	-27715.6	1810.21	13.77	9.39
	3	21123.7	-26477.6	1273.83	15.51	12.09
	4	21570.7	-28187.1	1134.04	14.76	11.82
	5	18783.5	-24783.4	1020.35	14.36	11.62
	6	18735.6	-25307.7	1639.99	14.74	10.49
	7	21623.5	-22747.4	4154.48	19.42	8.29
	8	23867.8	-23596.2	5068.35	21.15	7.58
	9	24460.4	-22576.1	6683.2	23.72	6.4
	10	25781.9	-20762.2	6029.26	22.9	6.75
	11	24361.2	-23961	4665.23	20.13	8.04
	12	24373.5	-22226.2	3868.06	18.88	8.52
1999	1	24934.4	-23706	1726.3	15.05	10.42
	2	19923	-25430.2	1409.75	13.05	9.64
	3	19366.8	-28701.1	1148.73	15.08	12.01
	4	20640.9	-27635.1	1032.67	14.52	11.84
	5	20813.3	-28699.4	1835.13	16.12	11.2
	6	21971.8	-23727.1	4356.62	18.65	7.36
	7	22777.4	-22933.5	5515.77	21.25	6.48
	8	24257.4	-20690.6	8412.9	26.8	4.26
	9	25756.3	-19321.3	8684.02	26.79	4.28
	10	26603.4	-18572.3	8424.28	27.54	4.97
	11	26118.9	-21041.9	7463.54	24.02	4.67
	12	25137.9	-23307	5279.01	20.57	6.43
2000	1	22115.9	-25122.4	2137.3	15.22	9.49
	2	20707	-26054.3	1932.8	14.15	9.47
	3	19912.5	-24580.6	1725.93	15.16	10.54
	4	20036.5	-23748.7	1329.44	14.76	11.32
	5	20967.5	-25535.4	2049.18	16.19	10.7
	6	21079.1	-23542.7	4441.73	19	7.49
	7	22271.7	-22231	7919.17	25.39	4.18
	8	24831	-17369.1	9391.36	28.3	3.15
	9	26732.3	-17643.3	10362.02	29.9	3.04
	10	27154.6	-18512.2	10052.94	30.61	3.69
	11	25969.3	-17487.4	7976.74	24.82	4.15
	12	24713	-20686.7	5800.64	21.47	5.93
2001	1	22764.3	-25204.5	2142.38	15.16	9.42
	2	22220	-26553.9	1960.76	14.04	9.29
	3	20901.8	-27655.1	1614.08	15.62	11.3
	4	19835.5	-26865.4	1331.66	15.16	11.71
	5	19981.6	-25249.7	1409.15	15.2	11.42

	6	21336.9	-23817.1	3646.45	17.93	8.48
	7	23999.2	-20105.4	7057.27	23.88	4.98
	8	25686	-19731.9	8790.08	27.14	3.6
	9	27413.4	-17130.2	10430.84	29.98	2.95
	10	27003.4	-17500.9	9593.45	29.28	3.58
	11	26863	-16813.1	7984.85	24.85	4.15
	12	25336.4	-19147.7	5839.51	21.22	5.58
2002	1	22333.9	-25862.1	2200.58	15.35	9.46
	2	22228.6	-26368	2060.79	13.75	8.77
	3	20815	-27104	1682.8	16.27	11.76
	4	20636.9	-27557.6	1232.54	14.94	11.74
	5	19709.4	-27641.4	1372.8	15.05	11.37
	6	21608.9	-23637.8	3377.21	17.19	8.43
	7	22688	-20396.4	6897.77	23.13	4.66
	8	24627.4	-19564.4	8846.47	27.21	3.52
	9	26523.7	-18652.6	10365.08	29.43	2.56
	10	28453	-18180.3	9668.75	29.43	3.54
	11	26958.7	-20190.3	7469.13	23.99	4.63
	12	24760.8	-22234.1	5588.94	20.95	5.98

7. Tran De branch

Year	Month	Qmax out (m3/s)	Qmax in (m3/s)	Qtb (m3/s)	W out (10^9m^3)	W in (10^9m^3)
1996	1	19217.4	-24308.2	1024.65	12.84	10.09
	2	17480.2	-24256.8	954.69	11.88	9.57
	3	17005.5	-23476.3	677.95	13.06	11.25
	4	17621.2	-25143.2	486.41	12.93	11.67
	5	16669.8	-24693.6	822.76	13.18	10.97
	6	17588.2	-26639.8	1103.41	13.54	10.68
	7	18622.5	-24117.2	2156.38	15.61	9.84
	8	19608.3	-23161.8	4968.87	20.1	6.79
	9	21246.8	-19095.2	5710.4	20.35	5.55
	10	22046.2	-21515	6409.2	22.48	5.31
	11	20381.7	-22282.1	5681.2	19.96	5.24
	12	20721.7	-19971	4110.9	17.2	6.19
1997	1	17564.2	-22990.4	1559.25	14.15	9.98
	2	17589.5	-25359.5	1319.19	12.51	9.32
	3	19252.3	-24616.7	848.94	13.52	11.25
	4	16472.8	-31141	644.84	12.93	11.26
	5	16604.8	-28366.5	526.5	13.04	11.63
	6	16042.2	-26341	972.68	13.06	10.54
	7	20645.1	-24372.8	3206.42	16.47	7.88
	8	20291.6	-20733.6	5969.36	21.1	5.11

	9	21827.2	-18603.2	6427.99	21.73	5.07
	10	21528.7	-20738.5	5897.7	21.74	5.94
	11	20689.1	-22125.4	4360.9	17.94	6.64
	12	20390	-20777.4	2920.37	15.57	7.74
1998	1	18541.3	-23475.2	992.08	12.97	10.31
	2	17701	-26653.7	840.14	11.59	9.56
	3	17881.5	-25463.9	443.04	13.25	12.06
	4	18224.7	-26708.3	381.61	12.63	11.64
	5	15426.8	-23550.5	347.21	12.35	11.42
	6	15750.3	-24073.8	758.46	12.41	10.45
	7	17293	-23595.9	2414.02	15.62	9.15
	8	19470.3	-23684.1	2969.6	16.76	8.8
	9	19912.1	-23115.2	4069.32	18.46	7.91
	10	21143.5	-21477.8	3750.45	18.1	8.06
	11	19828.5	-24609.2	2824.47	16.21	8.89
	12	19800	-21724.8	2290.74	15.37	9.24
1999	1	20594	-23139	823.8	12.68	10.47
	2	16543.2	-24446.9	573.6	11.09	9.7
	3	15936.2	-27353.5	409.08	12.93	11.83
	4	17455.2	-26027.8	335.74	12.47	11.6
	5	16726.1	-27772.1	871.87	13.57	11.23
	6	18068.1	-22938.3	2660.94	14.96	8.07
	7	18037.7	-23350.1	3387.66	16.67	7.59
	8	19777.6	-22308.5	5362.89	20.35	5.99
	9	21317.4	-21083.3	5521.92	20.38	6.07
	10	21679.3	-20134.3	5382.67	21.16	6.74
	11	21079.1	-22183.2	4837.34	18.69	6.16
	12	20305.2	-23495.9	3328.69	16.41	7.49
2000	1	18042.9	-24114.1	1083.04	12.68	9.78
	2	16849.1	-24981.5	920.61	11.88	9.66
	3	16753.9	-23613.2	831.27	12.81	10.58
	4	16764.7	-23017.1	545.97	12.59	11.17
	5	16802.3	-25220.2	1046.98	13.59	10.78
	6	16755.3	-23530.2	2684.77	15.19	8.23
	7	18120.1	-23006.6	5187.16	19.42	5.53
	8	20063	-18774.9	6168.05	21.31	4.79
	9	21547.8	-19221.1	6894.29	22.58	4.71
	10	21915.1	-20557.6	6668.4	23.32	5.46
	11	21620.8	-19306.7	5277.16	19.27	5.59
	12	20235.5	-21489.5	3742.07	16.98	6.96
2001	1	18679.2	-24349	1157.16	12.65	9.55
	2	18351	-25493.8	951.89	11.74	9.44

	3	17469.2	-25834.9	693.79	13.21	11.35
	4	16938.6	-25645.4	532.97	12.87	11.49
	5	16734	-24099.3	628.45	12.88	11.19
	6	17444.7	-23628	2141.39	14.49	8.94
	7	19297.2	-20458.3	4521.64	18.42	6.3
	8	21292.7	-21000.3	5787.43	20.57	5.07
	9	22544.2	-18971.6	6951.92	22.64	4.62
	10	22027.5	-19118.7	6375.19	22.39	5.31
	11	21714.3	-18824.9	5242.3	19.25	5.66
	12	20548.9	-19769.9	3769.06	16.73	6.64
2002	1	18302.4	-24566.9	1223.02	12.82	9.54
	2	18293.3	-25091.1	1060.66	11.5	8.93
	3	17461.5	-26172	764.81	13.73	11.68
	4	17034.8	-26460.1	487.43	12.76	11.5
	5	16452.4	-26116.8	623.03	12.8	11.13
	6	17254.2	-22389.8	2023.39	14.04	8.8
	7	18116.7	-20409	4444.82	17.82	5.92
	8	19793.9	-20651.9	5805.34	20.58	5.03
	9	21535	-20482.4	6925.13	22.1	4.15
	10	23276.4	-19789	6457.89	22.48	5.18
	11	21926.4	-21876.1	4889.42	18.68	6.01
	12	20094.7	-22905.3	3579.76	16.62	7.03

Annex 3.2. Example of river cross-section calculation for Ham Luong branch

For cross-section i :

- The river width is B_i;
- For every 100 m wide, the measured depth is h_j and the average depth for cross-section i is calculated as:

$$h_i = \frac{\sum_j h_j \times 10}{B_i}$$

Then for each river branch:

- The average river width is calculated as:

$$B = \frac{\sum_i B_i \times L_i}{\sum_i L_i}(m)$$

- The average river depth is calculated as:

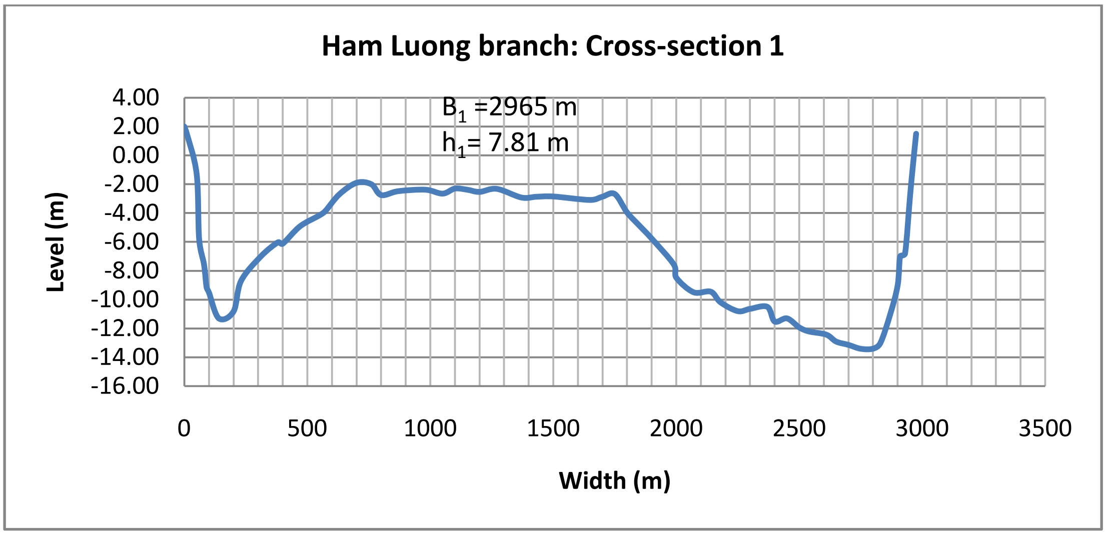
$$h = \frac{\sum_i h_i \times L_i}{\sum_i L_i}(m)$$

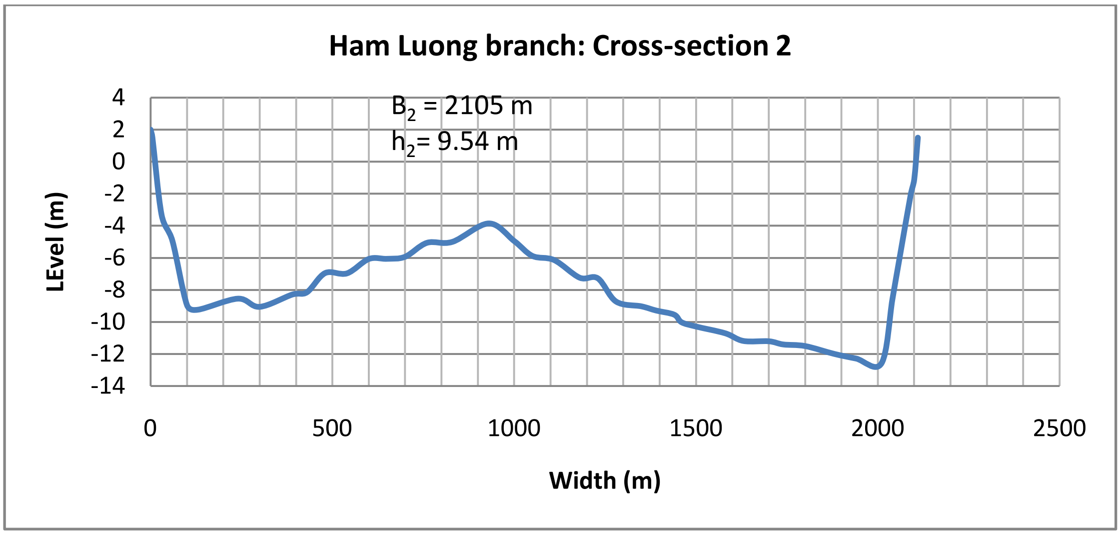
Table 6.4: Example of average river depth and river width calculation for one branch (Ham Luong branch)

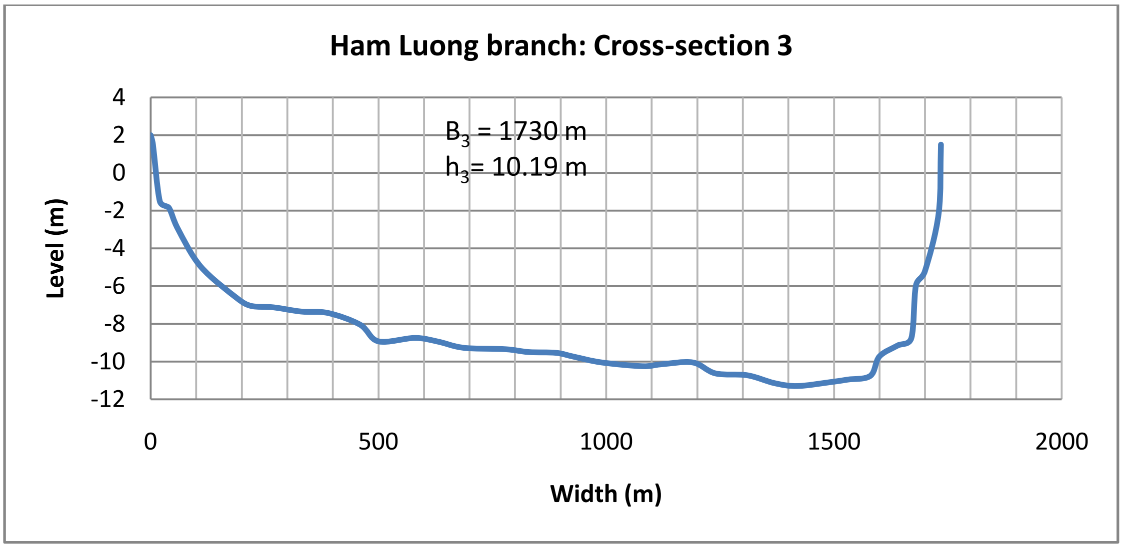
Cross-section	Width B_i (m)	Depth h_i (m)	Distance between 2 cross section Li(m)	Bi.Li	hi.Li
1	2965	7.81	-	-	-
2	2105	9.54	1740	4410900	15095
3	1730	10.19	1610	3087175	15892
4	1785	9.20	1400	2460,500	13581
5	1935	9.01	1380	2566800	12569
6	2280	8.29	1370	2887275	11858
7	2780	8.08	1830	4629900	14989
8	2610	8.25	1500	4042500	12257
9	2400	8.58	1630	4083150	13729
Total			**12460**	**28168200**	**109971**

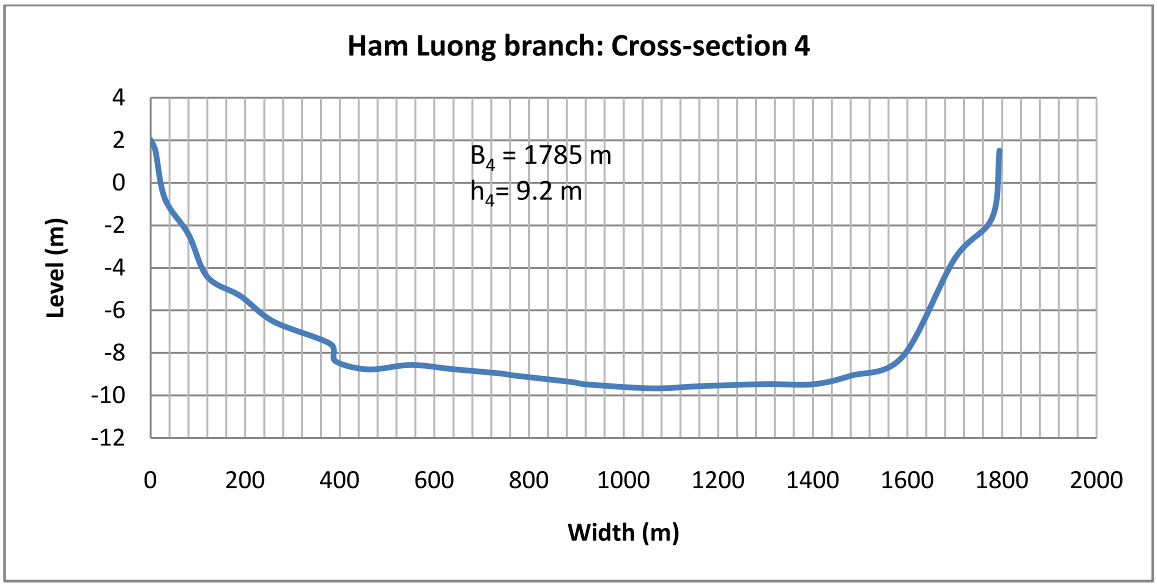
$$B_{av} = \frac{\sum_i B_i \times L_i}{\sum_i L_i} = 2260.7(m)$$

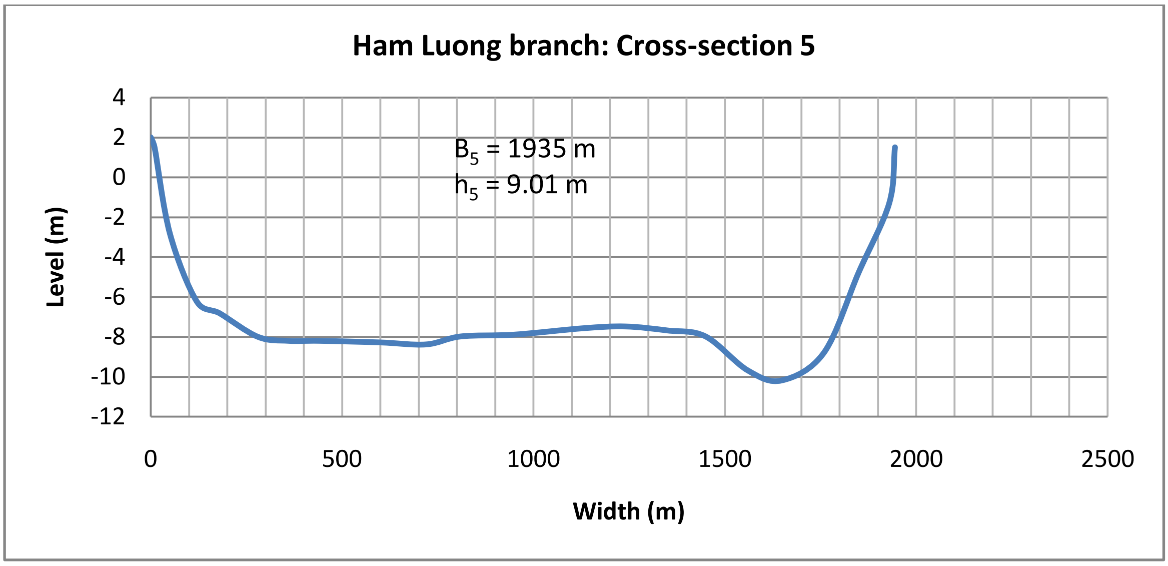
$$h_{av} = \frac{\sum_i h_i \times L_i}{\sum_i L_i} = 8.83(m)$$

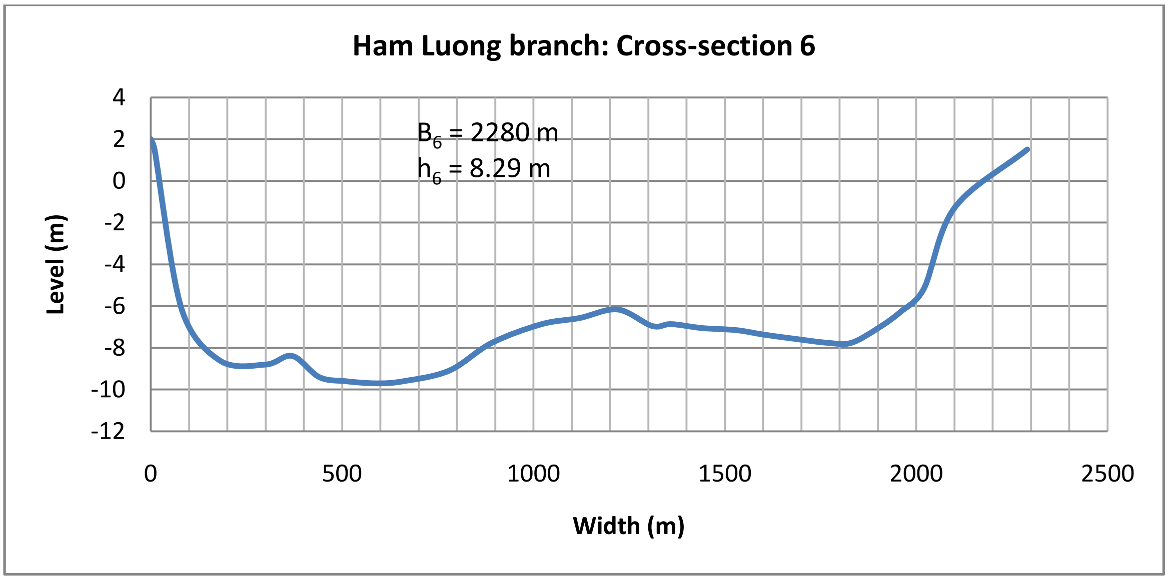

Ham Luong branch: Cross-section 1
B_1 =2965 m
h_1= 7.81 m
Level (m)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
0
500
1000
1500
2000
2500
3000
3500
Width (m)

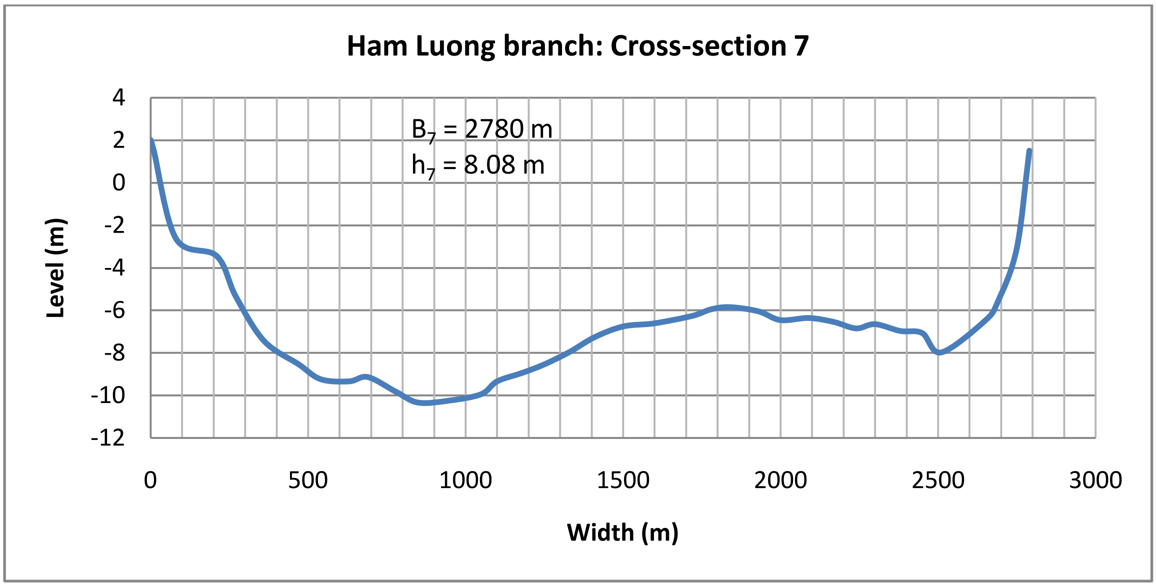

Ham Luong branch: Cross-section 2
B_2 = 2105 m
h_2= 9.54 m
LEvel (m)
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
500
1000
1500
2000
2500
Width (m)

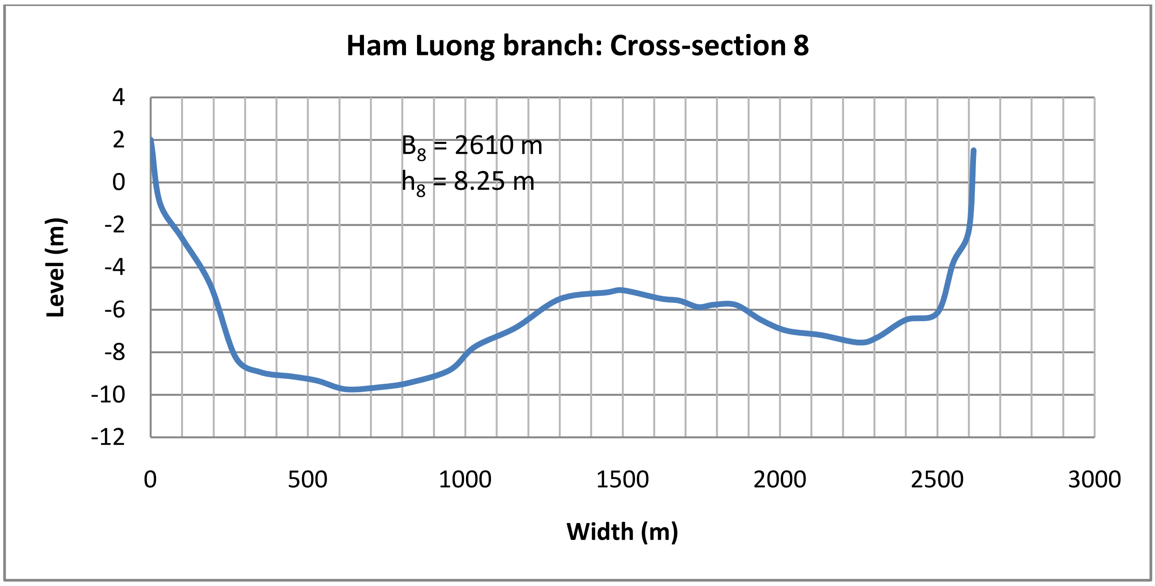

Ham Luong branch: Cross-section 3
B_3 = 1730 m
h_3= 10.19 m
Level (m)
4
2
0
-2
-4
-6
-8
-10
-12
0
500
1000
1500
2000
Width (m)

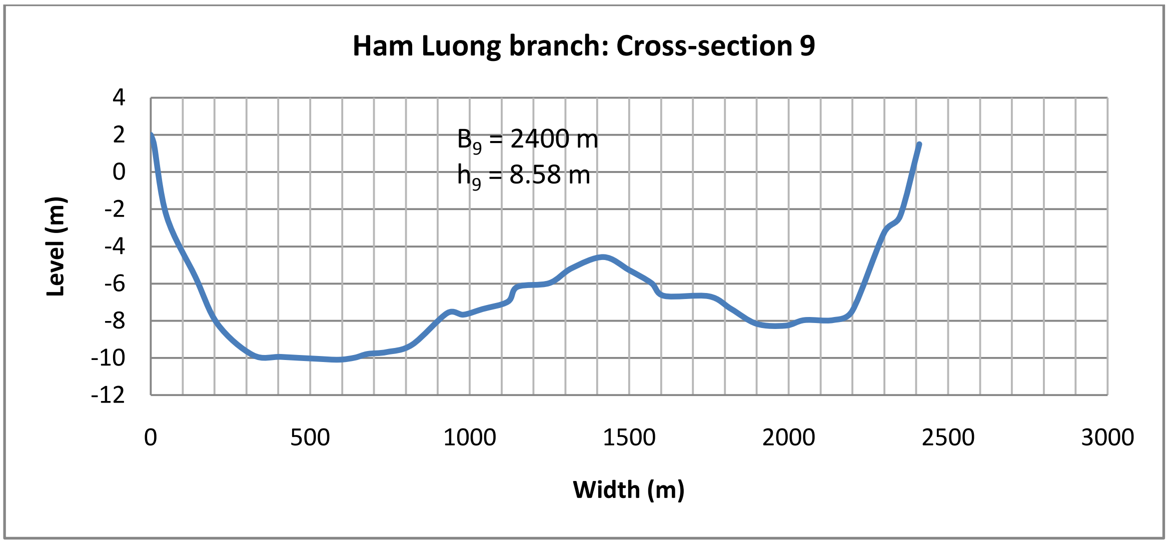

Ham Luong branch: Cross-section 4
B4 = 1785 m
h4= 9.2 m
Level (m)
Width (m)
4
2
0
-2
-4
-6
-8
-10
-12
0
200
400
600
800
1000
1200
1400
1600
1800
2000


Ham Luong branch: Cross-section 5
B5 = 1935 m
h5 = 9.01 m
Level (m)
Width (m)
4
2
0
-2
-4
-6
-8
-10
-12
0
500
1000
1500
2000
2500


Ham Luong branch: Cross-section 6
B6 = 2280 m
h6 = 8.29 m
Level (m)
Width (m)
4
2
0
-2
-4
-6
-8
-10
-12
0
500
1000
1500
2000
2500


Ham Luong branch: Cross-section 7
B_7 = 2780 m
h_7 = 8.08 m
Level (m)
4
2
0
-2
-4
-6
-8
-10
-12
0
500
1000
1500
2000
2500
3000
Width (m)


Ham Luong branch: Cross-section 8
B_8 = 2610 m
h_8 = 8.25 m
Level (m)
4
2
0
-2
-4
-6
-8
-10
-12
0
500
1000
1500
2000
2500
3000
Width (m)

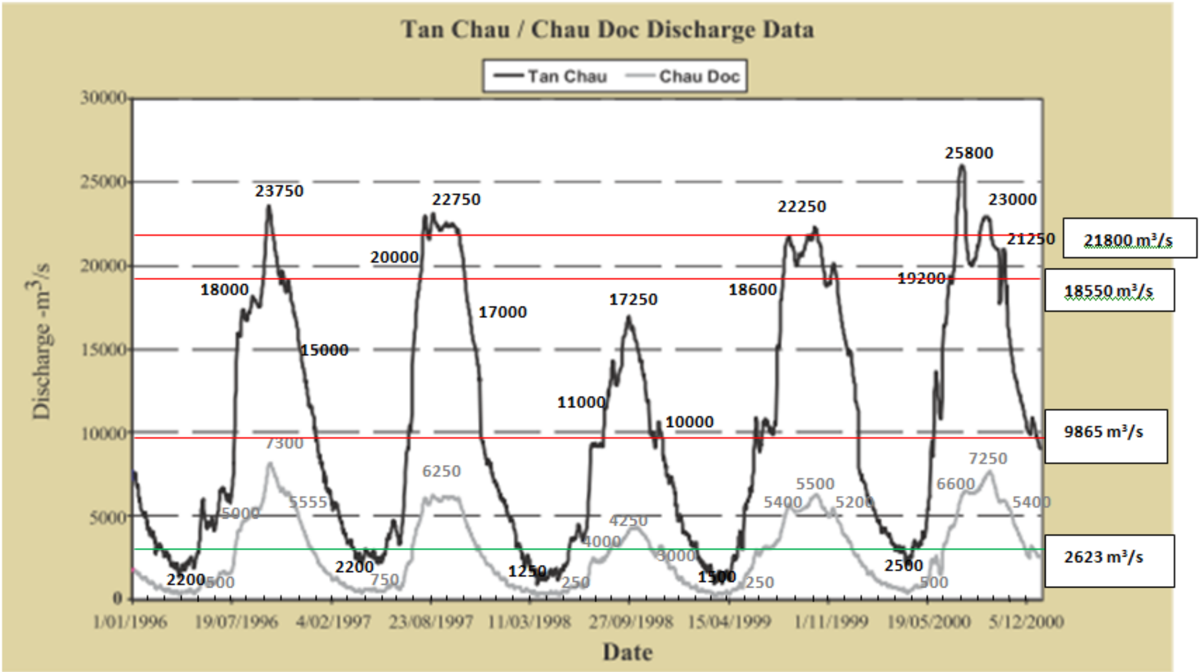

Ham Luong branch: Cross-section 9
B_9 = 2400 m
h_9 = 8.58 m
Level (m)
4
2
0
-2
-4
-6
-8
-10
-12
0
500
1000
1500
2000
2500
3000
Width (m)

Annex 3.3. Empirical relationship between tidal prism & river cross-section calculation

1. First Approach

1. Step 1:

Based on the river discharge recorded at Tan Chau and Chau Doc to calculate: annual river discharge, the river discharge exceeded in 3 months and the river discharge exceeded in 1 month for Tan Chau and Chau Doc as in the Figure below.



Tan Chau

- Average river discharge annually: 9865 (m^3/s)
- Average river discharge exceeded 3 month/year: 18550 (m^3/s)
- Average river discharge exceeded 1 month/year: 21800 (m^3/s)

After transferring 40% of water discharge to Hau River through Vam Nao, the river discharge at Tien River will be:

- Average river discharge annually: 5919 (m^3/s)
- Average river discharge exceeded 3 month/year: 11130 (m^3/s)
- Average river discharge exceeded 1 month/year: 13080 (m^3/s)

Chau Doc

- Average river discharge annually: 2623 (m^3/s)
- Average river discharge exceeded 3 month/year: 5547 (m^3/s)
- Average river discharge exceeded 1 month/year: 6110 (m^3/s)

2. Step 2: Justify the river discharge for each branches based on the 2 weeks data measurement

-Based on the river discharge of each branch of Tien River measured in 2 weeks (Annex 3.3) calculate

- The average river discharge($Q_{average}$), the river discharge out (Q_{out}) and in (Q_{in}) for each branch
- And the ratio of Q_{out}/Q_{total} and Q_{in}/Q_{total}

-Use the ratio to calculate the average river discharge annually ($Q_{out\text{-}average}$), average river discharge exceeded 3 months/year ($Q_{out\text{-}3months}$) and average river discharge exceeded 1 month/year ($Q_{out\text{-}1month}$) for each branch. And then calculate the average tidal discharge for each branch as:

Average tidal discharge = Average discharge observed in 2 weeks –Average river discharge observed in 2 weeks (data from Figure 6.11.)

Branch name	River discharge (m^3/s)			Average Tidal discharge (m^3/s)
	$Q_{river\text{-}average}$	$Q_{river\text{-}3months}$	$Q_{river\text{-}1month}$	
Ham Luong	1308.1	2459.7	2890.7	14304
Co Chien	1882.2	3539.3	4159.4	9366
Cung Hau	1308.1	2459.7	2890.7	6228
Dai	1018.1	1914.4	2249.8	9741
Tieu	361.1	678.9	797.9	4502

3. Step 3 and 4: calculate the ebb tidal prism

Ebb tidal prism = 0.5T<Q>

T: tidal period =44700 (s) for semidiurnal tide.

Branch name	Average(River+Tidal discharge)(m^3/s)			Ebb Tidal Prism (m^3)		
	$Q_{ebb\text{-}average}$	$Q_{ebb\text{-}3months}$	$Q_{ebb\text{-}1month}$	$P_{ebb\text{-}average}$	$P_{ebb\text{-}3months}$	$P_{ebb\text{-}1month}$
HamLuong	15612.1	16763.7	17194.7	348930435	374668695	384301545
Co Chien	11248.2	12905.3	13525.4	251397270	288433455	302292690
Cung Hau	7536.1	8687.7	9118.7	168431835	194170095	203802945
Dai	10759.1	11655.4	11990.8	240465885	260498190	267994380
Tieu	4863.1	5180.9	5299.9	108690285	115793115	118452765

2. Second approach

Branch name	Ebb flow volume (m^3)					
	Average		3 months exceeded		1 month exceeded	
	Per month	Per 1 tidal period	Per month	Per 1 tidal period	Per month	Per 1 tidal period
Tieu	4923809524	82063492	593238095	98873015	626000000	104333333
Dai	7543809534	125730159	899619048	149936508	948857143	158142857
H. Luong	1150309524	191718254	1394666670	232444444	1443571430	240595238
C.Chien	1046702381	174450397	1473476190	245579365	1529000000	254833333
C.Hau	1153238095	192206349	1602380952	267063492	1667000000	277833333
Tran De	1606380952	267730158	2098476190	349746031	2851571400	475261905
Dinh Anh	2013047619	335507937	2752476200	458746032	2175428571	362571429

Annex 3.4. Calculate the impact of closing down three main branches

1. Tide propagation estimation

Tide velocity: $c = \sqrt{gh} = \sqrt{9.81 \times 10} = 9.9(\frac{m}{s})$

Tide length: L= c×T = 9.9×44700= 442520 (m) =442.52 (km)

2. River depth increase due to closing branches

$P_{ebb-before}$: tidal prism before closing branch

$P_{ebb-after}$: new tidal prism after closing branch

A_c: river cross section after closing branch

$$A_c = 0.001 \times P_{ebb-after}^{0.861} \ (m^2)$$

h: river depth after closing branch (m)

$$h = A_c / B$$

a. Shut down one branch

Branch name	% ($P_{ebbafter}/P_{total}$)	$P_{ebb-before}(m^3)$	$P_{ebb-after}$ (m^{-3})	A_c (m^2)	h (m)
HAM LUONG BRANCH					
Tieu	0.133	89272605	125533957.6	9397.96	9.8
Dai	0.306	205537305	288747566.7	19253.35	9.62
Co Chien	0.329	229235010	318552446.8	20952.64	15.91
Cung Hau	0.204	143826720	199172995	13984.19	8.12
CO CHIEN BRANCH					
Tieu	0.124	89272605	117702534.4	8890.92	9.27
Dai	0.285	205537305	270776511.5	18217.05	9.1
Ham Luong	0.376	271769295	357956870.6	23165.85	11.31
Cung Hau	0.189	143826720	187219770.2	13258.51	7.7
CUNG HAU BRANCH					
Tieu	0.111	89272605	105253351.7	8075.05	8.41
Dai	0.255	205537305	242208913.1	16549.60	8.26
Ham Luong	0.337	271769295	320216190.2	21046.83	10.27
Co Chien	0.274	229235010	268598112.3	18090.79	13.73

b. Shut down two branches

Branch name	% ($P_{ebbafter}/P_{total}$)	$P_{ebb-before}$(m^3)	$P_{ebb-after}$ (m^{-3})	A_c (m^2)	h (m)
HAM LUONG & CO CHIEN					
Tieu	0.198	89272605	188844590.3	13357.53	13.95
Dai	0.456	205537305	434028808.1	27346.61	13.69
Cung Hau	0.303	143826720	295805013.4	19657.84	11.43
HAM LUONG & CUNG HAU					
Tieu	0.168	89272605	158905094.3	11512.77	12.02
Dai	0.384	205537305	365325543.6	23575.86	11.79
Co Chien	0.413	229235010	400750825.7	25531.41	19.41
CO CHIEN & CUNG hAU					
Tieu	0.153	89272605	146343240	10724.72	11.19
Dai	0.351	205537305	336499393.8	21965.12	10.98
Ham Luong	0.464	271769295	444783430.7	27929.04	13.65

c. Shut down three branches

Branch name	% ($P_{ebbafter}/P_{total}$)	$P_{ebb-before}$(m^3)	$P_{ebb-after}$ (m^{-3})	A_c (m^2)	h (m)
Tieu	0.285	89272605	273233407.9	18359.28	19.21
Dai	0.715	205537305	666407527.1	39558.52	19.85

Annex 3.5. Erosion and accretion status of the Mekong River in 2002

Table 6.5: Erosion and accretion status of difference branches of Tien and Hau River, observed in 2002 (SIWRR 2005b)

Bank	Section	Location	Length	Deposition/Erosion
TRAN DE BRANCH				
Left bank	L1	Located at Dai An Mot village	7.5km	Flat relief, lots of sediment deposition in flood season but erosion 1÷2m from Nov to April
	L2	Located at An Thuan Ba village	3km	Stability
Right bank	R1	Located in Long Phu village	4km	Deposition in flood season, lots of mangroves, erosion 1÷2m from Nov to April
	R2	Located in Dai An Hai village	5.25km	Erosion 1÷2m/yr
	R3	Located in Trung Binh village	4km	Flat bank, dense of mangroves, small erosion rate
CUNG HAU BRANCH				
Left bank	L1	From Hoa Minh village to upstream	8km	No erosion, slightly deposition
	L2	Located at Hai Thu village	3.5km	Deposition 1÷2m/yr
Right bank	R1	From Bai Vang river to Noc isle	8km	Slightly erosion 1÷2m/yr
	R2	Con Ban to My Long town	4km	stable
	R3	My Long town to Ben chua river	10km	Large alluvial flat (500÷2000m) with mature healthy mangroves
CO CHIEN BRANCH				
Except the river mouth at Thanh Phu Province and some short distance bank, almost the left bank of Co Chien branch is erosion.				
Left bank	L1	From Ot canal to An Thuan village	2.5km	Erosion 1÷2m/yr for 1.5km from An Thuan village to Ben Tre village Erosion 3÷4m/yr for the rest, lost hundreds hectares of cultivation land and house
	L2	From Ca Bay canal to Ot canal	3.5km	Erosion 3÷4m/yr
	L3	From Ben Kinh canal to Ca Bay canal	4km	Strongly erosion 10÷15m/yr
	L4	From Khau Bang canal to Ben Kinh canal	1.5km	Deposition 2÷3m/yr
	L5	From the mouth of the river to Khau Bang canal	2km	Deposition 2÷3m/yr
Right bank	R1	From Hoa Minh village to Mai Dam canal	2km	Erosion 0.5÷1m/yr
	R2	From Mai Dam canal to Bung Binh canal	6km	Erosion 2÷3m
	R3	From Bung Binh canal to Thu isle		erosion

		HAM LUONG BRANCH		
Left bank	L1	From Muong Dao to upstream	2.2km	Slightly erosion
	L2	From Muong Dao canal to Ba Hien canal	5.6km	Quite stable
	L3	From Ba Hien canal to Bai Ngao canal	1.4km	Erosion 1÷m/yr
	L4	From Bai Ngao canal to Ong Hai canal	2.2km	Quite stable, mangroves develop
	L5	From Ong Hai canal to Dung canal	1.5km	Erosion 15÷20m/yr
	L6	From Dung canal to the river mouth	2km	Large alluvial flat exist and getting more and more bigger with the deposition rate of 0.5÷1m/yr.
Right bank	R1	From Dat isle to downstream about 3.5km	3.5km	Erosion 4÷5m/yr
	R2	From the end of R1 to Det canal	2km	Erosion 1÷2/yr
	R3	From Det canal to downstream about 1.5km	1.5km	Erosion 1÷2m/yr
	R4	From the end of R3 to Cu canal	2km	Slightly deposition, mangroves develop
	R5	From Cu canal to Giam Rong canal	8.4km	Large alluvial flat exist and getting 1÷2m/yr deposition
		DAI BRANCH		
Left bank	L1	Ba No isle to Ly Hoang canal	2.5km	Deposition 8÷10 m/yr
	L2	From Ly Hoang canal to Ly Hoang village	1km	Stable
	L3	From Ly Hoang village to Ba Tu canal	3.5km	Erosion rate 1÷2 m/yr
	L4	From Ba Tu canal to Ho Lon canal	2.8km	Deposition 10÷15 m/yr
	L5	From Ho Lon canal to river mouth	2.5km	Strongly erosion with the rate of 10÷20 m/yr
Right bank	R1	From the end of Ba No isle to Binh Thoi village	1.6km	Considerably erosion with the rate of 7÷8 m/yr
	R2	From Binh Thoi village to Ba Trang canal	2km	Erosion rate 5÷6 m/yr
	R3	Ba Trang canal to Binh Chau river	1.5 km	Stable and slightly deposition 0.5÷1 m/yr
	R4	Binh Chau river to Muong Da canal	5.1 km	Deposition
	R5	From Muong Da canal to Thua Duc village	0.8 km	Large alluvial flat with wide of 800÷1000m from the river bank, deposition 20÷30 m/yr
		TIEU BRANCH		
Right bank	R1	From Long Binh canal to Tan Long canal	3.5 km	Deposition 2÷ 3m/yr, lots of mangroves forest exist
	R2	From Tan Long pontoon to	2.2 km	Deposition 1÷2 m/yr

		Gia canal		
	R3	From Gia canal to Ben Chua canal	2.5 km	Considerable erosion with the rate of 5÷6 m/yr
	R4	From Phuoc Trung village to Cong Hai canal	2.4 km	Erosion from Phuoc Trung village to downstream with the erosion rate of 4÷5 m/yr; but deposition at the last 500 m to Cong Hai canal with the rate of 1 m/yr
	R5	From Cong Hai canal to Vam Kinh river	2.3 km	Deposition 0.5÷1 m/yr, large mangroves forest exist
	R6	From Vam Kinh river to the Red Line	2 km	Erosion, reach 10÷12 m/yr at the area without protection
	R7	Located at Tan Thanh village	3 km	Deposition
Left bank	L1	From Tan Xuan pontoon to Ly Hoang canal	1.2 km	Erosion 2÷3 m/yr
	L2	From Ly Hoang canal to Ba Tai canal	4.4 km	Strongly erosion with the rate of 5÷6 m/yr
	L3	From Ba Tai canal to Ba Lam canal	3.5 km	Depositon with highest rate of 8÷10 m/y
	L4	From ba Lam canal to Bang Ranh canal	1.9 km	Slightly deposition
	L5	From Bang Ranh canal to Phao Dai canal	3.7 km	Erosion rate 3÷4 m/yr
	L6	From Phao Dai canal to the river mouth	3 km	Deposition 4÷5 m/yr

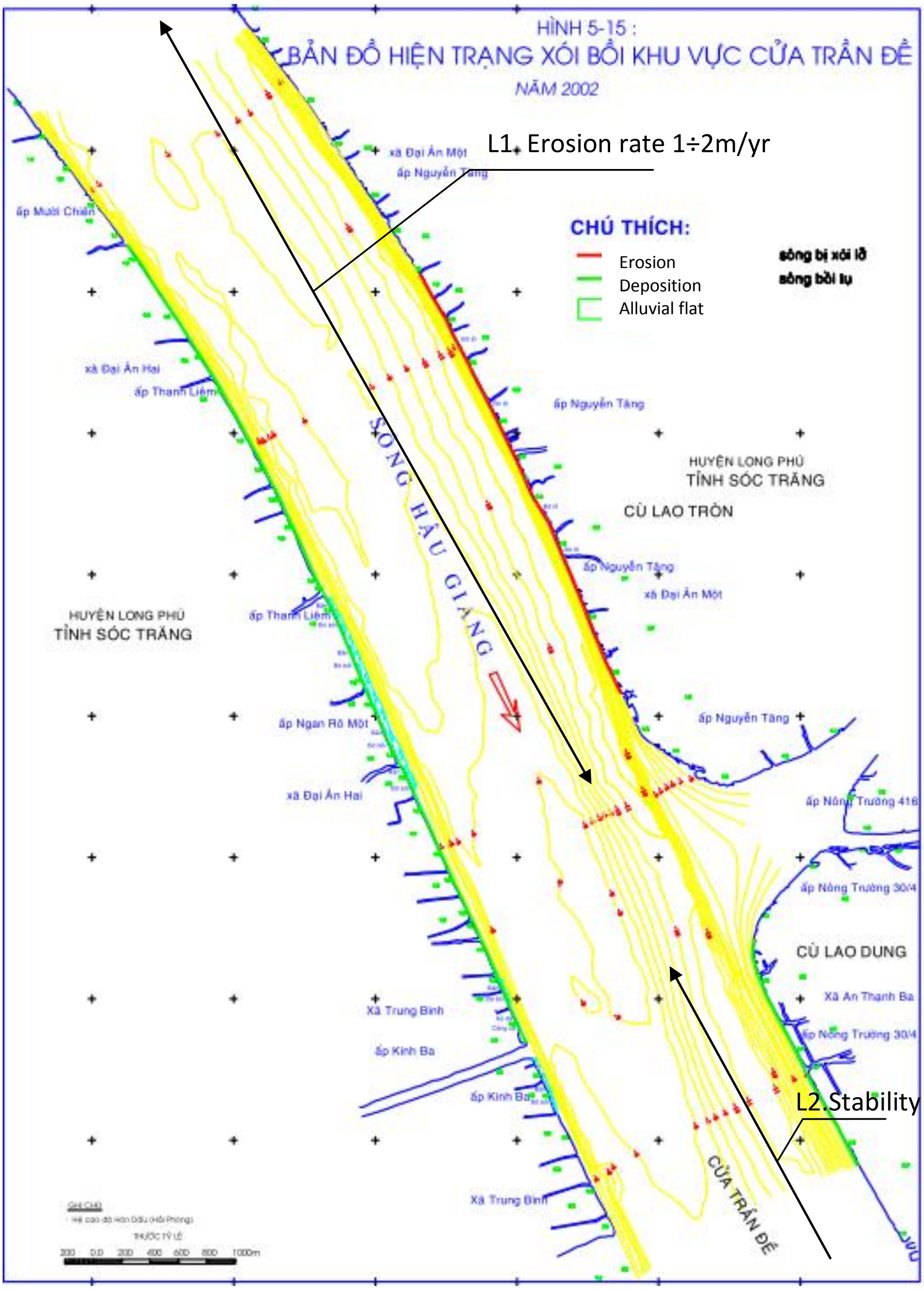


Figure 6.12: Erosion and deposition map of Tran De branch in 2002 (SIWRR 2005b)

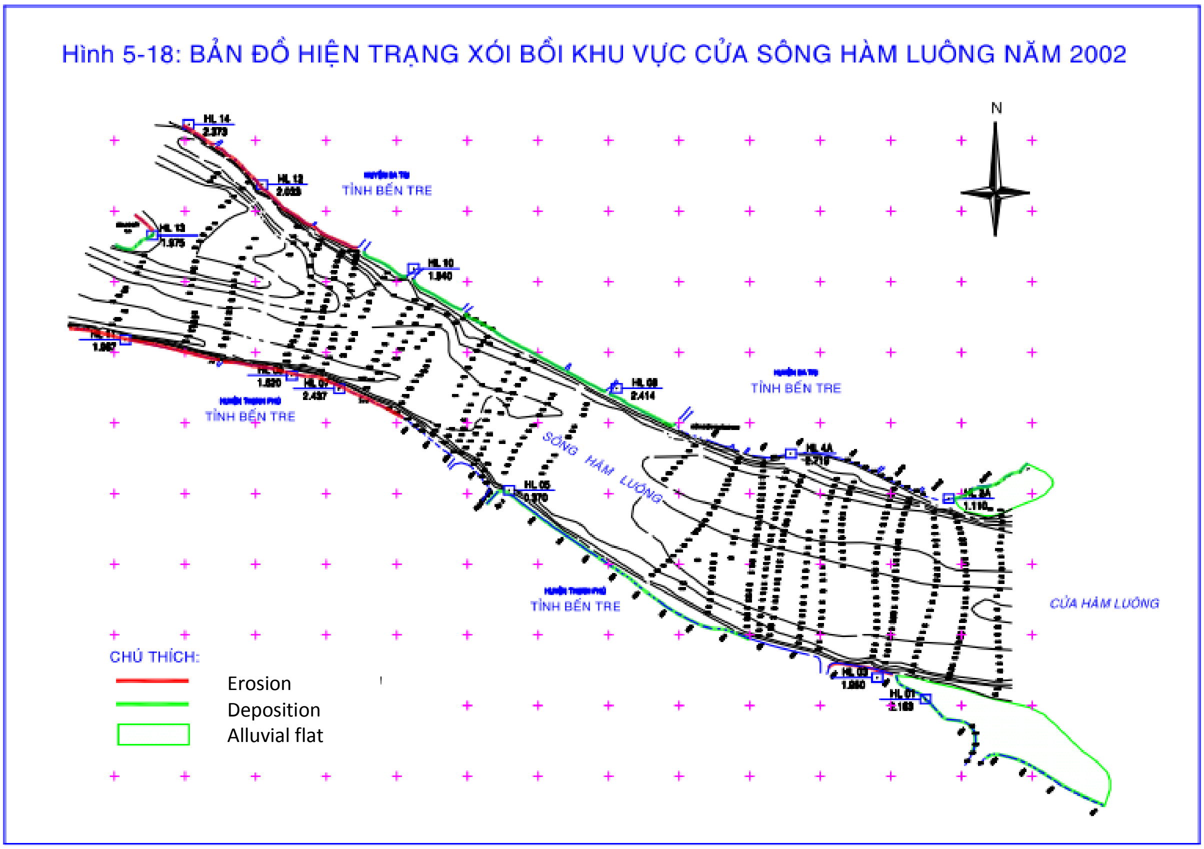


Figure 6.13: Erosion and deposition map of Ham Luong branch in 2002 (SIWRR 2005b)

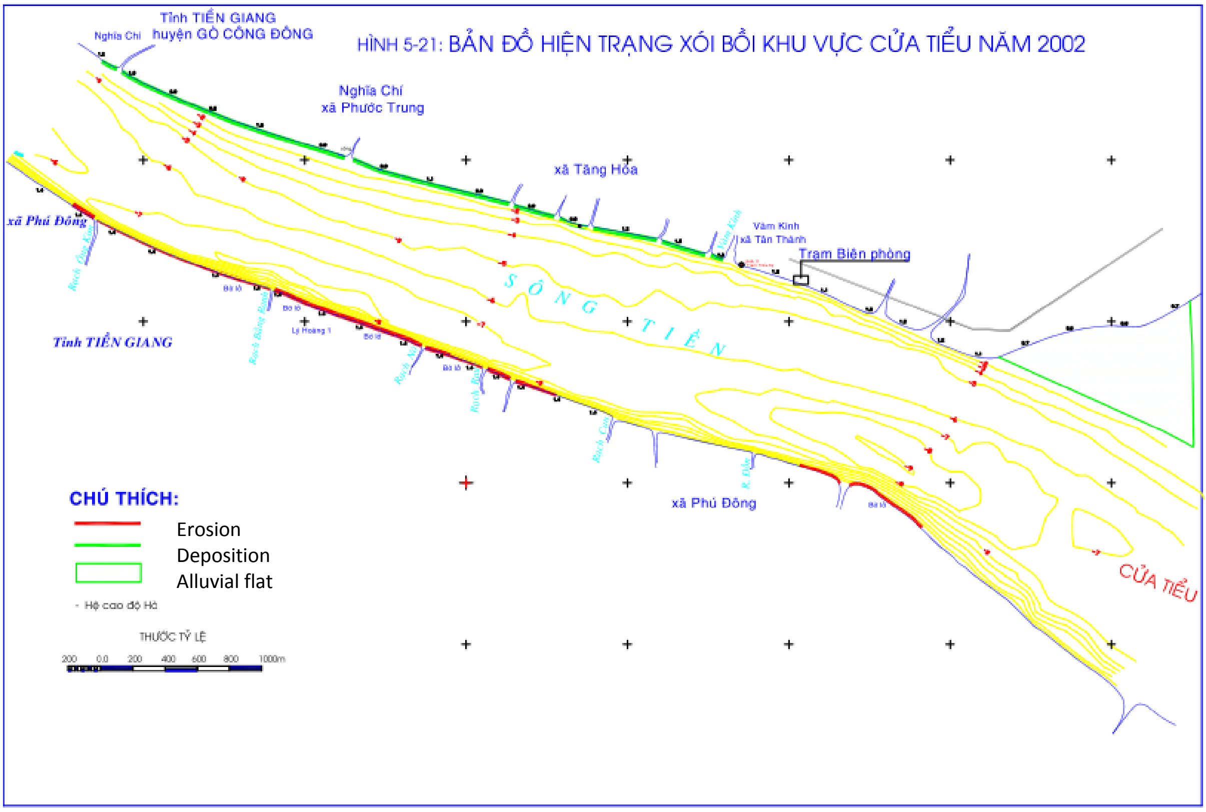


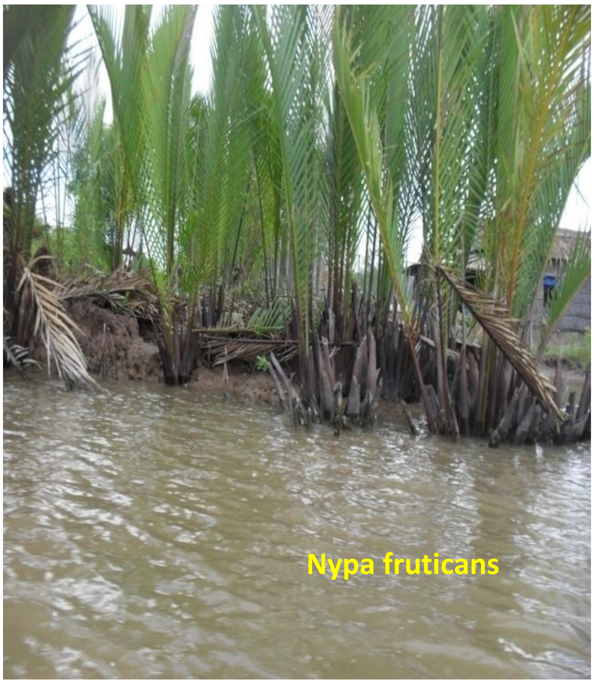
Figure 6.14: Erosion and deposition map of Tieu branch in 2002 (SIWRR 2005b)

Annex 4.1: Mangroves in Vietnam: species, status, roles and influencing factors.

1. Suitable mangrove species selected for planting in Southern Coast of Viet Nam

Table 6.6: Some mangrove species in Viet Nam

Order	Vietnamese name	Scientific name
1	Bần chua	Sonneratia caseolaris
2	Bần đắng	Sonneratia alba
3	Mắm biển	Avicennis marina
4	Mắm trắng	Avicennia alba
5	Mắm đen	Aicennia officinalis
6	Đước	Rh. apiculata
7	Dừa nước	Nypa fruticans
8	Cóc vàng	Lumnitzera racemosa
9	Dà vôi	Ceriops tagal
10	Dà quánh	Ceriops decandra



2. Status of mangroves in Viet Nam

During the Viet Nam war (1962-1971) there is nearly 40% of the mangrove forests in southern Viet Nam was destroyed (Phan Nguyen Hong and Hoang Thi San 1993). In Ca Mau province for instance, it was estimated that there was 200000 ha of highly diverse mangrove forest but after the war, approximately 100000 ha had been destroyed.

Mangrove clearance for shrimp farms is a major issue in the coastal area of the Mekong Delta of Vietnam. In the eastern coastal zone of the Mekong delta, the area of mangrove has been depleted from 190,812 ha in 1953 to 29,534 ha in 1995, which implies that after 42 years, 161,277.5 ha of mangrove forest have been destroyed for shrimp farming and other activities (Minh et al. 2011)

In the 1980s and early 1990s the mangrove forest was again heavily destroyed due to the overexploitation of timber for construction and charcoal and conversion of forest land into

Silvo-Aquaculture-Fisheries Farming Systems (SAFS) (Christensen et al. 2008). Then, the highly diverse mangrove forests of Ca Mau had by the end of the 1980s been turned into 51000 ha monoculture forest consisting mainly of planted Rhizophora apiculata.

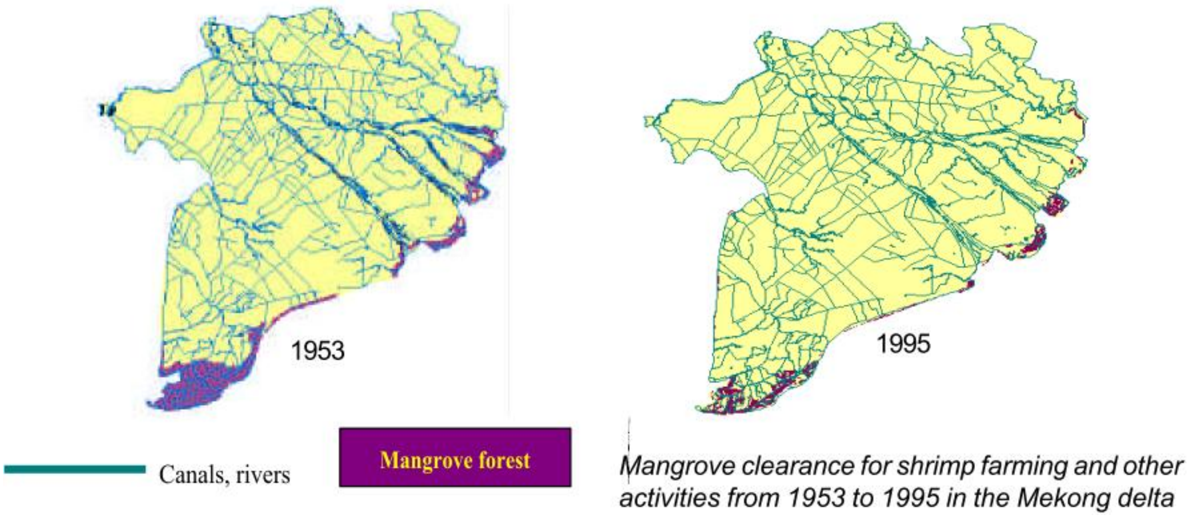


Figure 6.15: Mangroves disappear during the period from 1953-1995 (Minh et al. 2011)

By the mid-1990s forest felling bans were imposed and the forest enterprises were now to replant and protect forest rather than utilise it, by 1999 the felling ban ceased.

3. The role of the mangrove forests in controlling erosion and protecting the coast

There are lots of realistic event for the collapse and breakage of coastal sections without mangrove forests in Viet Nam by waves. For instance typhoon No 7 in 2005 which landed the coast of Thanh Hoa and the coastal provinces of the Red river delta during 3 days from 26 to 28 August 2005 caused 150 km long and 5 m high national dike to collapse and broken 11km of national sea dike, which cost 2000 billion VND for repairing (General Department of Meteorology and hydrology – 2005).

However, in the mean time, in Bang La commune (Do Son township, Hai Phong city) after 2 typhoons No 2 and No 7 in 2005, the national sea dike system within the commune was neither collapsed nor collapsed thanks to the protection of 150 m wide and 4000 m long mangroves forest in front of the sea dike. Beside, According to the reports of the local authorities of the Red river delta, where there are dike protection mangrove forests, the annual cost of repairing the sea dikes is only 1,5 million VND/ km of sea dike, while where there are no dike protection mangrove forests the cost reaches as much as 5 million VND/1km of sea dike (in average) and the reconstruction of 1km of destroyed sea dike costs 100 billion VND (Ngo Ngoc Cat et al.2005).

Although the Southern coast of Viet Nam is not experienced larger typhoon, mangroves forest is still play an important role in protecting the coast. With mangroves forest, sea dike height and therefore sea dike cross-section could be reduced significantly. The effective of wave height reduce depend on type of mangroves, wave characteristic. For example the results of the experimental model of planting sea dike protection mangrove forests in Tan Thanh commune, Kien Thuy district, Hai Phong city implemented by the Forest Ecological Centre of the Viet Nam Institute of Forestry in 2001- 2002 showed that the wave height is reduced from 1.06 m before entering the mangrove forest to 0.42 m when reaching the distance of 130 m away from the foot of the dike and then after passing the protective mangrove forest and reaching the distance of 50 m from the dike the waves are only 0.18 m high.

Mangroves forests are not reduce coastal erosion however they do enhance sedimentation through their roots. The mangrove trees obstruct the flow and therefore they stimulate sedimentation.

4. Factors influence the development of mangroves, applying in Viet Nam

There has been a spate of studies which have emphasized the strong relationship between the distribution of mangroves and climatic, edaphic and hydrological conditions. Factors effecting the distribution of worldwide mangroves could be found in many books such as: The Botany of Mangroves (Tomlinson 1986), The Biology of Mangroves (Hogarth 1999). Specific book for mangroves in Viet Nam was published in 1993 by Phan Nguyen Hong and Hoang Thi San (1993). Based on these books, factors effecting mangroves in Southern Viet Nam are summarised in the table below.

Table 6.7: Factors influence the development of mangroves in Viet Nam

Conditions	Factors	Impacts	Apply in Viet Nam
Climatic	Temperature	High or sudden fluctuation in temperature cause adverse impact to mangroves	The mean temperature is 27^0 at the sea. However, sometimes it can go up to 40^0. At this temperature, recognize the minimize of philosophy activities of mangroves
	Rainfall	Regulate salt concentration in soil and provide extra source of fresh water	Most of the area receives 2000 mm of rainfall annually; this is favourable conditions for the development of mangroves. E.g.: Mangroves flourish in Ca Mau
	Wind	Increase rate of evaporation and reduce temperature	Southern coast mainly influence by the northeast monsoon from the East Sea, occurring from December to April, causing serious erosion for the coast along the East Sea. The cold air due to monsoon also create adverse effect to mangroves.
Hydrological	Tide	-Tide range determines area where mangroves can grow. Larger tide range, more different	Southern coast is classified into 3 tide zones (part2.1 natural conditions): semi diurnal along the East Coast, diurnal along the West Coast and mixed tide at

		species in mangroves forest. - However tide with large amplitude and high velocity can cause erosion for the mangroves area. -Beside semi-diurnal tide are more suitable for the growth of mangroves	Ca Mau peninsula. At the north-western Ca Mau coastline, where tidal amplitude is 0.8÷1m there is little transportation of seedling and sediment, thus mangroves are distributed along a narrow track. Along the East Coast where the tide range about 2÷3m and the relief is flat, mangroves growth well.
	Wave	Although mangroves are capable of withstanding wave and tidal action, the settlement of propagules and seedlings requires a low (wave) energy environment.	There is still no threshold for favourable wave energy for mangroves growth.
	Fresh water	Fresh water from the river bring necessary nutrient and alluvium to mangroves forest	Mekong river is a source of sediment and water discharge for mangroves development along the Southern coast.
	Salinity	High salt concentration diminish the size and the number of species.	Mangroves develop well in Ca Mau Cape where mean salt concentration is 22-26 ppt
Edaphic	Soil	Mangroves can growth best in silt-clay soil	Soil in mangroves area in southern coast are formed by the alluvium from the Mekong River and the sediment from the ocean.

Annex 4.2: Previous research of MD evolution

The history of Holocene sedimentation is provided by:

- Late Holocene depositional environments and coastal evolution of the Mekong River Delta, Southern Viet Nam (Nguyen Van Lap et al. 2000).The result is the sedimentary map in figure 6.16.

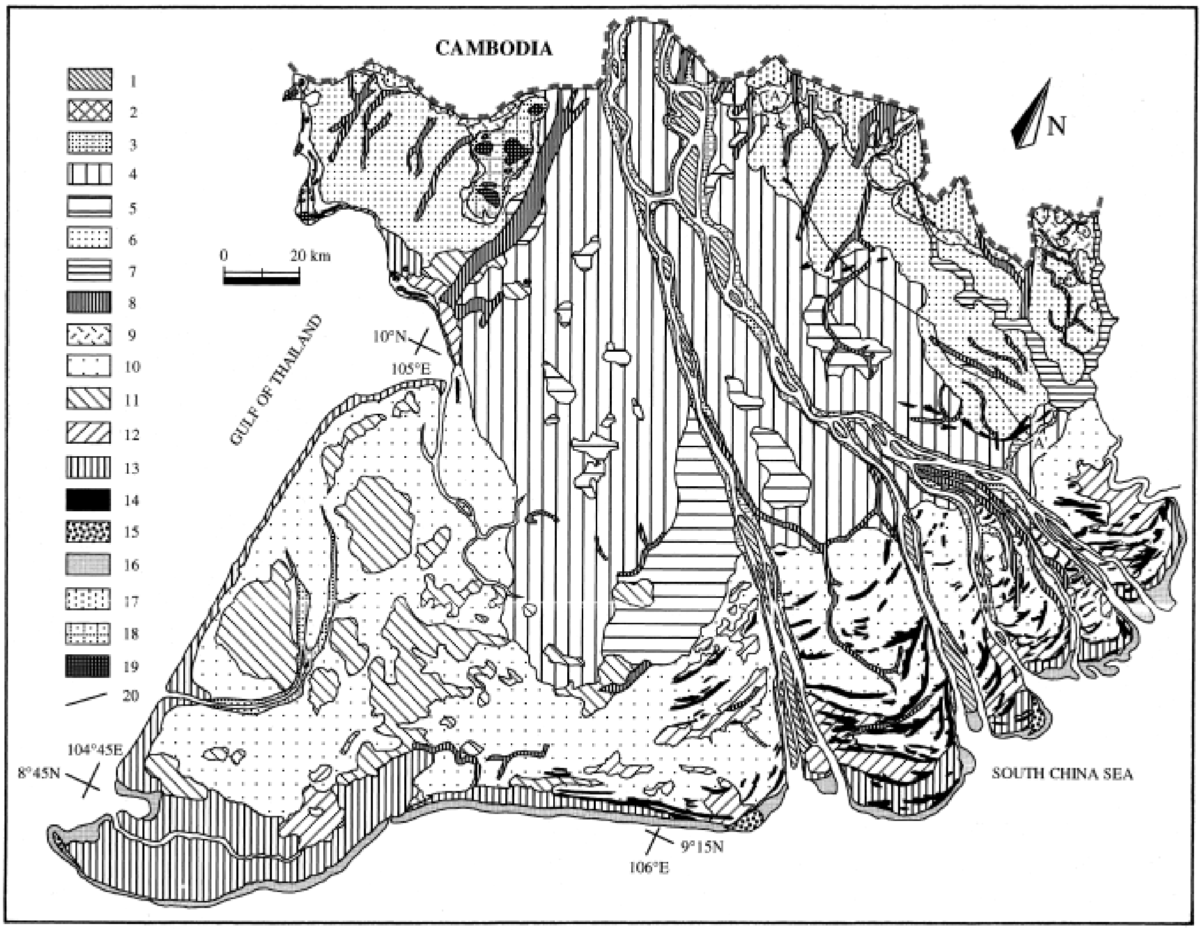


Figure 6.16: Environment sedimentary map of the Mekong River Delta (Nguyen Van Lap et al. 2000).

1. Channel bar, 2. Point bar, 3. Bank consisting of natural levee and crevasse splay, 4. Flood basin, 5. Back swamp, 6. Swamp, 7. Flood plain, 8. Abandoned channel, 9. Alluvial apron, 10. Coastal plain, 11. Marsh,12. Salt marsh, 13. Mangrove marsh, 14. Relict beach ridge or sand dune, 15. Sand spit, 16. Tidal flat, 17. Undivided deposits of late Pleistoceneage, 18. Weathered land, 19. Basement rock, 20. Line of profile.

- Sediment facies and Late Holocene progradation of the Mekong River Delta in Bentre Province, southern Viet Nam: an example of evolution from a tide-dominated to a tide- and wave-dominated delta (Ta Thi Kim Oanh et al. 2002)
- Early Holocene initiation of the Mekong River delta, Viet Nam, and the response to Holocene sea-level changes detected from DT1 core analyses (Nguyen Van Lap et al. 2010).
- Late Holocene Evolution of the Mekong Subaqueous Delta, Southern Viet Nam (Xue et al. 2010).

- Late Holocene sedimentary and environmental development of the northern Mekong River Delta, Viet Nam (Ulrike et al. 2011).

In the smaller evolution time scale research, in Viet Nam there are many erosion and sedimentation of MD projects such as:

- Current and Erosion Modelling Survey: A case study in Soc Trang province (Albers and Lieberman 2011).
- Study on deposition of Ba Lai estuary, Ben Tre province (Nguyen Tho Sao and Nguyen Minh Huan 2011).

Some of them have national level of important and doing under the requestion of Ministry of Agriculture and Rural of Viet Nam:

- Nghiên cứu xói lở song Cửu Long – Erosion along Mekong river (Le Sam 2001).
- Research; propose feasible cross-sections for sea dikes in accordance with different dike types and local conditions from Ho Chi Minh city to Kien Giang province (SIWRR 2005a).
- Nghiên cứu cơ chế hình thành, phát triển, đề xuất giải pháp thủy lợi, phương thức khai thác bãi bồi ven biển Nam Bộ- The development and Exploitation of Mekong Delta Viet Nam (Vu Kien Trung 2006).
- Nghiên cứu đề xuất giải pháp tổng hợp khai thác bền vững các bãi bồi ven biển khu vực từ cửa Tiểu đến cửa Định An- Sustainable solution for exploitation of Mekong Delta Viet Nam from Tieu branch to Dinh An branch (Vu Kien Trung 2009b).
- Phân tích quy luật hình thành bãi bồi – Analysis of alluvial flat development in MDV (Vu Kien Trung 2009a).
- Báo cáo tổng hợp (SIWRR 2010a).

Annex 4.3: SWAN input parameters

4.3.1. The most representative wave height calculation

The most representative wave height observed at Bach Ho station is calculated from table 6.1, the result is presented in table 6.8. It can be seen that, with the wave height is 3 m, the product of H^2 multiple the frequency is highest and therefore 3 m wave height is choosing as the most representative wave height.

Table 6.8: Representative wave height calculation

Height intervals	Max wave height (m)	Average Frequency (%)	(H^2 × Frequency)
0-0.5	0.5	16.93	4.23
0.6-1.0	1	18.63	18.63
1.1-1.5	1.5	21.23	47.77
1.6-2.0	2	16.03	64.12
2.1-2.5	2.5	10.76	67.25
2.6-3.0	3	7.7	69.3
3.1-3.5	3.5	3.75	45.94
3.6-4.0	4	3.43	54.88
4.1-5.0	5	2.2	55
5.1-6.0	6	0.41	14.76
6.1-7.0	7	0.16	7.84
>7.0	>7	0.03	-

4.3.2. Wind velocity

According to the Shore protection manual (1984), the wind velocity can be estimated based on the Wave forecasting nomograms as seen in Figure 6.17.

- First case: wave height 3m, wave period 7.9 s → U_A = 19 m/s → U_{10} = 14 m/s
- Second case: wave height 7.2 m, wave period 9.7 s → U_A = 47 m/s → U_{10} = 30 m/s

Where:

U_{10} is the wind speed at 10 m elevation;

U_A is the wind speed factor $U_A = 0.71\ U_{10}^{1.23}$

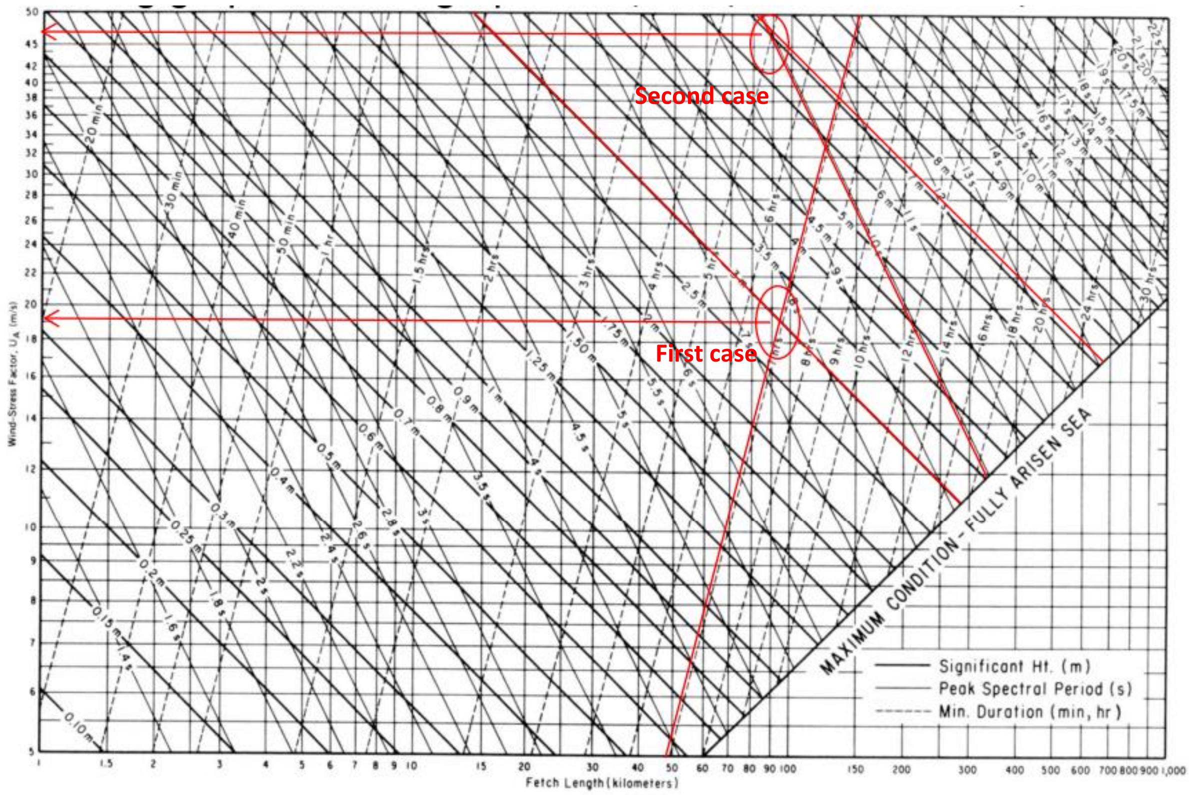


Figure 6.17: Wave forecasting nomograms (Shore Protection Manual 1984)

Annex 4.4. Sample of SWAN input file

An example of SWAN input files in case of Rhizophora species, average density and representative wave height is presented below.

Figure 6.18: Sample of SWAN input file

```
$*************HEADING****************************************
$
PROJ 'Mangroves' '002'
MODE STATIONARY ONEDIMENSIONAL
SET 1.6
$
$***********MODEL INPUT**************************************
$
CGRID 0. 0. 0. 101000. 0. 1010 0 CIRCLE 360 .03 1 36
$
INPGRID BOTTOM 0. 0. 0. 1010 0 100. 100.
READINP BOTTOM 1. 'bathymetry.dat'  1 0 FREE
$
INPGRID WIND 0. 0. 0. 1010 0 100. 100.
READINP WIND 1. 'wind.dat'  1 0 FREE
$
INPGRID NPLANTS 0. 0. 0. 2020 0 50. 50.
READINP NPLANTS 1. 'mangrove.dat'  1 0 FREE
$
BOUN SHAPESPEC JONSWAP
BOUN SIDE W CCW CONSTANT PAR 7.2 9.7 0. 500
$
FRICTION JONSWAP
$                [Height][Diameter][N][Drag*Density]
VEGEtation       0.8     1.0      1       4.5 &
                 6.0     1.0      1       0.175 &
                 2.0     1.0      1       50

$************  MODEL  OUTPUT  *************************
$
POINTS 'HS' FILE 'Hs.loc'
TABLE 'HS' HEAD 'Hs.tbl' XP DEP HS
$
$************ COMPUTATIONS************
$
TEST 1,0
COMPUTE
STOP
$
```

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