Department of Water Resources Engineering
Lund Institute of Technology, Lund University

Master of Science thesis in Coastal Engineering

COASTAL EROSION AT HAI HAU BEACH IN THE RED RIVER DELTA, VIETNAM

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A Master of Science Thesis by

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Photos taken by Martin Häglund & Pär Svensson

Cover: Photo showing section of eroded dike at Van Ly beach, Vietnam

Preface

This Master of Science thesis in Civil Engineering is the result from work in both Vietnam and Sweden during the university year 2001/02. It has been very interesting not only to learn more about coastal engineering but also to experience a new country and its history and culture. Altogether, it has contributed to both our professional and personal development. Hence we are very grateful and would like to thank every one involved at the Department of Water Resources Engineering in Lund and at the Center for Marine Environment Survey, Research and Consultation in Hanoi, who have made this study possible, especially our supervisors in Lund, Prof. Magnus Larson and Prof. Hans Hanson, and Dr. Nguyen Manh Hung, our supervisor in Hanoi, for support and advice during this time. We also thank Jonas Lindeman, at the Division of Structural Mechanics, for helping us with the programming and Bas Wijdeven, student at Delft University in Holland, for interesting discussions and sharing of data and ideas

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Abstract

Many coastal areas in Vietnam suffer from erosion. One of the worst affected areas is the Hai Hau beach, located in the Red River delta in northern Vietnam. Over the last hundred years, vast parts of the beach have eroded at an average rate of approximately 25 m per year. Important agricultural land has vanished into the sea and families have been forced to abandon their houses. The cause of the erosion is not explained but suggested reasons are for example dam construction, deforestation, weak dikes and unfavourable hydrodynamic conditions.

The wave climate, and thus the sediment transport, in northern Vietnam is highly dependent on the two main wind directions from the northeast and the south, because of the winter and summer monsoon, respectively. Vietnam is also subject to sporadic typhoons that cause great damage when they strike the coast, especially in combination with storm surges. Based on a 20-year long wind record from 1976 to 1995, obtained from two islands outside the coast of northern Vietnam, the longshore transport rate over these years was determined by a one-dimensional numerical wave model. The model consists of three independent parts: offshore waves, nearshore waves and longshore sediment transport. This model indicates a southward-directed transport along the Hai Hau beach. In addition, sea maps and satellite photos from the 20th century were compared in order to find out the historic shoreline development generally.

The main protection method that is generally used in Vietnam, as well as in Hai Hau district, is sea dikes. These dikes consist of an earth core covered by a revetment layer of cobbles. Unfortunately, these dikes are not strong enough to withstand the impact of harsh waves for any longer periods. Historically, a line of sea dikes has been destroyed at least once every decade. A couple of hundred meters behind the front sea dike typically lies another dike, ready to meet the waves when the first one breaches. Consequently, this defence arrangement is often recognized as a double dike system, but also as a retreat strategy since the erosion problem is not solved, just slowed down. The major cause of erosion is likely not due to human activities (such as dam buildings or river cut-offs), instead, because of the natural properties of Hai Hau coastal area, seasonally bounded longshore currents in combination with weak sea dikes favour erosion.

Keywords: Vietnam, Red River Delta, coastal erosion, wave prediction, sediment transport

Sammanfattning

Många kustområden i Vietnam är drabbade av erosion. Ett av de värst utsatta områdena är strandområdet i distriktet Hai Hau, belägget i Röda flodens delta i norra Vietnam. Under de senaste hundra åren har stora delar av stranden försvunnit med en hastighet av ungefär 25 m per år. Detta har lett till att viktig jordbruksmark försvunnit ut i havet och familjer har tvingats till att överge sina hem. Orsaken till erosionen är inte klarlagd men föreslagna anledningar är bland annat dammbyggen, skogsavverkning, svaga strandvallar och ogynnsamt hydrodynamiskt klimat.

Vågklimatet och därmed sedimenttransporten i norra Vietnam beror till stor del av sommarmonsunen från söder och vintermonsunen från norr. Vietnam är dessutom drabbat av tillfälliga tyfoner som orsakar stor förstörelse när de når kusten. Utifrån 20 års vinddata mellan åren 1976 och 1995, uppmätt på två öar i Tonkinbukten utanför norra Vietnam, bestämdes den kustparallella sedimenttransporten under dessa år med en endimensionell numerisk vågmodell. Modellen består av tre oberoende delar: djupvattenvågor, kustnära vågor och sedimenttransport. Denna modell visar på en södergående transportriktning utanför Hai Hau. Vidare jämfördes sjökartor och satellitbilder från 1900-talet för att klargöra den historiska kustnära utvecklingen.

Den huvudsakliga skyddsmetoden som generellt används mot erosion i Vietnam och Hai Hau är strandvallar. Dessa består väsentligen av en jordvall täckt med stenar och block för att möta vågorna och därmed motverka erosion. Emellertid är denna konstruktion inte tillräckligt stark för att motstå det hårda vågklimatet utan historiskt sett har en strandvall förstörts åtminstone vart tionde år. Bakom den första, yttre strandvallen finns en andra vall redo att skydda bakomliggande områden i fall den första förstörs. Härav kallas denna skyddmetod ofta för ett ”dubbelt strandvallssystem”, men även ”reträttstrategi” eftersom erosionen inte stoppas, utan endast bromsas. Huvudorsaken till erosionen är troligen inte mänsklig påverkan utan istället, på grund av kustområdets naturliga egenskaper i Hai Hau, säsongsbundna kustparallella strömmar som tillsammans med bristfälliga strandvallar gynnar erosionen i området.

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1. Introduction

1.1 Project background

Vietnam has a coastline that is approximately 3800 km long and much of it is located below an elevation of 1 m above mean sea level (Zeidler and Nhuan 1997, Pruszak 1998). Since the economic activity in Vietnam is mostly concentrated to the coastal areas, it is of vital importance that the physical and environmental conditions in these areas are well understood and may be assessed for a wide range of situations. For example, the Red River Delta located in northern Vietnam (see Figure 3.1) is under constant threat from waves and high water levels in the sea causing erosion, flooding, and intrusion of saline water. Large waves and high water levels are typically associated with storms during the monsoon periods or the occurrence of typhoons, although long-term sea level rise due to climate change is a concern as well (VCZVA, 1996).

Deposition of river sediment along the coastline of the Red River Delta combined with sediment transport by nearshore waves and currents induce variability in the shoreline position at many scales in time and space that must be estimated in order manage the delta and associated coastal areas in a rational manner. In spite of the importance of the delta and the other coastal areas in Vietnam, relatively few comprehensive studies have been carried out to clarify the dynamics of the coastal regions. A difficulty in carrying out such studies has been the limited amount of data that are available on nearshore waves, currents, sediment transport, and coastal evolution. Thus, the limited amount of available data must be supplemented by calculations in order to develop an understanding of the governing coastal processes.

This report focuses on coastal erosion at Hai Hau Beach located in the southern part of the Red River Delta. Serious erosion has been recorded here for more than one hundred years and sea dikes have been the common method for combating shoreline retreat. Available background material was compiled and combined with numerical model calculations to determine the cause of the erosion and its magnitude.

The loss of the important coastal land areas is today of major concern in Vietnam and have resulted in international cooperation between Vietnam and for instance Poland, Holland and Sweden to solve this problem. In Sweden, the department of Water Resources Engineering at Lund University has for almost three years been involved in a project with the Center for Marine Environment Survey, Research and Consultation (Hanoi, Vietnam), evaluating the causes of erosion and possible remedial actions in order to stop the coastal retreat. This project has been partly financed and supported by SIDA (Swedish International Development Cooperation Agency)

1.2 Objectives

The objectives of this study were to (1) establish the cause of the erosion at Hai Hau Beach, (2) quantify the erosion rate and the processes controlling this rate, and (3) propose measures to reduce or completely halt the erosion. Several different hypotheses concerning the cause of erosion at Hai Hau Beach were investigated, including the construction of a dam in the upstream part of the delta, the cutting of a sediment-transporting river branch close to the beach, and the imbalance between the prevailing wave direction and the shoreline orientation leading to gradients in the longshore sediment transport.

1.3 Procedure

Background data on coastal processes in the Red River Delta, with emphasis on erosion and conditions at Hai Hau area, were compiled from the literature and through contacts with the Vietnamese partners. A seven-week visit to Vietnam was carried out to gather available material and data as well as performing visits to the field site. Based on the compiled data, numerical calculations were made to determine an offshore wave climate from which the nearshore waves and associated longshore sediment transport were computed. The derived longshore transport rates formed a basis for assessing if gradients in this transport are the primary cause of the erosion at Hai Hau Beach. This mechanism was compared to other suggested causes for the erosion, such as the construction of a dam upstream, the cutting of river branches, deforestation, and changes in the sea level. Different measures to reduce the erosion were also discussed.

Before leaving for Vietnam, two months were spent in Sweden on preparations for the journey. The preparations consisted mainly of reading and searching for published material such as articles written about the Red River Delta with emphasis on erosion problems. Besides traditionally searches at libraries, much time was spent searching the Internet and electronic databases. Libraries were mainly used for finding articles and books about the Red River Delta but also for compiling background information on wave prediction and delta development. The electronic sources were mostly utilized to find information and facts about Vietnam in general, erosion protection measures, deforestation data, and pictures.

After these two months of work in Lund, seven instructive weeks were spent in Vietnam. The purpose of the trip was to collect data, discuss with Vietnamese experts, make field inspections, and perform measurements. To achieve first hand information about the area, two field inspections were performed. This was essential in order to map out local problems, possibilities etc. A total of seven days were spent in the field measuring, observing, taking photos, and collecting sediment. The field visits were performed together with and under the guidance of Center for Marine Environment Survey, Research and Consultation (CMERSC) in Hanoi. Visits were also made to the Hanoi State University and different institutes that are involved in matters concerning erosion, dike construction, and meteorology. Viewpoints, theories, problems and procedures used to prevent the erosion were exchanged and discussed. Most of the time in Vietnam was however spent at CMERSC, working together with and consulting their staff.

A program for numerical calculation of waves and sediment transport was developed both in Vietnam and in Sweden, consisting of three independent parts: offshore waves, nearshore waves and longshore sediment transport. The program was based on theories described in chapter 2.3-2.5. Moreover, the calculation module was built in the program language Fortran 90 and a graphical interface was made in Borland Delphi. All calculations were carried out using this program and the results were analyzed and described in appropriate graphs and tables, presented in this report. Historical coastline change was obtained by analyzing scanned old and new maps. The coastline coordinates were determined by digitization. Coastlines derived from every map was then plotted in a common graph, evenly covering the development for almost the entire 20th century, after each digitized data set had been transformed into a global coordinate system.

2. General Theory

2.1 Delta formation

The hydrodynamics, the sediment transport, and the coastal evolution of a delta are very much functions of the general delta properties as well as the historic evolution. Thus, a fundamental knowledge of deltas and their formation is necessary in order to understand and interpret the responses of the coastal areas in the Red River Delta. Thus, in the following section, a brief theoretical background is given to different types of deltas and their properties. The Red River Delta is then discussed in the context of this general overview in chapter 3.1.1.

Most rivers end up in the sea where they abruptly lose their velocity, and therefore, lose their ability to carry sediment. The sediments deposit near the river mouth where they form a plain. Heavy grains, such as sand and gravel, are deposited close to the shore while lighter particles, such as silt are carried further out to sea. Clay is transported until the grains flocculate and settle (Kearsley, 2000). During millions of years, every flood deposits a new layer of sediment that is spread over the former ones. Hereby, new parts of land with gently sloping sides are formed as the delta grows outwards. At the same time, the weight on the lower layers increases which slowly start to transform into solid rock. On the surface of the delta plain, mud banks forces the river channel to divide into smaller courses, distributaries, which form a treelike structure. Eventually, vegetation binds the sediment with its roots and stabilizes the newly built land. Because of alluvial sediments from the rivers, deltas are often very good farmland.

The name delta was given by a Greek historian, Herodotus, as he was observing the Nile delta and reflected that the triangular shape of the depositional plain was similar to the Greek letter delta. However, not all deltas have the typical triangular shape as the Nile delta and below three typical delta shapes are further described (LUCEC, 2001). As with all delta formations, the three typical shapes are determined by fluvial processes such as the flow in the river and how much sediment that is carried by the river and shallow marine processes such as waves, currents and tides. Large tides create strong ebb and flood currents in the distributaries, which becomes widened. The waves may balance the sediment supply rate and cause a static position of the delta front. In areas with very strong marine processes, the delta may be retreating if the subsidence is greater than the sediment supply.

Figure 2.1 Bird’s-foot delta (Drummond, 2002).

If there is a lot of sediment carried out into calm seawater, the distributaries (often only one or very few) stretch far out into the sea and the delta is mainly developed perpendicular towards the shore. Fine particles are deposited as a thin layer on the slope of the delta. This type of delta is called a bird's-foot delta because of the resemblance between the long and thin delta and an outstretched claw of a bird, see Figure 2.1. One example of such a delta is the Mississippi delta.

Figure 2.2 Arcuate delta (DT, 2002).

An arcuate (fan shaped) delta is formed when a river meets a shallow sea in a place where the waves attacks perpendicular to the shore. Sediments are not spread very much parallel the coast parallel due to very small longshore currents. In opposite of a bird foot delta, the arcuate delta has many short distributary channels that spread the sediment to the sea. The deltas of the Nile (Figure 2.2), Indus and Rhone, are shaped like this.

Figure 2.3 Cuspate delta (ARC, 2002).

A cuspate (tooth-shaped) delta is formed when a river drops its sediment to a straight shoreline, exposed to strong waves (e.g. an oceanic coast). In most cases, the river delivers its sediment to the sea in only one distributary. Coarse grains are spread parallel to the coast in both directions from the river mouth and create concave beaches and natural barriers, which protect land areas or the calm water behind. Fine particles are carried offshore in suspension. A typical cuspate delta is the Paraiba do Sul river delta in Brazil, see Figure 2.3, where two concave beaches can be seen on either side of the typical tooth-shaped mouth.

2.2 Methods of protection

The main defence measures used at Hai Hau beach, as well as in the Red River Delta and Vietnam in general, are dike constructions. There are however several other measures to stop beach erosion, which can be divided into two main groups: non-structural and structural (CSPST, 2001). Since non-structural ones often involve bioengineering and vegetative protection, these serve not only to reduce erosion but also to improve the near-shore habitats for animals and plants by contributing to a better water quality. However, vegetative actions are difficult to implement at locations exposed to harsh wave climate as the plants risk being shattered. Thus, they are often limited to shorelines exposed to tidal motion or small waves, e.g. tidal plains. Example of plants that have good wave reducing foliage, and a well-developed root system to stabilize the sand, are cord grass and salt meadow. Another widely spread plant is the mangrove tree (Figure 2.4).

Overall, vegetation is effective and may provide an aesthetical and inexpensive solution to erosion. Another non-structural measure is beach nourishment, which primarily means that beach material is brought back to sites in order to compensate for littoral drift. Although this action is aesthetically pleasing, one drawback is its temporary nature—material must be moved continuously over time—and thus, although low initial cost, it could be expensive in the end. It is often preferable to combine beach nourishment with e.g. groins in order to make the "buffer zone" last longer. In the case either man-made or natural barriers hinder the natural littoral drift, sand bypassing methods aid to reduce the impact of accreting and eroding areas. The method is however only applicable under special circumstances.

Figure 2.4 Mangrove tree

Where beaches suffer from high erosion rates being exposed to high water velocities and large waves, structural measures are often the only rational method of protection since non-structural are more vulnerable to strong wave impact. In general, these structures result in "hardening" of the shoreline by e.g. concrete and stones. Although these actions may stop the erosion, they also comprise an aesthetical drawback that should be considered. Frequently used structures are seawalls, revetments, breakwaters, dikes, groins and sills, of which dikes and groins are used at Hai Hau beach. Seawalls and revetments serve the same purpose, but seawalls are self-standing structures. Thus, seawalls can be used for a wider range of conditions whereas revetments require a suitable natural slope as they consist of a loose layer of armour. Breakwaters, on the other hand, are the only ones that are not directly connected to the shore. Instead, they are situated offshore to prevent waves from breaking at or near the shoreline, i.e. the erosion and sediment transport is reduced due to dissipation of energy. Although expensive, breakwaters can be very effective to protect for example marinas or natural harbours (CSPST, 2001).

Although dikes, normally earth structures, are perhaps not the best way to prevent shoreline retreat, they are simple and relatively inexpensive to construct by hand. However, being exposed to harsh coastal climate revetments on the side facing the sea is of major importance. Groins, structures positioned perpendicular to the coast, serve to interrupt and trap the littoral drift and thus reduce the erosion but when using these structures it is essential to investigate how less littoral drift affects the rest of the coast. In accordance with groins, sills also serve as a sand trapping structure and are typically shore parallel sub aquatic walls made from e.g. stones and concrete. The result will be a new, elevated beach, a so-called "perched beach". In order to retain sediment, the in-land side of the wall has to include some kind of fibre layer, or consist of material less than the sand particle. As for groins, the effect on nearby coast has to be evaluated in advance of construction. One must however observe that sills do not stop the shore parallel transport unless the shore is divided into sections by perpendicular structures such as for example groins. Over all, sills are most effective on shorter, delimited coastal areas.

2.3 Modified SMB wave theory

In order to predict waves from wind data several formulas have been suggested over the years and many are based entirely or partly on empirical relationships. One of the most popular methods that are used to estimate wind-generated waves is the Sverdrup-Munk-Bretschneider (SMB) method, which formulas are derived by combining empirical and analytic procedures.

The modified SMB method, presented in the Shore Protection Manual (SPM, 1984) offers a mathematically simple way of prediction and handles both fetch-limited and duration-limited conditions. If deepwater wave conditions prevail, i.e. d/L > 1/2, where *d* is the water depth and *L* the wave length, the following formulas can be used to estimate the spectral wave height H_{m0}, approximately equal to the significant wave height H_S determined as the mean of the $^1/_3$ heighest waves, and the peak spectral period T_m, equal to $\frac{1}{0.95} \cdot T_S$. In accordance with H_S, T_S is the significant wave period and defined as the mean period of the $^1/_3$ heighest waves.

$$\frac{gH_{m_0}}{U_A^2} = 0.0016\left(\frac{gF}{U_A^2}\right)^{1/2} \tag{2.1}$$

$$\frac{gT_m}{U_A} = 0.2857\left(\frac{gF}{U_A^2}\right)^{1/3} \tag{2.2}$$

where

U_A = windstress factor
F = fetch
H_{m0} = spectral wave height
g = acceleration of gravity

For any given fetch, the minimum wind duration, *t*, in order to have fetch-limited conditions can be determined from:

$$\frac{gt}{U_A} = 68.8\left(\frac{gF}{U_A^2}\right)^{2/3} \tag{2.3}$$

Duration-limited condition occur when the fetch do not limited the generation of waves but the duration of the wind do. However, equations (2.1) to (2.3) are not valid beyond the fully developed wave conditions determined by:

$$\frac{gH_{m_0}}{U_A^2} = 0.2433 \tag{2.4}$$

$$\frac{gT_m}{U_A} = 8.134 \tag{2.5}$$

$$\frac{gt}{U_A} = 7150 \tag{2.6}$$

For example, if equation (2.2) gives T_m = 5 seconds and equation (2.4) 4 seconds, T_m must be set to 4 seconds.

In deepwater, the wavelength L_0 can be calculated from $L_0=1.56 \cdot T^2$. If the period is long, for example 10 seconds, the water depth must be at least 156/2 = 78 m in order to achieve the conditions for the aforementioned formulas to be valid. In case the wave climate does not support deepwater condition, Larson and Hanson (1992) present the following forecasting equations for shallow water (after SPM, 1984).

$$\frac{gH_{m_0}}{U_A^2} = 0.283 \tanh C_1 \cdot \tanh\left(\frac{C_2}{\tanh C_1}\right) \tag{2.7}$$

$$\frac{gT_m}{U_A} = 7.54 \tanh C_3 \cdot \tanh\left(\frac{C_4}{\tanh C_4}\right) \tag{2.8}$$

where

$$C_1 = 0.530\left(\frac{gh}{U_A^2}\right)^{3/4} \tag{2.9}$$

$$C_2 = 0.565\left(\frac{gF}{U_A^2}\right)^{1/2} \tag{2.10}$$

$$C_3 = 0.833\left(\frac{gh}{U_A^2}\right)^{3/8} \tag{2.11}$$

$$C_4 = 0.0379\left(\frac{gF}{U_A^2}\right)^{1/3} \tag{2.12}$$

In accordance with (2.3), the minimum duration necessary for fetch-limited condition is given by:

$$\frac{gt}{U_A} = 537\left(\frac{gT_m}{U_A}\right)^{7/3} \tag{2.13}$$

The shallow water equations are less accurate than the deepwater ones due to a more complex wave environment and influences from the bottom. Furthermore, in shallow water H_{m0} will typically have a value less than the significant wave height H_s. It is also confirmed that the shallow-water equations in some cases yield larger wave heights than do the deepwater equations.

All the above presented equations can be solved explicitly for H_{m0}, T_m and t. If the prevailing conditions are duration-limited, a corresponding fetch can be determined by solving for t equal to the duration of the wind and using this equivalent fetch instead of the actual one.

Wind speed corrections

Wind generated waves develop due to the wind stress that acts on the water surface. The waves are primarily dependent on wind speed but, for example, surface roughness and air-sea temperature difference also affect the wind generating process.

Many 1000 meters above the surface, the winds are mainly driven by geostrophic balance between Coriolis and local pressure gradient forces. The wind can be considered driven by pressure differences in the atmosphere. Close to the earth's surface a boundary layer develops that depends on the roughness properties of the surface. The wind speed will vary from zero at the surface up to a constant value in the free stream, where the effects of the vertical turbulent mixing induced by the surface roughness are absent. It is customary to select the wind speed at 10 m as the reference speed when calculating wind-generated waves. Thus, if the wind has been measured at a different elevation, the speed has to be transformed to the reference elevation using some assumption about the vertical distribution of the wind speed near the surface. Furthermore, the wind speed should be specified for neutral stability in the atmosphere implying no temperature difference between air and the sea. If there is such a difference, a correction should be made that takes into account the effect of the temperature difference on the distribution of the wind speed.

Wind measurement elevation

Corrections of the wind speed that is not recorded at an elevation of 10 meter can be made using a simple equation (Johnson, 1999), based on the assumptions of a logarithmic profile as presented in SPM (1984), being valid up to roughly 100 meter above sea level:

$$\frac{u_{10}}{u_x} = \frac{\ln\left(10 / z_0 \right)}{\ln\left(x / z_0 \right)} \tag{2.14}$$

where u_{10} = wind speed at target elevation (z=10 m)
u_x = wind speed at recording elevation (x=70 m)
z_0 = sea surface roughness, estimated at 0.002 m (Hung, 2001a)

Air-sea temperature difference

If the air and sea temperature differ from each other, the wind speed at 10 meters elevation has to be transformed into an effective wind speed by using the following equation,

$$U_{effective} = R_T \cdot U_{10m} \tag{2.15}$$

where the coefficient R_T is obtained from Figure 3-14 in SPM (1984). If the air temperature is higher than the sea temperature, the boundary layer is stable and thus the wind is less effective in transferring energy to the water surface. For the opposite temperature condition, the boundary layer is less stable and the wind will transfer energy to the surface more effectively.

Wind stress factor
In order to use recorded wind speeds in the wave prediction formulas, they have to be adjusted into a wind stress factor U_A according to:

$$U_A = 0.71 \cdot U_{effective}^{1.23} \tag{2.16}$$

Test calculations indicated that the shallow water equations in some cases yield larger values that the deepwater ones. This does not comply with theoretical considerations stating that the smaller the depth, the more energy is dissipated and thus the wave height is reduced. One explanation for this may be that shallow-water equations are theoretically less well-founded compared to the deepwater ones, implying that the shallow-water equations sometimes are applied outside their range of validity. Due to this contradiction, the results from the shallow water equations are used but with the values from the SMB method as an upper limit. Finally, these above presented equations are only valid as a 1-D model under the assuming of shore parallel bottom contours.

2.4 Linear wave theory

In order to compute the longshore sediment transport, the nearshore wave properties must be determined. Normally the properties at breaking are used as reference for the transport calculations, where the break point is defined based on the ratio between wave height and water depth. Assuming no energy losses from the offshore to the break point, the equation for conservation of wave energy flux may be solved in parallel to the Snell's law describing wave refraction to obtain the wave properties at breaking. Waves break in shallow water and, thus, typically the linear shallow-water wave theory is employed to describe the waves at this location.

Assuming that the energy flux of an offshore wave equals the breaking wave energy flux, i.e. no energy is lost in the propagation from offshore to breaking, the following expression is obtained, saying that the energy flux per unit length of beach in the direction of wave propagation is constant from offshore to breaking:

$$(E_0 \cdot C_{g0} \cdot \cos\alpha_0)_{offshore} = (E_b \cdot C_{gb} \cdot \cos\alpha_b)_{breaking} \tag{2.17}$$

where

$$E_0 = \frac{\rho \cdot g \cdot H_0^2}{8} \tag{2.17a}$$

$$E_b = \frac{\rho \cdot g \cdot H_b^2}{8} \tag{2.17b}$$

$$C_{g0} = \frac{g \cdot T}{4 \cdot \pi} \tag{2.17c}$$

$$C_{gb} = \sqrt{g \cdot h_b} \tag{2.17d}$$

and

E = energy density
C_g = group wave velocity
ρ = water density (1024 kg/m^3)

In case of parallel, orthogonal bottom contours, Snell's law states that:

$$\sin(\alpha_b) = \frac{C_b}{C_0} \cdot \sin(\alpha_0) \tag{2.18}$$

where

$$C_b = C_{gb} = \sqrt{g \cdot h_b} \tag{2.18a}$$

$$C_0 = 2 \cdot C_{g0} = \frac{g \cdot T}{2 \cdot \pi} \tag{2.18b}$$

and

C = wave celerity

α_0 and α_b represent the angle between wave crest and bottom contour for offshore wave and breaking wave respectively.

Furthermore, over hundred years ago, McCowan (1891) demonstrated that the breaker wave index, γ, for a solitary wave equals 0.78 as the water particle velocity becomes equal to the wave celerity, i.e., the wave will break (laboratory investigations have later proved that this value agrees better with oscillatory waves than with solitary waves). Thus, the relationship between wave height and depth at breaking is given by:

$$H_b = \gamma \cdot h_b \tag{2.19}$$

After combining equations 3.17 to 3.19 and simplifying, the following expression is obtained, which can be solved numerically:

$$h_b^2 = \frac{\sqrt{g} \cdot T \cdot \cos(\alpha_0) \cdot H_0^2}{\gamma^2 \cdot 4 \cdot \pi \cdot \sqrt{h_b} \cdot \cos\left[\arcsin\left[\frac{2 \cdot \pi}{T} \cdot \left(\frac{h_b}{g}\right)^{1/2} \cdot \sin(\alpha_0)\right]\right]} \tag{2.20}$$

Unfortunately, there was not enough wave data available for validation of the model.

2.5 Sediment transport theory

In order to predict the development of a shoreline it is necessary to estimate the littoral drift of sediment. It is, however, very difficult to obtain accurate values that have good correspondence to the actual drift. In SPM (1984), three different approaches to estimate the longshore transport are mentioned. The first one, which also is considered to be the most accurate, states that the “best way to predict longshore transport at a site is to adopt the best known rates from a nearby site, with modifications based on local condition”. Unfortunately, this method requires similar, well-known areas and local data that may be impossible to obtain. The second and next best method is to use historical information, such as topographic charts and dredging records, to predict future transport rates. If neither of these two methods is suitable, or impossible to use due to lack of data, wave energy flux methods are commonly employed.

The wave energy flux methods are based on the assumption that the longshore transport rate only depends on the longshore component of wave energy flux in the surf zone. Equation (2.17) states that the energy flux per unit length of beach, in the direction of wave propagation, is equal to,

$$\widetilde{P} \cdot \cos(\alpha) = \frac{\rho \cdot g \cdot H^2}{8} \cdot C_g \cdot \cos(\alpha) \tag{2.21}$$

where $\widetilde{P}$ denotes the energy flux per unit length of wave crest. After multiplying equation (2.21) with sin(α) the longshore component P_l is obtained,

$$P_l = \frac{\rho \cdot g \cdot H^2}{8} \cdot C_g \cdot \cos(\alpha) \cdot \sin(\alpha) \tag{2.22}$$

Using significant wave height and breaking wave conditions, and that sin(2α) = 2·cos(α)·sin(α), will finally produce the expression:

$$P_l = P_{ls} = P_{lb} = \frac{\rho \cdot g \cdot H_{sb}^2}{16} \cdot C_{gb} \cdot \sin(2\alpha_b) \tag{2.23}$$

In order to relate P_{lb} to transport rate Q [m^3/unit time], SPM (1984) suggests that,

$$Q = \frac{K}{(\rho_s - \rho) \cdot g \cdot a'} \cdot P_{lb} \tag{2.24}$$

where

K = dimensionless coefficient = 0.39
ρ_s = mass density of sand
ρ = mass density of water
a' = 1-p and p = porosity

This equation is known as the CERC formula for longshore sediment transport. The formula must be used with care since the empirical investigations indicate that the estimation only lies within ± 50 per cent of actual measured transport rates (SPM, 1984). Nevertheless, for many applications the CERC formula has proved reliable, yet there are important limitations as noted by Graaff (1990). No information about the transport distribution along the breaker zone is obtained, implying that the use is limited to coasts without for example groins and bars that influence the longshore transport. Knowing that the formula was derived for beaches having an average grain size ranging from roughly 0.2 to 1 mm, and no properties of the bottom material are considered, investigated areas should be of the same kind. Other properties that are not taken into account are beach slope, breaker zone width, and driving forces besides breaking waves.

3. Site Description

3.1 The area

The Red River delta is situated in the north of Vietnam and in climatic terms the delta stretches from a temperate humid region into a tropical wet and dry one. Figure 3.1 shows an overview of Vietnam, which is a narrowly shaped country, having a long coastline with its two major cities Hanoi and Ho Chi Minh City positioned in opposite parts of the country. In the north the Red River together with is two most important tributaries are shown (Figure 3.1 is based on a map from Microsoft Encarta 2000 as are all the following maps).

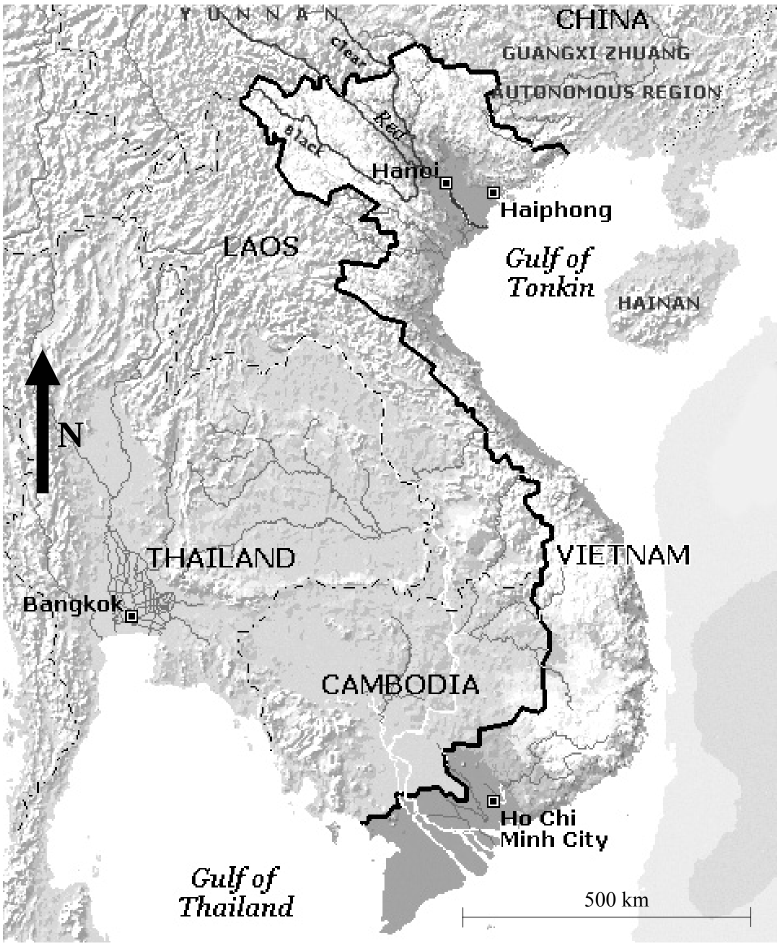


Figure 3.1 Overview of Vietnam and its coastline with Red River Delta located in the northern part of the country

The Red River (Song Hong in Vietnamese) originates in Yunnan province of China and reaches the Gulf of Tonkin through a number of mouths about 1,200 km downstream. The total catchment area in the two countries is 155,000 km^2 and its yearly average flow is 137×10^9 m^3 (4.3×10^3 m^3/s) (Vinh et al., 1996), which the two tributaries Clear River (Song Lo) and the Black River (Song Da) highly contribute to. Most of the water travels through the river during the rainy season when the average flow becomes 8×10^3 m^3/s. During this season, flooding is a common situation that the inhabitants of the delta have to deal with. Channels and irrigation systems along with dikes have been built for several centuries in order to tame the violent river and at the same time improve the conditions for agriculture.

The first dike known today was built in 1471, situated at the former shoreline of Lach Giang; see Figure 3.2 and Figure I.1.

The Red River Delta is composed of 3,000 fertile square kilometres, of which all are situated below three meters above sea level and much of it does not rise more than one meter above sea level (Pruszak et al., 2001). Together with the Mekong Delta, it constitutes the most important economical zone in Vietnam. The main occupation in the heavy populated region is agriculture, principally rice cultivation that makes use of nearly 70 per cent of the land in the coastal provinces (VCZVA, 1995).

Ba Lat estuary (Figure 3.2), the main river mouth of the Red River, receives large amounts of sediments, roughly 23 million ton/year (Pruszak, 1998), which result in a progressive development of the delta outward into the Gulf of Tonkin. In total, Red River carries 72×10^6 tonnes of sediment every year that all reaches the sea. The major river mouths in the Red River delta along with their annual average sediment discharge and accretion rate are shown in table 3.1 with locations given in Figure 3.2. Annually most parts of the delta advance between a few to several tens of meters depending on the exact position (see Figure I.2), but the beach of Hai Hau district (located in the middle of Nam Ha province) is eroding.

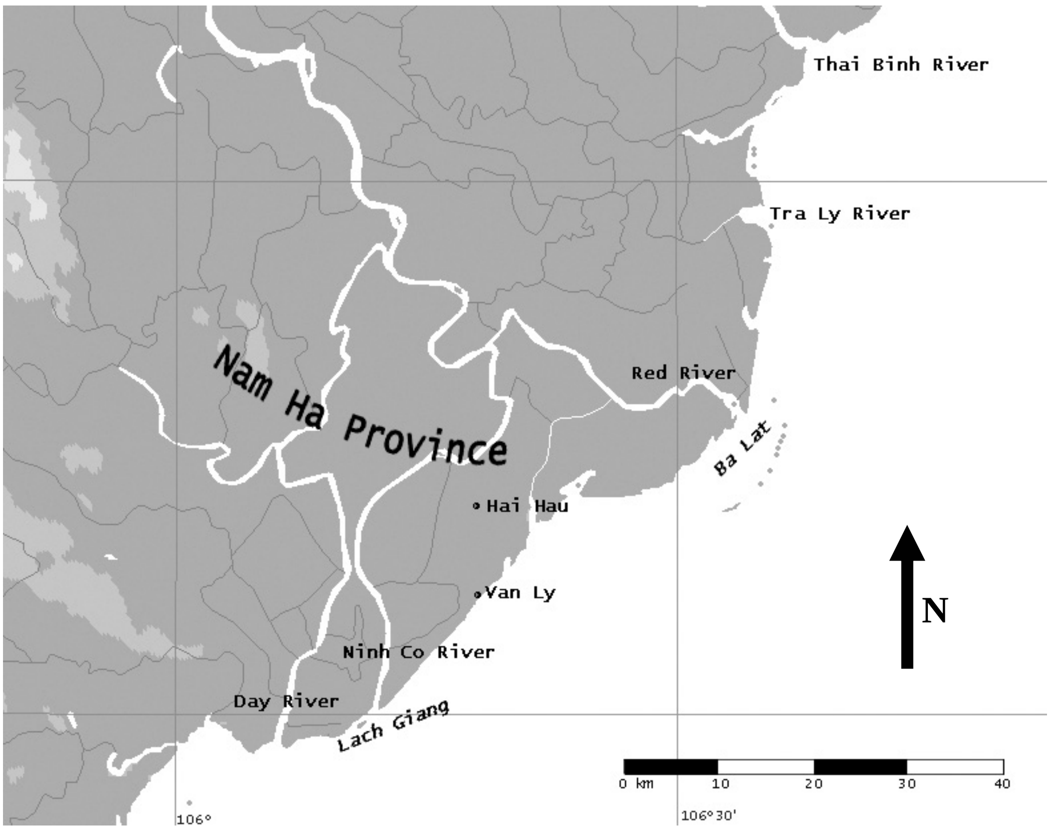


Figure 3.2 Nam Ha province and its nearby major rivers.

Table 3.1 River mouths and sediment discharge (Pruszak, 1998).

River mouth	Sediment discharge [10^6 tonnes/year]	Accretion [m/year]
Ba Lat	23	41-83
Thai Binh	15 – 20	8-41
Tra Ly	12 – 15	16-25
Lach Giang	18	N/A
Day	12	N/A

3.1.1 Red River Delta

The Red River delta has the typical triangular shape of an arcuate type of delta and is influenced rather equally by wave, tidal and fluvial processes. The coastal areas of the delta can, with respect to the prevailing influence, be divided into a northern and a southern region with the boundary near Thai Binh mouth (Mathers et al, 1999). The northern region is well sheltered against wave motion because of mainland China and Hainan Island in the Tonkin Bay and is therefore mainly dependent on tidal processes. The northern distributaries develop straight toward the sea and have some resemblance to the shape of a Bird's Foot delta.

The southern region is highly dependent on wave motion because of its exposure to waves with long fetches both from southeast and northeast. Several barriers (sandy ridges and beach-spits) formed "tangentially" to the open sea can be seen in this region (Figure 3.3 and more detailed in Figure 3.4 (satellite photos from 1995)), where the intermediate beaches are rather static and mainly serve as carriers of longshore sediment transport. The final form of this beach forming process is showed north of the mouth: a straight tangential ridge, often positioned at a seaward flank of clusters of ridges, i.e. mainly accreted land between the mainland and the beach ridge. The overall form of the river mouth area illustrates the effect of the wave climate leading to divergent longshore sediment transport that produces this typically convex shape.

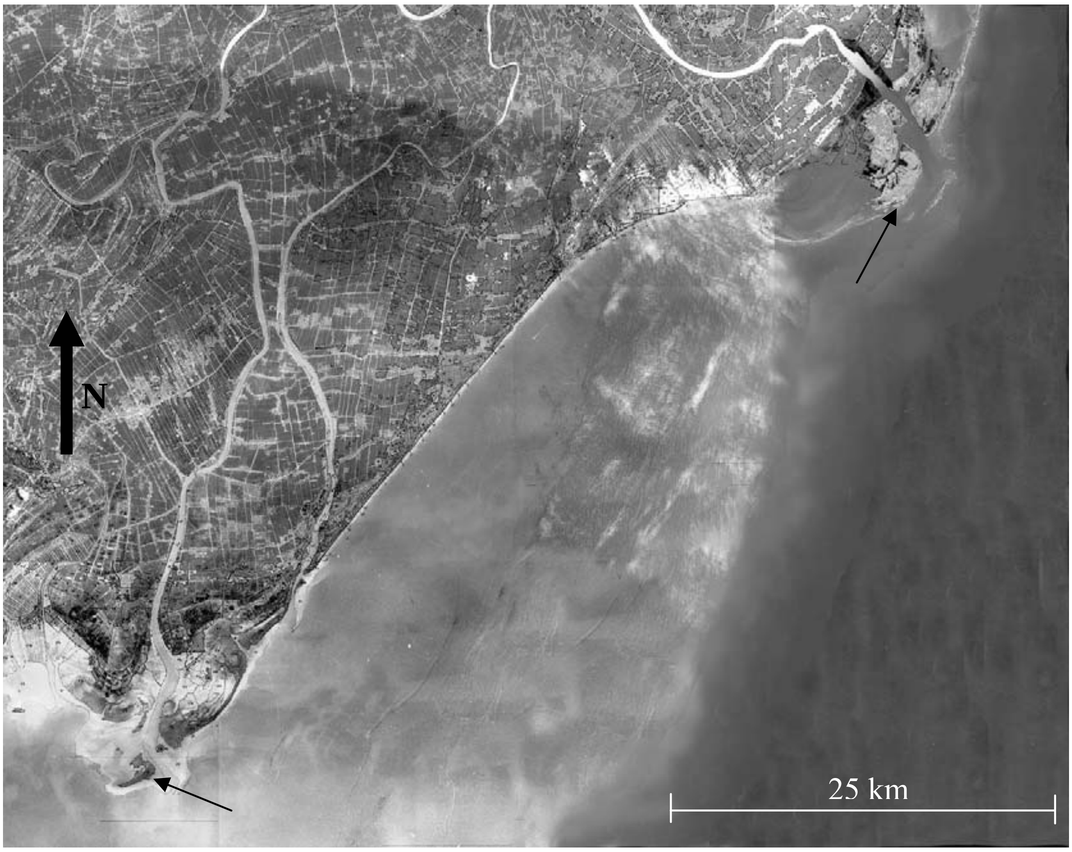


Figure 3.3 Coastline of Nam Ha province and marked barriers (Wijdeven, 2001).

Figure 3.4 Sandy ridges and beach-spits outside Ba Lat estuary (Wijdeven, 2001).

3.2 Climate

The Vietnamese climate is tropical in the south and characterized by summer and winter monsoons in the north. The winter monsoon originates from the inner parts of China and reaches Vietnam from northeast whereas the summer monsoon strikes Vietnam from southwest due to rising heated air of the Gobi Desert that causes moist air to flow inland from the sea outside Vietnam (VEN, 2002). However, while reaching the Red River delta the southern monsoon changes direction and creates waves mainly from south-southeast. Figure 3.5 illustrates the main wind directions reaching Red River Delta over the year. The hot rainy season lasts from mid-May to mid-September (summer monsoon) and the cooler and dryer season, which brings the strongest winds, lasts from mid-October to mid-March (winter monsoon). Between these two periods, there is a transitional period with eastern trade winds, created by subtropical high pressures. Annual rainfall in Vietnam ranges from 120 to 300 centimetres, of which nearly 90 percent falls during the summer; the rainfall in the Red River delta is close to 200 cm. Average annual temperatures range from a low of 5°C in December and January, the coolest months, to more than 37°C in April, the hottest month.

Once every five years, on the average, Nam Ha province is hit by a typhoon that may cause severe damage to the fragile dikes. These extreme storms occur between May and January and cause, in addition to damage on the dikes, serious flooding.

Figure 3.5 Main wind directions in northern Vietnam.

3.3 Hydrodynamics

The hydrodynamic climate is mainly a function of the general weather. Strong winter winds generate large waves, which in turn generate strong longshore currents. The Gulf of Tonkin encompasses a large surface area and combined with relatively long wind durations, the generated wave climate becomes fairly energetic. Normal wave heights range from 1.2-1.4 m offshore and 0.8-1.2 m nearshore, with a maximum height of 8 and 5 m, respectively. The water level is highly affected by tides and field observations show tidal levels ranging from 3.1 to 3.4 m between low 'low water' and high 'high water' in the Red River delta (Pruszak et al., 2001).

Being positioned in Southeast Asia, the coastline is subject to typhoons, which only are created over seas where the water temperature is above 27 ^{o}C. The Red River Delta is on average hit two times a year (VCZVA, 1996) and, as abovementioned, the Nam Ha province is hit once every five years. Concurrent hydrodynamic events, such as tide, storm surges and monsoon waves, also have great influence on the nearshore development. A mild bottom slope implies that normal conditions allow much of the wave energy to dissipate before impacting the coastline. Storm surges, which are large masses of water being "pushed" towards the coastline, can originate from typhoons and recordings estimate the probability of storm surges over 1 m at 50 per cent and over 2.5 m at 11 per cent (Pruszak, 1998).

In the offshore regions of the Gulf of Tonkin, ocean currents are dependent on the season. During the summer monsoon, cold water is blown in from the Pacific Ocean, causing downwelling movement of the water due to density differences of the cold Pacific water and the warmer water of the Gulf. During the winter the opposite occurs: winds blow out the warmer surface water to the Pacific and thus deeper water rises, causing upwelling movement.

Pruszak (1998) presents probable maximum values at 70-120 cm/s for the longshore current in the Hai Hau district, whereas currents during less strong storms lies around 40 cm/s. The longshore currents are highly affected by the tide in deeper water. For example, during winter (generally southward current) the currents increase at ebb and decrease at flood (during the summer the opposite applies). Moreover, the tidal contribution may exceed the wave contribution especially at low wind speed. Hence, in some cases the littoral drift can be directed towards the wind.

3.4 Geology

In general, as described by Mathers and Zalaziewicsz (1999), the coastal area within the Red River delta plain consists of a Quaternary sequence, which is around 200 meters thick at the coastline front and decreases to about 100 m near Hanoi. Furthermore, this sequence can be divided into three subformations: the lower formation, which consists of grains sizes ranging from cobbles to fine sand at depths of 100 to 190 meters; the middle formation, which in the lower and upper parts consists of coarse sand and clay sand respectively, with a thickness of 40 to 60 meters; and the upper formation with a thickness similar to the middle one. The upper formation may in addition be divided into three other geological members that, starting with the lower one, consist of swamp clay (including remains of animals and plants); clay of littoral facies; and sand, silt and clay of delta facies.

This geological mixture partly contributes to make deltaic areas fertile and suitable for agriculture due to accumulation of diverse nutrition provided by the rivers from extensive areas. In addition to fertile soil, the deposits also contain oil, coal, and gas in large amounts. The shallow groundwater resources, which are to be found in deltas, have provided opportunities for civilizations to thrive both in past and present times. As previously mentioned, the Red River delta is a very densely populated area and even as coastal areas are threatened by erosion and flooding, the fertile soil encourages agricultural expansion.

The delta has a total length of 150 km from its apex at Viet Tri (see Figure 3.6) in the northwest to the coast in the southeast. At the coastline front, the delta is 130 km long and continues subaqueously for some 10 to 20 km off the coast.

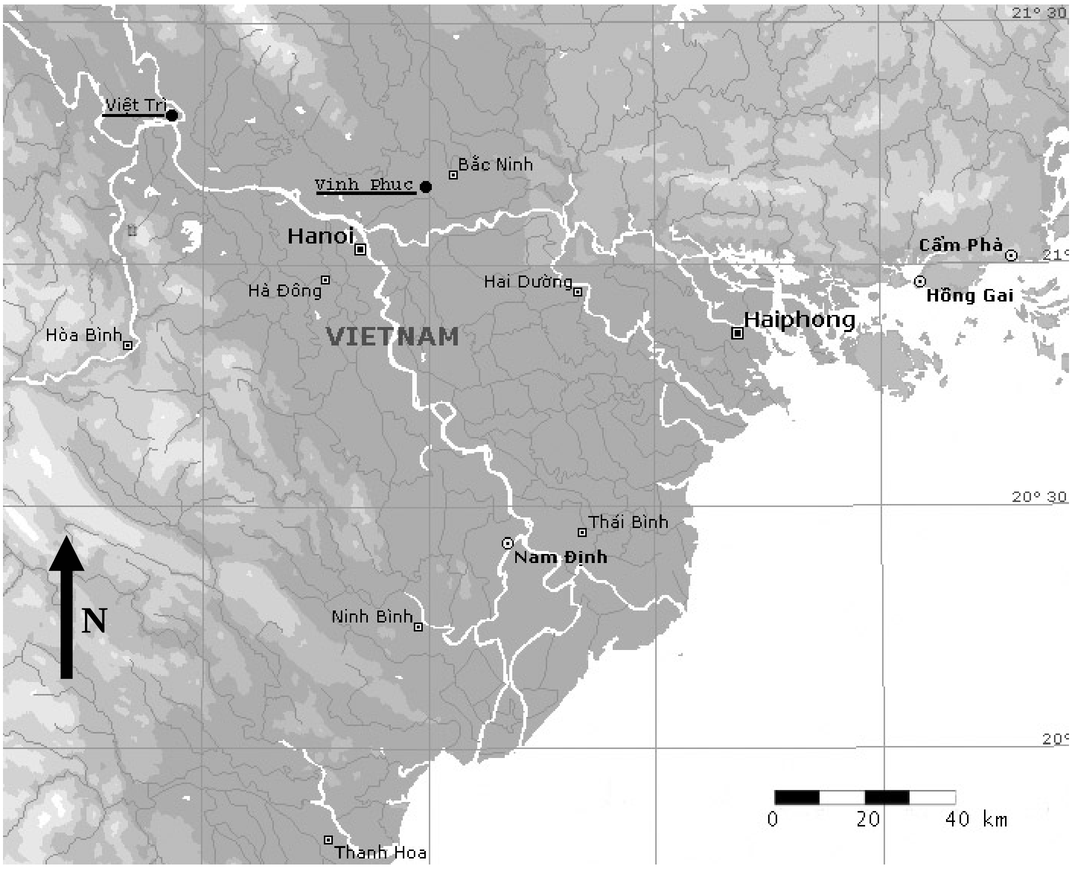


Figure 3.6 Extension of the Red River delta.

3.5 Coastal evolution

Based on lithological data, combined with hydrology, physiography and geology, it is found that there are large variations in the longshore sediment transport along the coast, which is greatly affected by shoreline orientation and wave climate (Zeidler and Nhuan, 1997). The coastline of the Red River delta mainly consists of cohesive material (12 percent sand, 59 percent aleurite and 29 percent clay) which annually is supplied with 72×10^6 tonnes of sediment. However, most of this river load, over 70 percent, passes through the intertidal plain and vanishes into the sea. The remaining sediment material contributes to the development of the delta. In the summer, the river flows are very high due to the heavy rains. Hence, 80-90 percent of the sediment discharged through the Red River is transported during June to October (Pruszak, 1998). This heavy sediment load is caused by the rain flushing particles and alluvium to the rivers, as well as erosion of the river banks because of the large flow.

Furthermore, at time scales of thousands of years, a predominant cause of shoreline change is a sea level rise, which has had great impact on the littoral process historically, but also the recent development of the Red River delta. Shoreline changes obtained from maps suggest that the Hai Hau erosion started around the beginning of the 20th century, but the erosion rate seems to have decreased during the late 60s (Vinh et al, 1996).

3.6 Defence measures

Sea dikes play a dominating roll concerning shoreline defence structures in Vietnam, and for the Hai Hau district dike systems are totally prevailing. The defence strategy regarding construction, maintenance and rehabilitation is overall governed by the Ministry of Agricultural and Rural Development (MARD) but is operationally run by the Department of Dike Management and Flood Control (DDMFC), which handles more than 3,000 km of coastal and estuarine dikes (Pilarczyk and Vinh, 1999). The main objective for DDMFC is to secure communities in coastal areas from erosion and flooding and thus increase agricultural production and income.

Construction of new dike systems and upgrading of old ones is a continuous process. In Van Ly, for example, the average annual coastline retreat has resulted in one destroyed dike line every 10 years. Due to the lack of proper equipment, upgrading and repair (in case of breach) of the front dike are rarely possible and the land behind the dike will be lost to the sea. Dike maintenance costs are extensive and in Hai Hau district they represent nearly 70 per cent of the total sea defence budget (VCZVA, 1995).

The normal design wave climate is based on an annual occurrence of 5 per cent, which is determined by both investment costs and level of protection. The dikes are fundamentally constructed to withstand concurrent design events, which are reflected in the employed dike crest elevation formula given by $z_{crest} = z_{tide} + z_{storm\ surge} + z_{wave\ run\text{-}up} + z_{free\ board}$, where z is elevation and the subscripts are self-explanatory. However, funding problems and shortage of for example vehicles have affected the construction of the dikes and thus resulted in both weak structures and serious overtopping (salinity intrusion). In the future the economical development in the coastal zone will expand and thus it is expected that investments will increase and more money be put into erosion control, i.e. better defence systems. The Vietnamese design standards are somewhat out of date and must be revised in order to meet contemporary international knowledge (Pilarczyk and Vinh, 1999).

The eroding impact from waves is in particular severe on beaches with steeper bottom slopes since waves hereby can propagate closer to the shore before breaking takes place. According to Vinh et al (1996), the bottom slopes in Hai Hau district ranges from 1:40 in eroding areas to 1:200 in other areas. At present, 75 per cent of the Hai Hau coastline is deteriorating and it is a major problem that has attracted wide attention, both domestically and internationally.

The dike system at Hai Hau beach is characteristically positioned as shown in Figure 3.7. When a breach takes place, the section dikes help to limit flooding and the second dike will be the new first line of defence. In general, the second dike is mainly made of soil (no true revetment) and thus it is weaker than the first. However, these dikes must and will be reinforced when the water reaches them; otherwise they will not last a longer period. The distance between the dikes vary but is roughly 200-250 meters. The land areas between the dikes are also divided into sections varying between several hundred meters up to 3 km. The division into sections causes only limited areas to be flooded when a breach occurs at the front dike and without sections greater land areas would have been destroyed at once. Recently taken photos of the front dike reveal major erosion problems and clearly show the earth core of the dike as seen in Figure 3.8. The photo also illustrates the *Casuarina tree*, which is frequently planted and used to reduce wind speed and bind the shoreline soil. The tree is common not only at Hai Hau beach but in Vietnam in general.

According to the VCZVA (1996), the front slope of the dikes in Nam Ha province is normally 1:3 and the crest elevation lies around 5 meters above mean sea level (MSL). The earth core consists of material from local sand and clay resources, which strongly affects the durability of the dikes since the fine soil is easily flushed out to sea. On top of the dike, revetments made from limestone cobbles are positioned on a layer of clay. A characteristic dike cross-section is shown in Figure 3.9. In total, dikes protect 75 per cent of the Hai Hau coastline. Finally, it is imperative to realize that the defence strategy in Hai Hau district is commonly known as a retreat strategy. This means that the rate of erosion is slowed down, not stopped.

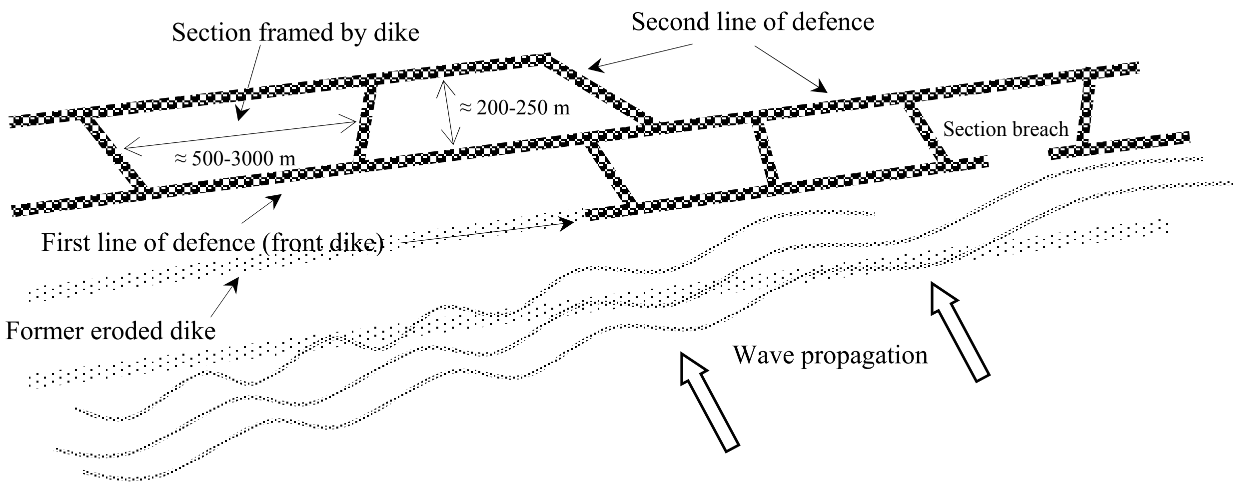


Figure 3.7 Sketch of double dike system at Hai Hau beach (after Pilarczyk and Vinh, 1999).

Figure 3.8 Severely eroded dike with planted Casuarina trees at Hai Hau beach.

Figure 3.9 Characteristic cross-section of an eroded dike near Van Ly village, (former shrimp farm to the left; open sea to the right).

3.7 Social aspects

The Red River Delta, with its 1,000 persons per km^2, is the most densely populated area in all of Vietnam (VCZVA, 1998). Hence, there are limited areas available for the rice fields, where the main part of the residents is working. The people living by the coast are therefore using the sea as a source of income. For example, in Van Ly village, where the largest salt farm in the north of Vietnam is situated, the tide is used for extracting salt from the seawater.

In addition, there are also many shrimp farms as well as fishermen in the region. The people living in the district are very poor and income can be as low as US$7 (100,000 dong) per month.

The men living in the coastal districts in Vietnam that suffer from erosion are on an average obliged to work for free about 10 days per year, building and maintaining the dikes in their district. If they would refuse or by any reason not be able to work, they would be forced to pay for a hired worker, taking their place. In Van Ly village, suffering from severe erosion, the men are obliged to work around 40 days a year.

4. Coastal Processes at Hai Hau Beach

4.1 Hai Hau beach area

The Nam Ha province is located south of the Red River and north of the Day River and its coast mainly faces east to southeast direction, see Figure 4.1. The three coastal districts of the province are Xuan Thuy, Hai Hau, and Nghia Hung. The middle district, Hai Hau, is despite its location between the two sediment-discharging rivers exposed to severe erosion. In the two other districts, the coastline is growing because of accretion. Since 1905, a clear pattern can be seen that shows a retreat of the Hai Hau coastline of about 29 m/year (Vinh et al, 1996).

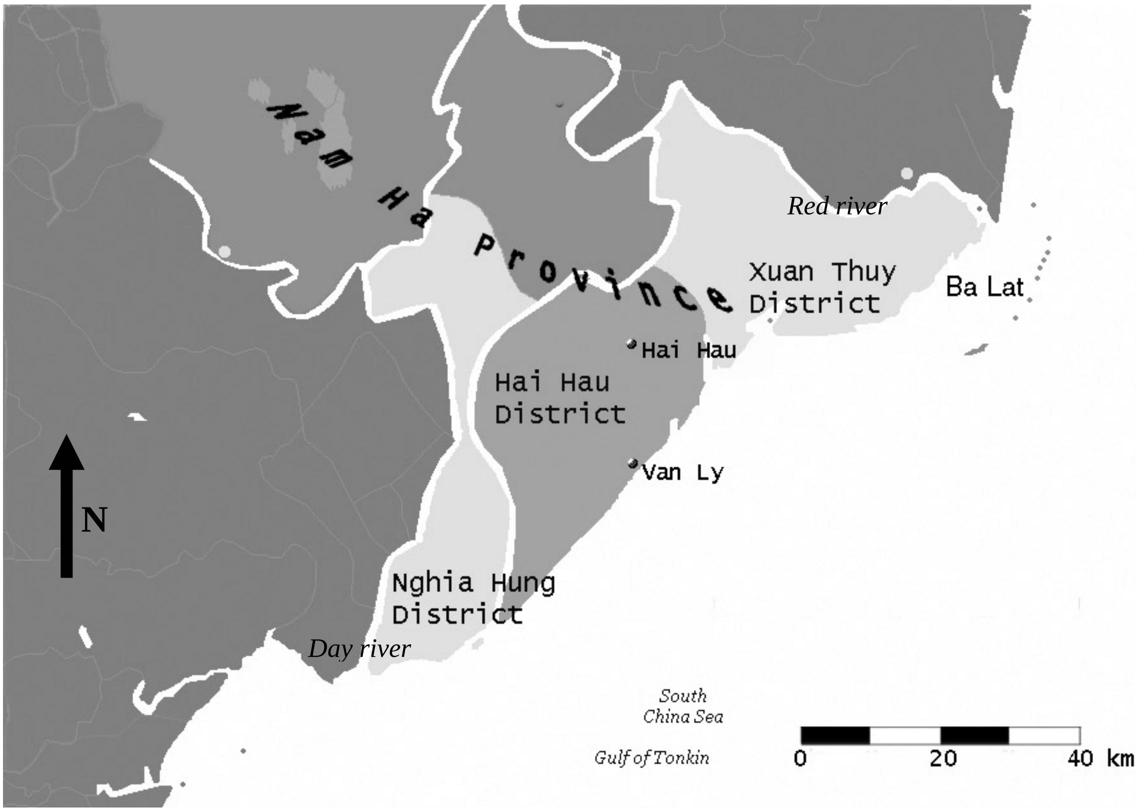


Figure 4.1 Nam Ha province with coastal districts.

4.1.1 Field inspections and measurements

Van Ly

The first inspection was made in Van Ly village, situated near the coast in the middle of the Hai Hau district. The village has a few thousand inhabitants whose main income is based on agriculture and a governmental salt farm (one of the largest in the country).

Government property is considered to be of greater importance than private property and the revetments of the second dike (i.e., second line of defence) in front of the farm are therefore made from inter-linking concrete slabs instead of just cobbles (see Figure 4.2). This construction will most likely withstand severe waves better than the cobble revetment but, as stated by Hung (2001a), although it looks quite strong on the outside, it may still be too weak if exposed to harsh waves. The condition of the present front dike also clearly supports Hung's observation.

Figure 4.2 Concrete revetments on a second sea dike in Van Ly.

According to old inhabitants of the district, the shoreline was in the early 20th century located between 5 to 10 km further offshore than today, and 50 years ago roughly 5 km offshore. Although very approximate figures, they point towards an average annual coastline retreat of 50-100 meters. In order for the local people to be able to make a fast repair of the dike in case of a breach, stone cobbles are stapled and stored on top of the dike. A widely used vegetative protection measure is to plant *Casuarina* trees (Figure 3.8), which helps to bind the soil and reduce the wind along the coast. The main shoreline protection method is otherwise sea dikes with stone and cobble revetment, in accordance with the rest of Hai Hau district. In addition, groins are also used at some places. The effect of the groins near Van Ly are however questionable as seen in Figure 4.3; the groins are permeable and too small and short to be able to capture any significant amount of sediment.

Figure 4.3 Groins with insignificant impact on the longshore sediment transport at Van Ly beach (photos taken at low water).

A common problem along the coastline is saltwater intrusion because of dike overtopping. Once the saltwater percolates into agricultural soil, the soil needs many years for recovery. During typhoons and hard storms, saltwater, carried by the winds, can reach hundreds of meters inland and cause severe economic and vegetative damage. Due to the risk of flooding there are evacuations plans available in order to secure endangered families and structures.

The construction of new dikes goes on continuously over time. Generally, there always exist two dikes—one front and one second dike. If the first is about to fail, a new dike is built behind the second one. When the front dike fails, the land between the front and the second dike will be flooded with salt water and cause land and house destruction. Some days before we arrived, a new breach had occurred in the front dike, letting seawater into a large private shrimp farm that now was entirely ruined. Besides the direct tragedy for the people, cultural buildings as old churches from the French colonization are ruined because of dike failure.

A dike failure will not instantaneously cause severe flooding and erosion on the second dike (although the area is below or near the sea water level between the front and second dike) since the low water depth will not allow high waves to propagate inland and impact the second dike (see Figure 4.4). Thus, it will take some time before eroding waves can reach the second dike, although the land between the dikes may erode at a larger rate due to the lack of protection from wave action.

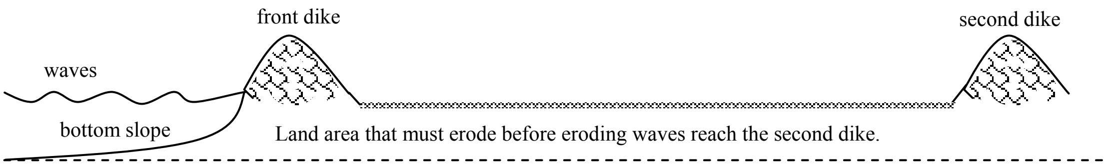


Figure 4.4 Simple sketch of Van Ly dike situation.

Up to now, the lifecycle of a dike in Hai Hau is about 5-10 years from when it becomes the first defence dike until it is destroyed. On average 600,000 m^2 of agricultural land and living areas are being lost to the sea every year.

Ba Lat

The Ba Lat estuary and its wetland (the Xuan Thuy site) is a part of the Ramsar Convention on Wetlands since September 1989 (Jones, 1993). Of all remnants of mangrove and mudflat ecosystems along the coast of Vietnam, this Ramsar site comprises the most significant one. Within this site, the vast existence of mangroves is very important in order to maintain the fish farm production, but also to protect coastal settlements from severe impact of typhoons. The expansion of fish farms began, according to Hung (2001a), about 20-30 years ago and has accelerated during the 80s and 90s.

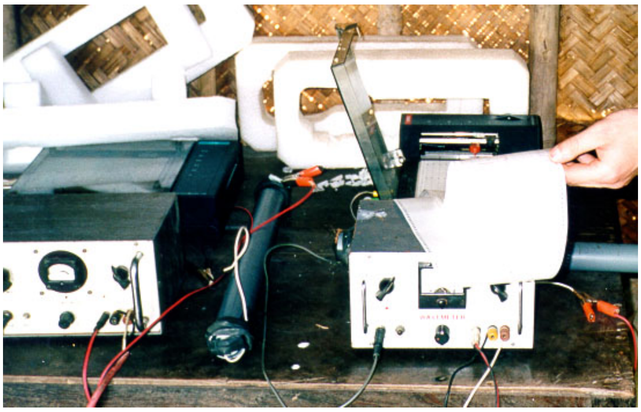
More than a decade ago, in 1990, the Vop river (a branch of the Red river) was closed but is now being reopened (Figure 4.5) since erosion southwards and disturbance to the ecological balance, for example mangrove death downstream of the river resulting from increasing salinity, might originate from the cut-off. The average difference between low and high tide within Ba Lat is roughly 1.5 – 2.0 m. Hung (2001a) states that there are indications suggesting that maybe as much as 90 per cent of the erosion occurs when monsoon and high

‘high water’ levels coincide. When the water level is normal or low more wave energy is dissipated through bottom friction due to mild bottom slopes, roughly 1:100 but down to 1:200. Figure 4.6 illustrates the mild beach slope at Ninh Co bank in the south of the study area.

Figure 4.5 Opening of the Vop River (north and upstream is the left).

Figure 4.6 Mild beach slope at Ninh Co bank.

Wave measurements
Wave measurements were performed during the second day in the field at Van Ly. The recording device was a resistance gage based on the principle that resistance in air and salt water differs substantially. Figure 4.7 shows the wave recorder and illustrates how the measure pole was positioned in the breaker zone (at a depth of 2 meters). Depending on the elevation of the water (caused by waves) the resistance will vary i.e. high water level gives low resistance and vice versa since salt water is ionized and thus leads electricity well.



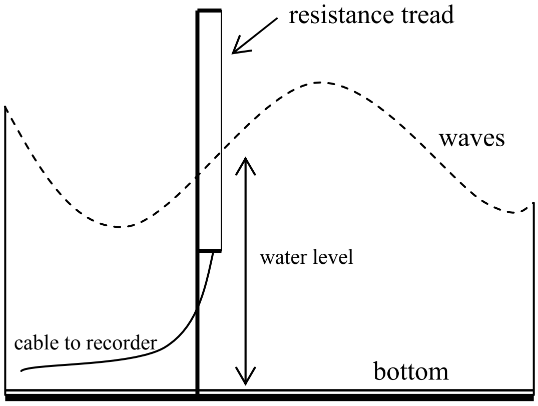


Figure 4.7 Wave recorder to the left and measurement arrangement in the sea to the right.

Unfortunately the impact of the waves caused the cobbles at the dike to move and cut off the cable connecting the recorder and the measurement pole (see Figure 4.8) after some hours. Therefore, the obtained measurement series was too limited in time to be used in calibration and validation of the developed nearshore wave model. The wave heights and periods during this short period were typically 0.6-1.0 m and 10 s, respectively.

Figure 4.8 Waves and measuring pole in the breaker zone.

The observed waves during these measurements were mainly swell and the nearshore wind was blowing towards the propagating waves. This is an example of the importance, and difficulty, of choosing the right wind data for hindcasting, relevant to the investigated area. In this case, wave predictions based on wind recordings from Van Ly would have given very wrong estimates.

Sediment sampling
Sediment samples from Quat Lam swimming area, Van Ly beach, and Ninh Co bank (see Figure 4.9), covering Hai Hau beach from the north to the south, were taken and analyzed regarding grain size. The analysis showed about equal distribution at all sites with 96-98 percent sand ranging from 0.1 mm to 0.25 mm with D_{50} approximately equal to 0.17 mm (see Appendix II). This result is in accordance with generally accepted sediment theories saying that fine material discharged by rivers, such as silt and clay, will not deposit (and contribute to the build-up of beaches and deltas) within the nearshore zone but is transported further out into the sea. Furthermore, the average grain size presented in Vinh et al (1996), being 80 μm, corresponds well to the present results, especially since measurements indicate an increasing average grain size at eroding coastlines.

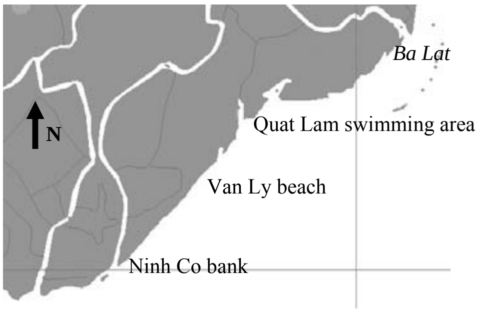


Figure 4.9 Sediment sample sites.

4.2 Offshore wave climate

In order to determine the offshore wave climate, wind data were employed from the meteorological stations at the islands Bach Long Vi and Con Co (see Figure III.1) for the years 1976 to 1995. The differences in calculated waves and periods, based on the wind data time series from Con Co and on measurements from Bach Long Vi are given in Appendix IV. From these figures it is clear that there will be a large difference in results whether wind data from Bach Long Vi or Con Co are used. The wind measurements were obtained at an elevation of 72 m every six hours as instantaneous values and thus not weighted in order to better represent the whole six-hour period. However, in the calculations the recordings are considered to be valid for the whole period.

Fetch lengths were obtained at a position approximately 40 km outside Hai Hau beach to be used for the offshore wave calculations and the estimated fetches are shown in Figure III.1. In the transport calculations only winds from sea are handled, which means that if, as for Hai Hau beach, the shoreline orientation is 40 degrees (true north), all winds that do not come from a section 40 to 220 degrees are not accounted for. Furthermore, winds are considered to be constant along all fetches. Temperature data was taken as monthly values from Institute of Meteorology (1986). In Appendix III, the used temperature values are summarized in a table.

In general, the water depth of the Tonkin Bay varies between 30-40 meters but can reach 50 meters in some places. For the calculations, a depth of 30 meters was generally used since this depth was considered applicable to most parts of Tonkin Bay. However, for winds coming from the south the depth was adjusted (reduced) to better represent nearshore conditions. The depth adjustment did however not cause any major differences in results, probably because of the suspected overestimation in the shallow equations, discussed in chapter 2.3.

4.2.1 Comparison with field data from Bach Long Vi

In order to validate the offshore wave calculations, bar diagrams comparing the wave heights and periods, as shown in Figure 4.10 and 4.11, was made to illustrate the agreement between calculated and measured waves for the years between 1976 and 1995. The measured wave heights and periods were visually observed three times per day at the Bach Long Vi Island (BLV) at a depth of 7 meters by the use of a buoy. No observations were performed at night due to lack of daylight. The wind data used in the calculations were also obtained at BLV.

The measured and calculated wave heights and periods in general match each other rather well, especially the heights. Moreover, comparison of an arbitrary sequence of 13 consecutive days in 1984 (Figure 4.12) shows good agreement between calculations and observations. Another approach of comparing the calculated and the measured wave heights are shown in a scatter plot (Figure 4.13). Measured and calculated wave heights for 1984 are plotted against each other and the size of the rings reflects the number of coinciding events. This method also indicates good correlation, although some minor systematic error may be observed. Altogether, the comparisons validate the modelling of the offshore waves.

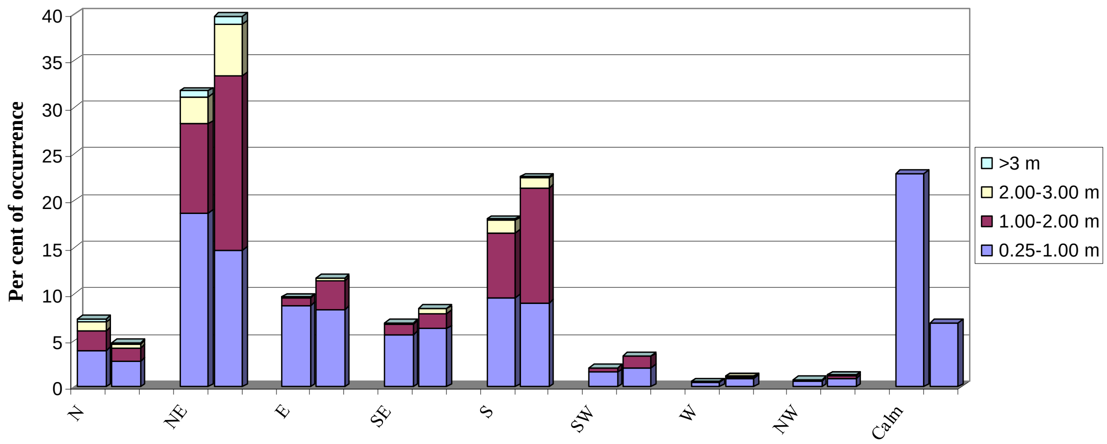


Figure 4.10 Comparison of calculated (left bar for each direction) and measured (right bar) wave heights outside Bach Long Vi for the period 1976-1995.

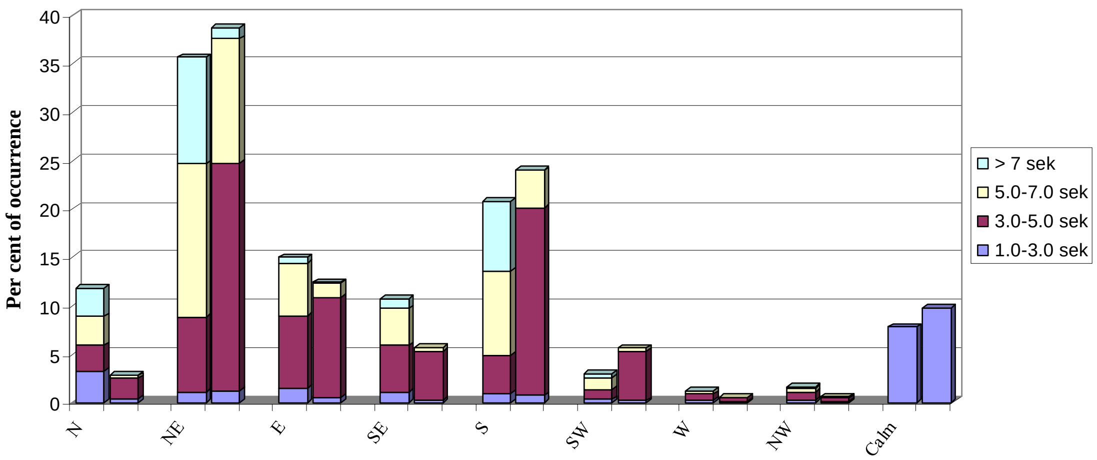


Figure 4.11 Comparison of calculated (left bar for each direction) and measured (right bar) wave periods outside Bach Long Vi for 1976-1995.

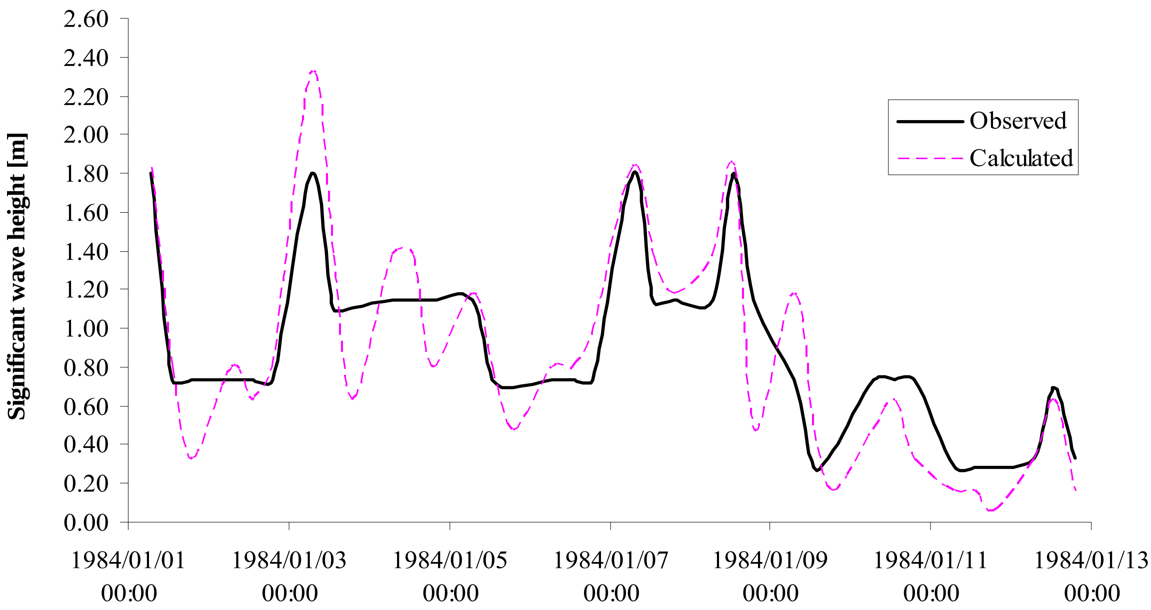


Figure 4.12 Comparison of calculated and measured wave heights for 13 arbitrarily selected and consecutive days in 1984 at Bach Long Vi.

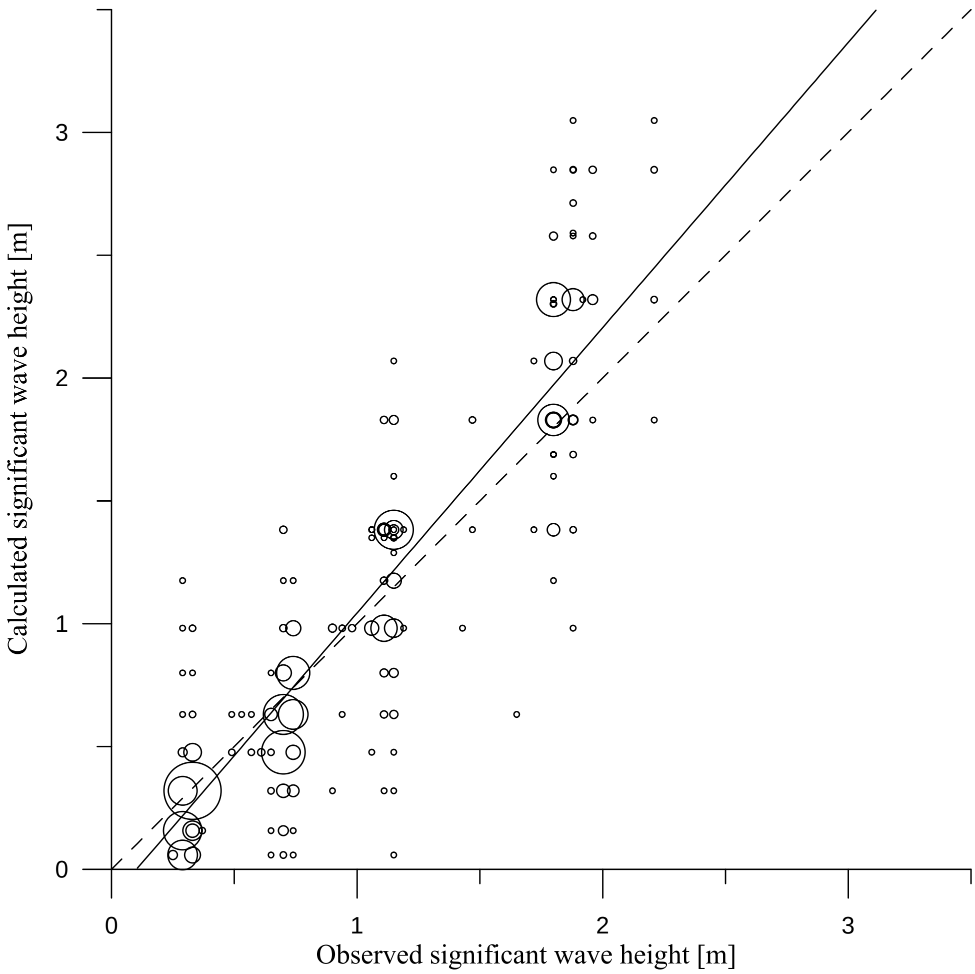


Figure 4.13 Scatter plot of calculated and measured wave heights at Bach Long Vi during 1984 (solid line = linear regression, dashed line = perfect correlation; size of circle proportional to the number of points).

4.2.2 Comparison with field data

The offshore wave calculations were also compared with wave measurements from two different occasions taken outside Hai Hau beach. The first measurement was made with a Norwegian wave rider 12/12 1991 – 26/12 1991 at a depth of 18 m immediately offshore Van Ly village (Figure 4.1) in Hai Hau district. A second series of waves measurement were visually obtained 16/7 1993 – 21/7 1993 at the same depth and location. The measured wave heights together with calculated ones are plotted in Figures 4.14 and 4.15. Initial trial calculations were based only on wind data from the BLV station, which was considered representative for Hai Hau beach because of its adjacent location (see Figure III.1). However, since the CCO station is more representative for the fetches from the south for the area outside Hai Hau Beach, a modified approach was then adopted to specify the wind input for the wave predictions. This approach involved a weighting of the wind speeds from BLV and CCO for winds coming out of the southern sector.

By combining the two wind stations (BLV and CCO), the overall agreement was better for the two series. The BLV station alone was considered being valid for the northern winds, whereas for southern winds (direction determined by the BLV station), the magnitude was obtained by interpolation of the values from the two stations. This resulted in a reduction of the southern waves, similar to that of the northern waves (see Figure 4.14 and 4.15), which led to an overall picture more similar to the real situation. Therefore, the calculated waves based on the combined wind data were considered representative for the nearshore wave climate at Hai Hau beach and thus be used in the sediment transport calculations (described in the following chapters).

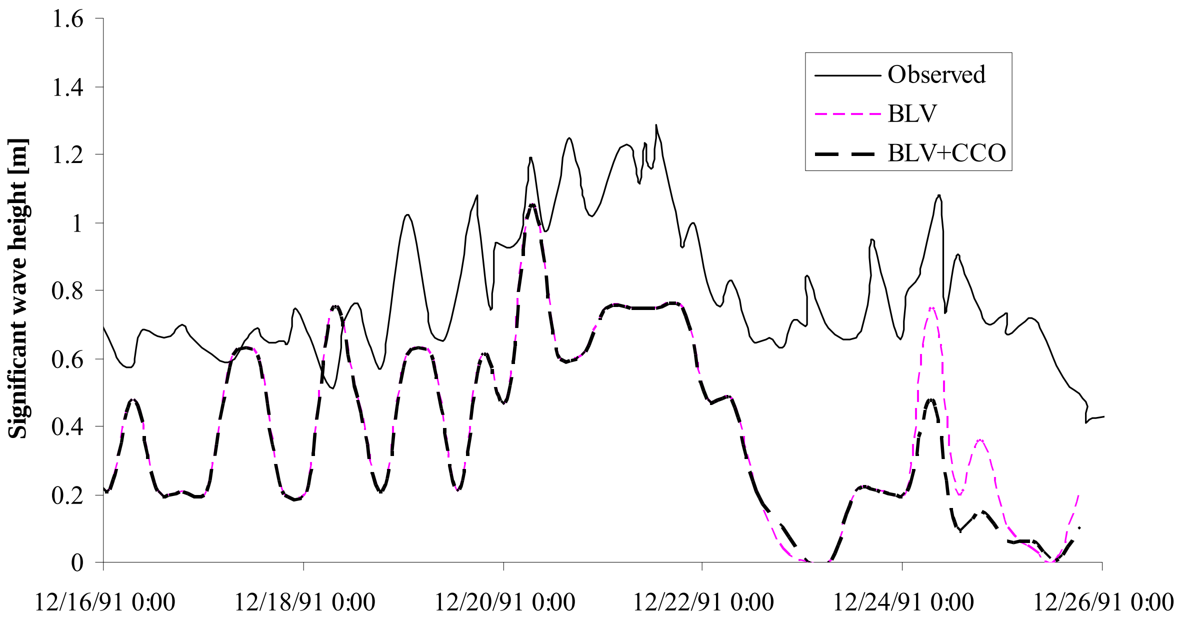


Figure 4.14 Observed and calculated waves outside Van Ly in December 1991 (wave from the north).

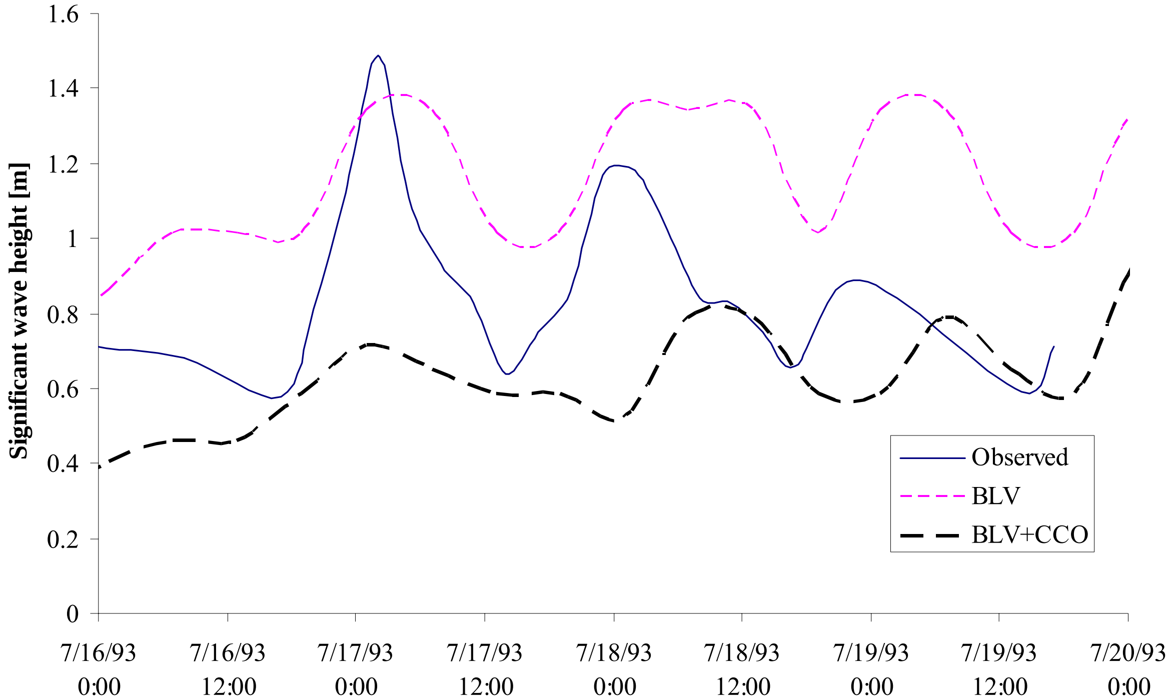


Figure 4.15 Observed and calculated waves outside Van Ly in July 1993 (waves from the south).

4.3 Nearshore topography

The nearshore wave climate is determined by the offshore wave climate but is also highly dependent on the bathymetry. The bathymetry affects both the refraction and the breaking position of the waves. In Figures 4.16 and 4.17 a two-dimensional and a three-dimensional topographical view are given, respectively, showing the bathymetry from Day River in the south to a point some kilometres above Red River in the north. The figures are made from numerically interpolated data on water depths, which have been extracted from a Vietnamese navy map with bathymetry corrections from 1980. From the figures, the conclusion that the bottom contours have a rather constant slope and are more or less parallel outside entire Nam Ha province but more complex outside the river estuaries can be drawn (more detailed information about the Nam Ha province bathymetry is shown in Appendix V, where the results from a bathymetric survey, performed in 2001, are presented (Nghia, 2001)). This implies that a one-dimensional approach including linear wave theory should be applicable to Hai Hau beach since it is located in the middle of Nam Ha province. In reality is may not be that simple because of effects of wave diffraction that occur when the waves pass over the complex bathymetric areas bordering Hai Hau beach. This is the case for waves from both northeast and southwest, which, as previously mentioned, are the main wave directions in winter and summer.

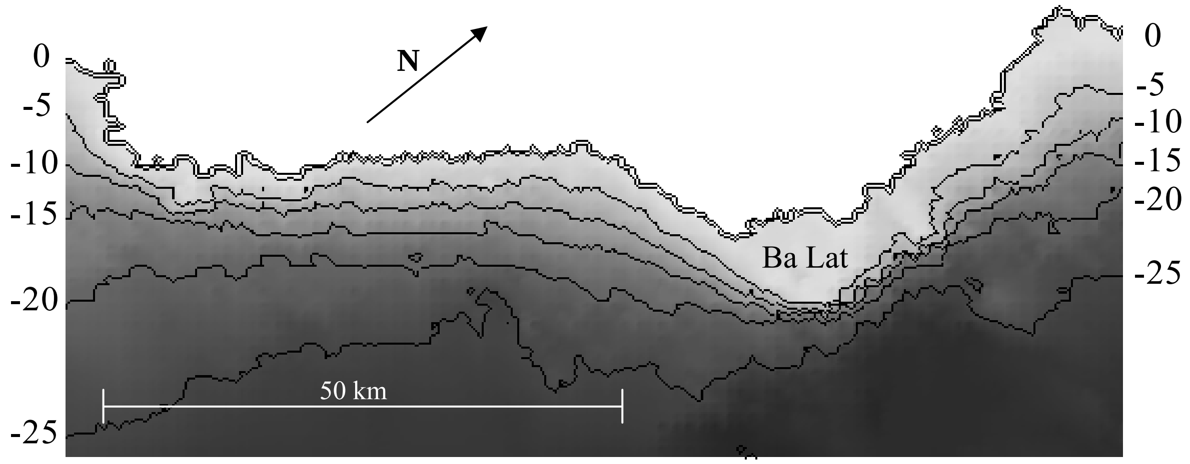


Figure 4.16 Two-dimensional view of the bathymetry outside the southern part of the Red River Delta.

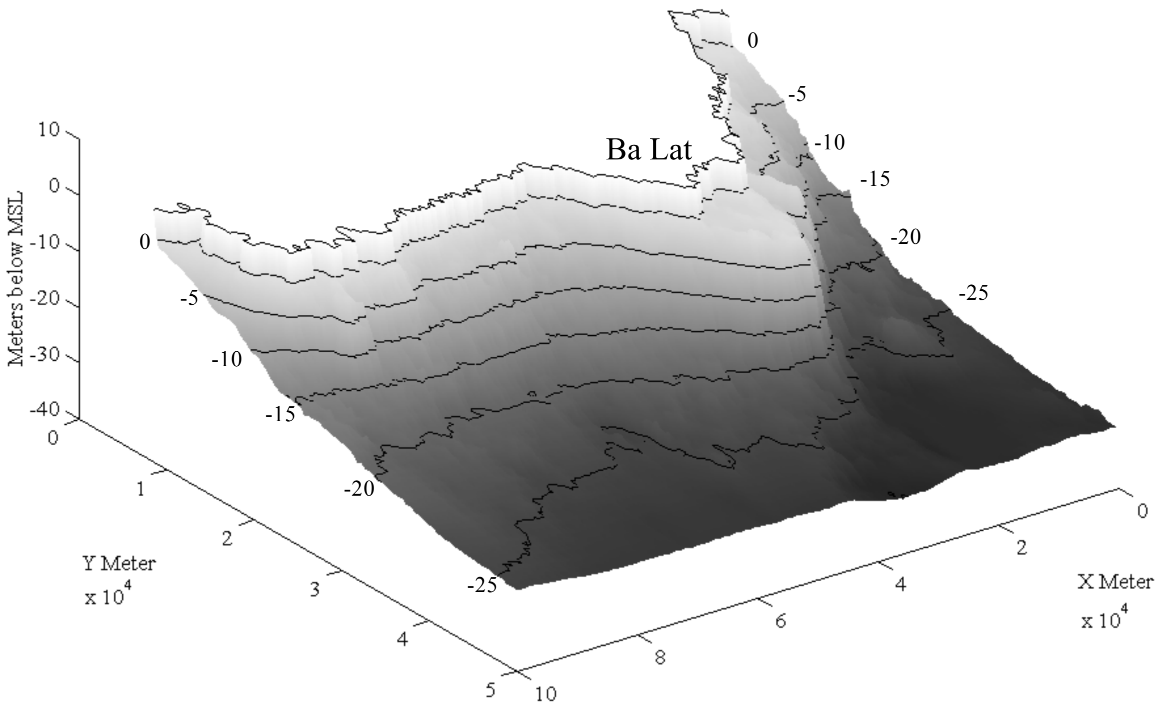


Figure 4.17 Three-dimensional view of the bathymetry outside the southern part of the Red River Delta (depths in meters).

4.4 Longshore sediment transport

4.4.1 Estimated Longshore Sediment Transport

The calculated mean annual sediment transport is presented for different shoreline orientations along the southern parts of the Red River delta in Figure 4.18. Positive and negative transport values represent southward and northward transport directions, respectively. The transport is obtained from the CERC formula, based on waves calculated by the SMB-method and then transformed to breaking with linear wave theory. Thus the result is based on a one-dimensional analysis with associated constraints on the bathymetric variation (described in 2.3 and 4.3).

The shoreline orientation from Day River to Ba Lat varies between 30 and 90 degrees and the Hai Hau beach orientation is rather constant between 40 and 45 degrees (see Figure 2.3). This implies that the Hai Hau beach is exposed to relatively low longshore transport rate when compared to the rest of the area, being directed towards the south.

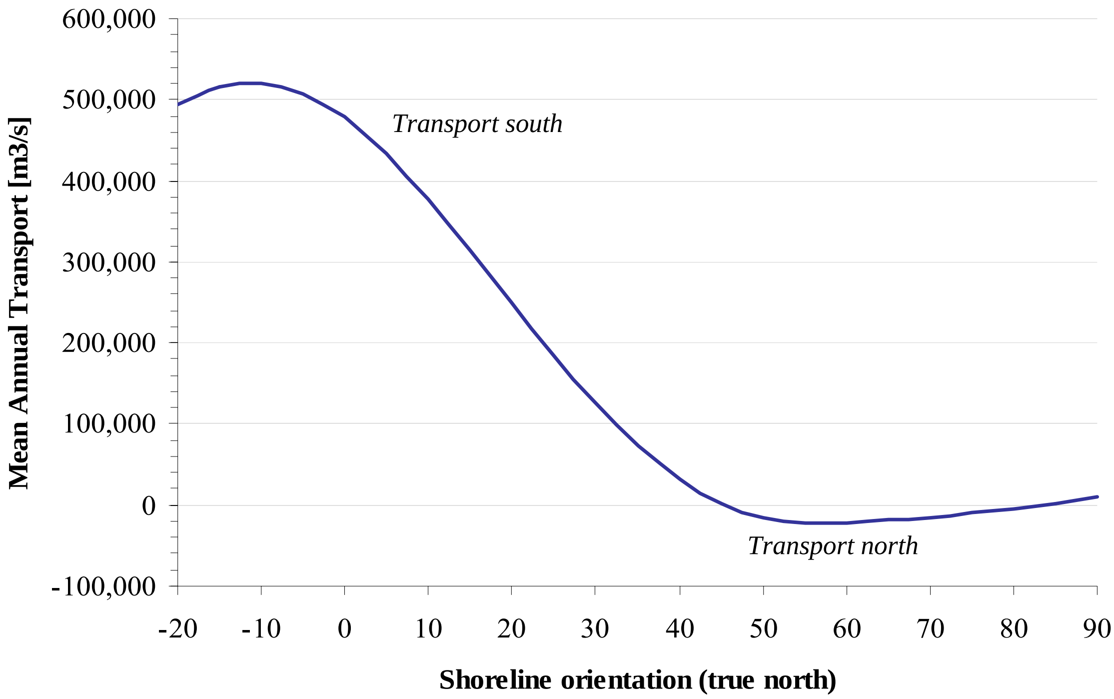


Figure 4.18 Mean annual longshore sediment transport rate for different shoreline orientations in the Red River Delta.

By using Figure 4.18 in combination with Figure 3.3 and maps covering the Red River Delta coastline, the transport rates along the coast from Day River mouth to Ba Lat have been extracted depending on the angle of the coastline at each location, see Figure 4.19. Just like in Figure 4.18, positive transport values represent southward transport and negative values represent northward transport. Negative and positive gradients correspond to erosion and accretion, respectively. Thus, it is clearly shown that erosion takes place south of Hai Hau beach, and that there is accretion some kilometres north of the beach.

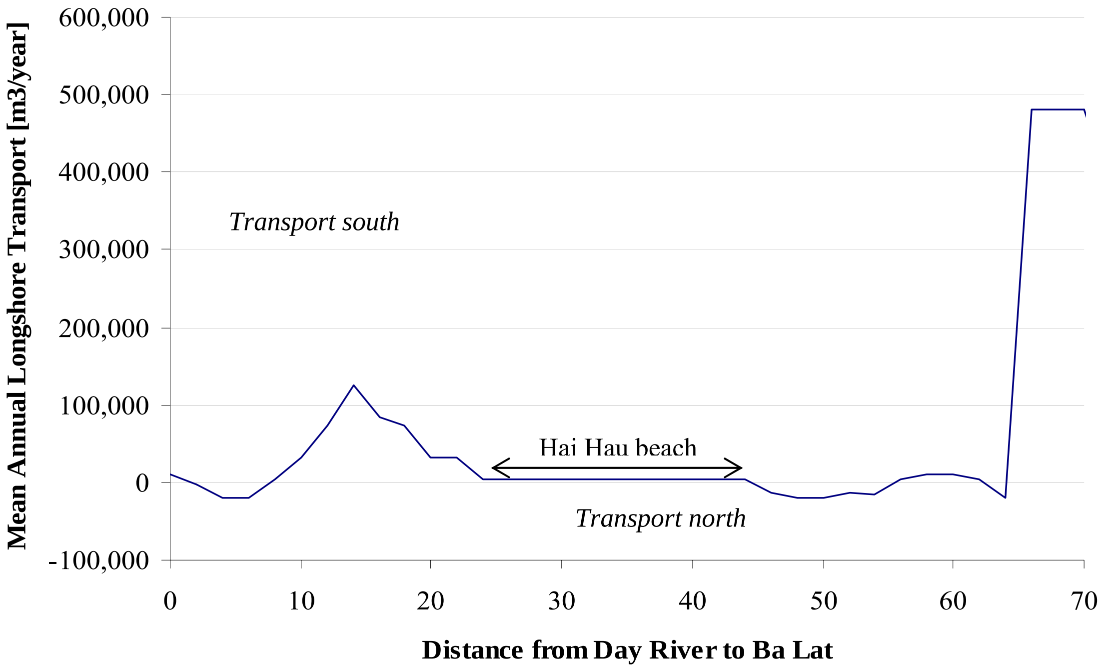


Figure 4.19 Longshore sediment transport from Day River to Ba Lat.

4.5 Sediment budget

The sediment transport is strongly dependent on the monsoon season. During the summer, 91.5 per cent of the total river sediment load reaches Tonkin Bay (Pruszak, 1998). At the same time, the main sediment transport direction is towards the north. This means that almost all sediment brought to the sea either is transported out to deep water, stays outside the river mouths, or is transported north. During the winter monsoon, there is less precipitation and therefore only 8.5 per cent of the total river sediment load is transported during this period. The wind direction is, as mentioned earlier, mainly from north to northeast, which results in south directed sediment transport.

The components of the river sediment load are sand (11.6 per cent), aleurite (59.2 per cent) and clay (13 per cent). Both clay and aleurite particles are too small to stay in the nearshore area and are transported directly out to deeper water. Therefore, only 11.6 per cent of the total load remains to supply the nearshore area (Pruszak, 1998).

The mean annual longshore sediment transport for the summer and the winter season was also calculated and is presented in Figures 4.20 and 4.21, respectively. As seen in the two figures, the transport rates for Hai Hau beach (45 degrees) differ in direction between the seasons; in the summer, the longshore transport rate are directed towards the north and in the winter towards the south. The magnitudes are, however, similar at a rate of 35,000 m^3/year.

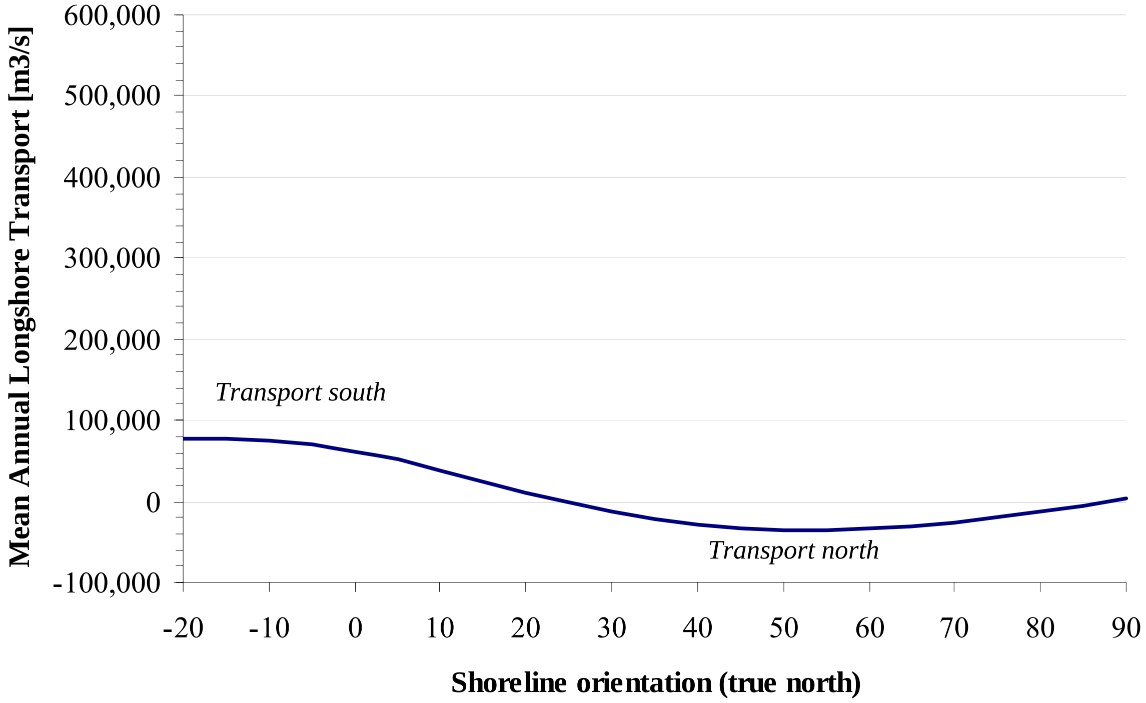


Figure 4.20 Mean annual summer (15 April to 30 September) longshore sediment transport rate for different shoreline orientations in the Red River Delta.

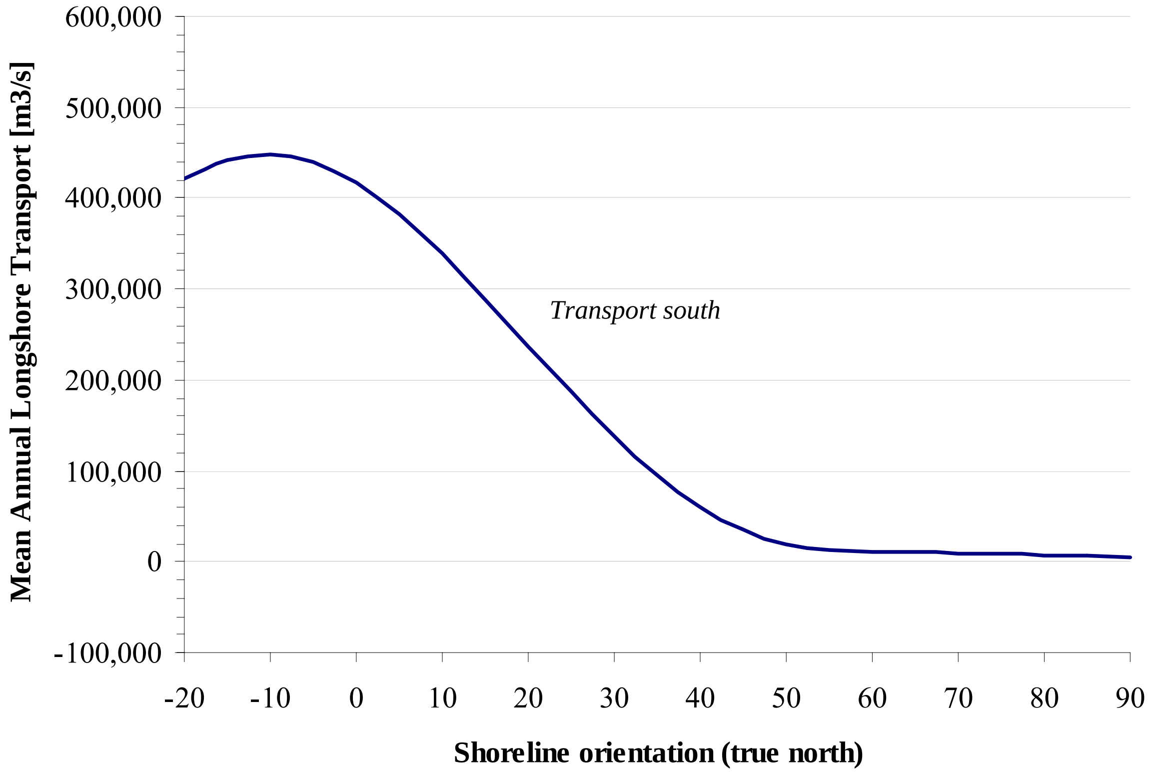


Figure 4.21 Mean annual winter (1 October to 14 April) longshore sediment transport rate for different shoreline orientations in the Red River Delta.

Longshore sediment transport rates along the coast from Thai Binh River to Day River, as presented in the Figures 4.22 and 4.23, were extracted from Figures 4.20 and 4.21 in the same way as was Figure 4.19. The river sediment discharge values is from table 3.1 but have been transformed from weight into volumes by using a density of 2,860 kg/m^3 (sand). The discharge values represent all sediment brought to the sea, not only the beach nourishing material.

The transport values in Figures 4.22 and 4.23 should only be considered as rough estimations to the real situation that is more complicated than the present model approach. Especially near Ba Lat mouth and Lach Giang mouth, the bathymetry is more complex than the parallel profile assumed in the wave modelling, which brings these values more in doubt. Moreover, the sediment transport values are calculated as the maximum potential transport that can occur.

In Figure 4.22 it is clear that the wave motion does not manage to remove much of the sediment brought through the mouths. This implies that during the summer most of the sediment either stays directly outside the river mouths or is transported out to deeper water and, hence, does not have any affect on the beach development.

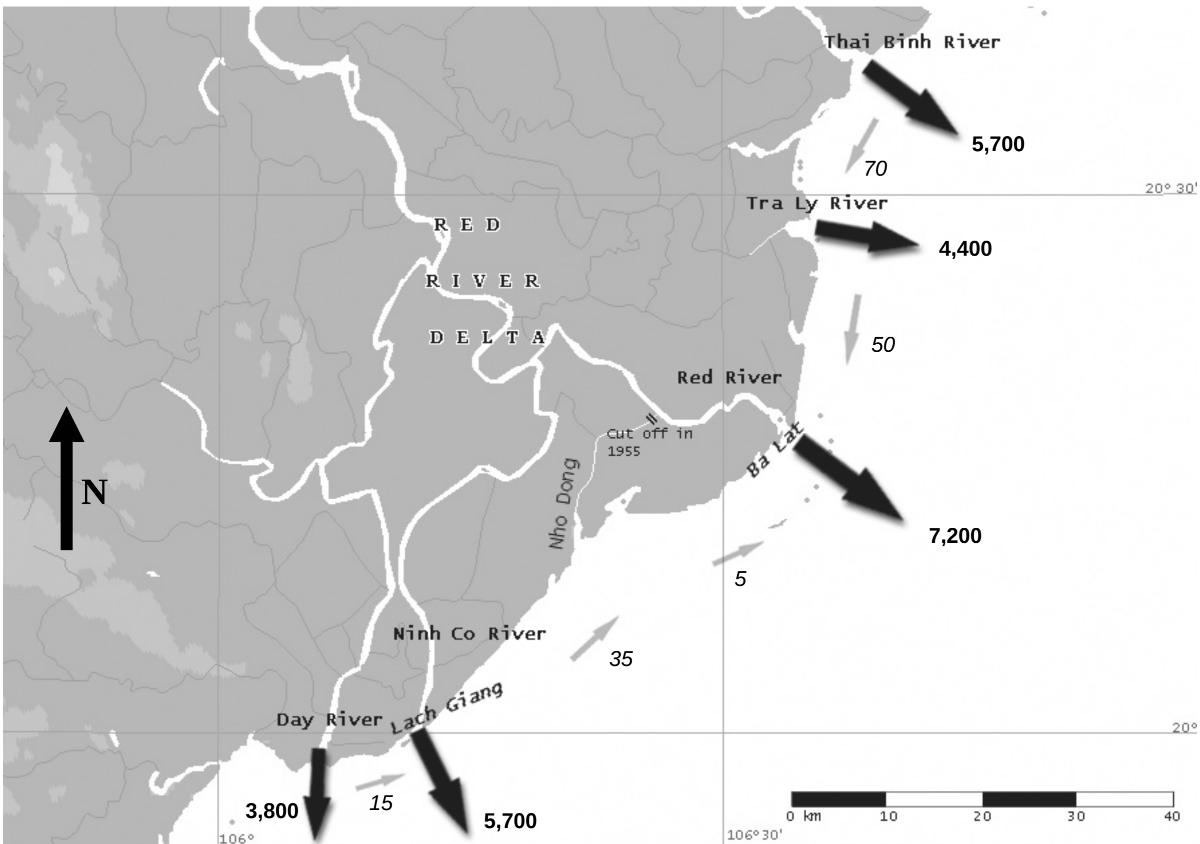


Figure 4.22 Summer (15 April to 30 September) sediment budget [×10^3 m^3/year].

During winter less sediment is suspended due to the low river flows (Figure 4.23). On the other hand, the attacking waves are stronger, which means that the bottom particles are more easily brought into suspension and transported. Because of the strong waves, the sediment transport is larger and due to the prevailing wave direction, the transport is towards the south.

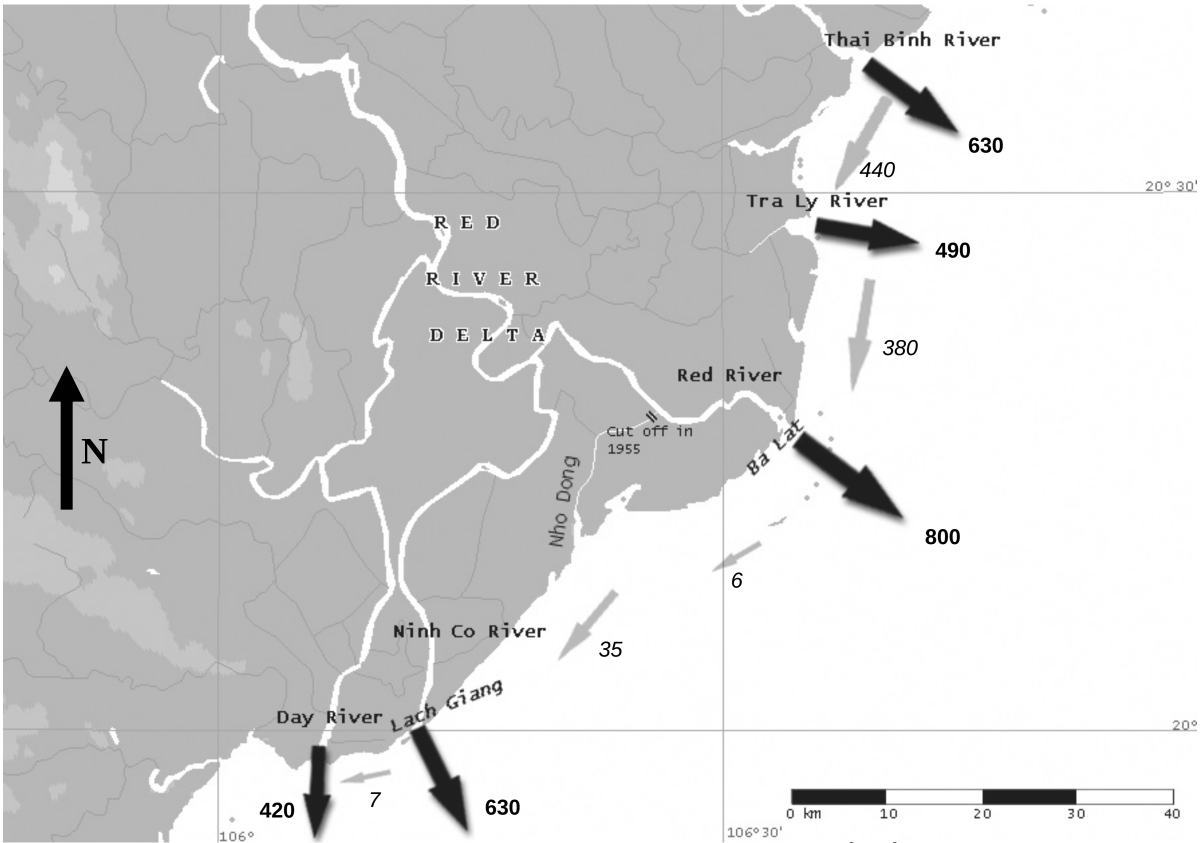


Figure 4.23 Winter (1 October to 14 April) sediment budget [$\times 10^3$ m^3/year].

The transport that passes Ba Lat has been reduced over the years due to expanding fish and shrimp farms, together with the growth of the mouth itself. Thus the longshore flow of sediment is either forced to pass the delta further outwards to deep water, where much is lost, or gets caught in the mouth, contributing to both longshore nourishing and the extension of sand ridges.

4.6 Coastline change

To estimate the historical coastline change maps from several different years have been used along with satellite images. The maps and the satellite photos were scanned and thereafter the coastline was digitized. The resulting graph of all the digitized coastlines is shown in Figure 4.24. The figure displays an expected pattern of erosion in the two southern districts (Hai Hau and Nghia Hung) in Nam Ha province and strong accretion in the northern district (Xuan Thuy) and outside the river mouths.

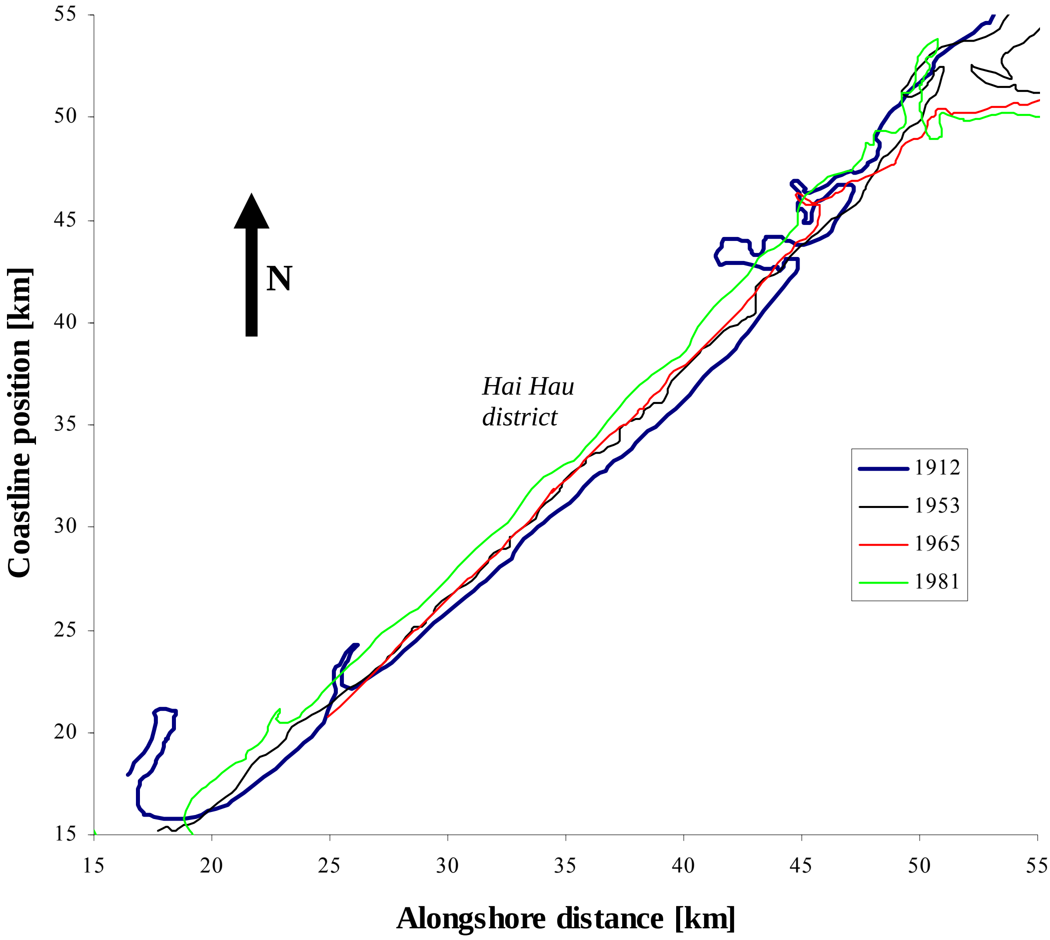


Figure 4.24 Coastline change at Nam Ha province from 1912 to 1981.

From the shorelines in Figure 4.24, the retreat at Hai Hau beach for the period 1912-1981 has been estimated at approximately 2 km. Hence, the yearly erosion rate over these years equals 24 m, which is similar to 29 m as stated by Vinh et al. (1996).

A more detailed view of the coastline change at Hai Hau beach is given in Figure 4.25. The coordinates in Figures 4.24 and 4.25 are not the same and the shorelines can therefore not be compared directly.

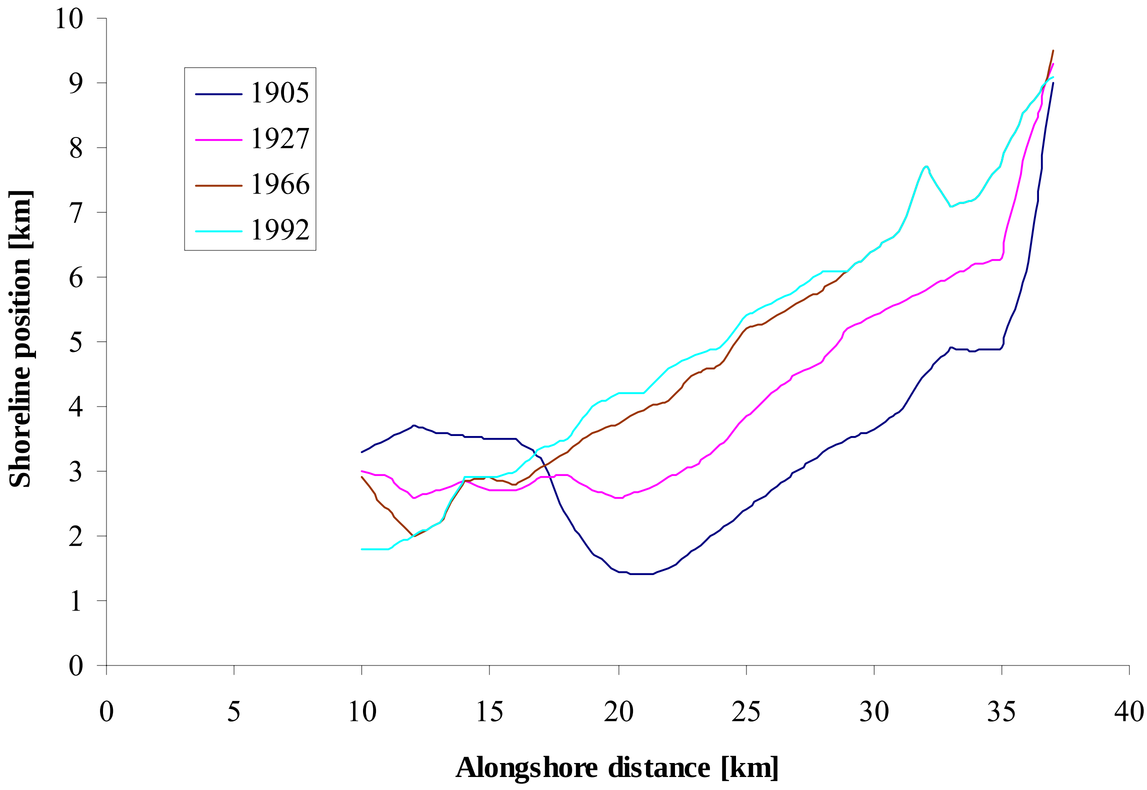


Figure 4.25 Coastline change at Hai Hau beach from 1905 to 1992 (Hung et al., 2001).

From Figure 4.25 the conclusion can be drawn that the erosion rate has slowed down over the last 40 years (the pattern is supported in Figure 4.24). The average erosion rate, estimated from this figure, is approximately 29 m/year.

When comparing Figure 4.24 with Figure 4.19, the strong accretion north of Hai Hau beach is easily explained with the large positive gradient that is situated there. The erosion that occurs at Hai Hau beach (see Figure 4.25) is however not that easily explained. As seen in the three Figures, 4.19, 4.22 and 4.23, the longshore sediment transport rate is low at Hai Hau beach, which indicates that the present orientation of the coast should be stable.

5. Causes for Coastal Erosion at Hai Hau Beach

5.1 Proposed causes of erosion

There are several different factors affecting coastal erosion at Hai Hau beach. The most important general factors are river flow, sea waves and currents, tidal regime, sea level rise, geodynamical conditions, and human activities (sea and river dam and dike construction, deforestation etc). In the section below, several theories concerning the cause of the erosion at Van Ly village are presented. All have influences from one or several of the factors mentioned above but all focusing on rather different main reasons. The principal thing that the most of the theories have in common is that they all suggest that something drastic probably happened during the last century, starting the strong erosion. If this was not the case, the shoreline should have previously stabilized over time. Since there are no maps, records of waves, winds etc. available before the early twentieth century it is very difficult to estimate how long time the area has been exposed to erosion. However, based on analyses of old maps and discussion with elder local residents it is evident that the shoreline was situated several kilometres seaward in the beginning of the last century.

Change of main wind direction

One possible theory is that the reason for the erosion is an imbalance of the shoreline with the waves. A shift in the main wave direction would have triggered this imbalance. Today the main wave direction is from northeast, generated by the winter monsoon. The Hai Hau beach is directed more or less perpendicular to the southeast, which is more the direction of the waves that reaches the beach during the summer monsoon. The shoreline wants to be oriented perpendicular to the main wave direction because the sediment transport is at minimum in this situation. These facts strengthen the "Change of wind direction" theory, which in general is hard to either support or reject because of lack of wind measurements before the middle of the last century. According to discussions with the Head of National Centre for Forecasting (Hanoi, Vietnam), Mr. Le Van Thao (2001a), there has not been a change of main wind (monsoon) direction. His opinion is that for at least several hundred years the winter monsoon has been stronger than the summer monsoon. This opinion, however, has not been verified through data. Furthermore, if the wind direction has been similar over hundreds of years, the orientation of the shoreline is likely to have been adjusted to the corresponding wave climate and, thus, there would be no or little erosion.

Sea level decrease

The second theory presented is also based on the hypothesis that the erosion of today is dependent on a large natural change. This time the natural change is a decrease in relative sea level. The cause of this decrease can be argued but the most plausible reason would be that the raise of land level has exceeded that of the sea. This is partly confirmed in Nguyén (1978), which presents results from geological surveys showing that the shoreline position once was situated at *Viet Tri* (apex of the Red River delta) and *Tinh Phuc*, north-west of Hanoi (Figure 3.6). Hence, the changing shoreline orientation caused imbalanced sediment transport at the affected beaches.

Dam building, branch cut-off

There have been many human activities in the northern Vietnam region, especially near the Red River itself. For hundreds of years dikes have been built on its banks to prevent flooding and render possible a relatively secure living beside the large river. The farmers have irrigated the flood plains and used them for growing rice. During the twentieth century, there have been a couple of larger human interferences with the delta that may have affected the shoreline evolution:

- *1955* Ngo Dong River, a branch of the Red River, was cut off.
- *1980* a hydropower plant in Hoa Binh was built on the Da River, a tributary to the Red River.
- *1990* the Vop river, a small branch of the Red River, in the Ba Lat estuary was closed but is now being reopened.

These events are all preventing sediment to reach the Hai Hau beach. The closing of the two branches decreased natural southward transport of the sediment, which is supported by for example Nghia (2001a). Hence, instead of spreading along the shoreline, the sediments tend to be concentrated near the Ba Lat mouth. The Hoa Binh dam traps lots of sediment every year and according to Imhof (1998), a result of the increased sedimentation in the Hoa Binh dam is a decreased life span of the dam from about 100 to about 50 years. When the river reaches the reservoir, it abruptly looses its speed and capacity to carry sediment. Thus, the sediment is deposited in the reservoir, the capacity is decreasing and at the same time, the shoreline is impacted because reduced sediment supply.

Deforestation
The fourth hypothesis that is presented also relates to human activities. The essence of this hypothesis is that during some years there was too much sediment brought to Ba Lat mouth, due to severe deforestation. Deforestation has been a commonly applied technique around the world in order to create land for agricultural areas, Vietnam being no exception. However, the deforestation was not a problem in Vietnam until the 1920s when the French colonial administration tried to colonize the forests on Central Highlands for economic and strategic purposes. In the 1930s, the deforestation in these areas increased as the French and later on the Americans tried to clear them to find the Vietnamese revolutionary forces. From 1945 to 1975 it is estimated that 22,000 square kilometres of forests were destroyed trough bombing, mechanical clearing etc. (De Koninck, 1999).

Deforestation leads to land erosion due to diminishing of roots binding the sediment, which consequently is washed out to sea by rivers. During years of severe deforestation, the sediment balance in Red River delta was disturbed. The currents were not strong enough to transport away the sediment-filled water entering Tonkin Bay. Thus, instead of an even distribution all over the delta and its surroundings, the sediment accumulated outside the river mouth and a 'natural groin', as discussed in Hung et al. (2001), was created that interfered with the longshore transport. A similar phenomenon is discussed in Addad and Martins-Neto (2000) and is suggested to be the reason of the erosion at Alcobaca beach in Brazil. Today, the delta might still be acting like a groin, causing erosion of beaches southward of its mouth. The reason that only the beaches located south of Ba Lat are eroding is that 90 per cent of the sediment is brought to the sea during the summer months with northward transport. The sediment reaches the Tonkin Bay through Ba Lat mouth and is spread over the northern districts such as Thien Hai, which has accreting beaches. During the winter monsoon the main transport is southward, but the longshore currents coming from north of Ba Lat are stopped by the delta groin and very little of the northern sediment passes the delta.

Unfavourable circumstances

Dr. Quy (2002), director of DOSTE Nam Dinh and Project Director of the Nam Dinh ICZM Pilot Project, suggests that the high erosion rate can be explained by natural properties of the coastal area. Being relatively flat and having a shoreline at a low elevation, the Nam Dinh coastline with a NE –SW orientation (compare with main wind directions) and no larger protective coastal formations (cliffs, rocks, islands) proves to have favourable circumstances for erosion.

Weak dikes

One last hypothesis, although indirect, focuses on the construction of the sea dikes at Hai Hau beach. It is known that these dikes do not last much more than a decade before they collapse under the impact of waves. It is also known that the nearshore land areas are low-lying, sometimes even below the MSL, which is illustrated in the Figures 4.4 and V.3. Low-lying coastal areas may be subject to erosion based on typically two reasons: (1) once under water, the soil (sediment) is under influence of waves and current and can be transported, and (2) the lower the elevation, the less soil to buffer the coastline retreat. Due to these circumstances, land areas without proper protection erode at a high rate at Hai Hau beach. To put it briefly, the dikes are not strong enough to obstruct the natural coastal development of Hai Hau.

5.2 Discussion

The abovementioned hypotheses about why Hai Hau beach is subject to erosion focus on generally different reasons, of which some are less probable than are the others. For example, the sea level decrease is referring to a too large time scale ('geological') and, therefore, not applicable as an explanation to this contemporary erosion problem. If instead assuming that there has been no change in the main wind direction (as above stated by Thao, 2001a), the shoreline orientation should have adjusted to the prevailing wave climate. Furthermore, calculations of the longshore transport rate at Hai Hau beach have shown that the erosion rate is rather low, which may seem unexpected since the shoreline evidently has withdrawn tens of meters every year. One plausible hypothesis is therefore that the Hai Hau beach *is* adjusted to the prevailing wind climate, i.e. no change of main wind direction, and hence, *the dikes are too weak* to keep the coastal retreat at bay. Dam constructions and river cut-offs have certainly contributed to a higher erosion rate, as may deforestation, but are no major reasons since the erosion started several decades earlier. Because the wave climate is dominated by two main wind directions that are seasonally bounded, the longshore current outside Hai Hau district are more or less constantly directed northward or southwards during many consecutive months. This may also contribute to the high erosion rate since not all sediment material transported in one direction will be transported back as the direction of the longshore current alters, despite calculations indicating no net transportation. Beach material transported too far away from the area of influence will never turn back. As a final remark, 80 to 90 per cent of the Red River sediment is discharged during June to October (Pruszak, 1998) when the longshore currents are directed northward. Hence, this sediment load will not nourish the beaches south of Ba Lat.

In conclusion, the erosion is affected by several different factors, some more important than other, but to stop the coastal retreat, stronger dikes or equivalent defence structures are necessary since the natural properties of the Hai Hau coastal area make the beach subject to erosion.

6. Conclusions

The wave climate in the north of Vietnam is determined by two main wind directions generated by the summer and winter monsoons from the northeast and south, respectively. The generated waves produce longshore currents that transport nearshore sediment and thus cause coastline deterioration. It is apparent that the Hau Hai beach has been suffering from severe erosion over at least hundred years. Maps and satellite photos illustrate a continuous retreat of approximately 25 m per year (however, some part of the Nam Ha province indeed experiences accretion).

The prevailing situation at Hai Hau beach is alarming. Vast land areas encompassing villages, houses and agricultural fields are at risk due to the fast-paced coastal retreat. Over the last century more than 2,000 meters of the coastal zone has been lost to the sea, causing devastating circumstances for the exposed people. Besides the direct personal tragedy, the erosion also affects the economy on both regional and national basis. The fertile coastal zone is very productive (as being part of a delta) and large salt farms located adjacent to the sea hold great economical assets. Defence measures at Hai Hau beach are indeed necessary in order to maintain the shoreline position and to protect the fertile and important coastal areas. As discussed in the previous chapter, the reason behind the erosion involves different theories of which weak dikes (indirect cause of erosion) are of major importance considering the natural properties of the coastal areas, for example low-lying coastal land areas and constant wind directions. Constant northward or southward longshore currents during several consecutive months, transports beach material away from the area of influence and, hence, there is a greater loss of sediment than the calculations present. If the longshore currents would have alter direction more often, the beach material would not be transported so far away from its original position and the net loss at Hai Hau beach would decrease. This mechanism may also explain why the calculated longshore sediment transport rate only yields a couple of thousand square meters per year, whereas a simple estimation of the transport rate, $Q = L \times W \times d$, where L is the length of the eroded stretch, B the width and d the annual deepening of the bottom, indicates a annual transport rate in the order of 10^4 cubic meters.

Protective measure, as mentioned in chapter 2.2, can be divided into two main groups: structural and non-structural one. A well-planned non-structural action (mainly consisting of vegetative control) can generate more positive effects than solely erosion reduction, such as increased biodiversity and aesthetically pleasing beaches, but is often not sufficient for beaches suffering from severe erosion, as does Hai Hau beach. One possible non-structural measure is beach nourishment, which involves bringing back eroded material to its original location. This may initially be rather cheap but being a non-permanent solution, it is expensive over time. Hai Hau beach is approximately 25 km long and pumping sand from nearby accretion areas demands long pipes, technical knowledge and extensive working efforts. Whether this will be economically or technically feasible or not is yet to be answered.

A more realistic action is to focus on wave energy dissipation and measures that protect the existing shoreline. Structural actions are often the only rational methods at beaches suffering from severe erosion. The sea dikes used today indeed serve as energy dissipaters but they are not stable enough to withstand the wave impact over time. Alternative to dikes are for example seawalls but they are expensive and not as easy constructed as sea dikes that are relatively simple to construct without advanced equipment. Considering the present situation in Vietnam, the use of dike should continue but must be improved. The dike core deteriorate far too easy; usage of fibre material between the core and the revetment would for example reduce the suspension of the clay material and thus make the construction last longer. Moreover, the revetment is not adequate; the cobbles and stones are not sufficiently attached and thus not stabile. This can be improved by for instance inter-linking concrete slabs or varying of revetment slopes.

It is essential that the construction of the dikes is modified in the near future. Otherwise, the there will not be a sustainable development of the coastal zone due to the retreat strategy. Overall, the trade-off between costs and future possible consequences is delicate, but it is imperative to always evaluate the economic importance of a threatened area concerning natural reserves and human lives before making any decisions on dike constructions—what is acceptable, what is not—in order to find feasible solutions.

One major problem in Vietnam is the lack of resources—being a developing country, obtaining funding is generally a challenge. It would be possible to construct dikes or other revetment structures that will sustain decades, if the necessary means are available, but they are typically not. Local and central authorities have tried to direct both human and financial resources towards the threatened areas but due to missing or obsolete long-term strategies, action are more or less of temporary nature. Therefore, as stated by Quy (2002):

> "…Nam Dinh needs to develop its specific and detailed policies and projects along with a long-term strategy for integrated coastal zone management. These aim at the protection and sensible use of the coastal zone, its resources and environment, and also aim at the protection of the sea dykes, for a sound socio-economic development of the coastal zone in particular, and of the Nam Dinh province in general".

As the situation looks today, such plans must be implemented in the near future. Otherwise, the retreat strategy unfortunately might be the only available option, how bad a solution it ever may be.

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Appendix I — Maps showing shoreline development

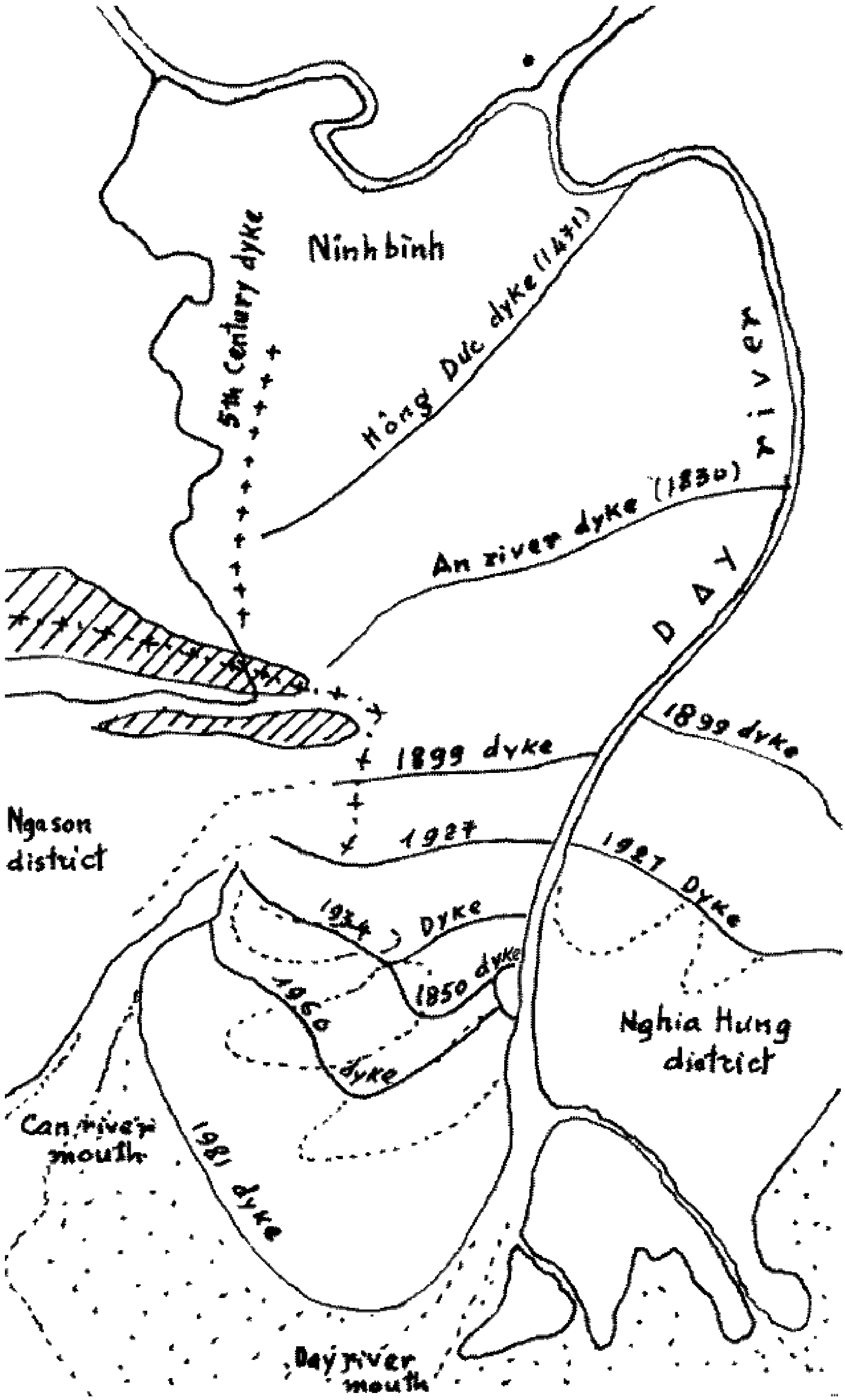


Figure I.1 Delta and dike development at Lach Giang (Wijdeven, 2001).

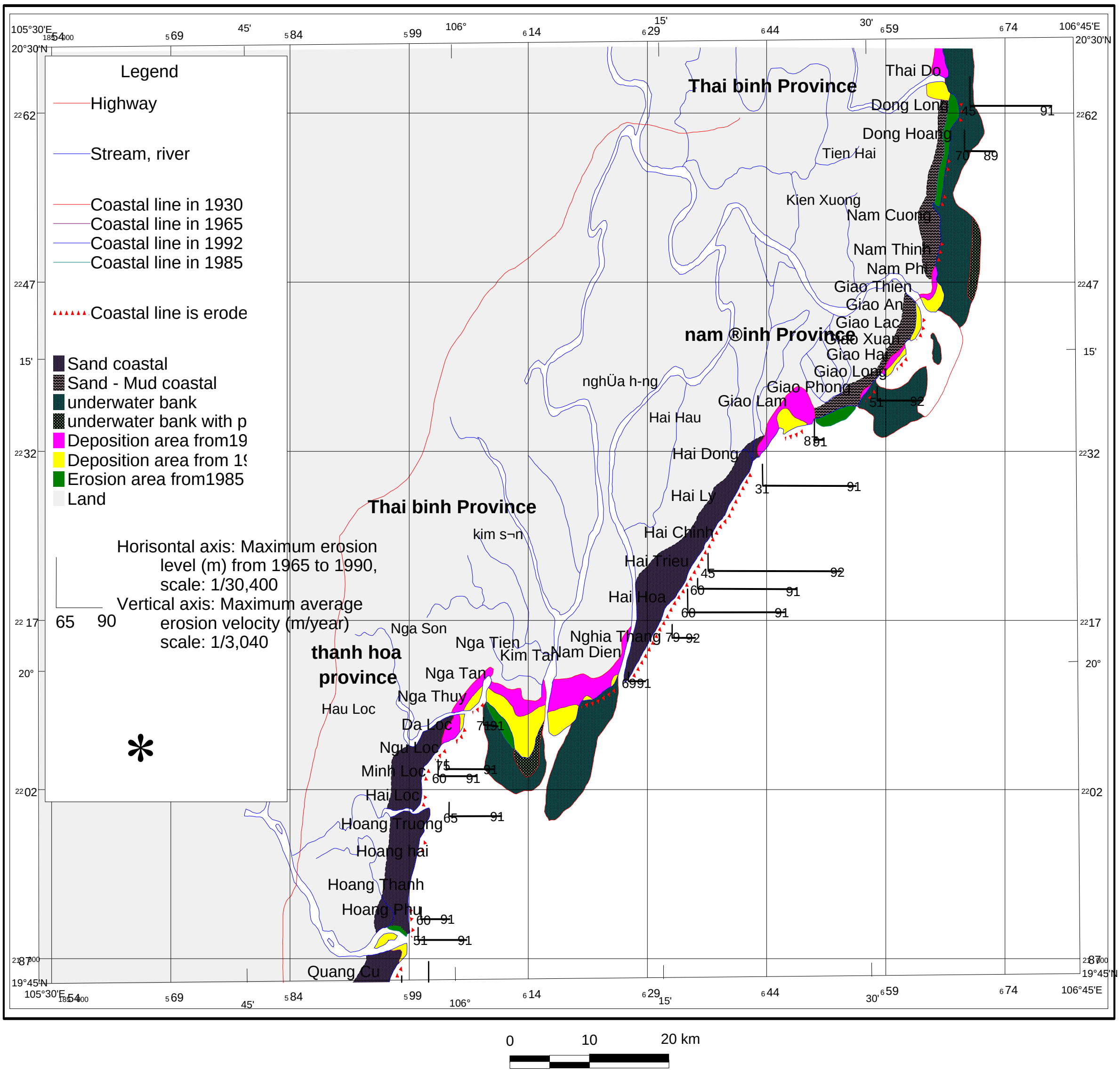
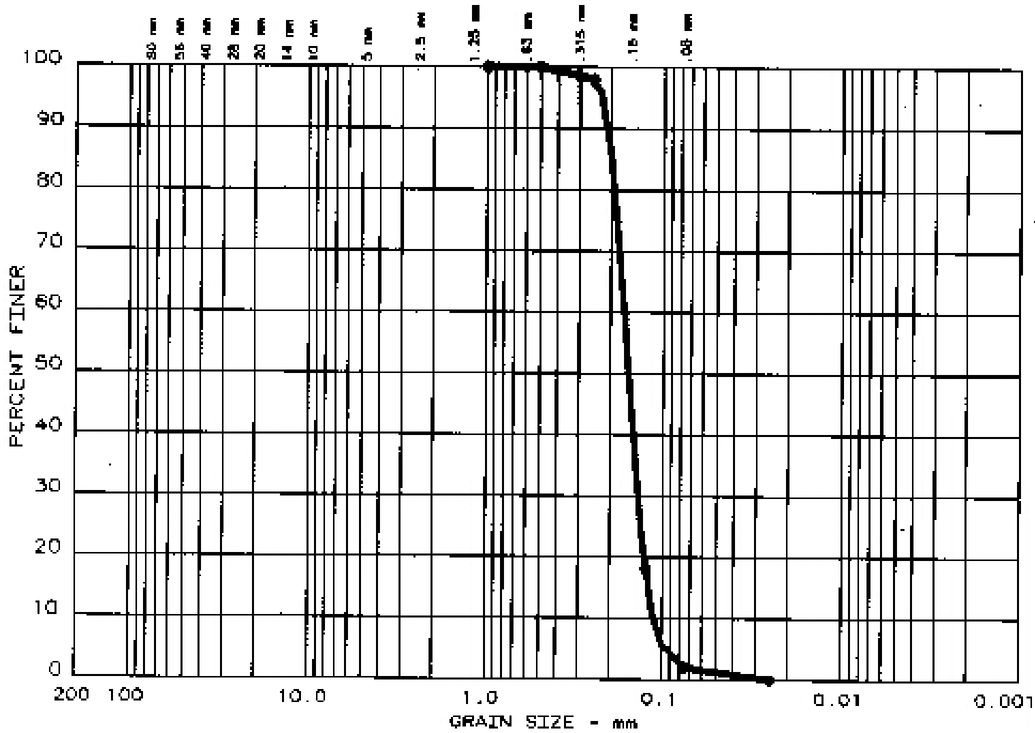


Figure I.2 Shoreline development at Nam Ha province and adjacent coastal areas (Hung, 2001a).

Appendix II — Sediment grain size analysis

The grains size curves below are in order from the north to the south.

VIEN CO HOC-PHONG CO DAT NEN MONG



Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
● 1	0.0	0.0	98.0	2.0	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.199	0.167	0.157	0.138	0.121	0.113	1.01	1.5

MATERIAL DESCRIPTION	USCS	AASHTO
●		

Project No.:
Project:
● Location: Sample No:1

Date: 19/12/2001

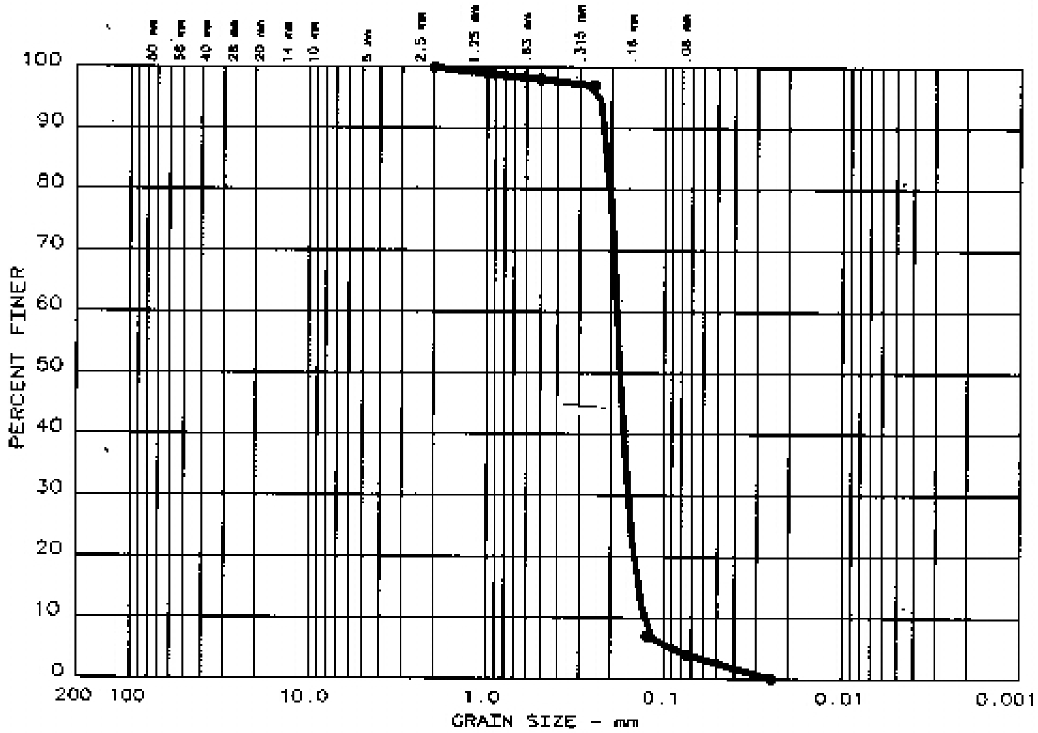
Remarks:

VIEN CO HOC-PHONG CO DAT NEN MONG
SEA DYKE ENGINEERING SERVICES

Fig. No.:

Figure II.1 Nearshore grain size distribution at Quat Lam swimming area.

VIEN CO HOC-PHONG CO DAT NEN MONG



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	2	0.0	0.0	98.0	4.0	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.207	0.184	0.177	0.163	0.137	0.129	1.11	1 4

MATERIAL DESCRIPTION	USCS	AASHTO
●		

Project No.:

Project:

● Location. Sample 2

Date: 19/12/2001

VIEN CO HOC-PHONG CO DAT NEN MONG

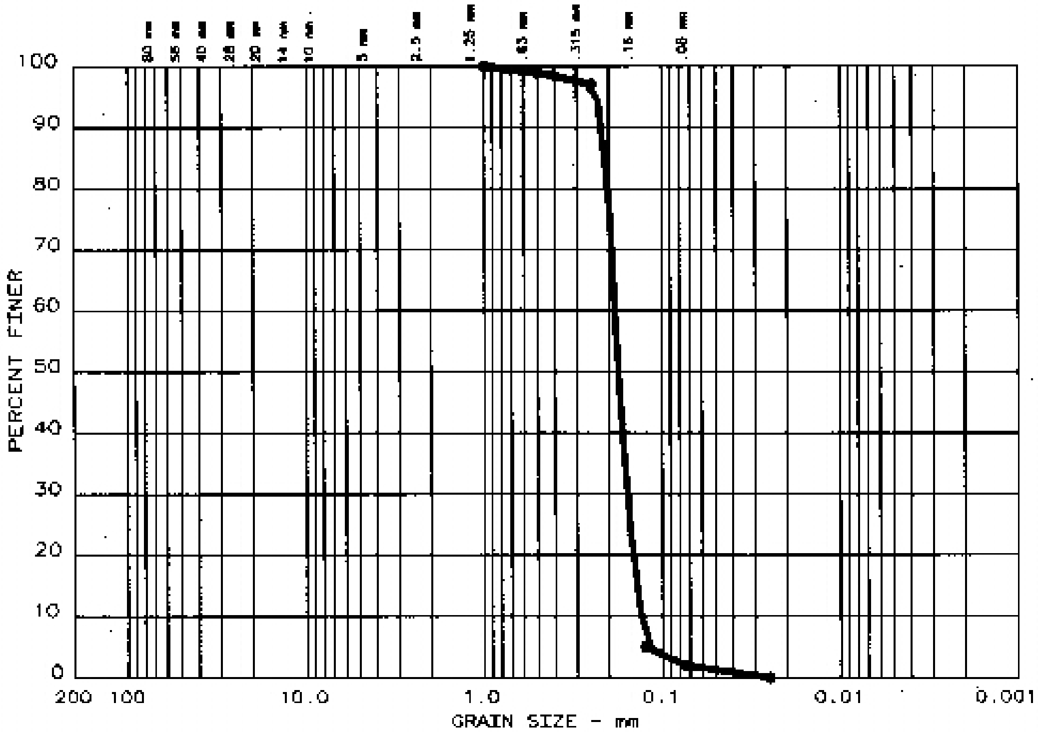
SEA DYKE ENGINEERING SERVICES

Remarks:

Fig. No.: ______

Figure II.2 Nearshore grain size distribution at Van Ly beach.

VIEN CO HOC-PHONG CO DAT NEN MONG



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	3	0.0	0.0	98.0	2.0	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.207	0.183	0.176	0.160	0.138	0.131	1.07	1.4

MATERIAL DESCRIPTION	USCS	AASHTO
●		

Project No.:
Project:
● Location: Sample 3

Date: 19/12/2001

VIEN CO HOC-PHONG CO DAT NEN MONG
SEA DYKE ENGINEERING SERVICES

Remarks:

Fig. No.: ______

Figure II.3 Nearshore grain size distribution at Ninh Co bank.

Appendix III — Fetch lengths and temperatures

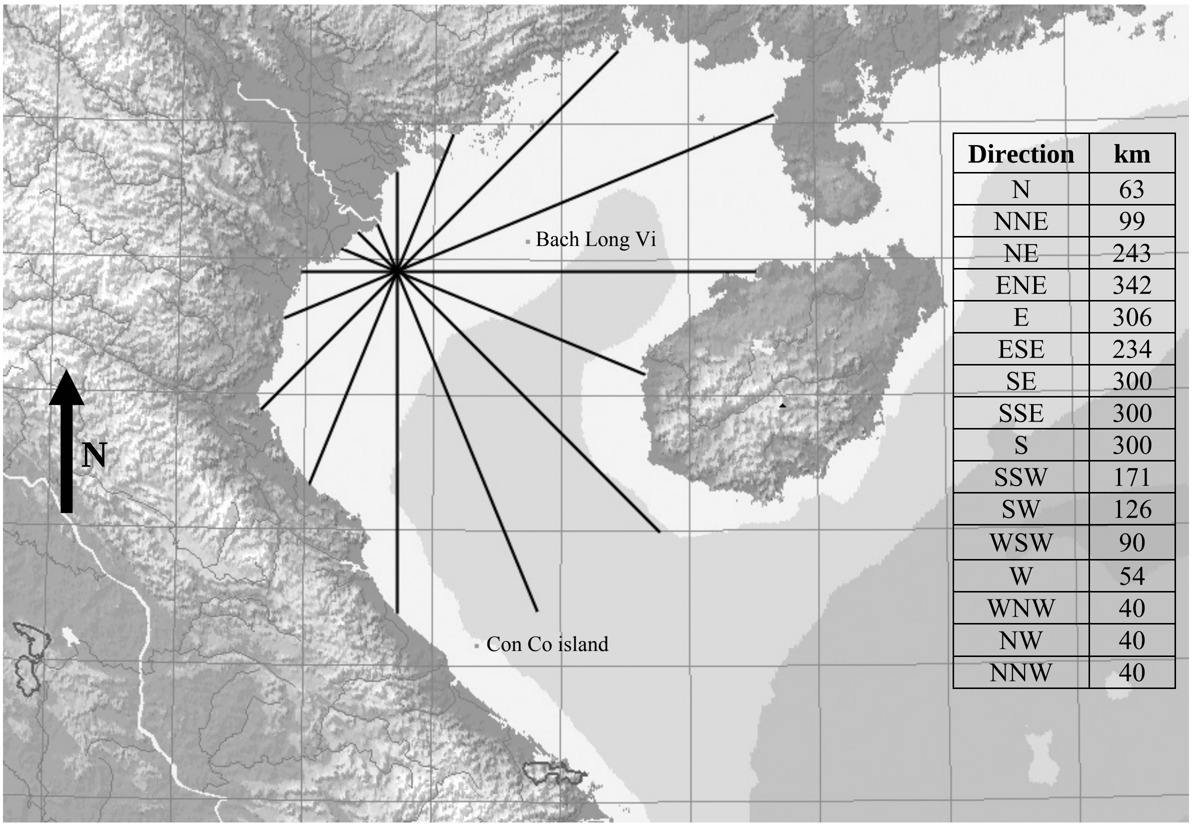


Figure III.1 Used fetches and locations of the wind recording stations.

Table III.1 Temperature data used in calculations.

Month	Air	Water
Jan	18.0	19.0
Feb	17.6	18.5
March	20.6	20.4
April	22.5	23.6
May	26.9	28.1
June	28.4	29.6
July	29.3	29.9
Aug	28.9	29.8
Sep	27.8	29.2
Oct	26.8	28.1
Nov	24.3	24.3
Dec	19.1	20.3

Appendix IV — Calculated wave parameters

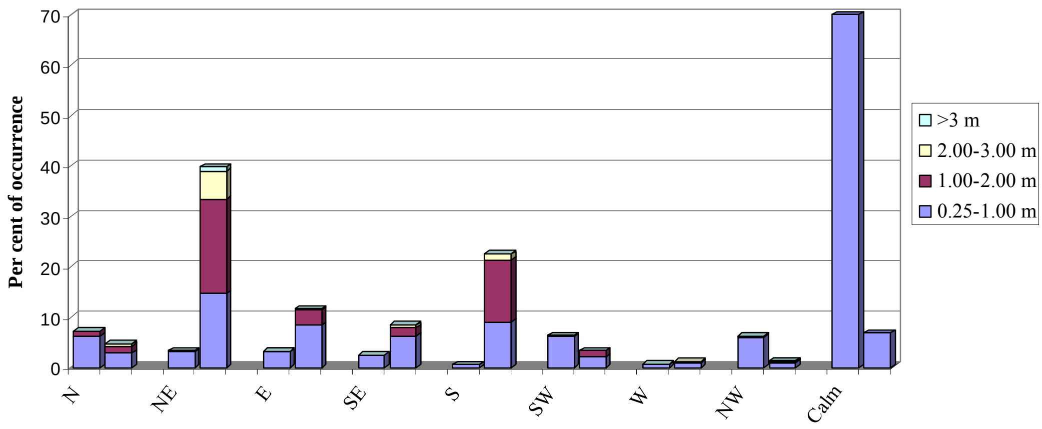


Figure IV.1 Calculated waves heights based on wind data from Con Co (left bar for each direction) compared with waves heights measured at Bach Long Vi (right bar).

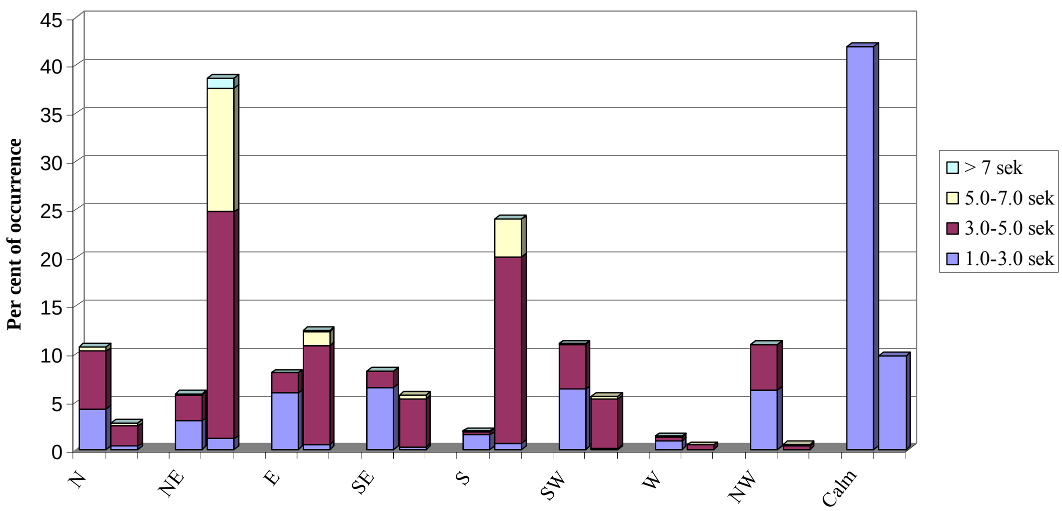


Figure IV.2 Calculated wave periods based on wind data from Con Co (left bar for each direction) compared with periods measured at Bach Long Vi (right bar).

Appendix V — Bathymetric profiles

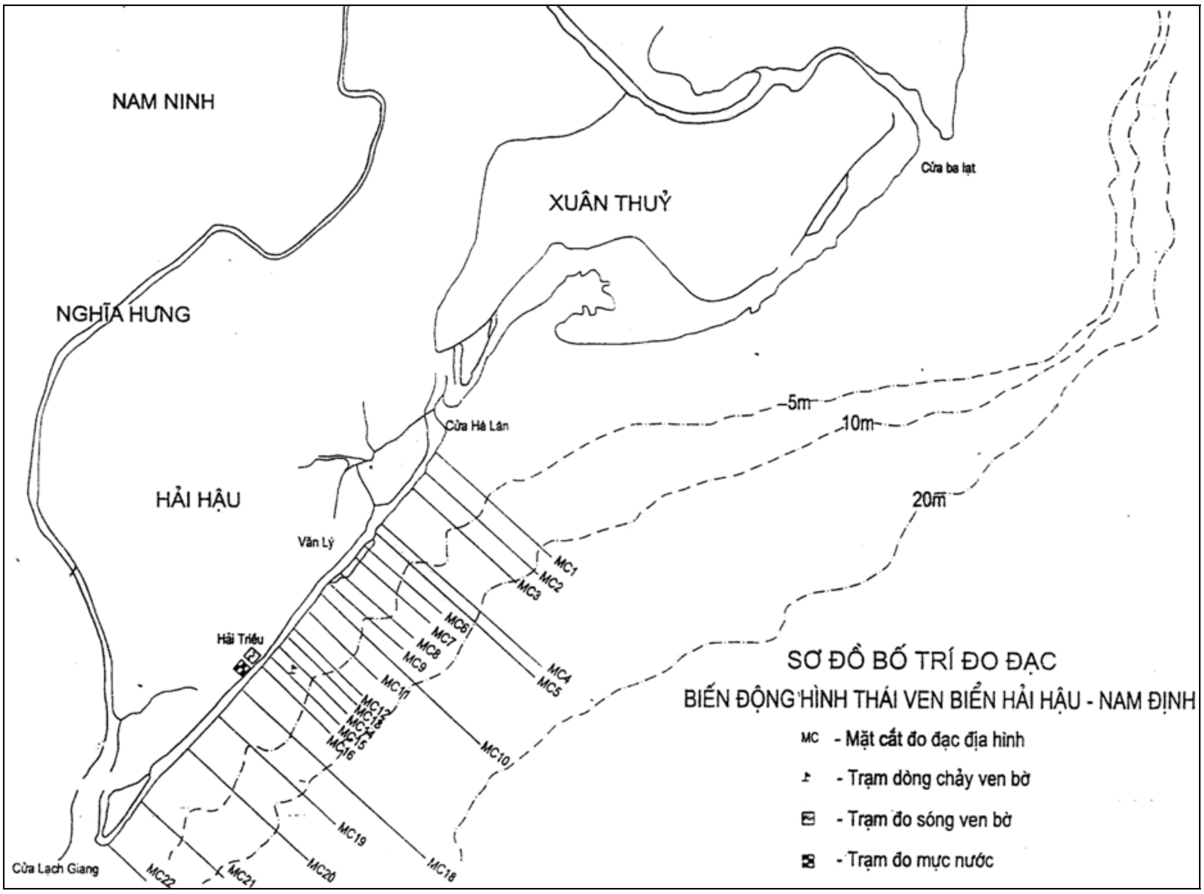


Figure V.1 Locations of bathymetry profiles.

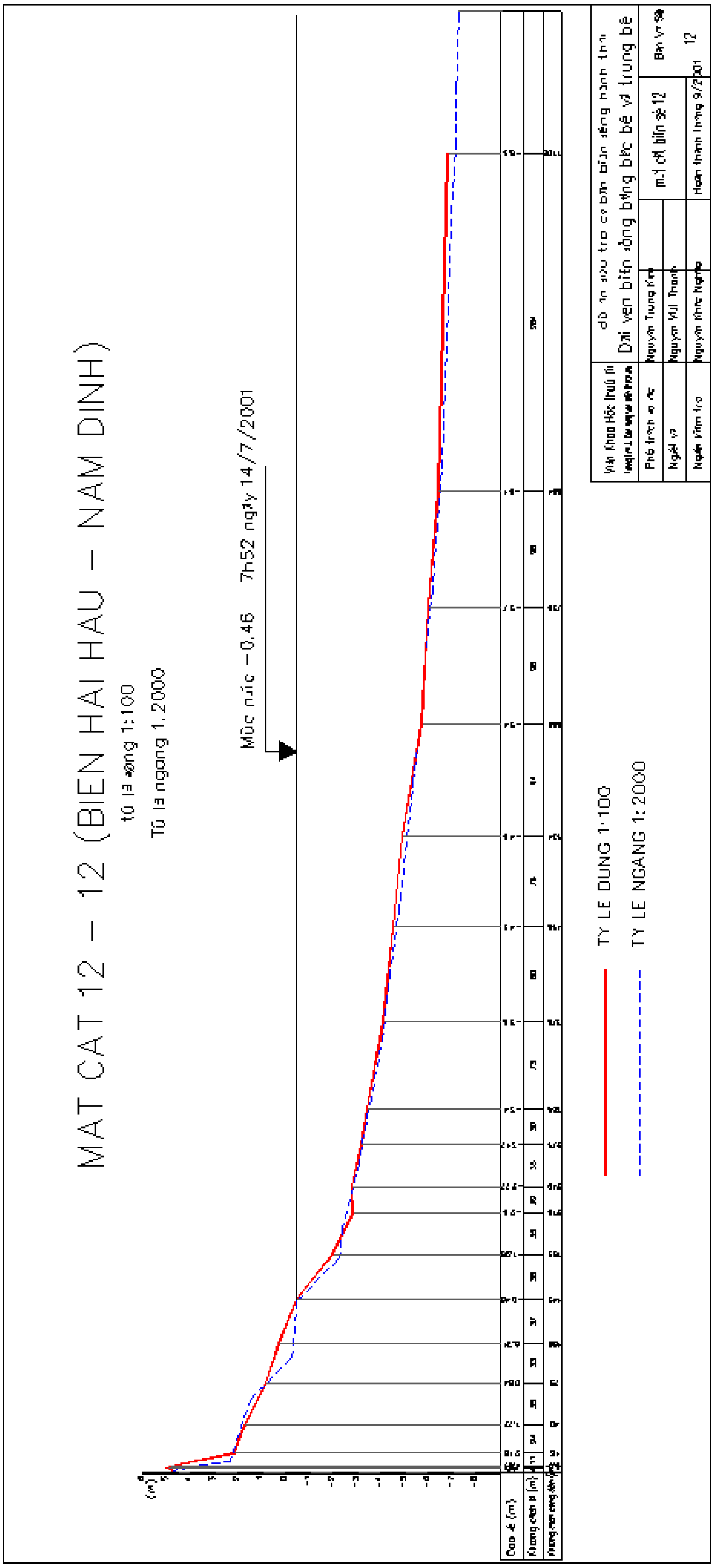


Figure V.2 Bathymetry profile MC12.

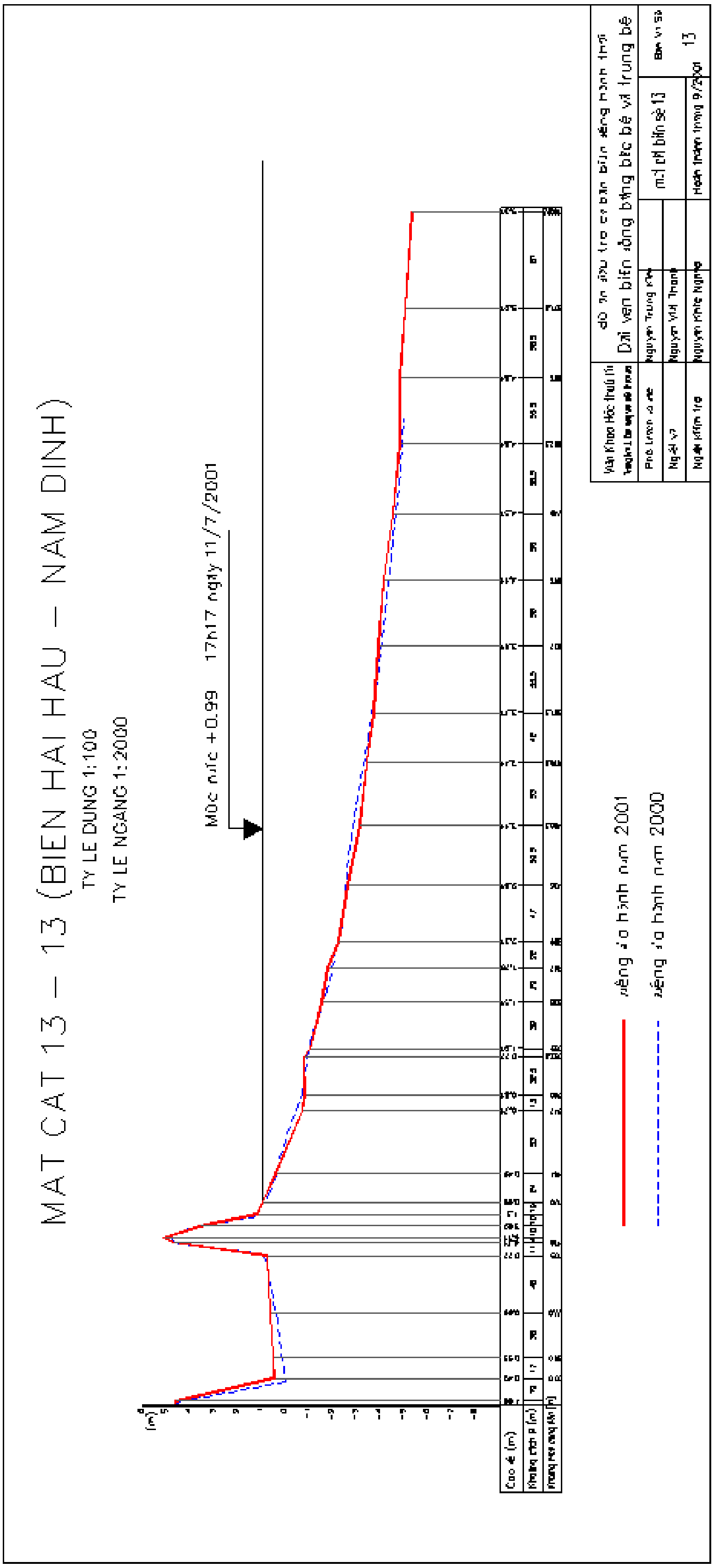


Figure V.3 Bathymetry profile MC13.

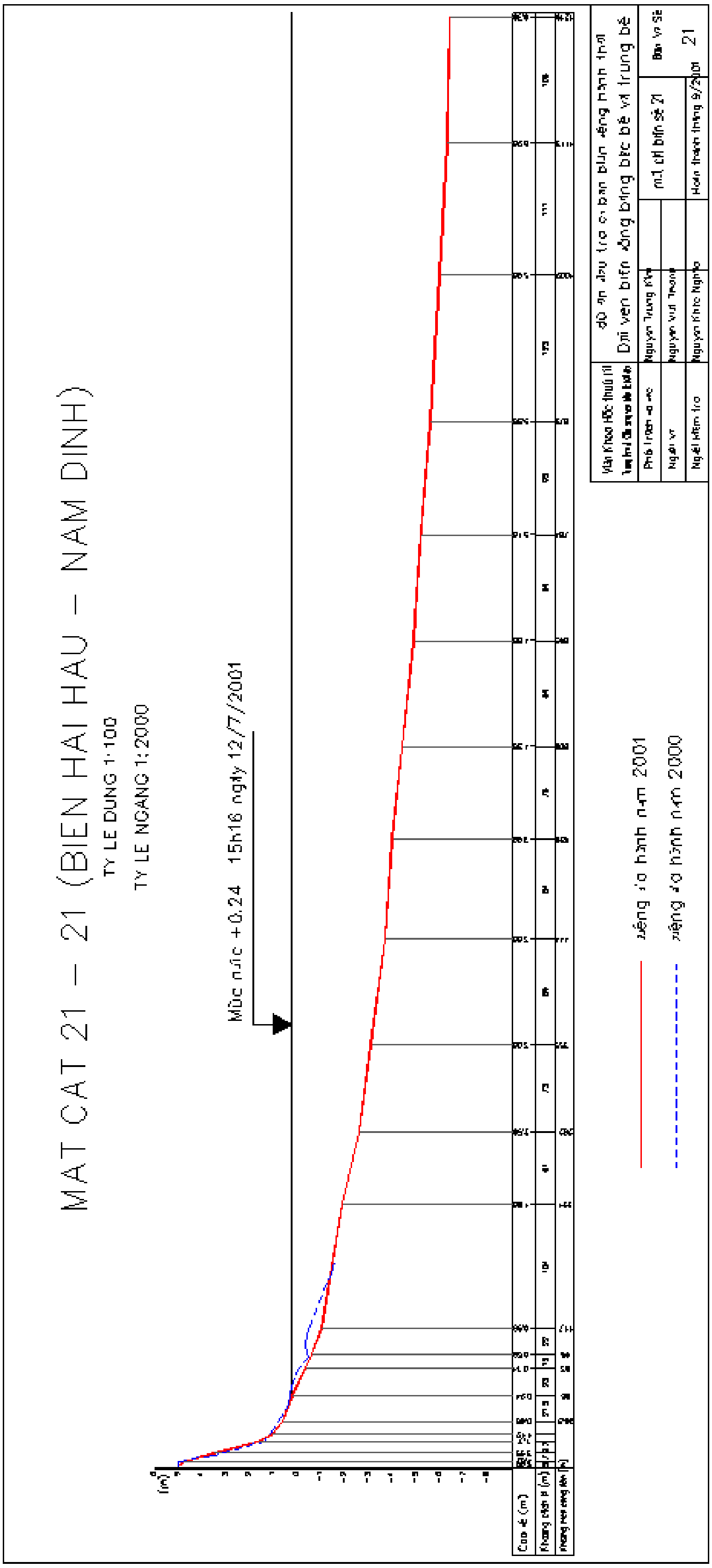


Figure V.4 Bathymetry profile MC21.

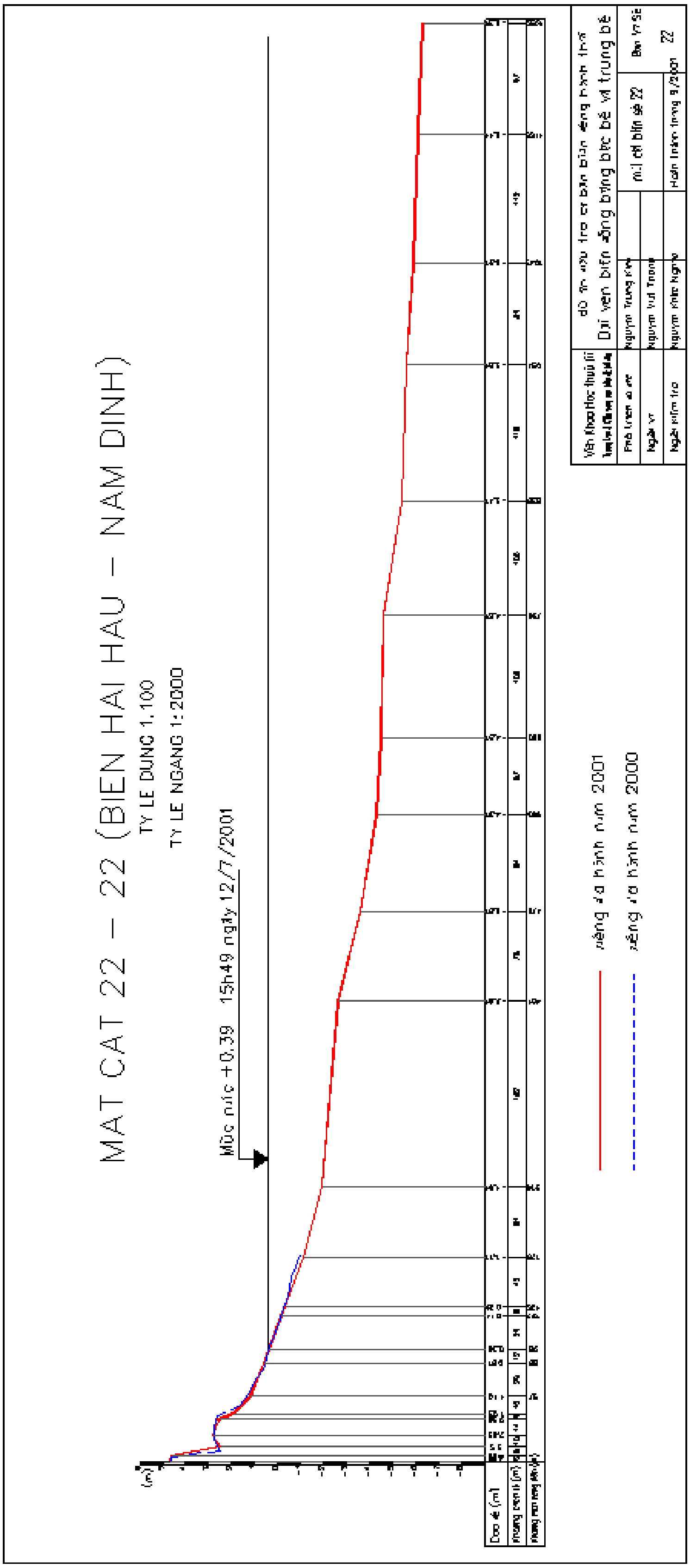


Figure V.5 Bathymetry profile MC22.