CHAPTER - 4

RESULTS AND DISCUSSIONS
The results and discussions of the present study, which includes: features of hurricane; distribution features of wind and wave characteristics over South China Sea, offshore and nearshore region of Hoian coast; features of tide; Thubon River discharge; variations of longshore sediment transport rate and breaker characteristics; distribution of net longshore sediment transport rate; extent of erosion, deposition of shoreline; shoreline change under the influence of wave action; shoreline change under the combined influence of river flow and wave actions; interpretation and prediction of shoreline changes are detailed in this chapter.

4.1 Hurricane wave

Hurricane/storm generated waves play a significant role in the design of almost all coastal and offshore structures in tropical and semitropical regions. More tropical cyclones form over the western North Pacific and South China Sea regions than in any other ocean basin (McBride, 1995). The primary reason for this high incidence of occurrence is the persistently warm sea surface temperatures and the location of the intertropical convergence zone (ITCZ). The ITCZ occurs as a convergence zone in the westerly monsoon flow, known as the monsoon trough (Gray, 1968). The trough is the shear line separating the monsoonal westerlies from the trade easterlies and is a preferred region for tropical cyclone development.

4.1.1 Features of hurricane in the Hoian area

In all, 69 hurricanes occurred in the vicinity of the Hoian coastline during the period from 1945 to 2003 (with an average of 1.2 per year), among which include 36 typhoons with maximum wind speed ($V_{\text{max}}$) > 33m/s, 20 tropical storms with 17m/s < $V_{\text{max}}$ < 33m/s, and 13 subtropical storms with $V_{\text{max}}$ < 17m/s (Table 4.1).
Table 4.1 Classification of hurricanes based on Saffir-Simpson scale

<table>
<thead>
<tr>
<th></th>
<th>Typhoon</th>
<th>Tropical storm</th>
<th>Subtropical Storm</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers of occurrence</td>
<td>36</td>
<td>20</td>
<td>13</td>
<td>69</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>52</td>
<td>29</td>
<td>19</td>
<td>100</td>
</tr>
</tbody>
</table>

Tracks of hurricane crossed the Hoian coastline during 1945 to August 1997 is shown in Figure 4.1, and tracks of hurricane crossed near Hoian coastline during September 1997 to August 2003 (shoreline change simulation period) is shown in Figure 4.2.

Figure 4.1 Tracks of hurricane crossed the Hoian coastline during 1945 to August 1997
Figure 4.2 Tracks of hurricane crossed near Hoian coastline during September 1997 to August 2003

The yearly distributions of hurricanes in the study area were not regular. The years of 1964, 1972 and 1995 each have 4 times of occurrences (Figure 4.3), especially during 13 to 27 September 1964, 3 hurricanes crossed the Hoian coastline.
In general radius of maximum wind speed of all hurricanes was 34 km. Thirty-five (51%) hurricanes were formed inside the South China Sea and 34 (49%) hurricanes were formed outside the South China Sea i.e. in the west Pacific Ocean. Occurrences of hurricanes were mostly in September (26.1%), October (30.4%) and November (13%). (Table 4.2)

Table 4.2 Monthly distribution of hurricanes

<table>
<thead>
<tr>
<th>Month</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>18</td>
<td>21</td>
<td>9</td>
<td>01</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>26.1</td>
<td>30.4</td>
<td>13</td>
<td>1.5</td>
</tr>
</tbody>
</table>

4.1.2 Comparison of estimated wave characteristics based on Young's and SPM methods

The significant wave height and wave period estimated using the SPM method (Eqs. 3.5 and 3.6) is found to deviate from the value obtained using the Young's method (Eqs. 3.1 and 3.2) as shown in Figure 4.4. The reason for the deviation is due to the fact that SPM method is for a slow moving hurricane, whereas the average speed of hurricanes in the present study is 6 m/s.
4.1.3 Comparison of estimated data with measured data

The computed wave height and wave period using Young's and the SPM model have been compared with the observed ones at Station O3 (15°53.852' N, 108°30.033' E) during September 1997 before the passage of the hurricane Fritz is presented in Table 4.3. The comparison shows a good agreement between the values computed using Young’s model and observed wave characteristics.

Table 4.3 Comparison between computed and measured wave characteristics during September 1997 off Hoian coast

<table>
<thead>
<tr>
<th>Time (GMT+7)</th>
<th>Wave Characteristics</th>
<th>Measured</th>
<th>Young's method</th>
<th>SPM Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>01h/21/9/1997</td>
<td>Wave height - Hs(m)</td>
<td>0.9</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Wave period - T(s)</td>
<td>6.1</td>
<td>7.3</td>
<td>6.1</td>
</tr>
<tr>
<td>04h/21/9/1997</td>
<td>Wave height - Hs(m)</td>
<td>1.0</td>
<td>1.0</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>Wave period - T(s)</td>
<td>5.9</td>
<td>7.4</td>
<td>6.2</td>
</tr>
<tr>
<td>07h/21/9/1997</td>
<td>Wave height - Hs(m)</td>
<td>1.0</td>
<td>1.1</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Wave period - T(s)</td>
<td>6.0</td>
<td>7.5</td>
<td>6.4</td>
</tr>
</tbody>
</table>

4.1.4 Significant wave height and peak wave period

Significant wave height and peak wave period estimated for different hurricanes that crossed the Hoian coastline along with the input parameters such as: longitude, latitude, maximum wind speed, speed of forward motion and fetch are given in Table 4.4a.
Table 4.4a Estimated significant wave height ($H_s$) and peak wave period ($T_p$) for maximum wind speed of hurricane crossed the Hoian coastline

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Time of occurrence (GMT)</th>
<th>Latitude ($\circ$N)</th>
<th>Longitude ($\circ$E)</th>
<th>Maximum Wind speed $V_{max}$ (m/s)</th>
<th>Speed of forward motion $V_m$ (m/s)</th>
<th>Fetch $F$ (km)</th>
<th>Significant wave height $H_s$ (m)</th>
<th>Peak wave period $T_p$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18h/30/10/1952</td>
<td>15.7</td>
<td>108.5</td>
<td>20.6</td>
<td>5.7</td>
<td>187.6</td>
<td>4.6</td>
<td>9.4</td>
</tr>
<tr>
<td>2</td>
<td>12h/08/10/1955</td>
<td>15.7</td>
<td>108.6</td>
<td>12.9</td>
<td>3.7</td>
<td>149.5</td>
<td>2.5</td>
<td>7.4</td>
</tr>
<tr>
<td>3</td>
<td>18h/14/04/1956</td>
<td>15.3</td>
<td>109.0</td>
<td>10.3</td>
<td>5.2</td>
<td>119.2</td>
<td>1.8</td>
<td>6.4</td>
</tr>
<tr>
<td>4</td>
<td>6h/12/10/1957</td>
<td>15.5</td>
<td>108.5</td>
<td>33.4</td>
<td>5.2</td>
<td>264.8</td>
<td>8.8</td>
<td>12.4</td>
</tr>
<tr>
<td>5</td>
<td>0h/15/9/1964</td>
<td>15.7</td>
<td>108.3</td>
<td>38.6</td>
<td>6.4</td>
<td>281.5</td>
<td>10.5</td>
<td>13.3</td>
</tr>
<tr>
<td>6</td>
<td>0h/27/9/1964</td>
<td>16.1</td>
<td>108.0</td>
<td>20.6</td>
<td>6.2</td>
<td>180.3</td>
<td>4.5</td>
<td>9.3</td>
</tr>
<tr>
<td>7</td>
<td>6h/25/10/1970</td>
<td>15.7</td>
<td>108.3</td>
<td>28.3</td>
<td>4.7</td>
<td>240.6</td>
<td>7.1</td>
<td>11.4</td>
</tr>
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<td>8</td>
<td>6h/23/10/1971</td>
<td>15.6</td>
<td>108.2</td>
<td>38.6</td>
<td>6.0</td>
<td>284.7</td>
<td>10.5</td>
<td>13.4</td>
</tr>
<tr>
<td>9</td>
<td>0h/04/9/1972</td>
<td>15.4</td>
<td>108.9</td>
<td>36.0</td>
<td>3.9</td>
<td>272.5</td>
<td>9.6</td>
<td>12.9</td>
</tr>
<tr>
<td>10</td>
<td>12h/06/9/1982</td>
<td>15.7</td>
<td>109.0</td>
<td>31.0</td>
<td>6.2</td>
<td>245.1</td>
<td>7.8</td>
<td>11.8</td>
</tr>
<tr>
<td>11</td>
<td>6h/27/9/1984</td>
<td>15.5</td>
<td>108.6</td>
<td>12.8</td>
<td>5.2</td>
<td>138.5</td>
<td>2.4</td>
<td>7.2</td>
</tr>
<tr>
<td>12</td>
<td>18h/21/10/1986</td>
<td>15.2</td>
<td>108.8</td>
<td>25.7</td>
<td>4.7</td>
<td>226.6</td>
<td>6.3</td>
<td>10.8</td>
</tr>
<tr>
<td>13</td>
<td>18h/24/5/1989</td>
<td>15.8</td>
<td>108.6</td>
<td>36.0</td>
<td>3.1</td>
<td>263.5</td>
<td>9.4</td>
<td>12.7</td>
</tr>
<tr>
<td>14</td>
<td>18h/21/10/1996</td>
<td>15.5</td>
<td>108.8</td>
<td>13.0</td>
<td>3.6</td>
<td>150.3</td>
<td>2.6</td>
<td>7.5</td>
</tr>
<tr>
<td>15</td>
<td>0h/25/9/1997</td>
<td>15.5</td>
<td>108.8</td>
<td>38.6</td>
<td>3.1</td>
<td>271.9</td>
<td>10.3</td>
<td>13.2</td>
</tr>
<tr>
<td>16</td>
<td>0h/19/10/1999</td>
<td>15.6</td>
<td>108.8</td>
<td>23.2</td>
<td>5.8</td>
<td>203.4</td>
<td>5.3</td>
<td>10.1</td>
</tr>
<tr>
<td>17</td>
<td>0h/22/8/2000</td>
<td>15.6</td>
<td>109.2</td>
<td>23.2</td>
<td>5.3</td>
<td>201.2</td>
<td>5.4</td>
<td>10.1</td>
</tr>
</tbody>
</table>

In all, 17 hurricanes crossed the Hoian coastline during 1945 to 2003 with maximum wind speed 38.6 m/s, maximum significant wave height 10.5 m, and maximum peak wave period 13.4 s. Mostly of the above hurricanes crossed the southern coastline of Thubon River mouth that means the Thubon River mouth fall in to the maximum wave height region with incident wave from NE to E directions.

4.1.5 Variation of storm parameters for hurricanes crossed near the Hoian coastline during September 1997 to August 2003

During September 1997 to August 2003, 4 hurricanes have crossed near the Hoian coastline (Figure 4.2). Variation of the storm parameters of these
hurricanes, at six hourly intervals are shown in Figures 4.5 to 4.8.

**Hurricane FRITZ:** The low pressure was formed at 18 hrs on 20.9.1997 at 12.7° N, 110.7° E (off Southern Central Vietnam coast) and it moved in the northerly direction. It formed a tropical storm at 18 hrs on 22.9.1997 at 16.3° N, 110.5° E and then slowly moved in varied direction. Further it formed a typhoon at 0 hrs on 24.9.1997 at 15.9° N, 110.8° E and then slowly moved in the westerly direction with increasing wind speed and significant wave height towards Nolan coast. The maximum wind speed was 38.6 m/s, maximum significant wave height was 10.3 m and peak wave period was 13.2 s at 0 hrs on 25.9.1997 (Figure 4.5).

**Tropical Storm EVE:** The low pressure was formed at 6 hrs on 15.10.1999 at 11.2° N, 127.7° E (west Pacific Ocean) and crossed the Philippine Islands. It slowly moved in the northwesterly direction and then moved towards the west. It formed a tropical storm at 0 hrs on 19.10.1999 at 15.6° N, 109.6° E. The maximum wind speed was 23.2 m/s, maximum significant wave height was 5.3 m and peak wave period was 10.1 s at 0 hrs on 19.10.1999 (Figure 4.6).

**Tropical Depression 04W:** The low pressure was formed at 18 hrs on 30.5.2000 at 12.3° N, 110.5° E off Southern Central Vietnam coast and it moved nearly parallel to the Central Vietnamese coast in the northerly direction. It crossed southern Hoian area at 18 hrs on 31.5.2000 at 14.4° N, 109.4° E and passed Hoian area at 0 hrs on 01.6.2000 at 16.1° N, 108.8° E and then slowly but continuously moved in the northerly direction towards Gulf of Tonkin. The maximum wind speed was 12.9 m/s, maximum significant wave height was 2.5 m and peak wave period was 7.4 s when the depression was close to the coast (Figure 4.7).

**Tropical Storm KAEMI:** The low pressure was formed at 06 hrs on 20.8.2000 at 13.0° N, 113.0° E in Central South China Sea and slowly it moved in the northwesterly direction. It formed into tropical storm at 12 hrs on 21.8.2000 at 15.2° N, 111.0° E and then continuously moved towards northern portion of Hoian coast. The maximum wind speed was 23.2 m/s, maximum significant
wave height was 5.4 m and peak wave period was 10.1 s at 0 hrs on 22.8.2000 at 15.6° N, 109.2° E (Figure 4.8).

Figure 4.5 Storm variables and wave parameters for Hurricane FRITZ (September 1997)

Figure 4.6 Storm variables and wave parameters for Tropical Storm EVE (October 1999)
Figure 4.7 Storm variables and wave parameters for Tropical Depression 04W (May 2000)

Figure 4.8 Storm variables and wave parameters for Tropical Storm KAEMI (August 2000)
4.1.6 Derivation of empirical expression

A regression analysis was carried out between the wind speed and significant wave height and it was found that the following empirical relation holds good for the hurricanes considered in the present study with a correlation of 0.9 (Figure 4.9a) when the wave height was more than 2 m.

\[ H_s = 0.243 \ V_{\text{max}} \]  

(4.1)

Spectral peak period, \( T_p \) can also be estimated using the empirical relation (Eq. 4.2) from known value of significant wave height, \( H_s \) (Figure 4.9b).

\[ T_p = 4.7 \ H_s^{0.45} \]  

(4.2)

![Figure 4.9 Correlation (a) significant wave height and wind speed (b) peak wave period and significant wave height.](image)

4.1.7 Design wave

Since the hurricanes have not occurred at regular intervals, a Weibull distribution to the estimation of design wave height would not be realistic. However, for design purposes, wave height for different return periods is required. Considering the wave height (Table 4.4b) for the hurricanes that
occurred in the vicinity of the study region during 1960 to 2003, the design wave heights estimated by fitting a two-parameter Weibull distribution are 5.1, 7.1, 9.1, 10.5 and 11.7 m for return periods of 5, 10, 25, 50 and 100 years respectively.

Table 4.4b Estimated significant wave height ($H_s$) of hurricanes off Hoian coast for design wave calculation

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Years</th>
<th>Time of occurrence (GMT)</th>
<th>Latitude ($^\circ$ N)</th>
<th>Longitude ($^\circ$E)</th>
<th>Maximum wind speed $V_{max}$ (m/s)</th>
<th>Maximum significant wave height $H_s$ (m)</th>
<th>Significant wave height off Hoian coast $H_s$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1960-1961</td>
<td>0h/25/6/1961</td>
<td>17.1</td>
<td>108.0</td>
<td>23.0</td>
<td>5.1</td>
<td>3.1</td>
</tr>
<tr>
<td>2</td>
<td>1962-1963</td>
<td>0h/16/9/1962</td>
<td>16.0</td>
<td>109.3</td>
<td>23.2</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td>3</td>
<td>1964-1965</td>
<td>0h/15/9/1964</td>
<td>15.7</td>
<td>108.3</td>
<td>38.6</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>4</td>
<td>1966-1967</td>
<td>0h/28/8/1967</td>
<td>16.4</td>
<td>109.4</td>
<td>18.0</td>
<td>3.3</td>
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</tr>
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<td>1968-1969</td>
<td>6h/5/9/1968</td>
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<td>108.4</td>
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<td>7.8</td>
<td>4.9</td>
</tr>
<tr>
<td>6</td>
<td>1970-1971</td>
<td>6h/23/10/1971</td>
<td>15.6</td>
<td>108.2</td>
<td>38.6</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
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<td>1972-1973</td>
<td>0h/4/9/1972</td>
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<td>108.9</td>
<td>38.0</td>
<td>9.6</td>
<td>9.6</td>
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<tr>
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<td>1974-1975</td>
<td>0h/4/11/1974</td>
<td>14.9</td>
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<td>23.2</td>
<td>4.8</td>
<td>2.9</td>
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<td>1976-1977</td>
<td>6h/4/9/1977</td>
<td>17.4</td>
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<td>3.0</td>
<td>2.3</td>
</tr>
<tr>
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<td>1978-1979</td>
<td>12/21/9/1979</td>
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<td>107.9</td>
<td>18.0</td>
<td>3.7</td>
<td>2.2</td>
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<td>1980-1981</td>
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</tr>
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<td>7.8</td>
</tr>
<tr>
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<td>1984-1985</td>
<td>6h/27/9/1984</td>
<td>15.5</td>
<td>108.6</td>
<td>12.8</td>
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<td>2.4</td>
</tr>
<tr>
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<td>18h/24/5/1989</td>
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<tr>
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<td>1990-1991</td>
<td>0h/16/11/1990</td>
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<td>7.7</td>
</tr>
<tr>
<td>17</td>
<td>1992-1993</td>
<td>0h/28/10/1992</td>
<td>14.3</td>
<td>109.4</td>
<td>30.9</td>
<td>7.7</td>
<td>4.2</td>
</tr>
<tr>
<td>18</td>
<td>1994-1995</td>
<td>6h/1/11/1995</td>
<td>14.7</td>
<td>108.4</td>
<td>36.0</td>
<td>9.6</td>
<td>5.3</td>
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<tr>
<td>19</td>
<td>1996-1997</td>
<td>0h/25/9/1997</td>
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<td>38.6</td>
<td>10.3</td>
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<td>20</td>
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<td>2000-2001</td>
<td>0h/22/8/2000</td>
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<td>23.2</td>
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<td>5.4</td>
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<td>22</td>
<td>2002-2003</td>
<td>12h/17/11/2003</td>
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<td>109.1</td>
<td>33.2</td>
<td>8.7</td>
<td>4.2</td>
</tr>
</tbody>
</table>
4.2 Offshore wind and wave climate

Wave climate is the temporal distribution of wave conditions averaged over the years. A wave condition is the particular combination of wave heights, wave periods, and wave directions at a given time. A specific offshore wave condition is the result of local winds blowing at the time of the observation and the recent history of winds in the more distant parts of the same water body. The offshore wave condition depends on the wind velocity, duration and fetch. Offshore wave climate varies among different coastal areas because of differences in exposure to waves generated in distant parts of the sea and because of systematic differences in wind patterns around the Earth. The variations in offshore wave climate affect the amount of littoral wave energy available and the directions from which it comes. The orientation of a shoreline to the seasonal distribution of winds and to storm tracks is a major factor in determining the wave energy available for littoral transport.

In the present study, NCEP (National Center for Environmental Prediction) analyzed winds was used as input to WAM wave model over South China Sea and compared the measured and computed offshore wave characteristics.

4.2.1 Statistical characteristics of wind and wave off Central Vietnamese coast (based on the ship observed wind and wave data)

Statistical wind data from 1975 to 1984, based on the ship observed wind data compiled from Vietnamese daily weather report, for offshore of Central Vietnam coast (Mau, 2002a) shows that, from June to August (SW monsoon) the major wind direction was SW and S for 50% of the time. Wind speed was 6-10 m/s for 35% and 11 - 15 m/s for 15% of time. From October to April (NE monsoon) the major wind direction was NE for 60% of the time. Wind speed was 6-10 m/s for 40% and 11-15 m/s for 15% of time, and remaining time it was greater than 20 m/s. In the transition periods (May and September) the wind direction was varying and wind was weak.
Monthly percentage distribution of wave height and direction in the offshore of Central Vietnam based on the ship observed wave data compiled from Vietnamese daily weather reports from 1961 to 1982 (Mau, 2002a) shows that during June to August (SW monsoon) the major wave direction was SW for 62% of time and the average significant wave height was 0.5 to 1.5 m with average wave period of 6 s. From October to April (NE monsoon), the major direction was NE for 75% of time and the average significant wave height was 0.5 to 2.5 m with average wave period of 7 s. In the transition period (May and September) the wave direction varies and the wave height was less than 0.5 m. Maximum wave heights occur during hurricane seasons i.e. from October to December. The location of study area (Figure 1.1) shows that the effects of wave is significant during NE monsoon period, when incident wave comes from offshore region, whereas, during SW monsoon period the incident wave goes away from the coast.

4.2.2 Seasonal distribution of wind velocity over South China Sea

According to Wyrtki (1961) and also Hellerman and Rosenstein (1983), the oceanographic conditions in the South China Sea are driven by the monsoon winds. Winds prior to September are dominated by the southwest monsoon. In September, the northeast monsoon begins to appear in the seas north of 20°N. In the south of that latitude, the southwest monsoon still prevails. The northeast monsoon, expanding southward against the diminishing southwest monsoon in October, reaches its maximum strength and covers the entire South China Sea by December. April marks the end of the winter monsoon. The southwest monsoon first appears in the central basin in May and expands over the entire basin by July and August.

Wind velocity and direction over South China Sea during NE monsoon (12h/02/01/2000) and SW monsoon (0h/19/7/2000) periods were extracted from NCEP re-analysis wind data with resolution of 2.5° x 2.5°, and then linearly interpolated to 1° x 1°. The results are shown in Figure 4.10 and Figure 4.11 respectively for NE and SW monsoons.
During NE monsoon period (Figure 4.10), over South China Sea, wind direction was predominantly NE with average wind speed around 10 - 12 m/s. High wind speed of 14 - 15 m/s occurred along the central deep basin. The area of Gulf of Tonkin and Thailand had average wind speed of 4 - 6 m/s, and wind direction was NE to E. Offshore of Central Vietnam coast wind direction was NE, wind speed was around 6 - 14 m/s. Offshore region of southern Vietnam coast wind direction was NE with speed around 10 - 14 m/s. Wind direction was NE, with wind speed around 6 - 10 m/s in the offshore region of the Hoian area.

Figure 4.10 North-east monsoon wind velocity pattern over South China Sea at 12h/02/01/2000
During SW monsoon period (Figure 4.11), over South China Sea, the major wind direction was SW with average wind speed around 5 - 10 m/s. High wind speed of 12 m/s occurred off southern of Central Vietnam coast. The area of Gulf of Tonkin had average wind speed of less than 5 m/s, and the major wind direction was SE. These changes of wind direction were caused by the landmass around the Gulf of Tonkin. The area of Gulf of Thailand had average wind speed of less than 5 m/s, and the major wind direction was S to SW. In the offshore of Central Vietnam coast, the wind direction was SW, wind speed was around 5 – 12 m/s, wind direction was SW with speed around 5 – 10 m/s in the offshore region of southern Vietnam coast.

Figure 4.11 South-west monsoon wind velocity pattern over South China Sea at 0h/19/7/2000
In the offshore region of the Hoian area, wind direction was SW, with wind speed around 5 to 7 m/s. The wind field along Central and Southern Vietnam coast caused popular upwelling region of Vietnam and South China Sea.

4.2.3 Seasonal distribution of wave characteristics over South China Sea

Using WAM wave model with NCEP re-analysis wind data set as input, the wave characteristics over South China Sea was estimated for grid size of 1° x 1° for NE monsoon (12h/02/01/2000) and SW monsoon (0h/19/7/2000) periods. The computed results are shown in Figure 4.12 and 4.13 respectively.

- During NE monsoon period (Figure 4.12): over South China Sea, the wave direction was predominantly NE with average significant wave height of 2 to 3 m. High significant wave height of 3 to 4 m occurred along the central deep basin. Significant wave height was around 0.5 m, and major direction was NE to E in the area of Gulf of Tonkin. The area of Gulf of Thailand experienced significant wave height less than 0.5 m, and major direction was NE. In the offshore of Central Vietnam coast, the wave direction was NE, significant wave height was around 1 – 2 m. Wave direction was NE with significant wave height around 2 – 3 m in the offshore region of South Vietnam coast. In the offshore region of the Hoian area, significant wave height was around 1 to 2 m from NE direction.

- During SW monsoon period (Figure 4.13): over South China Sea, the major wave direction was SW with average significant wave height around 1 to 2 m. High significant wave height of 2 to 3 m occurred off southern of Central Vietnam coast. In the area of Gulf of Tonkin, significant wave height was less than 0.5 m, and major direction was SE. Similar to wind conditions, these wave directions were also caused by the landmass around the Gulf of Tonkin. In the area of Gulf of Thailand, significant wave height was less than 0.5 m, and major direction was S. In the offshore of Central Vietnam coast, wave direction was SW to S, with significant wave height around 1 to 2 m. In the offshore region of southern Vietnam coast, wave direction was SW with significant wave height
around 0.5 to 1 m. Significant wave height was less than 1 m and coming from S to SW direction in the offshore region of the Hoian area.

Figure 4.12 Computed significant wave height pattern over South China Sea at 12h/02/01/2000
From the distribution patterns of wave characteristics during NE and SW monsoons, we can see that the effects of wave energy on offshore region of Hoian coast during NE monsoon were stronger than that of SW monsoon periods.
4.2.4 Variation of wind and wave characteristics off Hoian coast

In order to get boundary conditions for nearshore wave model, the wind and wave characteristics off Hoian coast (at location: 109° E, 16° N) during different periods: from September 1997 to August 1998, September 1998 to August 1999, and September 1999 to August 2000 were estimated. The wind characteristics from August 2000 to September 2001 were also considered for the shoreline changes. The wind characteristics were extracted from NCEP reanalysis wind data set. The wave characteristics were extracted from WAM model output.

Since evaluation of marine surface wind fields produced in the NCEP-NCAR reanalysis project, Swail and Cox (2000) found that storm peak wave heights in extratropical storms were systematically underestimated at higher sea states due to underestimation of peak wind speeds. In addition, in situ data were incorrectly assimilated and tropical cyclones were poorly resolved. Therefore, the wave parameters during hurricane condition were estimated using Young's model and used for further analysis. In general variation in winds and waves off Hoian coast was similar with highlight of seasonal variations and are shown in Figure 4.14 to Figure 4.17.

- Variation of wind velocity shows that from June to August (SW monsoon) the major wind direction was SE to SW with wind speed around 4 - 7 m/s; from October to April (NE monsoon) the major wind direction was N to E with wind speed around 5 - 8 m/s; May and September the wind direction was varying with wind speed around 3 - 6 m/s. Maximum wind speed occurred during hurricane conditions i.e. during August to October with direction from the sector N to E.

- Variation of offshore waves shows that during SW monsoon period (June to August) the average significant wave height was around 0.5 to 1 m, average peak wave period was 6 s, mean wave direction was SE to SW. During NE monsoon period (October to April), the average significant wave height was 1 to 3 m, average peak wave period was 7 to 8 s and mean wave direction was NE.
During transition periods (May and September), the average significant wave height was 0.5 to 1.5 m, average peak wave period was 5 to 7 s, mean wave direction was varying. Maximum significant wave height occurred during hurricane season (August to October) with direction from the sector N to E.

In general, the magnitude of wind and wave during NE monsoon was larger than that of SW monsoon, and maximum wind speed usually coincides with maximum significant wave height. The maximum values of wind and wave characteristics were mostly occurred during hurricane seasons (from August to October):

- The period from September 1997 to August 1998 have maximum wind speed of 38.6 m/s, wind direction of E, maximum significant wave height of 10.3 m, maximum peak wave period of 13.2 s and wave direction to E during Hurricane FRITZ (September 1997) (Figure 4.14).

- The period from September 1998 to August 1999 have strong intensity of wind and wave during NE monsoon (December), with maximum wind speed of 17 m/s, wind direction of NNE, maximum significant wave height of 5.6 m, maximum peak wave period of 15.4s (Figure 4.15).

- The period from September 1999 to August 2000 has maximum wind speed of 23.2 m/s with wind direction of E, maximum significant wave height of 5.3 m, maximum peak wave period of 10.1s and wave direction was E during Tropical Storm EVE (October 1999). During Tropical Storm KAEMI (August 2000) maximum wind speed was 23.2 m/s, wind direction was NE, maximum significant wave height was 5.4 m, maximum peak wave period was 10.1s and wave direction was NE. During Tropical Depression 04W (May 2000) maximum wind speed was 12.9 m/s, wind direction was N, maximum significant wave height was 2.5 m, maximum peak wave period was 7.4s and wave direction was N (Figure 4.16).

- Distribution features of wind characteristics from September 2000 to September 2001 in general was similar with the above mentioned periods,
except the occurrence of Tropical Storm KAEMI in August 2000 which formed the wind and wave fields having NE direction with relatively long duration of approximately 12 hrs (Figure 4.8 and 4.17).

Figure 4.14 Variation of wind and wave characteristics off Hoian coast during September 1997 to August 1998
Figure 4.15 Variation of wind and wave characteristics off Hoian coast during September 1998 to August 1999
Figure 4.16 Variation of wind and wave characteristics off Hoian coast during September 1999 to August 2000
4.2.5 Comparison between measured and computed offshore wave characteristics

Limited wave data measured in September 1997 using submerged pressure gauge at Station O3 (15° 27.798'N, 108° 42.789'E) at water depth of 20 m was used for comparing the estimated values. The measured data was collected in the transition period, therefore, over South China Sea wave direction varies. The computed significant wave height pattern over South China Sea at 13h on 27 September 1997 is shown in Figure 4.18. The comparison between measured and computed values is shown in Figure 4.19.

At 13h on 27 September 1997 (GMT+7) over South China Sea, significant wave height was weak with average value around 0.7 – 1.0 m, maximum value around 1.0 – 1.5 m occurred along deep basin. The wave direction was from
deep basin region to the coast. In the offshore region of Hoian coast average significant wave height was 0.7 – 1.0 m and wave direction was SE. The comparison results show that the maximum absolute difference between the computed and measured wave height was 0.29 m and wave period was 4.4 s. The average relative difference between the computed and measured significant wave height was 17.3% and peak wave period was 18.1%.

Figure 4.18 Computed significant wave height pattern over South China Sea at 13h/27/9/1997 (GMT+7)
Figure 4.19 Comparison between computed and measured wave characteristics off Hoian coast (Station 03) during September 1997

The computed significant wave height is slightly over estimated, whereas the computed peak wave period is slightly under estimate.

4.3 Tidal characteristics and river discharges
4.3.1 Tidal characteristics

Tide is a periodic rising and falling of sea level caused, by the gravitational attraction of the Moon, Sun, and other astronomical bodies acting on the rotating Earth. The expression water level is used to indicate the mean elevation of the water when average over a period of time long enough (about 1 minute) to eliminate high-frequency oscillations caused by surface gravity waves. In the discussion of gravity waves the water level was also referred to as the still water level (SWL) to indicate the elevation of the water if no gravity waves were present. In the field, water levels are determined by measuring
water surface elevations in a stilling well. Inflow and outflow of the well is restricted so that the rapid responses produced by gravity waves are filtered out, thus reflecting only the mean water elevation.

In addition to wave-induced currents, there are other currents affecting the shore that are caused by tides. Tide-induced currents can be impressed upon the prevailing wave-induced circulations, especially near entrances to bays and lagoons and in regions of large tidal range. Tidal currents are particularly important in transporting sands at entrances to harbors, bays, and estuaries. The change in water level caused by tides is a significant factor in sediment transport since, with a higher water level, waves can then attack a greater range of elevations on the beach profile.

Prediction of water level changes is complex because many types of water level fluctuations can occur simultaneously. It is not unusual for surface wave setup, high astronomical tides, and storm surges to occur coincidentally at the shore on the open coast. It is difficult to determine how much rise can be attributed to each of these causes, although astronomical tides can be predicted rather well where water levels have been recorded for a certain period.

In the present study, based on the measured tidal data for the month of September 1997 at Danang Station, the predominant tidal constituents were estimated and presented in Table 4.5. The amplitudes of the principal tidal constituents Q1, K1, M2, O1 and S2 were 20.9, 19.3, 16.9, 12.8 and 5.98 cm respectively. The characterization of the tide can be determined using the Form Number, which is the ratio of the sums of the amplitudes of the diurnal constituents (K1 and O1) to that of the semi-diurnal constituents (M2 and S2). Form Number indicates that the tide is mixed in nature, having a value of 1.4.

In general, along Hoian coast average tidal height was less than 1m. Therefore, in the estimation of the sediment transport rates and coastline changes, the water depth was considered as constant.
Table 4.5  Predominant tidal constituents for Danang Station

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Constituent name</th>
<th>Frequency (deg./hr)</th>
<th>Amplitude (cm)</th>
<th>Phase lag (deg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Q1</td>
<td>13.3986609</td>
<td>20.8928</td>
<td>141.486</td>
</tr>
<tr>
<td>2</td>
<td>O1</td>
<td>13.9430356</td>
<td>12.8376</td>
<td>146.277</td>
</tr>
<tr>
<td>3</td>
<td>M1</td>
<td>14.4920521</td>
<td>1.2090</td>
<td>180.473</td>
</tr>
<tr>
<td>4</td>
<td>K1</td>
<td>15.0410686</td>
<td>19.3403</td>
<td>181.493</td>
</tr>
<tr>
<td>5</td>
<td>J1</td>
<td>15.5854433</td>
<td>1.2751</td>
<td>236.558</td>
</tr>
<tr>
<td>6</td>
<td>OO1</td>
<td>16.1391017</td>
<td>.5368</td>
<td>352.963</td>
</tr>
<tr>
<td>7</td>
<td>MU2</td>
<td>27.9682084</td>
<td>.3564</td>
<td>343.224</td>
</tr>
<tr>
<td>8</td>
<td>N2</td>
<td>28.4397295</td>
<td>4.0660</td>
<td>73.824</td>
</tr>
<tr>
<td>9</td>
<td>M2</td>
<td>28.9841042</td>
<td>16.9399</td>
<td>97.780</td>
</tr>
<tr>
<td>10</td>
<td>L2</td>
<td>29.5284789</td>
<td>.4453</td>
<td>172.999</td>
</tr>
<tr>
<td>11</td>
<td>S2</td>
<td>30.0000000</td>
<td>5.9814</td>
<td>138.651</td>
</tr>
<tr>
<td>12</td>
<td>2SM2</td>
<td>31.0158958</td>
<td>.3272</td>
<td>117.741</td>
</tr>
<tr>
<td>13</td>
<td>MO3</td>
<td>42.9271398</td>
<td>.4530</td>
<td>208.639</td>
</tr>
<tr>
<td>14</td>
<td>M3</td>
<td>43.4761563</td>
<td>.4872</td>
<td>358.651</td>
</tr>
<tr>
<td>15</td>
<td>MK3</td>
<td>44.0251729</td>
<td>.0941</td>
<td>222.587</td>
</tr>
<tr>
<td>16</td>
<td>MN4</td>
<td>57.4238337</td>
<td>.1128</td>
<td>109.937</td>
</tr>
<tr>
<td>17</td>
<td>M4</td>
<td>57.9682084</td>
<td>.5545</td>
<td>217.572</td>
</tr>
<tr>
<td>18</td>
<td>SN4</td>
<td>58.4397295</td>
<td>.0807</td>
<td>106.264</td>
</tr>
<tr>
<td>19</td>
<td>MS4</td>
<td>58.9841042</td>
<td>.8769</td>
<td>212.257</td>
</tr>
<tr>
<td>20</td>
<td>2MN6</td>
<td>86.4079380</td>
<td>.1778</td>
<td>210.027</td>
</tr>
<tr>
<td>21</td>
<td>M6</td>
<td>86.9523127</td>
<td>.2127</td>
<td>49.849</td>
</tr>
<tr>
<td>22</td>
<td>MSN6</td>
<td>87.4238337</td>
<td>.2167</td>
<td>129.688</td>
</tr>
<tr>
<td>23</td>
<td>2MS6</td>
<td>87.9682084</td>
<td>.1113</td>
<td>156.859</td>
</tr>
<tr>
<td>24</td>
<td>2SM6</td>
<td>88.9841042</td>
<td>.3051</td>
<td>333.802</td>
</tr>
</tbody>
</table>

4.3.2 Thubon River discharges

Thubon River joins the South China Sea at Dai mouth, Hoian Town, Quangnam Province, Central Vietnam, having drainage-basin of 10,350 km² and mean rainfall of 2,500 mm (Bac, 2002). According to Hung (1995) based on the measured data from 1976 to 1993 the monthly distribution of rainfall and Thubon River discharge were mostly concentrated in September, October, November, and December (Table 4.6).

Maximum mean rainfall value was 1252 mm and occurred in October, and the mean rainfall was low (3 to 10 mm) during February to April. Highest value of Thubon River discharge was 826 m³/s during November, and lowest was 67.8 m³/s during April.
Table 4.6 Monthly distribution of mean rainfall and Thubon River discharge

<table>
<thead>
<tr>
<th>Months</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall mm</td>
<td>73</td>
<td>4</td>
<td>3</td>
<td>10</td>
<td>100</td>
<td>93</td>
<td>52</td>
<td>47</td>
<td>180</td>
<td>1252</td>
<td>515</td>
<td>334</td>
</tr>
<tr>
<td>%</td>
<td>2.7</td>
<td>0.2</td>
<td>0.1</td>
<td>0.4</td>
<td>3.8</td>
<td>3.5</td>
<td>1.9</td>
<td>1.8</td>
<td>6.8</td>
<td>47.1</td>
<td>19.3</td>
<td>12.5</td>
</tr>
<tr>
<td>Discharge m$^3$/s</td>
<td>214</td>
<td>123</td>
<td>87.9</td>
<td>67.8</td>
<td>98.3</td>
<td>103</td>
<td>72.7</td>
<td>71.8</td>
<td>139</td>
<td>609</td>
<td>826</td>
<td>505</td>
</tr>
<tr>
<td>%</td>
<td>7.3</td>
<td>4.2</td>
<td>3.0</td>
<td>2.3</td>
<td>3.4</td>
<td>3.5</td>
<td>2.5</td>
<td>2.5</td>
<td>4.8</td>
<td>20.9</td>
<td>28.3</td>
<td>17.3</td>
</tr>
</tbody>
</table>

Based on study by Trinh (2000), during dry season the mean depth average of tidal current velocity was approximately 0.15 to 0.25 m/s. During wet season river flow dominated and mean depth average current velocity was approximately 0.3 to 0.5 m/s. Mean depth-averaged suspended sediment concentration during dry and wet season was approximately 13 and 150 mg/l respectively.

4.4 Nearshore waves

The present study is taken up with an objective to understand the coastal processes along the Hoian coast. Wave condition along the Hoian coast was estimated using SWAN model, and the estimated values of significant wave height and peak wave period were compared with the limited measured wave data available at few locations.

4.4.1 Distribution features of wave characteristics in the Hoian area for normal conditions

To study the changes in wave height in the nearshore region for 4 different wave directions, the significant wave height in the Hoian area was computed using SWAN model for the following offshore input parameters:

- Local wind speed: $V = 10$ m/s
- Offshore significant wave height: $H_s = 1.5$ m
- Offshore spectral peak wave period: \( T_p = 5.0 \text{ s} \)
- Offshore wave direction \( \theta = \text{N, NE, E and SE} \)

Wherein, the offshore wave characteristic was computed using WAM model with offshore wind velocity of 10 m/s. Distribution of significant wave height in different direction of wave approach is shown in Figure 4.20 to Figure 4.23.

**For N direction of incident wave**

In case of incident wave coming from N direction (Figure 4.20), in the area of

![Diagram](image_url)

**Figure 4.20** Computed significant wave height pattern in the Hoian area
(Offshore wave conditions: \( H_s = 1.5 \text{ m} \); \( T_p = 5.0 \text{ s} \); Direction = N; Local wind conditions: \( V = 10 \text{ m/s} \); Direction = N)
water depth greater than 30 m, significant wave height $H_s \approx 1.5$ m, which reduced to $H_s \approx 1.2$ m when it met the isobath of 20 m, and then, to significant wave height, $H_s \approx 1$ m, in the nearshore region. In general, in offshore region wave direction was N, but in the nearshore, wave direction was NE. Along the coastline of Sontra headland, wave direction was E to SE. In the area behind of Cham Island wave direction was NW due to the effect of refraction. The coastline from Sonthuy to Sontra is protected from the wave action due to the presence of Sontra headland here significant wave height recorded is $H_s \approx 0.5$ m. The shoals in front of northern Thubon River mouth and the coastline at Anbang and Antuyen are subjected to concentration of wave energy with significant wave height $H_s \approx 1.2 - 1.5$ m. The remaining coastline have significant wave height $H_s \approx 1.0$ m. Cham Island is not affecting the Thubon River mouth from incident wave of N direction.

For NE direction of incident wave

NE direction of incident wave (Figure 4.21) is the major direction of wave climate in offshore of Hoian coast, especially during NE monsoon period. In all, the whole Hoian area wave direction was NE, except the coastline of Sontra headland and the area behind Cham Island.

Significant wave height reduces gradually from the deepwater value of about 1.5 m to 1.2 m in front of the shoal and in the nearshore zone. The coastline from Mykhe to Sontra is protected from the wave action due to the presence of Sontra headland. Significant wave height recorded here is $H_s < 0.5$ m. The coastline from Anbang to Mykhe, shoals in the north of Thubon River mouth and coastline at Antuyen are subjected to concentration of wave energy with significant wave height $H_s \approx 1.2 - 1.5$ m. The shoals in the south of Thubon River mouth and southern shoreline were fallen in the wave shadow region of Cham Island. Significant wave height recorded here is $H_s \approx 1.0$ m, where wave energy is predominantly generated by local wind.
The features of wave breaking patterns in and around the Thubon River mouth during NE monsoon (January 2000) is shown in Plates 4.1 and 4.2.
Plate 4.1 Wave breaking pattern at Thubon River mouth during flood tide (on 19th January 2000)

Plate 4.2 Wave breaking pattern along Northern shoreline of Thubon River mouth (on 20th January 2000)
For E direction of incident wave

Incident wave from E direction (Figure 4.22) mostly occurs during NE monsoon and transitional periods in offshore of Hoian coast. In general, in the whole Hoian area, wave direction was E, except the area between Thubon River mouth and Cham Island, where wave direction was affected by refraction and diffraction. The coastline at Mykhe and the coastline from Station S4 to Antuyen are subjected to concentration of wave energy with significant wave height $H_s \approx 1.2 - 1.5$ m. The coastline from Station S2 to Sonthuy was fallen in the wave shadow region of Cham Island, where wave energy is predominantly generated by local wind.

Figure 4.22 Computed significant wave height pattern in the Hoian area (Offshore wave conditions: $H_s = 1.5$ m; $T_p = 5.0$ s; Direction = E; Local wind conditions: $V = 10$ m/s; Direction = E).
For SE direction of incident wave

SE direction of incident wave (Figure 4.23) mostly occurs in offshore of Hoian coast during SW monsoon period. In general, in the whole Hoian area, wave direction was SE, except the area behind Cham Island, where wave direction was S to SW. The coastline from northern part of Thubon River mouth to Mykhe was fallen in the wave shadow region of Thubon River mouth with a significant wave height $H_s = 1.0$ m. The coastline at Sontra headland is falling in the wave shadow region of Cham Island with $H_s = 1$ m, where wave energy is

![Wave pattern diagram](image)

Figure 4.23 Computed significant wave height pattern in the Hoian area (Offshore wave conditions: $H_s = 1.5$ m; $T_p = 5.0$ s; Direction = SE; Local wind conditions: $V = 10$ m/s; Direction = SE).
generated predominantly by local winds. The coastline from Mykhe to Sontra headland has significant wave height $H_s \approx 1.2$ m. The coastline from Anluong to Antuyen is subjected to concentration of wave energy with significant wave height $H_s \approx 1.2 - 1.5$ m.

Distribution of climatic waves off Hoian coast, shows that major wave direction was NE to E (Figure 4.14 to 4.16). Therefore, the northern shoreline of Thubon River mouth is subjected to concentration of wave energy from the waves of NE direction. Whereas, the southern shoreline of Thubon River mouth is subjected to concentration of wave energy from E and SE directions, and Cham Island have important role in the distribution of wave energy along Hoian coast.

4.4.2 Distribution features of wave characteristics in the Hoian area for typical hurricane conditions

**Hurricane FRITZ (September 1997)**

Hurricane FRITZ (Figure 4.24) crossed Hoian area at 0h on 25.9.1997 with maximum wind speed of 38.6 m/s, wind direction of E, significant wave height of 10.3 m, peak wave period of 13.2 s, and wave direction of E.

Calculated significant wave height pattern in the Hoian area shows that: in general, wave direction was E, except the area between Thubon River mouth and Cham Island, where wave direction was affected by refraction. In the area of water depth greater than 30 m, significant wave height $H_s$ was $10 - 12$ m and gradually reduced to $H_s \approx 8$ m when it met the isobath of 20 m, and then significant wave height reduced to $H_s \approx 6$ m in the nearshore region. The coastline at Sonthuy and the coastline from Dongson to Antuyen were subjected to concentration of wave energy with significant wave height $H_s \approx 6$ m, especially, the coastline between Stations S1 to S2 (Phuoctrach) have $H_s \approx 6$ m. These high waves crossed the Phuoctrach coastline due to surge during the hurricane. The coastline from Phuoctrach to Anbang was falling in the wave shadow region of Cham Island with $H_s < 4$ m.
Tropical Storm EVE (October 1999)

Tropical Storm EVE (Figure 4.25) crossed Hoian area at 0h on 19.10.1999 with maximum wind speed of 23.2 m/s, wind direction of E, significant wave height of 5.3 m, peak wave period of 10.1 s and wave direction of E. In general, wave direction was E, except for the area at Thubon River mouth and Cham Island, where wave direction was affected by refraction. In the area of water depth
greater than 20 m, significant wave height $H_s$ was 5 - 6 m and then gradually reduced to $H_s \approx 4$ m in the nearshore region. The coastline at Sonthuy and the coastline from Dongson to Antuyen were subjected to concentration of wave energy with significant wave height $H_s \approx 4 - 5$ m. The coastline from PhuocTrach to Anbang was falling in the wave shadow region of Cham Island with $H_s \approx 2$ m, where wave energy was predominantly generated by local wind.

Figure 4.25 Computed significant wave height pattern in the Hoian area during Tropical Storm EVE - 0h/19/10/1999
(Offshore wave conditions: $H_s = 5.3$ m; $T_p = 10.1$ s; Direction = E. Local wind conditions: $V = 23.2$ m/s; Direction = E).
Tropical Depression 04W (May 2000)

Tropical Depression 04W (Figure 4.26) crossed Hoian area at 0h on 01.6.2000 with maximum wind speed of 12.9 m/s, wind direction of N, significant wave height of 2.5 m, peak wave period of 7.4 s and wave direction of N. In the area of water depth greater than 30 m, significant wave height $H_s$ was 2.5 m and gradually reduced to $H_s \approx 2$ m when it met the isobath of 20 m, and then

Figure 4.26 Computed significant wave height pattern in the Hoian area during Tropical Depression 04W - 0h/01/6/2000
(Offshore wave conditions: $H_s = 2.5$ m, $T_p = 7.4$ s; Direction = N. Local wind conditions: $V = 12.9$ m/s; Direction = N).
significant wave height $H_s$ was 1.5 m in the nearshore region. In general, in the offshore region, wave direction was N, but in the nearshore region wave direction was NE due to refraction processes. The shoals in front of Thubon River mouth, coastline at Anbang and Antuyen were subjected to concentration of wave energy with significant wave height $H_s \approx 2.0$ m.

Tropical Storm KAEMI (August 2000)

Tropical Storm KAEMI (Figure 4.27) crossed Hoian area at 0h on 22.8.2000

Figure 4.27 Computed significant wave height pattern in the Hoian area during Tropical Storm KAEMI – 0h/22/8/2000
(Offshore wave conditions: $H_s = 5.4$ m; $T_p = 10.1$ s; Direction = NE.
Local wind conditions: $V = 23.2$ m/s; Direction = NE).
with maximum wind speed of 23.2 m/s, wind direction of NE, significant wave height of 5.4 m, peak wave period of 10.1 s and wave direction of NE. Calculated significant wave height pattern in the Hoian area shows that in general, wave direction was NE, except the area behind Cham Island and Sontra headland, where wave direction was affected by refraction. In the area of water depth greater than 30 m significant wave height $H_s \approx 6$ m and gradually reduced to $H_s \approx 5$ m when it met the isobath of 20 m, and then significant wave height reduced to $H_s \approx 4$ m in the nearshore region. The coastline from Anbang to Sonthuy, coastline from Lamloc to Antuyen, and coastline at Phuoctrash are subjected to concentration of wave energy with significant wave height $H_s \approx 4 - 5$ m. Along the coastline of Phuoctrash (Northern shoreline of Thuon River mouth), wave direction was from NE. Whereas, along the coastline of Anluong (Southern shoreline of Thubon River mouth), wave direction was from E to SE.

### 4.4.3 Comparison between measured and computed nearshore wave characteristics

Comparisons between measured and computed nearshore wave characteristics based on SWAN model were carried out at Stations S1 during May 1998 and August 1999; at Station O4 during August 1999. Location of measured stations is shown in Figure 3.5.

- **Station S1**: Stations S1 lies in the nearshore region (Northern shoreline of Thubon River mouth) with average water depth of 2 m. In general, the maximum absolute difference between the computed and measured wave height was 0.23 m, wave period was 2.7 s and wave direction was 31°. The average difference between computed and measured wave direction was 13.5°. The average relative difference between the computed and measured wave height was 26%, wave period was 18% (Figure 4.28).
- **Station O4**: average water depth at Station O4 was 7 m. In general the maximum absolute difference between the computed and measured wave height was 0.21 m, wave period was 1.6 s and wave direction was 25°. The average difference between computed and measured wave direction was 12.5°. The average relative difference between the computed and measured wave height was 25.7%, wave period was 14% (Figure 4.29).
Figure 4.29 Comparison between computed and measured wave characteristics during August 1999 at Station O4 (depth ≈ 7 m)

At Station S1 (mean depth of 2 m) the computed values of wave height and wave period was under-estimated the measured ones. Whereas, at Station O4 (mean depth of 7 m) the computed values of wave height and wave period was more than the measured ones. Since the comparison is good, SWAN model was used to estimate the wave condition in the Hoian area and Central Vietnam waters for the period of study where measured data is not available. Further, the above comparison was carried out for fair weather conditions. Comparison during rough weather conditions could not be carried out since there was no measured data for this period.
4.5 Breaker characteristics and longshore sediment transport rate

The longshore current generated due to wave breaking plays an important role in transporting the sediment in the surf zone. The longshore current velocity varies across the surf zone, reaching a maximum value close to the wave breaking point (Galvin, 1967; Basco, 1982). For practical purposes, the average longshore current measured in the surf zone would be sufficient for estimating longshore sediment transport rate (LSTR). LSTR in general is estimated using semi-empirical equations, which are mostly based on laboratory data.

4.5.1 Variation of breaker characteristics and longshore sediment transport rate

Daily variation of breaking wave height, wave period and wave direction calculated using SWAN model along with the longshore sediment transport rate calculated using Van Rijn formula at four stations S1 to S4 during September 1997 to August 1998 are shown in Figure 4.30 to Figure 4.33.

Station S1: During SW monsoon (June to August) the significant wave height varied from 0.2 to 0.8 m and wave period varied from 2 to 6 s (Figure 4.30). During NE monsoon period (October to April) significant wave height was around 0.4 to 1 m and the wave period varied from 5 to 10 s. Breaking wave direction with respect to north mostly varied from NNE to NE throughout the year. LSTR was predominantly of suspended load transport in compared to bed load transport and the transport was mainly towards south throughout the year. During NE monsoon average LSTR was around 2 – 7 kg/sm, during SW monsoon average LSTR was around 2 kg/sm. Maximum value of LSTR obtained was 8.1 kg/sm. Maximum significant wave height was 1.8 m during Hurricane FRITZ, since wave direction was nearly normal to the shoreline, LSTR was 4.9 kg/sm and transport was towards south.
Figure 4.30 Variation of breaker height (a), breaker period (b), breaker angle (c), and sediment transport (d), during September 1997 to August 1998 at Station S1.

**Station S2:** As in Station S1, during SW monsoon, the significant wave height varied from 0.2 to 0.6 m and the wave period varied from 2 to 6 s (Figure 4.31). During NE monsoon period the wave height was around 0.3 to 0.8 m and the wave period was around 4 to 9 s. Breaking wave direction with respect to north varied from NNE to E during SW monsoon period, and from NE to E in the remaining time of the year. LSTR was predominantly of suspended load transport compared to bed load transport and the transport was predominantly...
towards south. During NE monsoon period the transport direction was varying and the LSTR was higher than that of the SW monsoon. Average value of LSTR was less than 0.5 kg/sm. Maximum value was 6.5 kg/sm (during Hurricane FRITZ) and transport direction was towards north.

Figure 4.31 Variation of breaker height (a), breaker period (b), breaker angle (c), and sediment transport (d), during September 1997 to August 1998 at Station S2

Station S3: Station S3 is located in the southern bank of Thubon River mouth, and hence the river flow here will have significant role in sediment transport. Since the measured river flow data was not available for the entire study period, in the present study, the effect of river flow is not considered. In general the
significant wave height was around 0.1 to 0.6 m and the wave period varied from 2 to 6 s during SW monsoon period and from 0.2 to 0.8 m wave height, and from 4 to 9 s wave period during NE monsoon period (Figure 4.32). The breaking wave direction was mostly from NE during NE monsoon period and from NNE during SW monsoon period. The transport was mainly toward west throughout the year. During NE monsoon period the LSTR was higher than that of the SW monsoon. The average value of LSTR was around 0.5 kg/sm. Maximum value was 13.4 kg/sm (during Hurricane FRITZ) and transport direction was towards west.

Figure 4.32 Variation of breaker height (a), breaker period (b), breaker angle (c), and sediment transport (d), during September 1997 to August 1998 at Station S3
**Station S4:** During SW monsoon the significant wave height varied from 0.2 to 0.8 m and during NE monsoon period the wave height was around 0.4 to 1.1 m. In general the wave period was from 2 to 6 s during SW monsoon period, and from 4 to 9 s during NE monsoon period (Figure 4.33). The breaking wave direction with respect to north was mostly from E during NE monsoon period and from NE to SE during SW monsoon period. The transport was mainly towards south throughout the year. During NE monsoon the average LSTR was around 1 to 2 kg/sm. During SW monsoon the average value of LSTR was mostly less than 0.5 kg/sm and maximum value of LSTR was 2.2 kg/sm. During

![Figure 4.33 Variation of breaker height (a), breaker period (b), breaker angle (c), and sediment transport (d), during September 1997 to August 1998 at Station S4.](image-url)
Hurricane FRITZ, since wave direction was nearly normal to the shoreline, LSTR was only 0.7 kg/sm and transport was towards south, as in Station S1.

In general the computed results show that the LSTR was high at Stations S1 and S3 and lower at Stations S2 and S4. The LSTR was predominantly towards south at Stations S1, S2 and S4, and towards west at Station S3.

4.5.2 Comparison between measured and computed vertical distribution of sediment transport rate

Computed and measured vertical distribution of sediment transport rate at Stations S1 to S4 is shown in Figure 4.34. Input parameters are shown in Table 4.7.

Table 4.7 Input parameters for calculation of vertical distribution of sediment transport rate at Stations S1 to S4

<table>
<thead>
<tr>
<th>Stations</th>
<th>Time (GMT+7)</th>
<th>Significant wave height (m)</th>
<th>Wave period (s)</th>
<th>Current velocity (m/s)</th>
<th>Angle between wave and current (deg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>13h 28/9/1997</td>
<td>0.3</td>
<td>6.3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>9h 1/10/1997</td>
<td>0.3</td>
<td>6.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>8h 2/10/1997</td>
<td>0.5</td>
<td>5.5</td>
<td>0.3</td>
<td>45</td>
</tr>
<tr>
<td>S4</td>
<td>14h 2/10/1997</td>
<td>0.4</td>
<td>5.3</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Since Station S3 is in the south bank of the river, river flow was considered while estimating the sediment transport rate, whereas for Stations S1, S2, and S4, the current velocity was not considered. In general the measured and computed values show a good agreement, although the model tends to slightly over-estimate sediment transport rate especially from the level of 0.15 m above the bed, whereas the model tends to slightly under-estimate sediment transport rate at level below 0.15 m.
Figure 4.34 Comparison between computed and measured of vertical distribution of sediment transport at Stations S1 to S4.
4.5.3 Comparison of calculated longshore sediment transport rate using CERC and Van Rijn formulas

The breaking wave characteristics were extracted from the outputs of SWAN model at four stations (S1 to S4). Computed LSTR values based on Van Rijn formula shows that, the gross transport at Stations S1 to S4 was 567315, 118157, 222272 and 167900 m$^3$/year respectively, and the net transport was 567315, 100552, 222272 and 167300 m$^3$/year respectively (Table 4.8). Net transport was towards south at Stations S1, S2, and S4 and towards west at Station S3 (Figure 4.35).

<table>
<thead>
<tr>
<th>Stations</th>
<th>Shoreline orientation w.r.t. north (deg.)</th>
<th>Average surfzone width (m)</th>
<th>Formulas</th>
<th>Gross transport (m$^3$/year)</th>
<th>Net transport (m$^3$/year)</th>
<th>Net transport direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>340</td>
<td>25</td>
<td>Van Rijn CERC</td>
<td>567,315</td>
<td>695,733</td>
<td>south</td>
</tr>
<tr>
<td>S2</td>
<td>5</td>
<td>30</td>
<td>Van Rijn CERC</td>
<td>118,157</td>
<td>281,822</td>
<td>south</td>
</tr>
<tr>
<td>S3</td>
<td>255</td>
<td>20</td>
<td>Van Rijn CERC</td>
<td>222,272</td>
<td>285,812</td>
<td>west</td>
</tr>
<tr>
<td>S4</td>
<td>10</td>
<td>25</td>
<td>Van Rijn CERC</td>
<td>167,900</td>
<td>224,132</td>
<td>south</td>
</tr>
</tbody>
</table>

Computed LSTR values based on CERC formula shows that the gross transport at stations S1 to S4 was 695733, 281822, 285812 and 224132 m$^3$/year respectively, and the net transport was 695733, 242366, 285812 and 221386 m$^3$/year respectively. The net transport was towards south at Stations S1, S2, and S4, towards west at Station S3. LSTR estimated using Van Rijn formula was found to be lower than that estimated following CERC formula at all 4 stations. At Stations S1 and S3 the LSTR was in same direction throughout the year, but at Station S2 and S4 the transport direction was varying. It is important to note here that shoals formed at Station S2 supports sediment accumulation at this location.
Figure 4.35 Time series plot of calculated sediment transport rate according to Van Rijn and CERC formulae during September 1997 to August 1998
At all stations, the LSTR were higher during NE monsoon than that of SW monsoon period, and the LSTR was higher at Stations S1, S3, and lower at Stations S2, S4. Stations S2, S3 and S4 were falling into the wave shadow region of Cham Island for the north-easterly wave conditions. The LSTR was lowest at Station S2 and S4, since breaking wave direction was mostly from E which is normal to the shoreline. Whereas, at Station S3 the predominantly wave breaking direction was mostly from N to NE which made an oblique angle to the shoreline. Stations S1 was located relatively far away from the river mouth and have relatively open sandy coast. Kumar et al. (2001) estimated the longshore sediment transport based on CERC formula, they found that the estimates was reasonably agreeing well for a long and open sandy beach. Bayram et al. (2001) compared the cross-shore distribution of longshore sediment transport calculated based on six predictive formulae and that measured during the DUCK85, SUPERDUCK, and SANDYDUCK field data collection projects. They found that the Van Rijn formula gave the most reliable prediction over the entire range of wave conditions (swell and storm). Kumar et al. (2003a) was also found that the LSTR could be calculated reasonably well using Van Rijn formula compared to CERC formula for pocket beaches with headlands. In view of the above, the LSTR estimated based on Van Rijn formula could be considered as representative values for the present study area.

4.5.4 Distribution of net longshore sediment transport rate by wave action

Accurate estimate of longshore sediment transport rates (LSTR) in the coastal zone are necessary both to develop better predictive tools for sediment motion and to quantify transport used in coastal engineering applications. The net and gross longshore sediment transport rates are probably the most important factors (and largest unknowns) in design of any structure that substantially impedes the flow of sediment along the coast. Net LSTR is the net amount of material passing a particular point in the predominant direction during a specified time. Net LSTR was computed based on GENESIS model for the following periods.
- From September 1997 to August 1998.
- From September 1998 to August 1999.
- From September 1999 to January 2000.
- From January to July 2000.

The model domains and input parameters are shown in Figure 3.5 and Table 3.3 respectively. The computed results are shown in Figure 4.36 to Figure 4.39.

**Period from September 1997 to August 1998**

- At the Northern shoreline, in general the net LSTR was towards north in northern sections with average transport rate of 200,000 to 300,000 m$^3$/year, and the values increase towards north (Figure 4.36).

![Figure 4.36 Distribution of net longshore sediment transport rate from September 1997 to August 1998 in and around the Thubon River mouth by wave action.](image-url)
Whereas, in the southern sections (near river mouth) the net LSTR was towards south with average value of 150,000 m³/year, and the values decrease further towards south. Therefore north of Station S1 there is erosion.

- At the Southern shoreline, the net LSTR was towards south with average transport rate of 150,000 m³/year, and the values decrease towards south.

- At the River bank, the net LSTR was towards west in most parts of the River bank with average transport rate of 150,000 m³/year, and the values decrease towards west with minimum value of around 5,000 m³/year occurred at the westernmost sections, except at the easternmost sections where the net transport was towards east.

**Period from September 1998 to August 1999**

- At the Northern shoreline, in general the net LSTR was towards north in northern sections with average transport rate of 250,000 m³/year, and the values increase towards north. Whereas, in the southern sections (near river mouth) the net LSTR was towards south with average value of 150,000 m³/year, and the values decrease further towards south (Figure 4.37).

- At the Southern shoreline, the net LSTR was from both sides towards the central region with average transport rate of 150,000 m³/year, and the values decrease towards the central region with minimum value of less than 5,000 m³/year. Maximum transport rate occurred at Cape Anluong with the values of 250,000 m³/year.

- At the River bank, the net LSTR was towards west in most parts of the bank with average transport rate of 60,000 m³/year, and the values decrease towards west with minimum value of less than 5,000 m³/year occurred at the westernmost sections.
Figure 4.37 Distribution of net longshore sediment transport rate from September 1998 to August 1999 in and around the Thubon River mouth by wave action

**Period from September 1999 to January 2000**

- At the Northern shoreline, in general the net LSTR was towards north with average transport rate of around 150,000 m³/year, and the values increase towards north. Whereas, in the southern sections (near river mouth) the net LSTR was toward south with average value of 100,000 m³/year, and the values decrease further towards south (Figure 4.38).

- At the Southern shoreline, the net LSTR was from both sides towards the central region with average transport rate of 100,000 to 200,000 m³/year, and the values decrease towards the central region with minimum value of less than 10,000 m³/year. Maximum transport rate occurred at Cape Anluong with the values of 230,000 m³/year.
At the River bank, the net LSTR was towards west in most parts of the bank with average transport rate of 100,000 m$^3$/year, and the values decrease towards west with minimum value of less than 5,000 m$^3$/year occurred at the westernmost sections.

Figure 4.38 Distribution of net longshore sediment transport rate from September 1999 to January 2000 in and around the Thubon River mouth by wave action.

**Period from January to July 2000**

At the Northern shoreline, in general the net LSTR was towards north with average transport rate of 150,000 m$^3$/year. Whereas, the southern part (near river mouth) the net LSTR was towards south with average value of 70,000 m$^3$/year, and the values decrease further towards south (Figure 4.39).
- At the Southern shoreline, the net LSTR was from both sides towards the central region with average transport rate of 50,000 m$^3$, and the values decreased towards the central region with minimum value less than 5,000 m$^3$. At the northern part (Cape Anluong) net LSTR was towards north.

- At the River bank, the net LSTR was towards west in most parts of the bank with average transport rate of 20,000 m$^3$, and the values decrease towards west with minimum value of less than 3,000 m$^3$ occurred at the westernmost sections.

Figure 4.39  Distribution of net longshore sediment transport rate from January to July 2000 in and around the Thubon River mouth by wave action

Distribution of net LSTR in and around the Thubon River mouth shows that the seasonal variation in direction of net LSTR was negligible. Net LSTR during September to January was higher than that during January to July.
4.6 Shoreline change

It is important to identify and understand both the short-term and long-term causes of coastline changes. There are causes of both natural and man-induced. Natural causes of erosion are those which occur as a result of the response of the beach to the effects of nature. Man-induced erosion occurs when human endeavors impact on the natural system. Natural and man-induced causes of erosion are listed in Table 4.9 (SPM, 1984).

Table 4.9 Causes of coastal erosion

<table>
<thead>
<tr>
<th>Natural</th>
<th>Man-induced</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Sea level rise</td>
<td>a. Land subsidence from removal of subsurface resources</td>
</tr>
<tr>
<td>b. Variability in sediment supply to the littoral zone</td>
<td>b. Interruption of material in transport</td>
</tr>
<tr>
<td>c. Storm waves</td>
<td>c. Reduction of sediment supply to the littoral zone</td>
</tr>
<tr>
<td>d. Wave and surge over wash</td>
<td>d. Concentration of wave energy on beaches</td>
</tr>
<tr>
<td>e. Deflation</td>
<td>e. Increase water level variation</td>
</tr>
<tr>
<td>f. Longshore sediment transport</td>
<td>f. Change natural coastal protection</td>
</tr>
<tr>
<td>g. Sorting of beach sediment</td>
<td>g. Removal of material from the beach</td>
</tr>
</tbody>
</table>

A beach may be temporarily eroded by storm waves and later partly or wholly restored by swells, and erosion and accretion patterns may occur seasonally. The long-range condition of the beach whether eroding, stable, or accreting depends on the rates of supply and loss of littoral material. The present study area is undergoing change mainly by the natural causes.

4.6.1 Extent of erosion, deposition in and around the Thubon River mouth during different periods from 1965 to 2001

September 2001, and a limited shoreline positions during August 2003 are shown in Figure 4.40.

![Figure 4.40 Shoreline positions measured during different periods from 1965 to August 2003](image)

The extent of erosion, deposition at different shoreline sections during the above mentioned periods is shown in Table 4.10.
<table>
<thead>
<tr>
<th>Periods</th>
<th>Northern shoreline</th>
<th>Southern shoreline</th>
<th>River bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 1997 to</td>
<td>Northern and central sections = -30m</td>
<td>Northern section ≈ +50m</td>
<td>East side of S3 ≈ +40m</td>
</tr>
<tr>
<td>August 1998 to August 1999</td>
<td>Northern section = +40m</td>
<td>Southern section = +20m</td>
<td>Other sections = -40m</td>
</tr>
<tr>
<td>(Fig. 4.41)</td>
<td>Central section = -60m (maximum = -100m)</td>
<td>All sections = -70m (maximum (western section) = -100m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Near River mouth = +70m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>August 1999 to January 2000</td>
<td>Northern section = +50m; Caman = 0m</td>
<td>Cape Anluong = +250m</td>
<td>Eastern section = -100m</td>
</tr>
<tr>
<td>(Fig. 4.42)</td>
<td>Central section = -100m; S1 = -50m; S2 = +20m</td>
<td>Other sections = +100m</td>
<td>S3 ≈ 0m</td>
</tr>
<tr>
<td></td>
<td>Near River mouth = -50m</td>
<td></td>
<td>Western section = -60m</td>
</tr>
<tr>
<td></td>
<td>Cape Cuadai southward = +50m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January 2000 to July 2000</td>
<td>Northern section = -30m</td>
<td>Cape Anluong = +100m</td>
<td>Eastern section = +15m</td>
</tr>
<tr>
<td>(Fig. 4.43)</td>
<td>Central section = +50m (maximum = +100m)</td>
<td>Central section = -50m</td>
<td>S3 ≈ -20m</td>
</tr>
<tr>
<td></td>
<td>Near River mouth = -50m</td>
<td>Southern section = +20m</td>
<td>Western section = +15m</td>
</tr>
<tr>
<td></td>
<td>Cape Cuadai northward = -50m</td>
<td>Southernmost section = -20m</td>
<td></td>
</tr>
<tr>
<td>July 2000 to September 2001</td>
<td>Northern section = -100m</td>
<td>Cape Anluong = +650m</td>
<td>Eastern section = -70m</td>
</tr>
<tr>
<td>(Fig. 4.44)</td>
<td>Southern section = -50m</td>
<td>Southern section = -150m</td>
<td>Western section = +100m</td>
</tr>
<tr>
<td></td>
<td>Cape Cuadai southward = +300m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>September 1997 to September</td>
<td>Northern section = -120m</td>
<td>Cape Anluong = +1000m</td>
<td>Eastern section = -150m</td>
</tr>
<tr>
<td>2001 (Fig. 4.45)</td>
<td>Southern section = -150m</td>
<td>Southern section = -30m</td>
<td>(maximum = -300m)</td>
</tr>
<tr>
<td></td>
<td>Cape Cuadai southward = +300m</td>
<td></td>
<td>Western section = +30m</td>
</tr>
<tr>
<td>1965 to September 2001</td>
<td>Northern section = -30m</td>
<td>Cape Anluong = +1200m</td>
<td>Easternmost section = -750m</td>
</tr>
<tr>
<td>(Fig. 4.46)</td>
<td>Central section = +50m</td>
<td>Southern section = +500m</td>
<td>Central section = -450m</td>
</tr>
<tr>
<td></td>
<td>Southern section = +500m</td>
<td></td>
<td>Western section = -150m</td>
</tr>
<tr>
<td></td>
<td>Cape Cuadai south-eastward = +700m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** (+): accretion; (-): erosion
S1, S2, S3, S4: nearshore current and wave measured stations
**Period from September 1997 to August 1998**

- **Northern shoreline:** The shoreline was eroded with an average value of -30 m, except southernmost section (near river mouth) wherein, shoreline was accreted with an average value of +40 m. Maximum value of accretion was +70 m at Station S2 (Figure 4.41).

- **Southern shoreline:** The shoreline was accreted with an average value of +20 m, except northernmost section wherein, shoreline was accreted with an average value of +50 m. Maximum value of accretion was +70 m at Cape Anluong.

- **River bank:** The shoreline was eroded with an average value of -40 m, except shoreline section at eastern side of Station S3 wherein it was accreted with an average value of +40 m.

*Figure 4.41 Shoreline change from September 1997 to August 1998*
Period from August 1998 to August 1999

- Northern shoreline: At northernmost section shoreline was accreted with an average value of +40 m. Shoreline at central section (Phuoctrach) was seriously eroded with an average value of -60 m and maximum value of erosion was -100 m at Phuoctrach. Shoreline section near river mouth was accreted with an average value of about +70 m (Figure 4.42).

- Southern shoreline: The shoreline was accreted with an average value of 60 m, especially the northernmost section (Cap Anluong) wherein, shoreline was accreted with an average value of 350 m.

- River bank: The shoreline was eroded with an average value of -70 m and maximum was about -100 m at the upstream section.

Figure 4.42  Shoreline change from August 1998 to August 1999
Period from August 1999 to January 2000

- Northern shoreline: The shoreline at Caman was stable, shoreline at northernmost section was accreted with an average value of +50 m, shoreline in the central section was eroded with an average value of -100 m, shoreline at Station S1 was eroded with an average value of -50 m, shoreline at Station S2 was accreted with an average value of +20 m, southernmost section (near river mouth) shoreline was eroded with average value of -50 m, whereas shoreline at Cape Cuadai was accreted with an average value of +50 m and expanded southward (Figure 4.43).

- Southern shoreline: The shoreline was accreted with an average value of +100 m and maximum value of about +250 m was recorded at Cape Anluong.

Figure 4.43 Shoreline change from August 1999 to January 2000
- River bank: The shoreline was eroded with an average value of -100 m (at eastern section), -60 m (at western section) and was stable at Station S3.

**Period from January to July 2000**

- Northern shoreline: The shoreline at northern section was eroded with an average value of -30 m. Shoreline in central section was accreted with an average value of +50 m and maximum value of +100 m at northern side of Station S1. Shoreline at Phuoctrach was slightly accreted with an average value of +10 m. At southernmost section (near river mouth) shoreline was eroded with an average value of -50 m and maximum was -150 m at Station S2. Cape Cuadai was eroded with value of -50 m, retreat northward, which expanded the river throat (Figure 4.44).

![Figure 4.44 Shoreline change from January to July 2000](image-url)
Southern shoreline: The shoreline at Cap Anluong was accreted with maximum value of +100 m. Shoreline at central section was eroded with an average value of -50 m. Shoreline at southern section was accreted with an average value of +20 m, whereas, at southernmost section shoreline was eroded with average value of -20 m.

River bank: In general, shoreline was slightly accreted. At eastern section shoreline was accreted with an average value of +15 m. At Station S3 shoreline was eroded with an average value of -20 m. In the remaining section of the shoreline, accretion was recorded with an average value of +15 m.

Period from July 2000 to September 2001

During this period the shoreline in and around the Thubon River mouth was seriously changed, especially at Cape Cuadai and Cape Anluong (Figure 4.45).
- Northern shoreline: The shoreline at northern section was eroded with an average value of -100 m. Shoreline at southern section was eroded with an average value of -50 m. Cape Cuadai was accreted with value of +300 m and it expanded southward.

- Southern shoreline: The shoreline at Cap Anluong was accreted with value of +650 m and expanded seaward. Shoreline at southern section was eroded with an average value of -150 m.

- River bank: The shoreline at the eastern section was eroded with an average value of -70 m, whereas shoreline at the western section was accreted with an average value of about +100 m.

Period from September 1997 to September 2001

The extent of erosion and deposition in and around the Thubon River mouth within the four years are as follows (Figure 4.46).

Figure 4.46 Shoreline change from September 1997 to September 2001
- Northern shoreline: The shoreline at northern section was eroded with an average value of -120 m. Shoreline at southern section was eroded with an average value of -150 m. Cape Cuadai was accreted with value of +300 m and expanded southward.

- Southern shoreline: In general, all shoreline sections were accreted with an average value of +500 m. At Cape Anluong accretion of large magnitude of approximately +1000 m was recorded, whereas, at southernmost section shoreline was eroded with an average value of -30 m.

- River bank: The shoreline at the eastern section was eroded with an average value of -150 m and maximum value of -300 m was recorded at Cape Anluong. However, the shoreline at westernmost (upstream) section was accreted with average value of +30 m.

Period from 1965 to September 2001

The extent of erosion and deposition in and around the Thubon River mouth within the 36 years are as follows (Figure 4.47).

- Northern shoreline: The shoreline at the northern section was eroded with an average value of -30 m, central shoreline section was accreted with an average value of +50 m and southern shoreline section was accreted with average value of +500 m. Cape Cuadai was accreted with value of +500 m and expanded southward, and also +700 m expanded towards south-east.

- Southern shoreline: Cape Anluong was accreted with value of +1200 m and expanded seaward. Shoreline at southern section was accreted with an average value of +500 m.

- River bank: The shoreline at eastern section (Cape Anluong) was eroded with average value of -750 m. Shoreline at central section was eroded with an average value of -450 m and shoreline at western section was eroded with average value of -150 m.
The tendency of shoreline changes from 1965 to September 2001 is as follows:

- **Northern shoreline**: From 1965 to September 1997 the shoreline was expanding seaward with gradual increase from northernmost section to southernmost section of 100 m to 500 m respectively. Cape Cuadai was expanded south-eastward with value approximately 700 m. But from September 1997 to September 2001 the shoreline was subjected to erosion over whole Northern section with an average value of approximately 150 m. Shoreline section around Caman started retreating with an average value of 50 m when compared with shoreline position of 1965. From July 2000 to September 2001 Cape Cuadai was suddenly further expanded southward with a distance of approximately 300 m.
- Southern shoreline: Throughout the period from 1965 to July 2000 the shoreline was continuously expanding seaward with average value of 400 m, Cap Anluong was expanded about 600 to 700 m. Especially, from July 2000 to September 2001 Cape Anluong was further expanded seaward with value of approximately 700 m, but at the southern section, shoreline was eroded with value of around 100 to 200 m.

- River bank: Throughout the period from 1965 to September 2001 the shoreline was eroded with an average value of 400 m, especially the shoreline at Cap Anluong was eroded with value of about 700 m. But from July 2000 to September 2001 shoreline at westernmost section was accreted with an average value of about 100 to 200 m.

In general from 1965 to 2001 shoreline in and around the Thubon River mouth has undergone changes with relatively large magnitude and complicated manner and especially from 1997 to 2001. The salient features are as below:

- Northern shoreline had undergone of accretion during 1965 to 1997, and then undergone erosion from September 1997 to September 2001, except Cape Cuadai which is continuously expanded southward.

- Southern shoreline had undergone accretion and expanded seaward but the rate of accretion/erosion was not regular, especially from July 2000 to September 2001. During this period, Cape Anluong expanded seaward with large magnitude, but shoreline at southernmost section was eroded.

- River bank from 1965 to 2001 had undergone erosion, except from July 2000 to September 2001 when shoreline at westernmost section was accreted.

From this it is clear that during the period from 1965 to 2001 the Northern shoreline was subjected to accretion and expanded seaward with an average rate of about 15 m per year. The Southern shoreline was also subjected to accretion with an average value of about 12 m per year. The River bank was subjected to erosion with an average value of about 13 m per year. Eventually,
the Thubon River mouth system moved towards south-east direction with a distance of approximately 800 m during 36 years, i.e. with an average rate of 22 m per year.

4.6.2 Seasonal and annual changes in the shoreline in and around the Thubon River mouth.

To understand the seasonal and annual changes in the shoreline in and around the Thubon River mouth, measured shoreline positions in August 1999, January 2000, and July 2000 were used.

4.6.2.1 Wet season

The period, August 1999 to January 2000, represents the rainy and hurricane season in the study area. Shoreline changes during this season are shown in Figure 4.43.

- Northern shoreline showed alternate erosion, stable, and accretion, but in general shoreline was eroded with an average value of 25 m and maximum value of erosion was 100 m at northern of Station S1, Cape Cuadai was accreted with value of 50 m and expanding southward.

- Southern shoreline was accreted with an average value of 100 m and maximum value of accretion was 250 m at Cape Anluong.

- River bank was eroded with an average value of 100 m at eastern section, and an average value of 50 m at the remaining sections.

In all, during wet season shoreline in and around the Thubon River mouth had undergone serious changes with magnitude of about 50-100 m.
4.6.2.2 Dry season

The period from January to July 2000 represents the dry season in the study area. Shoreline changes during this season are shown in Figure 4.44.

- Northern shoreline in general was stable, except at central section of the shoreline which was accreted with an average value of 50 m (maximum value of 100 m), shoreline near river mouth was eroded with an average value of 50 m (maximum value of 150 m) and Cape Cuadai was eroded with value of 50 m retreat northward.

- Southern shoreline was slightly eroded with an average value of 25 m, except Cape Anluong wherein accretion was recorded with value of 100 m.

- River bank was slightly accreted with an average value of 15 m, except shoreline section around Station S3 which was slightly eroded with an average value of 20 m.

In all, during dry season the shoreline in and around the Thubon River mouth had undergone slight changes, except Cape Cuadai and Cape Anluong.

The above mentioned features of seasonal changes in the shoreline in and around the Thubon River mouth indicate that:

- Magnitude of changes in the Northern shoreline during wet season was larger than (around 2 times) that of dry season.
- Southern shoreline was accreted, but the magnitude of accretion during wet season was larger than (around 2 times) that of dry season.
- River bank was seriously eroding during wet season, whereas it was slightly accreting during dry season.
- Cape Cuadai was accreted towards southward during wet season, whereas, it was eroding northward retreat during dry season.
4.6.2.3 Annual changes

Features of annual shoreline changes in and around the Thubon River mouth are as follows:

- Northern shoreline: The shoreline at northernmost section was accreted $\approx +50$ m during wet season, and eroded $\approx -30$ m during dry season. Shoreline at Caman was stable. Shoreline at central section was also stable (eroded $\approx -100$ m during wet season, and then accreted $\approx +100$ m during dry season). Shoreline at PhuocTrach was stable. Shoreline near river mouth was stable during wet season and eroded $\approx -100$ m during dry season. Cape Cuadai was also stable (expanded southward $\approx +50$ m during wet season, and then retreat northward $\approx -50$ m during dry season). In all, the Northern shoreline was slightly eroded, especially near river mouth (Figure 4.43, 4.44, and 4.40).

- Southern shoreline: Cape Anluong was continuously accreting throughout the year (accreted $\approx +250$ m during wet season, and $\approx +100$ m during dry season). Central shoreline section was slightly accreting (accreted during wet season $\approx +100$, and then slightly eroded $\approx -50$ m during dry season). Southern shoreline section had strongly accreted during wet season $\approx +100$ m, and then slightly accreted $\approx +20$ m during dry season. Southernmost shoreline section was accreting (strongly accreted $\approx +100$ m during wet season, and slightly eroded $\approx -20$ m during dry season). In all, the Southern shoreline was in accretion processes.

- River bank: The shoreline had strongly eroded $\approx -70$ m during wet season, and then slightly accreted $\approx +15$ m during dry season. In all, at River bank, shoreline was in the process of erosion.

4.6.3 Shoreline change under the influence of hurricane

Based on measured shoreline positions, in August 1997 i.e., before Hurricane FRITZ crossed, and in September 1997 i.e., after Hurricane FRITZ crossed.
The extent of erosion, deposition in and around the Thubon River mouth by Hurricane FRITZ (on 25/9/1997) is shown in Figure 4.48.

- Northern shoreline: In general, shoreline here had eroded with an average value of -30 m, Cape Cuadai was accreted towards south with value of +60 m. Especially shoreline at Phuoctrach had eroded and created with a new opening of approximately 200 m.

- Southern shoreline: In general shoreline had accreted with an average value of +25 m, except at Cape Anluong which had eroded with an average value of -70 m.

- River bank: In general, the shoreline here had eroded with an average value of -25 m, and maximum value of -75 m at S3 location.

Figure 4.48 Shoreline change by Hurricane FRITZ (September 1997)
4.6.4 Shoreline change under the influence of normal wave action

The results of the calculated shoreline positions during different periods, August 1998, August 1999, January 2000, and July 2000 using GENESIS model (considering only wave action) are presented in Figures 4.41 to 4.44. The results reveal that -

- Northern shoreline had undergone erosion except the southern section (near river mouth) which showed alternative erosion and accretion with times, but predominant erosion process.

- Southern shoreline had undergone accretion, except at Cape Anluong, which showed erosion.

- River bank area had shown slight accretion for all computed periods, except at easternmost section.

In general the computed shoreline positions show good agreement with measured ones at Northern and Southern shoreline of Thubon River mouth, except shoreline sections which lie in the river flow dominated regions such as River bank, Cape Cuadai, Cape Anluong, or falls in the model boundaries.

4.6.5 Shoreline change in combined influence of river flow and wave

During August 1999 to January 2000 (wet season) shoreline at River bank had seriously eroded, but the causes resulted this change was not solely come from wave action (Figure 4.43). Therefore, estimation of shoreline changes along River bank by the combined influence of river flow and wave action was carried out. Average river flow velocity and surfzone width along River bank are shown in Table 4.11.
Table 4.11 Monthly distribution of mean river flow velocity and surfzone width during wet season along River bank

<table>
<thead>
<tr>
<th>Months</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
<th>January</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean river flow velocity (m/s)</td>
<td>0.20</td>
<td>0.35</td>
<td>0.40</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>Mean surfzone width (m)</td>
<td>17</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

The computed results are shown in Figure 4.49 and Table 4.12.

![Figure 4.49](image_url)

Figure 4.49 Predicted River bank change from August 1999 to January 2000 in the influence of river flow and wave

The results indicate that the River bank had undergone severe erosion by the combined action of river flow and wave during wet season.
4.6.6 Calibration/verification error of GENESIS model

According to Hanson and Kraus (1991), GENESIS calculates a number called the "calibration/verification error" (CVE) as the average of the absolute difference between the calculated shoreline position and the measured shoreline position at each grid point. This number conveniently summarizes in a single value, the degree of agreement between the calculated and measured shorelines. The CVE should not be used as the sole criterion to judge the degree of fit since a small value does not necessarily mean that the calculated and measured shorelines are in close agreement along the entire calculated shoreline. As an example, two shorelines may be in close agreement along most portions of the beach but may be far apart along a small but very important section of the beach. A small CVE value would not reveal this important discrepancy. Determination of the degree of fit is best done visually, which allows examination of the overall fit. Also, number $E$ is used as follows:

$$E = \frac{CVE}{EXT} \times 100\%$$  (4.1)

Where,

$E = \text{average relative difference between calculated and measured shoreline positions}$

$CVE = \text{calibration/verification error}$

$EXT = \text{extent of erosion or accretion}$

For conveniently determining the degree of agreement between the calculated and measured shorelines, the number $CVE$ and $E$ were estimated based on the measured shorelines at different periods and different calculated conditions, and shoreline sections (cell position) lie on Cape Cuadai, Cape Anluong, and the boundaries were not involved in calculation processes. Calculated results are shown in Table 4.12, Figures 4.41 to 4.44, and Figure 4.49.
Table 4.12 Calibration/verification error of GENESIS model

<table>
<thead>
<tr>
<th>Periods</th>
<th>Northern shoreline</th>
<th>Southern shoreline</th>
<th>River bank</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 1997 to August 1998</td>
<td>CVE = 10 m E = 22%</td>
<td>CVE = 6 m E = 15%</td>
<td>CVE = 40 m E = 90%</td>
<td>Only wave action considered</td>
</tr>
<tr>
<td>(Fig. 4.42)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August 1998 to August 1999</td>
<td>CVE = 12 m E = 17%</td>
<td>CVE = 10 m E = 16%</td>
<td>CVE = 80 m E = 91%</td>
<td>Only wave action considered</td>
</tr>
<tr>
<td>(Fig. 4.43)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August 1999 to January 2000</td>
<td>CVE = 11 m E = 21%</td>
<td>CVE = 12 m E = 19%</td>
<td>CVE = 80 m E = 95%</td>
<td>Only wave action considered</td>
</tr>
<tr>
<td>(Fig. 4.44)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January 2000 to July 2000</td>
<td>CVE = 9 m E = 23%</td>
<td>CVE = 10 m E = 25%</td>
<td>CVE = 16 m E = 90%</td>
<td>Only wave action considered</td>
</tr>
<tr>
<td>(Fig. 4.45)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August 1999 to January 2000</td>
<td></td>
<td></td>
<td>CVE = 21 m E = 26%</td>
<td>Both wave and river flow considered</td>
</tr>
<tr>
<td>(Fig. 4.49)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Notes:

- CVE = average absolute difference between calculated and measured shoreline positions;
- \( E = \) average relative difference between calculated and measured shoreline positions = \( \frac{CVE}{\text{extent of erosion or accretion}} \times 100\% \)

The estimated results show that:

- Along Northern shoreline and Southern shoreline average CVE ≈ 10 m, and average E ≈ 20%, these results are acceptable.
- Can't apply GENESIS model to simulate shoreline change along River bank.
- Simulation of shoreline changes along River bank can be carried out by the combined action of wave and river flow.
4.6.7 Interpretation and prediction of shoreline changes

4.6.7.1 Interpretation of shoreline changes

The aim of shoreline modeling is to simulate long-term changes in shoreline position; effects of extreme events are assumed to be accounted in the verification processes. An extreme event is a natural process or engineering activity that causes a substantial, perhaps irreversible change in the shoreline position. Without documentation of such events, interpretation of shoreline changes could be a mistake. Examples of extreme events are storms of record that greatly erode the beach and dredging during construction of coastal structures. It is possible that one or more extreme events may have dominated shoreline changes over the interval between shoreline surveys. It is important to have documentation on extreme events so that shoreline and beach processes can be properly interpreted.

Shoreline changes caused by nature are shown in Table 4.9. Sudden change in shoreline positions is primarily caused by the short-term effects of storms. In general, coincidence with crossed hurricane is flood of rain, eventually, larger river discharge and river flow occur (Hung, 1995; Trinh, 2000). The exposure of the coastline determines the possible directions from which waves reach the coast, exposure also determines the most likely direction of longshore transport.

Present study shows that in recent years, change in shoreline in and around the Thubon River mouth is different than other period like during:

- Shoreline change by Hurricane FRITZ on 25-26/9/1997 (Figure 4.48)
- Shoreline change during July 2000 to September 2001 (Figure 4.45)

**Shoreline change by Hurricane FRITZ**

Storm variables and wave parameters for Hurricane FRITZ are shown in Figure 4.5. Also according to Trinh (2000) Hurricane FRITZ crossed Hoian area at 0h/25/9/1997, under the effects of hurricane (wave and surge over wash) a new
opening (approximately 200 m in width) was formed at Phuoctrach (Figure 4.48). The opening was closed after the passing of the Hurricane on 26/9/1997. During the passing of Hurricane FRITZ both water level and river discharge increased (Trinh, 2000).

Significant wave height pattern over Hoian area during the crossing of Hurricane FRITZ is shown in Figure 4.24. From Figure 4.24 it is clear that the coastline between Stations S1 and S2 (Phuoctrach) was in the wave energy convergent area, which was formed by Cham Island coastline. This wave energy streak crossed the Phuoctrach coastline when water level increased. Therefore, the coastline section at Phuoctrach breached, and formed a temporary opening. After hurricane crossed, cross-shore wave energy component reduced and due to large longshore sediment transport (towards south) the opening got filled up.

**Shoreline change during July 2000 to September 2001**

As described and discussed under Section 4.6.1, during this period, shoreline in and around the Thubon River mouth was changed with the magnitude of hundred meters, especially shoreline sections which lie in Cape Cuadai and Cape Anluong (Figure 4.45). Distribution features of wind characteristics off Hoian coast (Figure 4.17) shows that the wind characteristics were normal, except during the occurrence of Tropical Storm KAEMI in August 2000 (Figure 4.2) with the track nearly parallel to the Hoian coast for duration of about 12 hrs, which is longer than duration of normal hurricanes (about 6 hrs.). Storm variables and wave parameters for Tropical Storm KAEMI are shown in Figure 4.8. Significant wave height pattern over Hoian area during the crossing of Tropical Storm KAEMI are shown in Figure 4.27 and it indicates that:

- Northern shoreline: The breaking wave direction made longshore sediment transport moved towards south, so Cape Cuadai was accreted and expanded southward. In case of incident wave direction from NE, Thubon River mouth was falling in the wave shadow region of Cham Island. Hence from Caman to
Cape Cuadai breaking wave height had gradually decreased. Therefore, the extent of erosion also gradually decreased from Caman to Cape Cuadai.

- Southern shoreline: From Dongson to Cape Anluong breaking wave height was gradually decreasing, because Cape Anluong was falling in the wave shadow region of Cham Island. The breaking wave direction made longshore sediment transport moved northward (from Dongson to Cape Anluong). Shoreline section near Dongson was eroded by large breaking wave coming normal to the shoreline, this sediment was transported towards north and deposited in Cape Anluong.

- River bank: Combination of river flow and wave action caused river bank eroded and transported this sediment seaward and deposited at Cape Anluong. At westernmost section, which is the upstream limit of wave action, the sediment was deposited under the interaction between river flow and wave action.

But huge amount of sediment deposited at Cape Anluong indicates that along with the effects of storm wave, sediment discharge from Thubon River during flood season especially during the activity of Tropical Storm KAEMI have significant role to build-up Cape Anluong (Figure 4.45).

4.6.7.2 Prediction of shoreline changes

Prediction of shoreline change in and around the Thubon River mouth from September 2001 to September 2006 was carried out based on following conditions:

- Wave conditions were taken from the average value of wave parameters during 1997 to 2000, and all input parameters were kept similar to previous shoreline change computation.
- Starting shoreline positions were taken from the measured shoreline positions of September 2001.
- Prediction of shoreline changes at River bank considering the influence of wave and river flow during wet season. Whereas, during dry season, only wave action was considered.

Predicted shoreline change results show that (Figure 4.50):

- Northern shoreline: In general, shoreline will continuously erode with an average value of around -50 m and maximum value of -150 m will occur at PhuocTrach.

- Southern shoreline: Cape Anluong will erode with an average value of around -600 m, the remaining shoreline sections will accrete with an average value of around +70 m.
River bank: In general the shoreline will erode with an average value of around \(-60\) m during September 2001 to August 2003, and with an average value of around \(-95\) m during August 2003 to September 2006. Therefore, River bank will erode with average value of around \(-150\) m during 5 years (September 2001 to September 2006).

Also, the study shows that:

- The predicted extent of erosion during September 2001 to August 2003 along River bank was less than the measured one. That indicates that during the above-mentioned period river flow velocity was actually larger than the average one which was used.

- The predicted extent of erosion during September 2001 to August 2003 at Cape Anluong was relatively with good agreement with that of measured one. This indicates that under the influence of normal wave action Cape Anluong will erode and the accretion at Cape Anluong mainly caused from the deposition of sediment of Thubon River discharge.

The features of shoreline in and around the Thubon River mouth in August 2003 are shown in Plate 1.1, 4.3, and 4.4.

Based on the results of present study the tendency of shoreline change in and around the Thubon River mouth for further next recent years can be predicted as follows:

- Northern shoreline: The shoreline at Caman will be stable or slightly get eroded, shoreline at central and southern sections will be continuously eroded. Whereas, Cape Cuadai will continuously accrete and expand south-eastward.
Plate 4.3 Accretion at Cape Cuadai (on 5th August 2003)

Plate 4.4 Accretion at Cape Anluong (on 5th August 2003)
- Southern shoreline will continuously accrete.
- River bank will continuously erode.

From these predictions, the present study reveals that the possibility of Thubon River mouth system to move towards south-east direction.