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นางสาวอินทุรัตน์ เหล่างาม

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MARINE GEOLOGY AND COASTAL EROSION PROCESSES OF PATTAYA BAY, EASTERN THAILAND

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Earth Sciences
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จากการแปลภาพถ่ายทางอากาศด้วยเทคนิคการวิเคราะห์ข้อมูลด้วยระบบสารสนเทศภูมิศาสตร์รวม 7 ช่วงเวลา ได้แก่ ปีพ.ศ. 2495, 2510, 2517, 2537, 2539, 2545 และ 2554 แสดงให้เห็นถึงการลดลงของเนื้อที่ชายฝั่งอย่างชัดเจนจาก 35 เมตร เป็น 5 เมตร และผลการคำนวณพื้นที่หน้าหาดและอัตราเฉลี่ยการกัดเซาะชายฝั่งพบว่า อัตราเฉลี่ยการกัดเซาะช่วงระหว่างปีพ.ศ.2495-2539 อยู่ที่ -0.78 เมตร/ปี และอัตราเฉลี่ยการกัดเซาะระหว่างปีพ.ศ.2539-2554 จะอยู่ที่ -1.8 เมตร/ปี โดยการตรวจสอบสภาพสมดุลธรณีสัณฐานชายฝั่งอ่าวพัทยาด้วยโปรแกรม MEPBAY ได้ให้ผลเช่นเดียวกันว่า อ่าวพัทยามีลักษณะสมดุลแบบพลวัต ที่แสดงรูปแบบการกัดเซาะชายฝั่งในอนาคต

ในการทำความเข้าใจกระบวนการกัดเซาะชายฝั่ง ได้ทำการศึกษาการเคลื่อนที่ของตะกอนท้องน้ำ 2 ฤดูกาล ในช่วงระหว่างฤดูมรสุมตะวันออกเฉียงเหนือและมรสุมตะวันตกเฉียงใต้ ซึ่งแสดงให้เห็นว่าตะกอนมีการเคลื่อนที่สัมพันธ์กับลมมรสุมที่มีกำลังเพิ่มขึ้น และมีทิศทางที่มีผลกระทบต่อชายฝั่ง โดยได้รับผลกระทบจากการเปลี่ยนแปลงการใช้ที่ดิน ระบบท่อระบายน้ำ และโครงสร้างบริเวณชายฝั่ง เป็นตัวแปรที่ก่อให้เกิดการเปลี่ยนแปลงสภาพสมดุลพลังงานภายในอ่าวพัทยา

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ภาควิชา ธรณีวิทยา ลายมือชื่อนิสิต ....

สาขาวิชา โลกศาสตร์ ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

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INTHURAT HLAONGAM: MARINE GEOLOGY AND COASTAL EROSION PROCESSES OF PATTAYA BAY, EASTERN THAILAND. ADVISOR: PROF. THANAWAT JARUPONGSAKUL, Ph.D., pp.

Seven aerial images serials, covering 1952, 1967, 1974, 1994, 1996, 2002 and 2011, were used to calculate the coastal erosion areas in Pattaya Bay by GIS interpretations. The results clearly showed a decrease in the beach width from 35 m to 5 m. Also, there has been an apparent average rate of erosion of -0.78 m/y between 1952 and 1974 and of -1.8 m/y between 1994 and 2011. In addition, the use of the MEPBAY program to inspect the coastal stabilization of Pattaya Bay indicated the erosion patterns of Pattaya Bay.

To understand the coastal erosion processes, bottom sediment movements within the Southeast and Northeast Monsoon seasons, were inspected and found to correspond with the stronger wind speed and affected wave direction. Also, the changing land use patterns around the beach, pipeline system and coastal structures affected the coastal stabilization of Pattaya Bay.

The features of erosion were interpreted from six bathymetry maps of Pattaya Bay covering the years 1975, 1983, 1995, 2000, 2003 and 2011. These indicated that there is accumulated sediments offshore. Marine geology using boring log data revealed Holocene offshore sand bars with mud particles in the same pattern as that at the shore of Pattaya Bay. From this information, it can be concluded that the problem of erosion in Pattaya Bay in recent years has become more significant. With the current rate of coastal erosion, Pattaya beach is forecasted to have disappeared within five years.

Department: Geology Student's Signature ....
Field of Study: Earth Sciences Advisor's Signature ....
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CHAPTER I

INTRODUCTION

1.1. Statement of the problem

Shoreline erosion is one of the major problems that originate from severe weather, in terms of strong wind, wave and storm action, and is compounded by anthropogenic changes to the coastal and inland areas around the shore. Moreover, different marine coasts (geological and topological) will show different rates of erosion to otherwise the same broad factors. It is necessary to understand, and hence study the causes of erosion in order to determine the best solution for limiting coastal erosion, so as to preserve the coast, be that for inland protection, natural environment or marvelous tourist attractions (tourism industry and related economies), as in the case for the Pattaya Bay in Eastern Thailand.

The development of the coastal structure along Thailand's coast has proceeded with a lack of sediment budget and by 30 years ago some 485 km (23% of the net area) of the Gulf of Thailand's coasts had been eroded (Department of Marine and Coastal Resources, 2008)(1) because of insufficient foundations of the coastal structure. In addition to these direct local anthropogenic-mediated changes, global changes, both stochastic natural and progressive indirect anthropogenic changes (such as global warming)(2) have also contributed additional natural factors that are beyond the control of the local community or even country (Uehara et al., 2010)(3).

Pattaya Bay, in the Bang Lamung district, Chonburi province, is one of the most famous tourist attractions on the east coast of Thailand and attracts up to 5 million tourists each year from all over the world (Department of Tourism, 2008)(4). Because of this and the associated economics of such tourism, Pattaya was once called the pearl city of the eastern coast of Thailand. But since 1987, there has been serious erosion of the Pattaya Bay beach, in part from coastal structures along and nearby the beach with obvious damage that was not remedied (Aquatic Resources Research Institute: ARRI, 2011)(5). This has caused an increased level and rate of coastal erosion between 1996 and 2011. Recently, Pattaya Bay beach has experienced critical erosion during high tides. The data from the Department of Tourism for the 2007–2009 period revealed a 1.55-fold decrease in the number of tourists at Pattaya from 6,680,658 in 2007 to 4,305,998 in 2009. Moreover, an economical study revealed that the decreasing number of tourists was related to the decreasing amount and quality of the beach (ARRI, 2011)(6, 7). Thus, the coastal erosion has negatively affected the Pattaya economy in a broad sense.

Marine geology deals with the history of the sea and earth and its associated life, including the evaluation of coastal erosion along shorelines by natural factors, such as wind, wave, tide, current, bottom sediment and coastal morphology, and the alteration of these by anthropogenic activities. This information provides an understanding of the coastal process related to erosion. In the case of Pattaya Bay, this would include evaluation of which factors have the greatest impact on the erosion of Pattaya Bay beach.

Accordingly, evidence from the bathymetry charts of the Royal Thai Navy and the aerial image interpretation using the ArcGIS program, which allows monitoring of shoreline changes due to coastal erosion over time, were used. However, it is a complicated process to understand the coastal factors that affect a given shoreline system, and so to study the erosion pattern in Pattaya Bay requires a concentrated study only in this specific bay.

Because the Pattaya Bay coast greatly affects the general local public (and through its economic contribution, to a slight extent the national population), as well as the tourists, then local agencies and all citizens should be informed and given an opportunity to participate in implementing solutions for preventing coastal erosion.

1.2. Objectives

1.2.1. To study the marine geology of Pattaya Bay and the natural factors that influence coastal erosion, such as the wind, wave, tides, current bottom sediment movement and the coastal morphology of Pattaya Bay, including the erosion and accumulation patterns of sediments in the Pattaya Bay area during the two monsoon seasons each year.

1.2.2. To use the geographic information system (GIS) to monitor shoreline changes and calculate the average rate of erosion of Pattaya Bay beach during the period of 1952 to 2011.

1.3. Scope and limitations

1.3.1. Pattaya Bay, Bang Lamung district, Chonburi province, is located at Latitude 12° 55.3' – 12° 57.1' N and Longitude 100° 51.5' – 100° 53.2' E, and is the one of the most famous tourist attractions of the eastern coast of Thailand.

1.3.2. Study of the Marine Geology data of Pattaya Bay from the Seismic Survey report of the Department of Mineral Resources (2011)(8), the data from offshore borehole samples BH 1–12 from the ARRI (2011)(9), and the bathymetry chart maps of Royal Thai Navy to monitor offshore seafloor level changes of Pattaya Bay between 1975 and 2011.

1.3.3. Processing the hydro-oceanography, meteorology and coastal engineering data from the ARRI (2011)(5-7) to study the variables that influence coastal erosion, including the wind, wave, tides, current, bottom sediment and coastal morphology.

1.4. Literature review

Department of Public and Town Planning (2003)(10). The project of Sea Exploration and Restoration of Pattaya Beach, Chonburi, reported on the near shore sediment changes by monitoring the level of Pattaya beach profiles every 6 months from October 2000 to March 2003. The project was divided into two cases - seasonal variation and non-seasonal variation. The amount of sand was calculated from the sand above the reference level. Then, the Arcview program was used to calculate and to project the 3D model of the sea floor. They reported that the monsoon wind had a direct effect upon the seasonal sand movement. The north and central part of

Pattaya Bay had a sand erosion pattern, while the southern part from the pier to Pattaya Cape had a high rate of accumulation. They presented a mathematical prediction of the coastal area for every 5 years from the present to 30 years in the future, which gave an overview of the change of the Pattaya Bay coastal system. The prediction showed the north part of Pattaya Bay will have a greater rate of erosion and more erosion features than the southern part, which is supported by field studies. Nonetheless, the conclusion showed that the scenario is stable because of the rate of erosion is less than 1 m per year, lower than the threshold of erosion in Thailand.

Department of Marine and Coastal Resources by Paritad Charoensit (2008)(1). This study concentrated on the erosion and the balance of the east coast of the Gulf of Thailand, which covers a large coastal structure that was reported to be the main cause of the declination of sediment. In summary, the net movement of sediment along the coastal area of Pattaya Bay area from the south to the north was 94,886 m^3/y, while sediment transport from the north to the south of Pattaya Bay was 4,421 m^3/y, and so the amount of transported sediment flowing from the southern part of Pattaya Bay was 21.5-fold higher than that from the north, giving a net south to north flow of 90,465 m^3/y.

Department of Marine and Coastal Resources (2009)(11). The study aimed to solve the problem of coastal erosion and form an expansion plan for the port industrial area on the east coast. The study explored patterns of coastal erosion along the eastern coast of the Gulf of Thailand, including Pattaya Bay. The GIS analysis of the data from 1952 to 2008 was divided into the five periods of (i) 1952-2008, (ii) 1974-1990, (iii) 1990-1996, (iv) 1996-2002 and (v) 2002-2008. They found two different periods of erosion of the Pattaya Special Administrative Region in Po-Bye Cape, Crescent Beach, Kalom-pom Cape and Ao Ta-tum with an erosion rate of -0.69 m/y in the period 1990–1996 and a 3.4-fold higher rate of -2.35 m/year in 2002–2008.

Department of Mineral Resources (2011)(8). This geological survey map of the sea floor, using echo sounding and shallow seismic reflection profiling with high resolution, to sample 525 sediments. The results revealed that in the eastern area at map sheets 5135 II (Sriracha District) and 5134 I (Bang lamung district) there is a low-sloped sea bottom, with sand dunes on the sea floor including marine mud and sandy mud with shell fragments scattered over the open area. The geology of the sea floor sediment was divided into the two series of a lower and an upper sequence. The lower sequence had accumulated since the Late Pleistocene period in a terrestrial environment and had a depth of -2 to -46 m below the mean sea level (bmsl). The upper sequence has accumulated since the Holocene period as marine sediments by transgression of the sea since 10,000 years ago and has depth of 0 to 15 m bmsl. The offshore sand dunes of Pattaya Bay were hence classified as Holocene sand dunes.

John R.-C Hsu et al. (2010)(12). The application of the mathematical model predicted an equilibrium of the Pattaya Bay beach in the future. The authors created a parabolic bay shape equation (PBSE) to simulate the scenarios into a state of equilibrium of the beach. The required important variables in the equation were the angle between significant waves (incident wave crest), with effect to the point (wave diffraction point), and the control (control line). This is a useful technique to manage coastal areas to mitigate and treat the shoreline with an academic theory.

Uehara et al. (2010)(3). The study evaluated the coastal erosion process at the Chao Phraya River Delta, and used the interpretation of a numerical simulation model. They summarized that the erosion condition is a seasonal variable of the wave and tides in the area. The seasonal variation of the sea floor elevation also had an effect through the wave height and direction via affecting the sediment movement. Accretion processes during the transitional period with the SW monsoon were determined by the direction of the wave energy flux, while the erosion process during the NE monsoon was affected by the dissipation of wave energy and tides. Moreover, the erosion and deposition pattern in the SW monsoon caused the water to discharge from the main canal that resulted in a large volume of sediment, especially after intensive rainfall in the area. The study revealed the importance of sediment monitoring along a coastal area to understand the coastal erosion processes.

Komar & Holman (1986)(13). This study evaluated the coastal erosion process and development of an erosion shoreline along the east coast of the United States of America. By overlay aerial photographs, the variation in the beach shoreline and wave processes were revealed. In conclusion, coastal processes and physical features of coastline indicate numerical equations and events.

1.5. Methodology

In this study of the coastal erosion process at Pattaya Bay, geographic information, marine geology, meteorology, hydro-oceanography, coastal engineering and geomorphology were used together to carefully describe the erosion phenomena of Pattaya Bay. All these information were compiled into a new consensus sequence including a comparative analysis and evaluation to find the main causes of the coastal erosion of Pattaya Bay. In addition, sediments were collected from the shore to offshore region of Pattaya Bay in each of the two monsoon seasons to evaluate the distribution of the sediments, which were then displayed graphically to compare the sediment patterns and any seasonal changes. The results of the field data helped to explain the erosion phenomenon. The approach taken to evaluate the studies and results of the Pattaya Bay erosion from past to present are summarized in the algorithm shown in Figure 1.

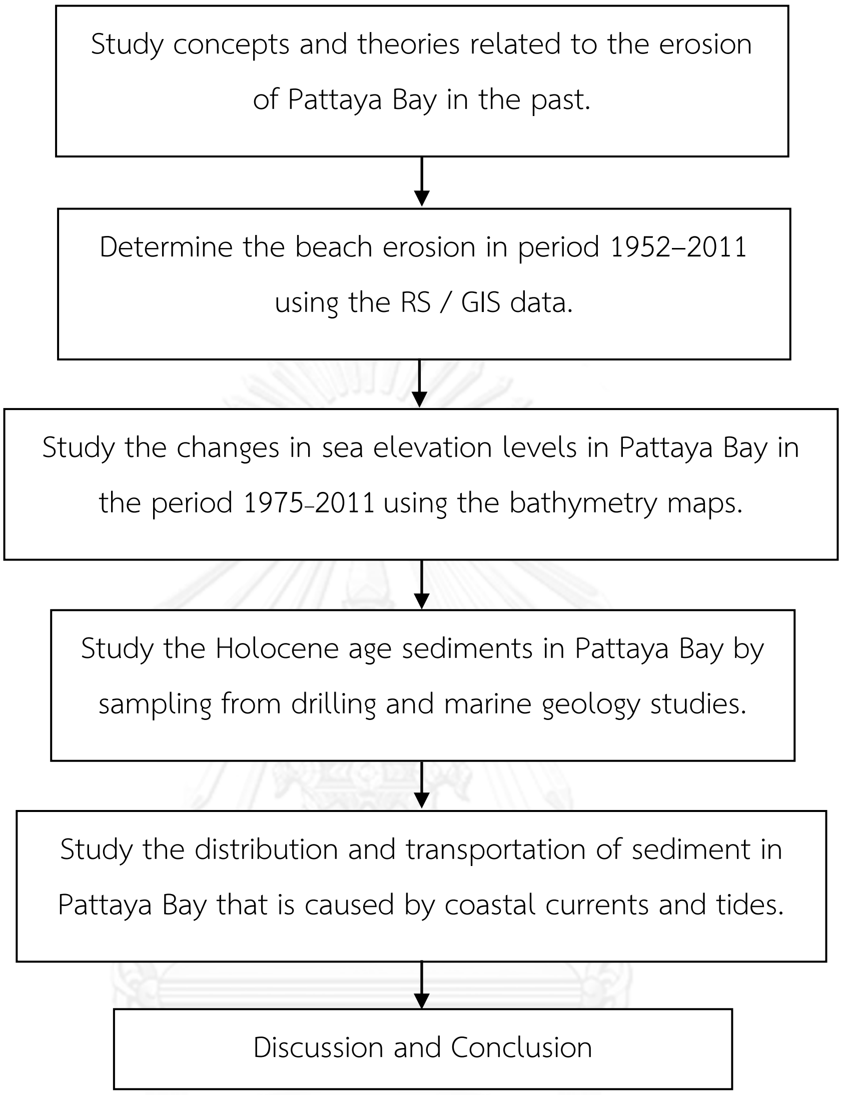


Figure 1 lgorithm of the approach used in this study.

1.6. Expected outputs

1.6.1. To improve the understanding of the processes that affect coastal beach erosion from both theoretical and practical information of the area in combination with the field data.

1.6.2. To identify and publicize the principal causes and processes of beach erosion to guide the appropriate future planning and development of the area.

CHAPTER II
PHYSIOGRAPHY OF THE PATTAYA BAY

2.1. Generalization

Pattaya is part of the special administrative region in Bang Lamung District, Chonburi province, in the eastern part of Thailand. It is located about 150 km southeast of Bangkok (the capital City of Thailand) at a latitude of 12° 55.3' N to 12° 57.1' N longitude and 100° 51.5' E to 100° 53.2' E (Figure 2).

Including Lan Island, Pattaya encompasses a total area of 208.10 km^2 (or 51,428.43 acres) and is comprised of the four districts of Nong Prue, Huay Yai, Nong Pla Lai and Na Kluea. The surrounding adjacent areas are the Gating Lai canal to the north, the area of the Huay Yai subdistrict to the south, Pattaya Sai 1 Rd. and Pattaya Beach Rd. to the east and the coast of The Gulf of Thailand to the west.

2.2. Topography

Most areas of Pattaya Bay are in the Nong Prue district but with some parts in the other three districts (Na Kluea, Huai Yai and Nong Pla Lai). The topography is mostly flat with a few hills to the plains, from where the site of the commercial sources can be seen. The residential area is located next to the beach on the upper part. The mountain is surrounded by low hills of less than 100 m above mean sea level (amsl). From the north the mountain (at about 35 m amsl) continues southwards to the low hills of Khao Noi, Khao Talo and Khao Sao Tong at about 65 m amsl. These hills are connected to the beach at the west side of Pattaya at a height of about 98 m amsl forming coastal plains between the hills that are located in the upper and the lower parts. The upper area is mostly located in the Na Kluea district, which is the hub of the community, whilst the lower plain is a long strip parallel to and about 1 km away from the coast. The hills and plains cause a natural drainage system. The canals, such as the Na Kluea, Sue Paew and Pattaya Canals, are generally small and are shallow in the dry season. There are also some nine (three principal) islands up to 8 km away from the coast, such as Koh Larn (the largest), Koh Krok and Koh Sak (Figure 2).

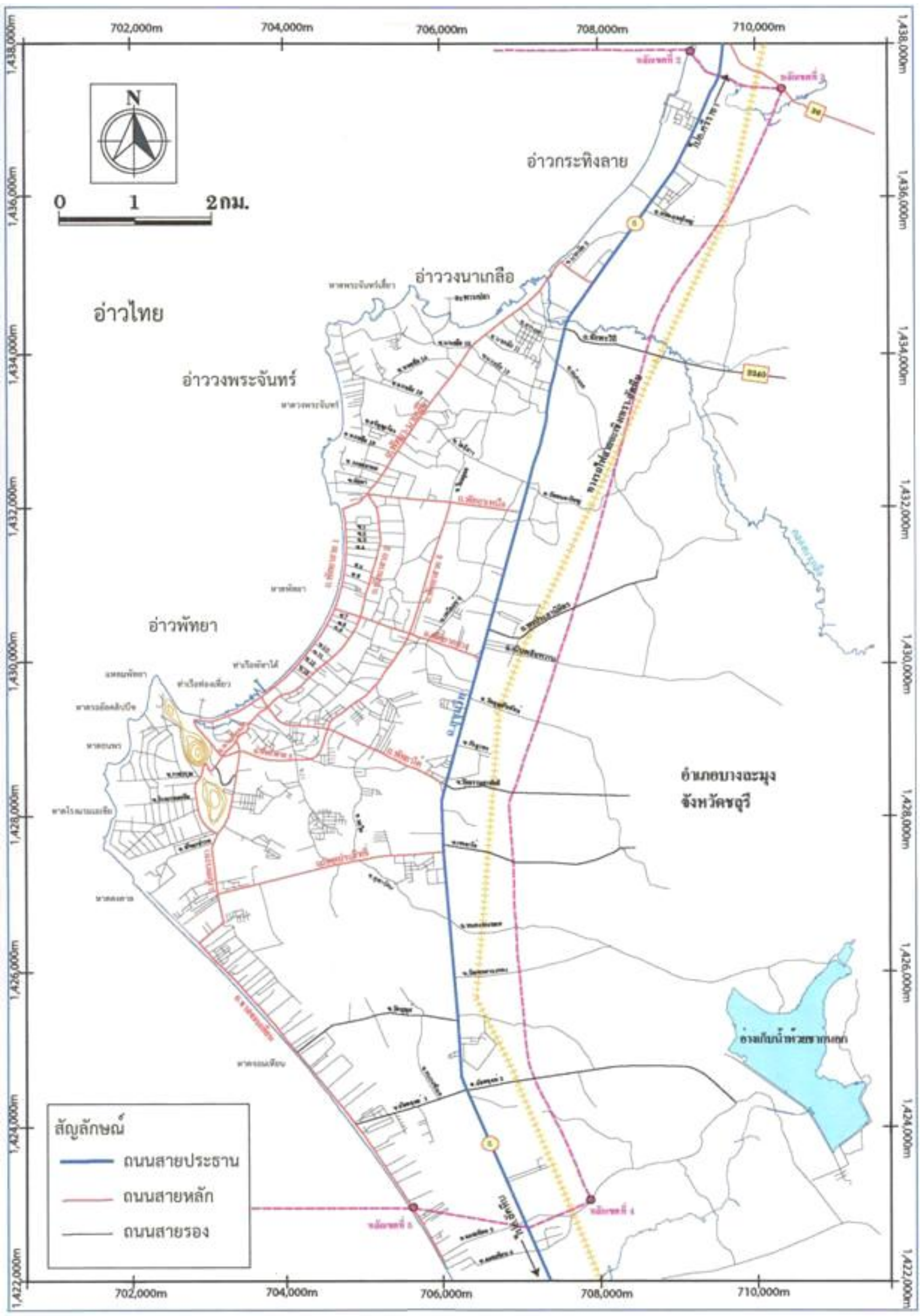


Figure 2 Map of mainland Pattaya (Pattaya City Hall, Chonburi, 2011: Online)(14)

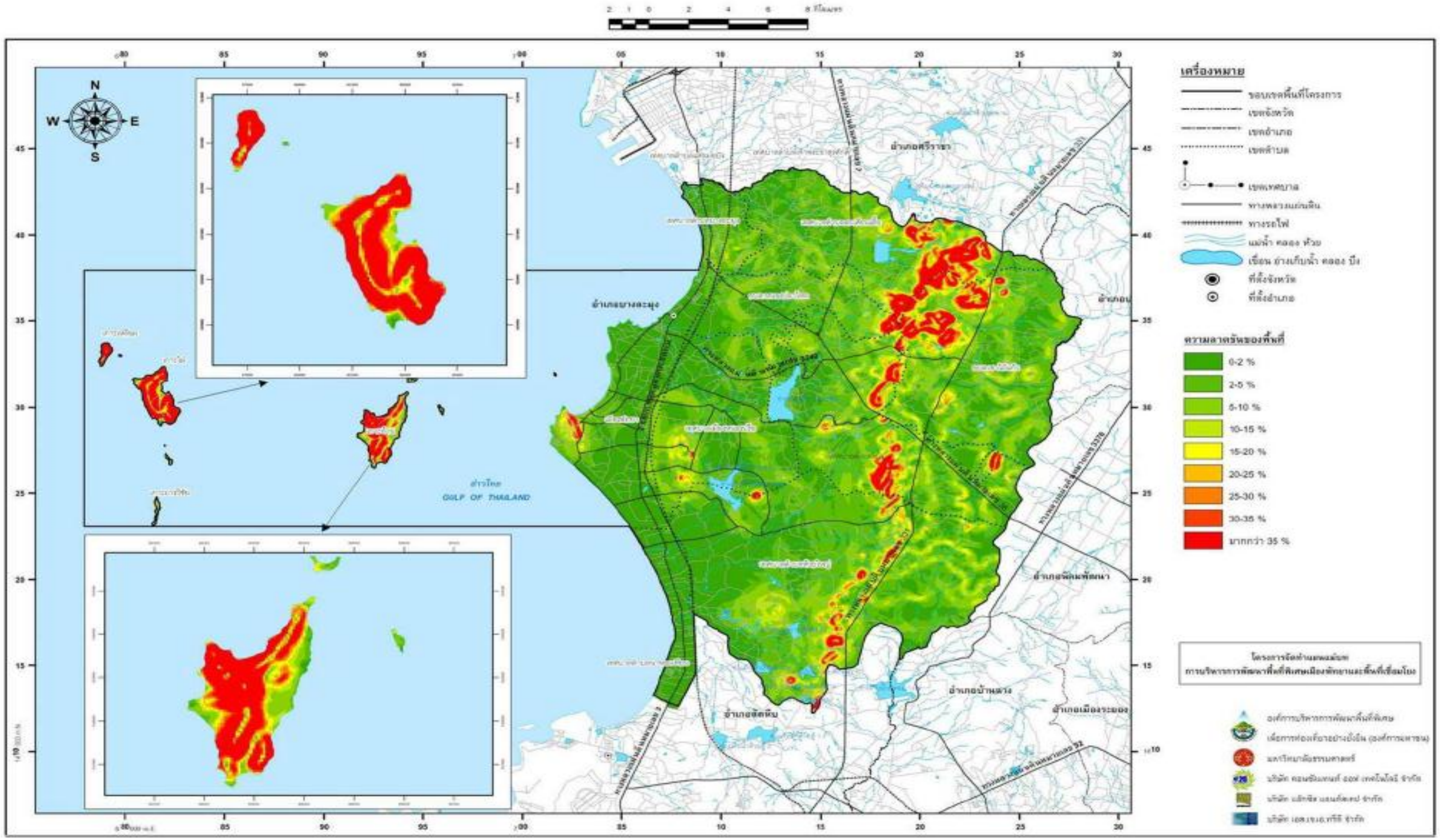


Figure 3 Topographic map of the eastern coast of The Gulf of Thailand in the region of Pattaya Bay (Thammasart University Research and Consultancy Institute, 2010). (15)

2.3. Soil characteristics

The monitoring plan of the Land Development Department reported the soil types found in the Pattaya bay region, as shown in Figure 4 and summarized below.

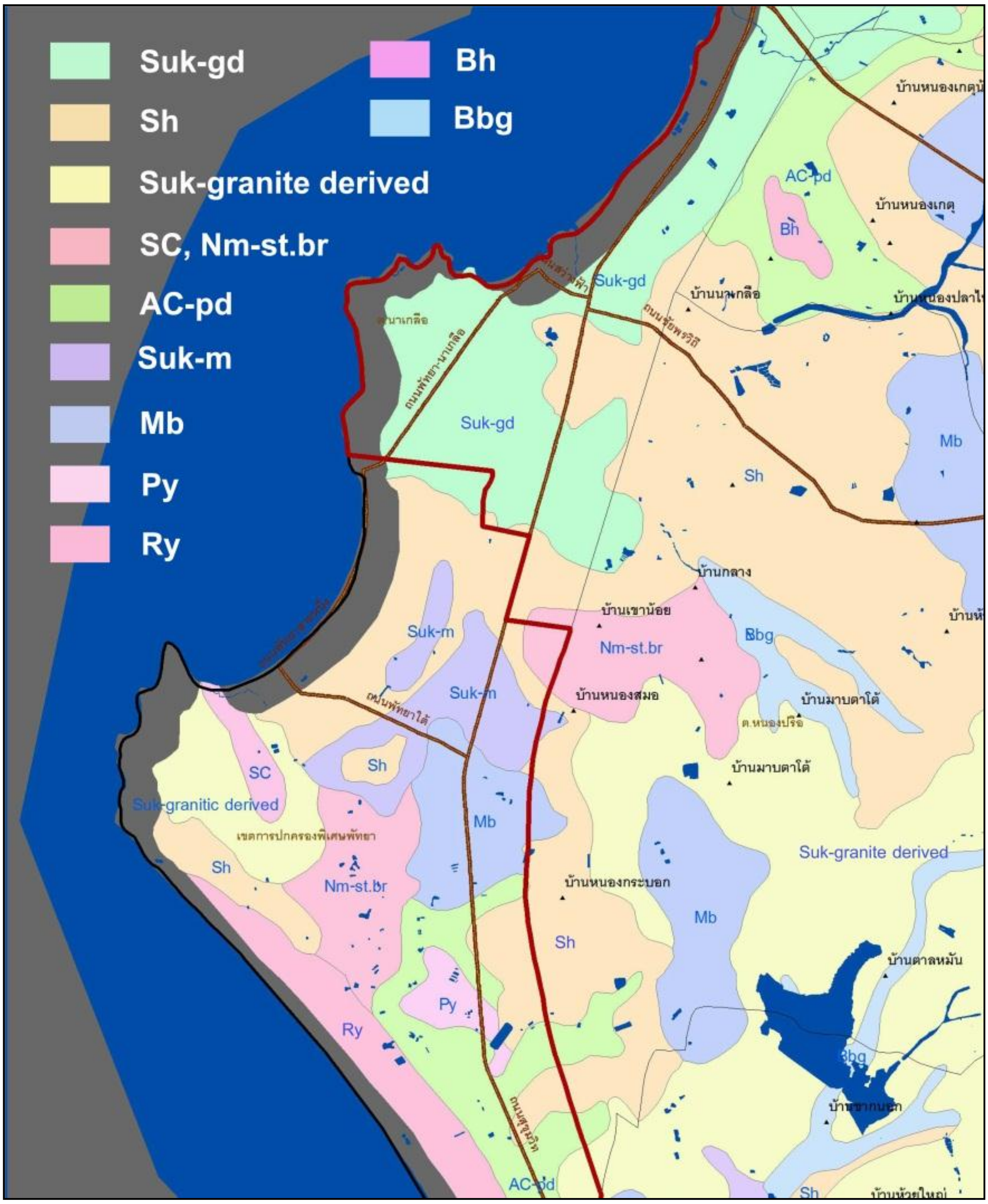


Figure 4 The soil types and locations in Pattaya bay

(adapted from the Land Development Department, 2004: Online) (16)

2.3.1. Sattahip series (Sh). Formed from the weathering process of granite rock, and / or moving a short distance by the force of gravity. The Sattahip series is found in an undulating terrain environment with a slope of 2–5%, is well drained and the highest permeability is in the deep layer. This soil type is a sandy loam, pink-grey in color, and is moderately acidic to neutral (pH 6.0–7.0). The upper soil layer is moderately to slightly acidic (pH 6.0–6.5). The lower soil layer has a low absorbency and is not suitable for growing crops.

2.3.2. Chonburi series (Cb). Formed by alluvium deposits on marine sediments around the coastal plains, it is found in a smooth flat area with a slope of 0–2%, is poorly drained and has a moderate permeability. The soil texture is a deep fine loamy soil. The upper soil texture is a sandy loam or sandy clay loam with a brown-grey color, slightly acidic to moderate alkaline (pH 6.5–8.0). The lower soil texture is a sandy clay loam with a grey, brownish-grey or pinkish-grey color, but the deep layers are a medium to coarse sandy clay. The soil is neutral to alkaline (pH 7.0–8.5) with a brown, russet or yellowish-red mottled color to all layers. At about 1.5 m depth from the surface is often found a rough soil with a greyish-blue color. Like marine sediments, it is suitable for farming.

2.3.3. Phattaya series (Py). Formed from alluvial sediments deposited on marine sediments along the coastal plains (beach sand), it is found in relatively flat or slightly undulating area (slopes of 1–5%). The soil (which used to be old sandy beaches) is well drained and very permeable, with a coarse sandy texture of a brown color and moderately acidic to neutral (pH 6.0–7.0). However, it is of a low fertility throughout the soil profile with a poor ability to absorb water and so is not suitable for cropping in general, except for some plants, such as coconut or cassava.

2.3.4. Rayong series (Ry). Formed from alluvial sediment deposits on marine sediments along the coastal plains with a relatively flat terrain (slopes of 0–1%), it is well drained with a high permeability. This soil type is found spread along the old coastal dunes and can be very deep. The upper soil layer is a sandy loam of a greyish-brown color and is acidic to neutral (pH 5.5–7.0). The lower soil layer is sandy with a brown or grey color and is moderately to slightly acidic (pH 6.0–6.5). The soil has a low fertility and ability to absorb water, and is only suitable for cultivation of some plants, such as coconut or jujube.

2.3.5. Satuk series (Suk). Formed from old fluvial deposits in undulating areas with slopes of 2–8%, this is a deep, well-drained and moderately permeable soil. The upper soil is a loamy sand with a brown, dark grey or dark brown color. The lower soil is a sandy loam or clay loam soil of a dark-brown, yellowish brown or reddish-yellow color and ranges from acidic to slightly acidic (pH 5.5–6.5), but it is strongly acidic (pH 4.5–5.0) in the deep layers. As found in the Pattaya Bay area, like Suk-gd, it has a deep gravel subsoil within which there is only a low amount of nutrients.

2.3.6. Mab Bon series (Mb). This is a fine textured and deep soil formed from fluvial deposits. It is strongly acidic, moderately drained, with a low fertility and water retention. In areas with steep slopes the soil is easily eroded.

2.3.7. Nong Mot series (Nm). This was formed by the decomposition of decaying granite rock around the mountain areas and incorporating soil material that moved in from nearby areas through gravity. The area is slightly undulating or hilly with slopes of 4–35%, well drained, moderately permeable and deep. The upper soil is loamy or loamy clay, dark brown to very dark greyish-brown in color, and extremely to moderately acidic (pH 5.0–6.0). The lower soil is clay or sandy clay, yellowish-red to red in color and very strongly to strongly acidic (pH 4.5–5.5). These soils have a low fertility and those in areas of a high slope are easily leached.

2.3.8. Ban Bueng series (Bbg). Formed from the alluvium or alluvial fan of the parent granite rock, it is located in a smooth and relatively flat area with slopes of 0–2%. The soil is moderately well to fairly poorly drained but with a good permeability. The upper soil is a sandy loam of a brown color with grey mottles or a yellowish-brown and brownish-yellow color, and is acidic to moderately acidic (pH 5.5–6.0). The lower soil is a loamy sand, grey or brown in color with yellow mottles in the deep layer, and is slightly acidic to moderately alkaline (pH 6.5–8.0) throughout the soil profile. It has a low soil fertility and in the rainy season it can originate shallow groundwater or water logging but with water shortages in the dry season. It is suitable for growing sugarcane or cassava.

2.3.9. Ban Thon series (Bh). This soil originated from old beach sand or sand dunes and is found spread along old beach sand or sand dunes in the coastal area in rather flat or slightly undulating terrain (slopes of 1–5%), with a well-drained and permeable upper soil and moderately to fairly poor drained lower soil. The sandy soil is of moderate thickness to deep, extending down to the organic bedrock. The upper soil is a loamy sand, grey or greyish brown in color, and acidic to moderately acidic (pH 5.5–6.0). The lower sandy soil has a white color on top with the next layer having a depth of 50–100 m and is dark brown or reddish brown in color due to the accumulated humus and aluminum. It also sometimes contains some iron settled on the loamy sand soil with a light brown or brownish-grey color and mottled. The ability to absorb water is very low and it is strongly to moderately acidic (pH 5.0–6.0) and has a low fertility. Poor water adsorption leads to a water shortage during the dry season. The organic bedrock within 100 m depth is suitable for making pastures but less suitable for growing cashew.

2.3.10. Alluvial complex, poorly drained (AC-pd). A group of coarse or fine loamy soils that were formed from complex alluvial deposits. The soil layer has switched and the texture is unstable, depending on the deposited sediment, and ranges from acidic to neutral and poorly to fairly poorly drained with a low soil fertility. The poor drainage can lead to flooding. When improved, it can be used for growing rice or other crops, like vegetables, fruit or legumes.

2.3.11. Slope complex (SC). This soil type is located within the mountainous area on a slope of more than 35% and has both deep and shallow soils. The characteristics of the soil and natural fertility of the rock vary depending on the type of the originating rocks in the area. The soil surface often has scattered rubble, stones or outcrops. The soil is not suitable for cultivation because it is shallow with mostly rocky outcrops on the surface, whilst the steep slope makes it prone to erosion. Thus, it should be preserved rather than cultivation attempted.

2.4. Geological features

The geological features of the area include the three main rock types as described below, and summarized in Figure 2.4-1.

2.4.1. Qa : Alluvium deposit, beach sand and river gravel. This is comprised of accumulated soil and gravel transported by water in the Quaternary period. Today, this feature is found in the upper area of Pattaya city.

2.4.2. Qb : Recent sand beach, sand, silt and shell fragment. This feature can see normally at Pattaya beach, north and south. It contain with shell fragment dominantly in sand composition which formed in Quaternary period.

2.4.3. Qc : High and low terrace deposite, laterite, gravel, sand, silt and clay. This is another feature of Pattaya bay and surrounding area which formed in Quaternary period. It consists of various group of sediments included laterite.

2.4.4. CP : Sandstone, red to deep red, fine to medium-grained; Conglomerate; pebby sandstone; light gray tuffaceous shale with chert interbedded. Formed in the Carboniferous period from the sedimentary and metamorphic rocks of the Ratburi group It consists of a group of shale and sandstone, can be seen in many areas along the coast from the north to the south of the city (mostly at Koh Lan island).

2.4.5. O : Yellowish-brown quartzite; quartz schist; gray slaty-shale; black slate; quartzitic sandstone interbedded with dark gray argillaceous limestone with fossil of nautiloid. This feature can found at Pattaya cape, south Pattaya. It formed in Carbonferous age. Fossils is dominantly in this feature with dark color.

2.4.6. $\overline{\mathrm{R}}$gr : Medium to coarse grained, porphyritic hornblende-biotite granite; mesocratic biotite granite. Igneous rock formed in the Triassic period and is commonly found along the coast. In Pattaya Bay region can be seen at Pattaya cape and Wong-amart bay, especially in Wong-amart bay at the north of Pattaya Bay.

Figure 5 Geologic map of Pattaya Bay

(adapted from geologic map scale 1:250,000 DMR, 1976) (17)

2.5. Climate

The general climate of Pattaya City is influenced by the Southwest (SW) and Northeast (NE) monsoon winds that influence the three seasons (rainy season, winter and summer). In addition to these monsoon winds, the climate is also influenced by tropical storm winds from the Bay of Bengal, a temporary wind that causes a large amount of rain in the area. The rainy season begins from mid-May and lasts until mid-October due to the SW monsoon wind that brings moist air and rain to the area. The winter season begins from mid-October and lasts until mid-February when the

NE monsoon wind blows cool-dry air to the region resulting in a lower temperature in December and January. The transition period of mid-February to mid-May is the summer period with higher temperatures, especially in April.

The meteorological data from a recent 30-y period (1971–2000), as summarized in Table 2.5-1, from the Pattaya meteorological station, revealed that the city had an annual average temperature of 27.7 °C over this period with monthly averages over this period varying from 26.2 ^{o}C to 29.2 ^{o}C. The monthly extended minimum and maximum temperatures were 14.6 ^{o}C and 37.3 ^{o}C. The average monthly relative humidity ranged from 70% to 84% with an all year average of 77%. The average monthly rainfall varied from 6.4 to 240.8 mm, with the highest and lowest average rainfall in October and December, respectively, every year. The annual average rainfall and evaporation was 1,123.8 mm and 1,800.7 mm, respectively, with the highest and lowest water vapor (evaporation) level in April and October, respectively. The average monthly wind speed ranged between 3.9 knots (September and October) to 6.5 knots (December), and came from the northeast during October to January of each year and S to SW the rest of the year.

2.6. Economic characteristics

Pattaya is a popular tourist attraction for tourists from Thailand and foreigners. The city has developed both economically and structurally as a center for tourism-related activities and services. Around 87% of the population is employed in trade and services, with the remainder in various occupations like agriculture, fisheries and industry. The level of trading revenue generated is ~270,000 baht person^{-1} y^{-1}, and is derived from the three main categories detailed below (www.pattaya.go.th)(18).

Table 1 Climate statistics[a,b] over the 30-y period (1971-2000) for the Pattaya bay region

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Mean	1012.3	1011.4	1010.2	1008.7	1007.6	1007.1	1007.2	1007.4	1008.4	1009.8	1011.1	1012.7	1009.5
Ext. max.	1021.4	1020.0	1019.8	1016.3	1013.5	1012.9	1013.0	1013.6	1016.0	1017.0	1019.2	1021.8	1021.8
Ext. min.	1001.5	1002.8	1001.7	1000.1	1001.0	1000.3	1000.4	1000.5	1001.5	1002.4	1003.7	1006.0	1000.1
Mean daily range	4.1	4.2	4.3	4.3	3.9	3.4	3.3	3.5	4.0	4.1	4.1	4.1	
Temperature (Celsius)													
Mean	26.2	27.2	28.2	29.2	29.2	28.9	28.4	28.3	27.6	26.9	26.5	25.6	27.7
Mean max.	30.6	31.0	31.8	32.8	32.4	31.6	31.3	31.1	31.0	30.6	30.4	29.8	31.2
Mean min.	23.0	24.4	25.5	26.5	26.5	26.5	26.0	26.0	25.1	24.2	23.4	22.1	24.9
Ext. max.	36.0	37.1	37.3	37.0	36.0	35.4	34.9	34.2	33.6	33.7	34.8	35.9	
Ext. min.	16.4	19.3	17.7	20.8	22.2	22.5	21.4	22.5	21.7	19.8	16.7	14.6	14.6
Relative Humidity (%)													
Mean	73	76	77	77	78	76	77	77	82	84	77	70	77
Mean max.	86	88	88	88	88	86	86	86	90	93	87	81	87
Mean min.	59	62	63	63	66	67	67	67	70	71	64	57	65
Ext. min.	20	24	25	37	39	45	49	50	52	42	36	32	20
Dew Point (Celsius)													
Mean	20.9	22.4	23.6	24.6	24.7	24.6	23.8	23.8	24.0	23.6	21.7	19.6	23.1
Evaporation (mm.)													
Mean-pan	137.9	143.7	178.8	174.1	164.7	161.8	159.9	160.4	131.1	114.9	129.1	144.3	1800.7
Cloudiness (0-10)													
Mean	3.6	3.8	4.2	5.2	6.9	7.9	8.0	8.3	8.1	7.3	5.1	3.6	6.0
Sunshine Duration (hr.)													
Mean													
Visibility (km.)													
0700 L.S.T.	5.6	6.5	7.4	8.3	10.6	11.5	11.4	11.0	10.4	8.5	7.6	6.2	8.8
Mean	6.8	8.0	8.7	9.2	11.6	12.1	12.0	11.7	11.3	9.1	8.3	7.1	9.7
Wind (Knots)													
Mean wind speed	4.1	4.3	4.8	4.1	4.1	6.2	5.7	6.0	3.9	3.9	5.7	6.5	-
Prevailing wind	NE	SW	S	SW	SW	SW	SW	SW	SW	NE	NE	NE	-
Max. wind speed	24	30	28	32	30	38	35	35	35	30	35	35	38
Rainfall (mm.)													
Mean	13.9	12.2	45.2	63.6	156.1	104.2	91.0	92.0	214.7	240.8	83.7	6.4	1123.8
Mean rainy day	1.5	2.3	4.2	5.8	12.1	11.6	12.6	13.0	17.1	18.2	7.2	1.2	106.8
Daily maximum	88.2	33.3	81.8	78.6	113.3	99.4	76.6	60.1	117.1	108.2	81.8	48.6	117.1
Number of days with													
Haze	16.2	9.5	9.4	7.9	1.2	0.4	0.5	0.1	0.3	3.0	10.5	21.7	80.7
Fog	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.6
Hail	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Thunderstorm	0.6	1.7	3.8	8.2	12.0	6.1	6.0	**5.4**	12.4	14.3	5.1	0.4	76.0

[a] Data, from the Pattaya (Phatthaya) meteorological station, are taken from the Thai Meteorological Department (2011)(19). Second row needs to be labeled “Pressure (10^{-1} kPa)”

[b] Details of the Phatthaya meteorological station (Index 48461) are as follows: 12^{o} 55’ N 100 ^{o} 52’ E, 59.0 m amsl. Barometer, thermometer, wind vane and rain gauge at 2.0, 1.2, 10 and 0.8 m above ground level, respectively.

2.6.1. Industry. Tourism is the most important economic activity of the city. Current employment in the travel industry accounts for more than 90% of the workforce in this area. Employment includes services in hotels, bungalows, nightclubs, etc. Only 3% of the work force is employed in industrial plants, including the manufacturing of concrete blocks and slabs, doors and window frames, and the processing of tapioca and cassava.

2.6.2. Agriculture. Agricultural areas of the city are located in the Tambon Huay Yai and Nong Pla La areas and principally cultivate cassava, pineapple and coconuts. Only around 3% of the population is employed in agriculture, largely because land prices are too high to make agriculture an economically viable investment.

2.6.3. Commerce and services. Pattaya city has a commercial complex that accounts for about 4% of the regional employment. These include the retail business, import-export and services to tourists, such as sale or rental of facilities and entertainment to tourists, including motorcycles, boats, jet skis, rental boats, parasailing and banana boat. There are 556 hotels and residences, 86 resorts, 96 guesthouses, eight bungalows, 20 banks (150 branches), 19 gas stations, 2 LPG service stations, 3 NGV stations, 32 shopping centers (general, computers and furniture), 993 restaurants, 634 entertainment venues (including beer bars) and also 62 attractions. In addition, there are 15 markets (Pho Lan, Pattaya Bazaar, Naklua, Buakaw, Tony Bazaar Village, Sophon, Amorn Nakhon, Lotus Central Pattaya, Potisan Center, Housing, Peerapol, Mother Wilai night, Wat Dhum Samakki, Rom Pho and Tops one markets).

2.7. Land use characteristics

The field survey for the evaluation and improvement of Pattaya City in 2010 (Department of Public Works and Town and Country Planning, 2010 cited in ARRI, 2011)(7) classified the land use of the urban areas in Pattaya City with respect to the land types, as detailed below and summarized in Table 2 and Figure 6.

Table 2 Details of the land use in Pattaya City

Type of land use	Area	
	Km^2	Percent
Residential	23.07	12.47
Commercial	7.89	4.26
Industrial and warehouses	0.99	0.54
Educational institutions	1.02	0.55
Religious institutions	0.80	0.43
Government sector	0.98	0.53
Recreation and leisure	0.48	0.26
Roads, alleys and lanes	6.38	3.45
River canals and marshes	7.55	4.08
Agriculture and unoccupied areas	135.84	73.43
Total	185.00	100.00

(Department of Public Works and Town & Country Planning, 2010 cited in ARRI, 2011)(7)

2.7.1. Unoccupied and agriculture. Comprised of a total area of 135.84 km^2 (73.43% of the total area), it is mostly unoccupied land with only a small amount as agricultural, which is mainly the cultivation of rice or tapioca, and is mainly located in the area of the Nong Pla Lai, Pong, Nong Prue and Huay Yai subdistricts. There is no agricultural area in Pattaya City itself.

2.7.2. Residential. With a total area of 23.07 km^2 (12.47% of the total area) this is the second largest land use category, but if unoccupied land is excluded then residential is the largest anthropogenic land use of the Pattaya City area. Areas with the highest density of residential land use include the community at the side road of Pattaya-Naklua, which originally settled around Phraya Rd. and Sukhumvit Rd., followed by the area east of Sukhumvit Rd., in Nong Prue Municipality, including Nern Plub Wan Rd., Pornprapa Nimit Rd. and Khao Talo Rd.

2.7.3. Commercial. Covers an area of about 7.89 km^2 (4.26% of the total area). The most dense areas of commercial land use include the commercial street of North Pattaya Rd. to South Pattaya Rd. and, especially, Pattaya Beach Road and Pattaya 2^{nd} Rd. in the central business district with shops, restaurants, hotels, resorts and entertainment services on both sides of the road. In addition, there are the stores or commercial areas by the major roads, including Thep Prasit Rd., Sukhumvit Rd. and Jomtien Rd.

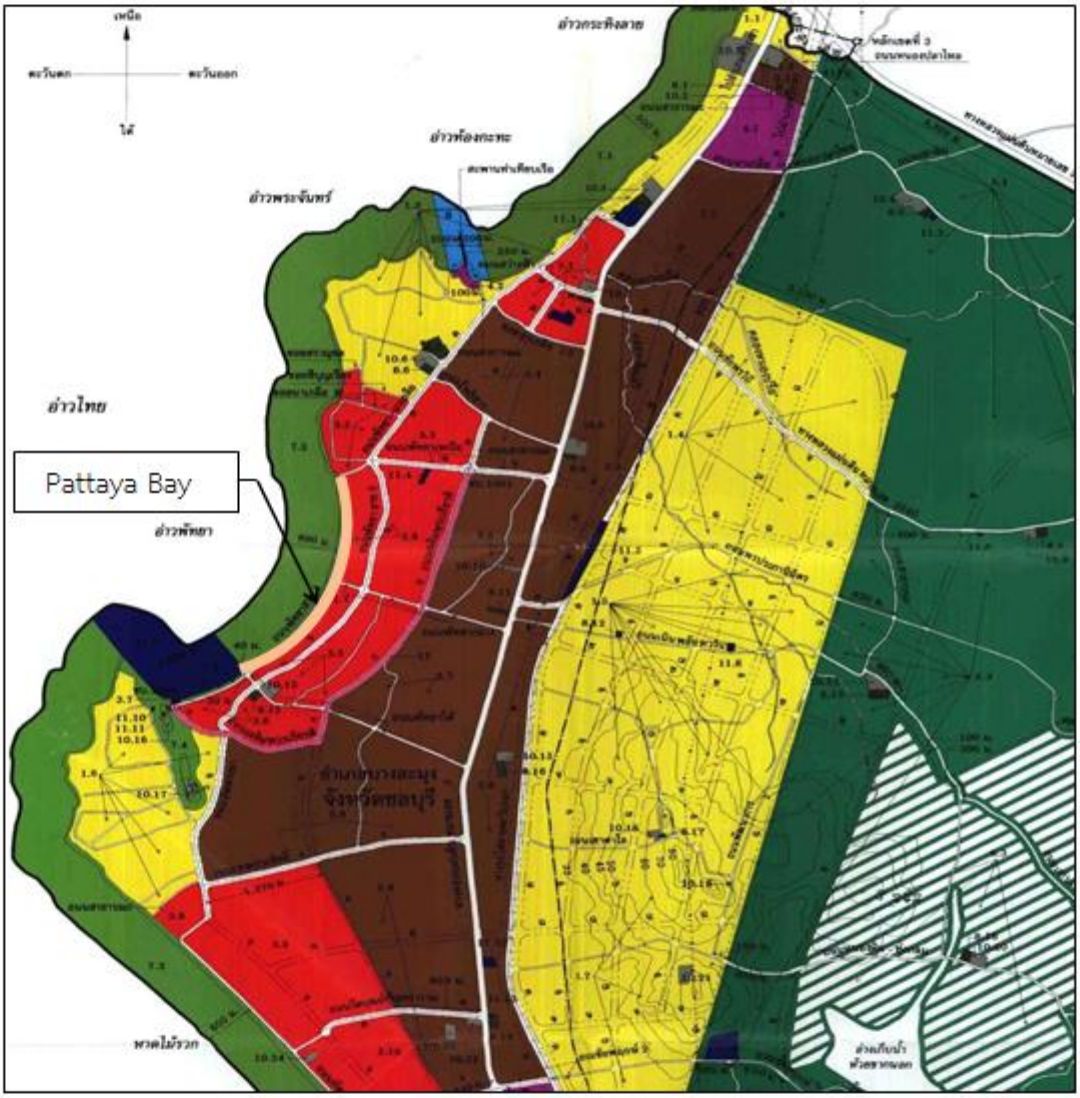
2.7.4. River canals and marshes. River canals and swamps cover a total of 7.55 km^2 (4.08% of the total area), with a specific stream flow direction of from the east to the west. The city has two dams (Mabprachan and Chak Nok reservoirs) with four main canals that run through the city to the sea (Na Kluea, Nong Prue, Sue Paew and Huay Yai (Yai brook) canals) as well as other minor ones.

2.7.5. Roads, alleys and lanes. Comprised of 6.38 km^2 (3.45% of the total area), the majority are found on the west side of the railway tracks, including Sukhumvit Rd., Pattaya-Naklua Rd., North Pattaya Rd., Central Pattaya Rd., South Pattaya Rd., Thep Prasit Rd. Pattaya 1st Rd. and Pattaya 2nd Rd. On the east side of the railway is a minor road with narrow streets, including Nong Pla Lai - Mabprachan Rd., Pornprapanimit Rd., Nernplubwan Rd. and Sukhumvit - Huai Yai Rd. etc.

2.7.6. Educational institutions. Covers 1.02 km^2 (0.55% of the total area) with clusters of schools or academies along Sukhumvit Rd., which is the main road in Pattaya City. Other areas are spread by the aboriginal communities in conjunction with the monastery.

2.7.7. Industrial and warehouses. Comprises 0.99 km^2 (0.53% of the total area), with a vague pattern of distribution of industries in the city, but they are mainly distributed along Sukhumvit Rd., Highway 36, Highway 3240 (Chaiyapornwidhi Rd.) etc., and are largely small scale industries, such as engine repair workshops within a row of houses.

2.7.8. Government sector. Covering 0.98 km^2 (0.53% of the total area) percent, the government agencies include local and regional government and are dispersed along Sukhumvit Rd., North Pattaya Rd., Central Pattaya Rd., South Pattaya Rd., Highway 3240.



Legend

Low density residental land	Land for open space, recreation and environmental protection
High density residental land	Clearing land for environmental conservation and fisheries.
Commercial land	Educational institution land
Specific Industrial land	Religious institutional land
Rural and Agricultural land	Transportation and transitional land
Rural and Agricultural land preservation	
Government institutional land and public utilities land	

Figure 6 Location of the different land uses in Pattaya Bay and City area.

(adapted from the Department of Public Works and Town & Country Planning, 2003) (10)

2.7.9. Religious places. Covering 0.80 km^2 (0.43% of the total area), they are spread along Sukhumvit Rd. with aboriginal communities including schools and temples.

2.7.10. Recreation and leisure. Covering 0.48 km^2 (0.26% of the total area) when parks are included. Although there are only few recreation areas they are largely replaced in interest and use by the beach and associated activities as well as the many other tourist attractions

2.8. Pattaya City history and development to the city of economic tourism

Pattaya, originally named "Phatthaya", was a peaceful seaside village that was used as a rendezvous location of King Taksin’s troops because of its relaxing and fascinating ambiance. It is now known as "Pattaya", which is derived from "Thap Phraya" (the royal army), and is now part of the Banglamung Municipality. Pattaya remained a small fishing village until the 1960’s when American soldiers from the military base at Nakhon Ratchasima during the Vietnam War began arriving at Pattaya for rest and relaxation, making it the most visited place at that time before the different resorts.

Most of the people in Pattaya at that time had moved there for employment leading to the relatively rapid expansion of the city. Consequently, the government then enacted the Act of Administration of the City of Pattaya B.E. 2521 (1978) that established Pattaya as a "city", and on 29 November 2521 a local government ("self-administrating municipality") with a mayor (City Manager) was enacted, giving Pattaya an equal status with the other city municipalities.

On the 30th of November, 1999 the city enforced the Act of Administration to the City of Pattaya B.E. 2542 (1999), which specified that the district administration and the city council must be selected by an open election. On the same day, it was formally announced by the National Economic and Social Development Act BE. N.5-6 (1982–1991) that Pattaya was the main economical city of the Eastern Region of Thailand, which resulted in an increased population and number of tourists.

Consequently, Pattaya City has been faced with social and environmental issues, including the destruction of the beach and its surroundings. Unless solved, these persist problems may discredit Pattaya City from being one of the most popular tourist attractions in Thailand.

CHAPTER III
MARINE GEOLOGY AND COASTAL EROSION PROCESSES

3.1. Introduction

Pattaya Bay contains a beautiful crescent shaped beach that is (tangentially) aligned north to south on the eastern coast of the Gulf of Thailand. The variation in the wind direction and speed affects the direction and strength of the waves and currents on the coast and so causes changes in the patterns of deposition and transportation of sediments. Sediment usually moves at a far greater rate from the south to the north (Department of Marine and Coastal Resources, 2008)(1) with a net flow of 90,455 m^3/y of sediment, but this is disturbed by coastal structures, such as piers, that obstruct the current movement. The construction of upstream dams is also a major cause of the decreasing downstream sediment in the Gulf of Thailand (Uehara et al., 2010)(3). With the causes mentioned above, accumulated sediment has been gradually been lost and coastal erosion has occurred.

In 1989 the Japan International Cooperation Agency (JICA) proposed a model scheme of Pattaya city restoration (ARRI, 2011)(5-7). This project focused on the public utility and recreational assets including Pattaya Bay beach, and revealed that Patttaya Bay beach has been declining, and then suggested improvements for 1990-1992. In 1993, the Department of Public Works and Town & Country Planning hired Team Co. Engineering and Management, Scott Wilson Kirkpatrick Asia-Pacific Co. Ltd. and Asdecon Corporation Co. Ltd. as advisors to develop an environmental impact assessment (EIA) for Pattaya City restoration. Then, the project for Pattaya City restoration was considered by the Office of Natural Resources and Environmental Policy and Planning (ONEP). After that, ONEP decided that the Department of Public Works and Town & Country Planning (DPT) should monitor Pattaya Bay beach for three years (2003-2005) to develop a suitable plan to restore the beach.

Then, in 2011 the ARRI combined with the Marine Department to restore the JICA city project initiating research into the problem to develop a plan for a model scheme for Pattaya Bay beach replenishment. This project focused on the erosion features of Pattaya Bay and decided on the proposed methods to improve the beach and the city economics.

Moreover, engineering structures, in an attempt to prevent the coastal erosion in Pattaya Bay and adjacent areas, such as a stone wall to protect against wave action near the shore (rubber mound) and a concrete sea wall, were constructed at Pattaya beach. However, these structures reflect the sediment carrying swells away from the shore and so the waves have become an agent for transporting the sediment off the coast to the offshore area. In combination with the increasing strength and duration of seasonal waves, most likely due to global warming, as a result of winds with more intense energy, the coastal erosion has become more severe. The result is that the deposition of sediments has occurred in the offshore area instead of at the coast and so coastal erosion has increased.

This research is a study of the processes and evidence of coastal erosion in Pattaya Bay, Chonburi province, using marine geological and GIS information in conjunction with field work based assessment of the amount and direction of sediment movement in the Pattaya Bay area and analysis of core sediment samples, plus examination of six bathymetric maps of the region over the period 1975-2009.

3.2. Application of GIS to determine the rate of coastal erosion

Preliminary studies on the rate of beach erosion in Pattaya Bay were performed by interpretation of the aerial images obtained from the Royal Thai Survey Department(20). The beach area in each year was calculated using the ArcGIS software to fix errors in the data and adjust the geometric correction before defining the photo-coordinates in UTM coordinate system in accordance of WGS_1984 Zone 47 N. Then the polygon layer boundaries of Pattaya Bay beach were created by dragging a line along the beach shoreline and determining the position of the back of the beach (backshore) from the aerial photo in 1974 (Figure 7), which is called the base line.

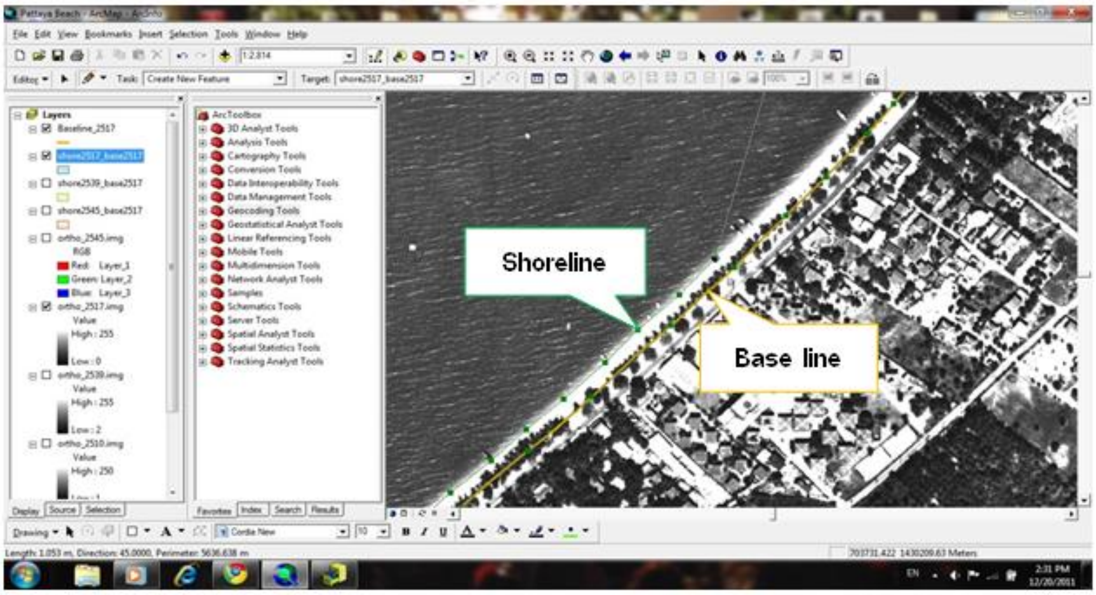


Figure 7 Making the beach polygon using the ArcGIS software.

The photo in 1974 was used to determine the base line because it had the highest resolution and there were not many buildings or tree cover obscuring the beach in that year. The base line was then set in the same place for every year to act as the index of the backshore. After that the beach area was created by dragging the base line to connect to the shoreline.

The spatial data (layer) created in ArcGIS (polygon) refers to the beach area. It can be used to calculate the real area by dragging the line to connect a shoreline on the image with the base line defined by the photo in 1974. One aerial image can create one layer of Polygon (shown in Figures 8 to 12)

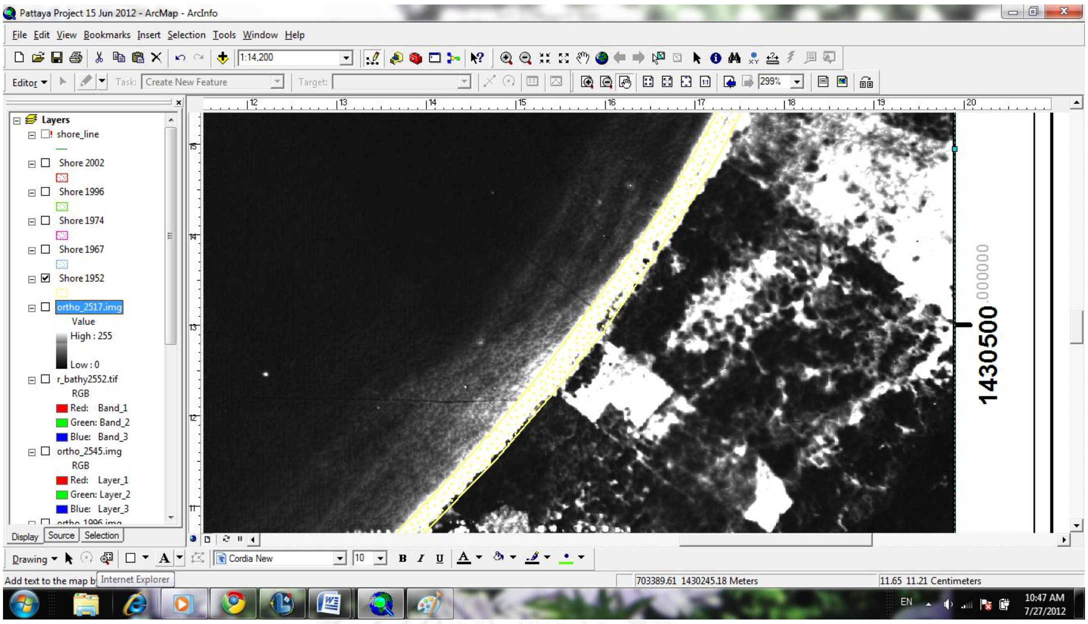


Figure 8 Beach polygon in 1952.

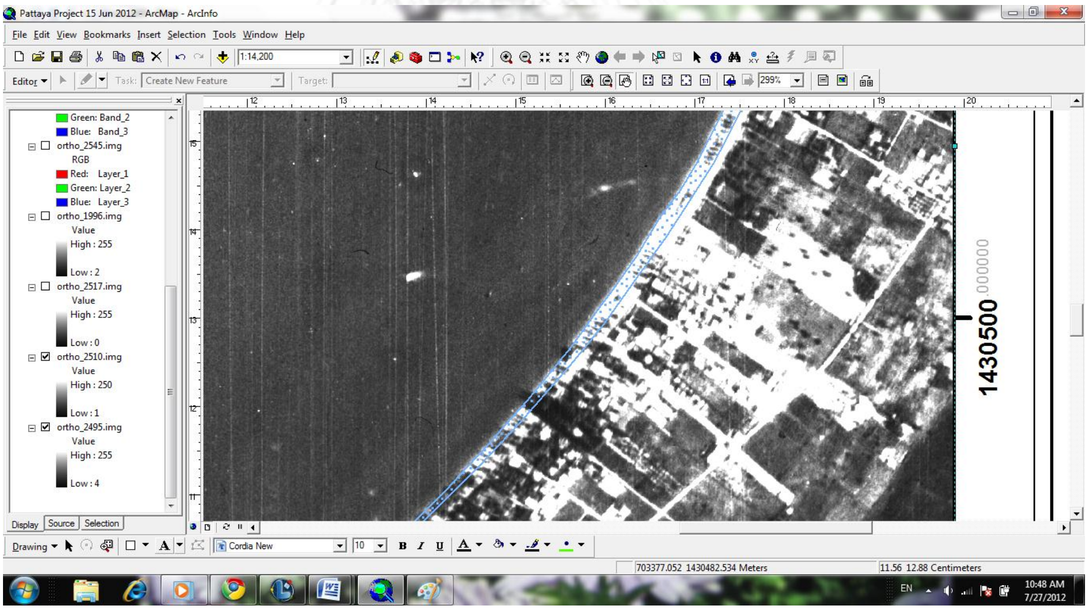


Figure 9 Beach polygon in 1967.

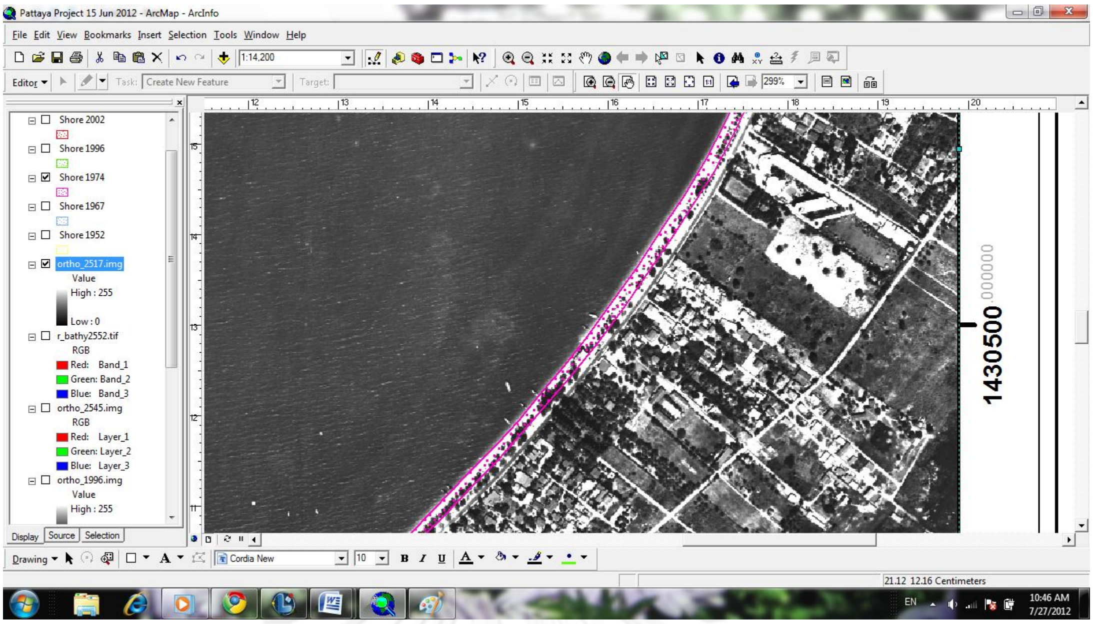


Figure 10 Beach Polygon in 1974.

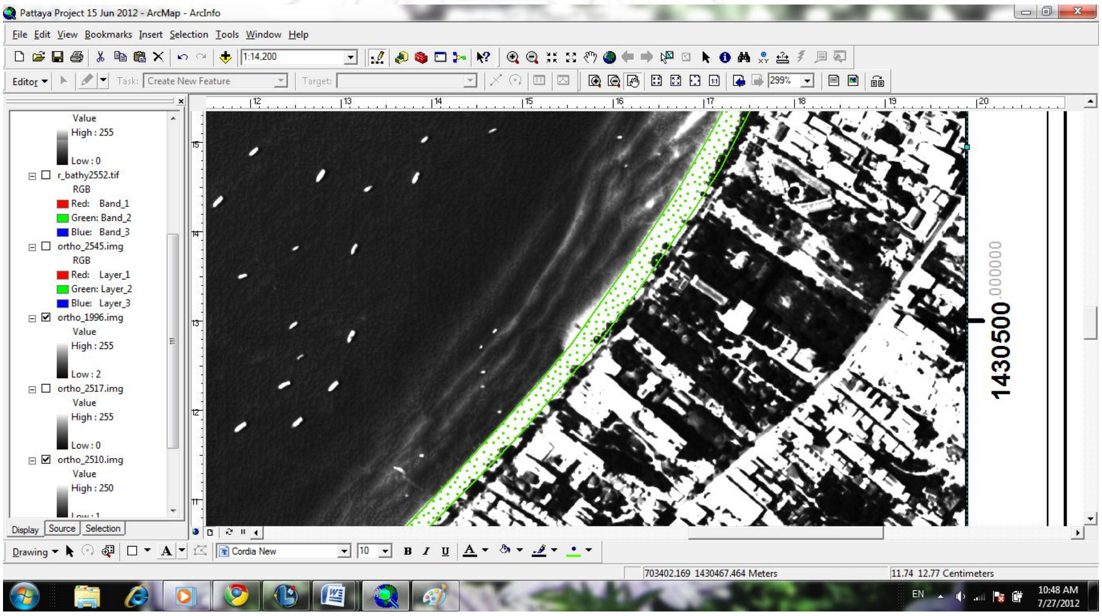


Figure 11 Beach Polygon in 1994.

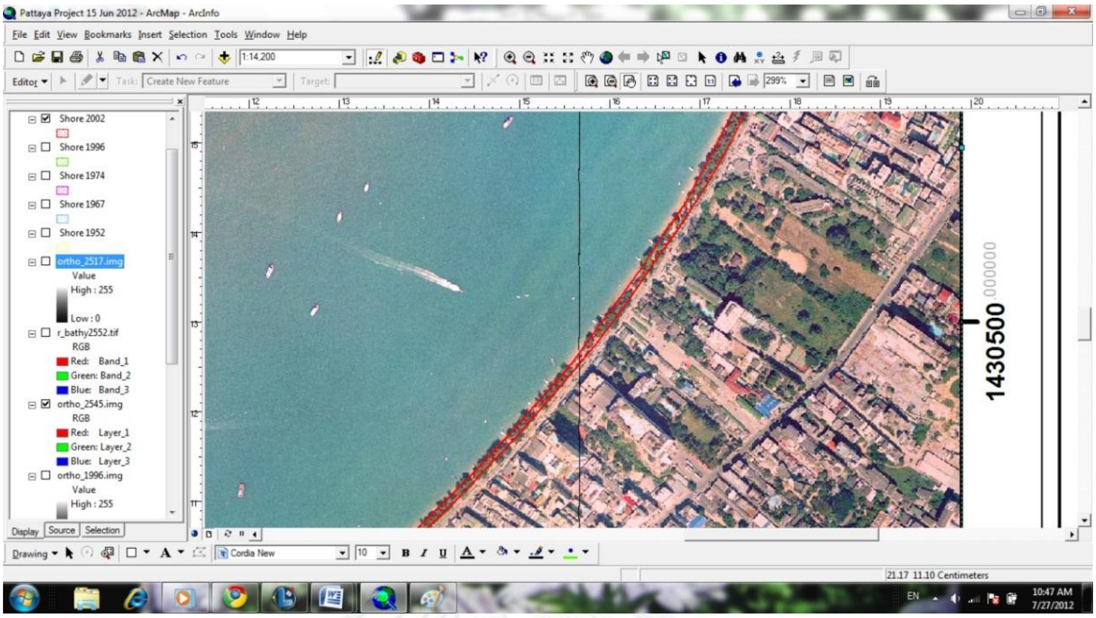


Figure 12 Beach Polygon in 2002.

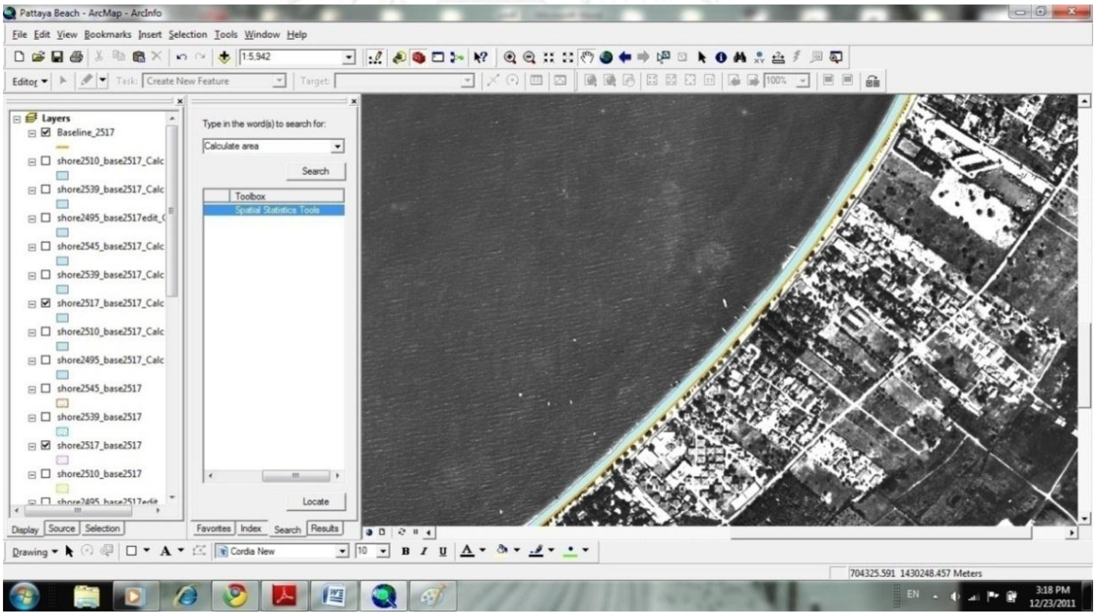


Figure 13 Use of the “Calculate area” tool to calculate the beach area.

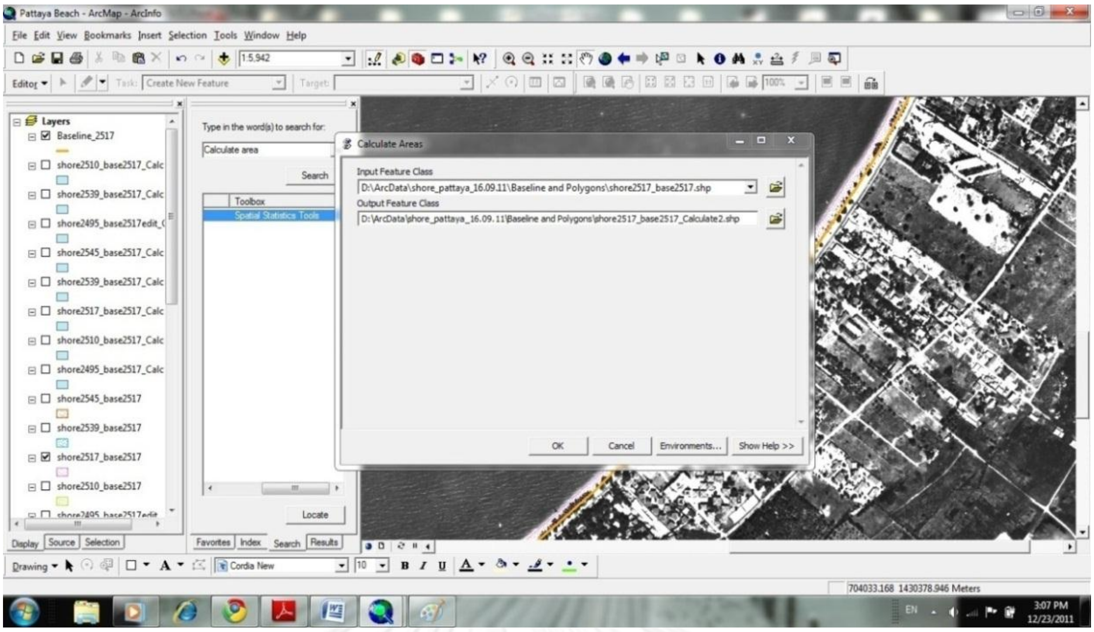


Figure 14 Spatial data layer (blue lined polygon) after using the "Calculate area" command.

Comparison of the beach polygons between the different years revealed that the beach widths between the years were obviously different. In 1952, the beach width was the highest while in 2002 the beach width was the lowest. When using the "Calculate area" tool the program creates a new layer of the same size as the edited polygon (blue layer in Figure 13). ArcGIS software then calculates the area of the beach in m^2 because the maps in the ArcGIS program have been defined to the UTM coordinates, are in m^2 in real space.

After calculating the beach area for each year, the beach width was calculated by dividing the value of the beach area by the distance of the beach, which has an arc length of 2,700 meters. Then, the beach areas and widths were compared among the different years (Table 3). With respect to the beach width, the beach width had obviously reduced during the period 1952–2011 by the erosion of over 90,000 m^2 (60 acres). During 1952–1974 the beach width decreased steadily and continued until 1996, when the beach width increased abnormally. This is because the local agency of Pattaya City re-filled sand on Pattaya beach at that period. As a result interpretations thereafter have to be as a separate period of 1996 to 2011, where the beach width was also observed to decrease steadily like in the first period.

Table 3 Beach width and area in each year, as calculated using ArcGIS

Year	Area (m^2)	Area (Rai)	Length (m)	Width (m)
1952	96128.359	60.08	2.700	35.603
1967	53891.902	33.68	2.700	19.960
1974	49919.385	31.19	2.700	18.489
1996	81778.901	51.11	2.700	30.288
2002	50500.723	31.56	2.700	18.704
2011	13500	5.91	2.700	3.500

In order to calculate the average rate of erosion of Pattaya Bay, the study period was divided into the two periods (see above) with the results shown in Table 4 The beach width (Table 3) was used as a reference. The average rate of erosion during the 22 years in the first period (1952-1994) is -0.78 m/y while that during the 15 years in the second period (1996-2011) is higher at -1.8 m/y.

Table 4 Average rate of erosion divided by the period of continuous erosion

Year	Average beach width (m)	Span (y)	Average rate of erosion
1952	35.603	22	35.603 – 18.489 = 17.114/22 = - 0.77790909 m / yr.
1967	19.960		
1974[1]	18.489		
1996	30.288	15	30.288-3.5 = 26.788/15 = -1.785866667 m / yr.
2002	18.704		
2011[2]	3.500		

[1] Average rate of erosion in the first period 1952–1974 using width beach data from year 1974 comparable to 1994 due to lack of information provided for users. To check the accuracy the satellite imagery in 1994 was used instead.

[2] This year refer from ARRI, 2011(6)

After calculating the average rate of erosion, the next phase was to predict (calculate) the expected beach width in the future using the average, highest and lowest rates of erosion. This was performed by subtracting the width of the then current beach (that in 2011) by the volume of sand lost from the system due to the average maximum erosion rate of -1.8 m/y and the lowest average erosion rate of -0.78 m/y along the 2.7 km coast of Pattaya Bay. The result (Table 4) shows that with the highest erosion rate (-1.8 m/y) the loss of sand in the system would be 30,009 m^3 and the beach will be completely eroded within three years, whilst at the lowest erosion rate (-0.78 m/y) the loss of sand would be 21,530 m^3 and the beach would be completely eroded within 5 years.

Table 5 Summary of the predicted Pattaya Bay coastal erosion based upon the current minimum and maximum erosion rates

Year	Volume of sand lost due to beach erosion		Erosion area at a maximum rate (-1.8 m/y).			Erosion area at a minimum rate (-0.78 m/y).		
	Maximum (m^3)	Minimum (m^3)	Area (m^2)	Area (Rai)	Width(m)	Area (m^2)	Area (Rai)	Width(m)
Year 2011	-	-	13,500	8.5	5	13,500	8.5	5
1st Year	10,003	4,306	8,640	5.4	3.2	11,394	7.12	4.22
3rd Year	30,009	12,918	-1,080	-0.68	-0.4	7,182	4.49	2.66
5th Year	50,015	21,530	-10,800	-6.75	-4.0	2,970	1.86	1.10
10th Year	100,030	43,060	-35,100	-21.94	-13.0	-7,560	-4.73	-2.8
15th Year	150,045	64,590	-59,400	-37.13	-22.0	-18,090	-11.31	-6.7

The calculated of the beach area in each year, which gives the average beach width, and the amount of sand lost from Pattaya Bay during 1952-2011 is shown in Figure 15. This information was used as the initial estimation for the publicity according to the Project of Survey and Design Model Scheme Planning for Pattaya Beach Nourishment, Chonburi (2011)(21).

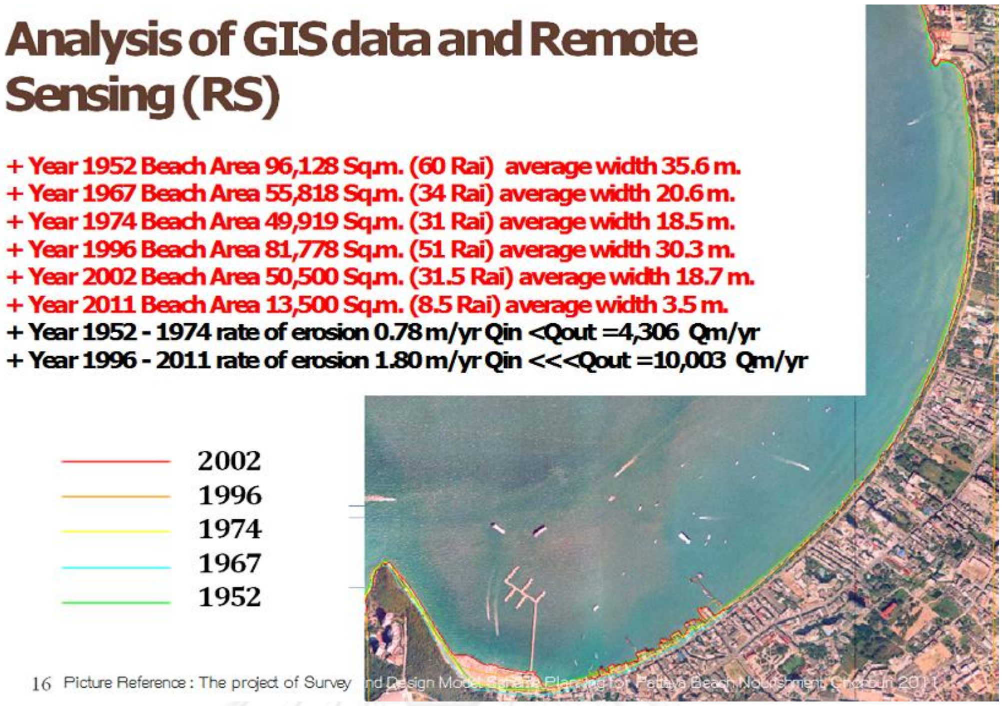


Figure 15 The beach width and area of Pattaya Bay in 1952–2011.

3.2.1. Analysis of the average rate of erosion in Pattaya Bay

In order to compare results of the data analysis in section 3.1 with the analysis of the changes in the coast and the average rate of erosion (section 3.2), the GIS data (ARRI, 2011)(5) was used to describe in more detail the coastal erosion phenomena in Pattaya Bay. From the same set of aerial photographs, the rate of change in the shoreline can be calculated by dividing the total coastline with the length from the north to the south of Pattaya Bay (including Pattaya Cape) of 5.8 km (follow the distance by ARRI, 2011). The beach length was divided into 100 meter and 50 m wide segments (105 ranges). Then, the rate of change in the area was calculated for each range by overlaying the aerial photographs and considering the reduction (or increase) in the beach area as shown in Figure 16.

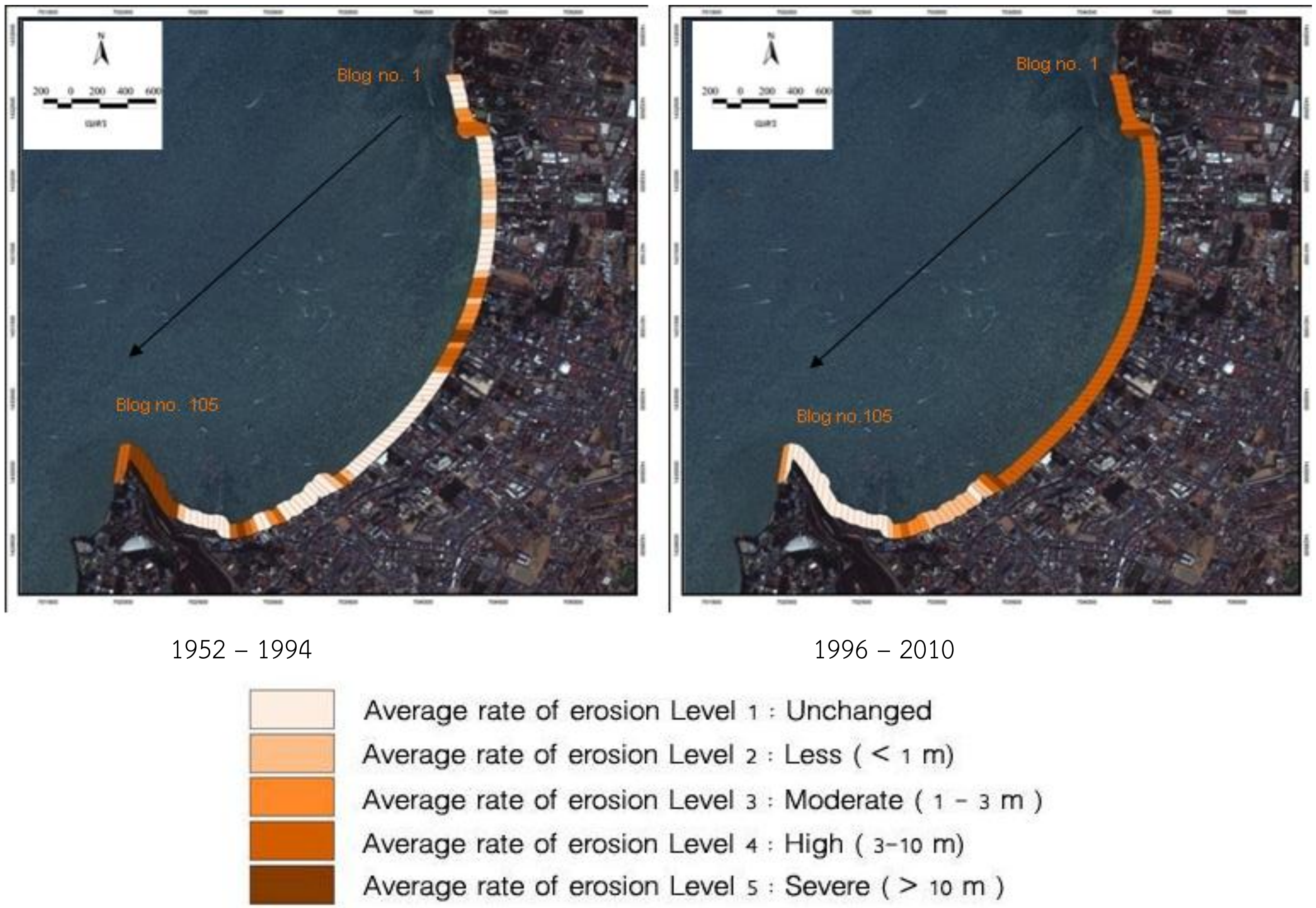


Figure 16 Shoreline changes and the average rate of coastal erosion obtained using GIS.

For the coastal area of Pattaya Bay during 1952-1994, the severity of the erosion was divided into five levels and found to have significantly changed, especially in the central Pattaya Bay and Pattaya Cape area. The maximum length change (40 m) was found at Pattaya Cape, while other areas had a shoreline change of between 0-13 m. During 1996-2010, all the lengths of Pattaya Bay changed between 1-3 m/y, except at Pattaya Cape where the rate of change decreased. In addition, the erosion in 1996-2010 mainly occurred from the north to the south area of Pattaya Bay beach with an average rate of erosion in this period of -1.8 m/y, increase from that in 1952-1994 with average erosion rate of -0.78 m/y (use the same rate as found by the analysis in section 3.2 because same set of data series). Thus, coastal erosion in the Pattaya Bay has tended to increase recently.

In summary, the coastal erosion of Pattaya Bay is separated into two periods. The first period (1952-1994), with a low rate of development of the city, had a low rate of erosion. But after 1996, the expansion of coastal structures and community correlates with, if not directly causes, the increased rate of erosion via a direct effect on the energy balance in Pattaya Bay. The severe coastal erosion in 1994 led to the refilling of sand on the beach. However, after 1996 Pattaya Bay beach continued to erode but at a faster rate. Consequently, the effect from coastal structures along Pattaya Beach that began with the development of Pattaya Bay and surrounding area, is likely to have influenced the erosion rate.

3.3. Changes in the sea floor level in Pattaya Bay from analysis of the bathymetry maps

After finding the average rate of erosion in Pattaya Bay, it was assumed that the eroded sand had moved offshore of Pattaya Bay. In order to monitor the area of deposition of sand in Pattaya Bay from the past to present, naval hydrographic maps were used, which are the major databases of the ground level under the sea (depth below mean seal level (bmsl) and are indicated by depth contours (bathymetry) and cross section images from Central Pattaya Road to Koh Jun, in the center of the Pattaya Bay. The bathymetry maps were updated using the ArcGIS software to input the coordinates and define the map projection into the system WGS_1984 Zone 47 N. The hydrographic maps used to compare with the cross sectional images covered 1975, 1983, 1988, 1995, 2000 and 2009, and were compiled with digital bathymetry of Pattaya Bay surveyed in 2003 and 2011 by Team Consulting Engineering and Management Co. Ltd, 2011(22). With this method, both the bathymetry chart and surveyed data could be calibrated to the same scale (1: 24,000) to reveal an overview of the ground level (below the sea level) of Pattaya Bay in 1975-2011. Sample maps are shown in Figures 17-24.

When the profile from the bathymetry map was drawn as a graph, the sea floor elevation of Pattaya Bay (m bmsl) was revealed as a cross sectional image. Comparing cross sectional images to one another revealed the variation in sea floor elevation in 1975-2011. Figure 25 shows the eroded area (red color) and accumulation area (blue color) at a map scale of 1:24,000 and vertical exaggeration of 240x.

From the profiles of Pattaya Bay, it was concluded that between 1975 and 2011, Pattaya Bay beach had been eroded for 0-500 m from the beach, and at a distance of 100 m offshore the ground level has been elevated by deposition and accumulation of this sediment.

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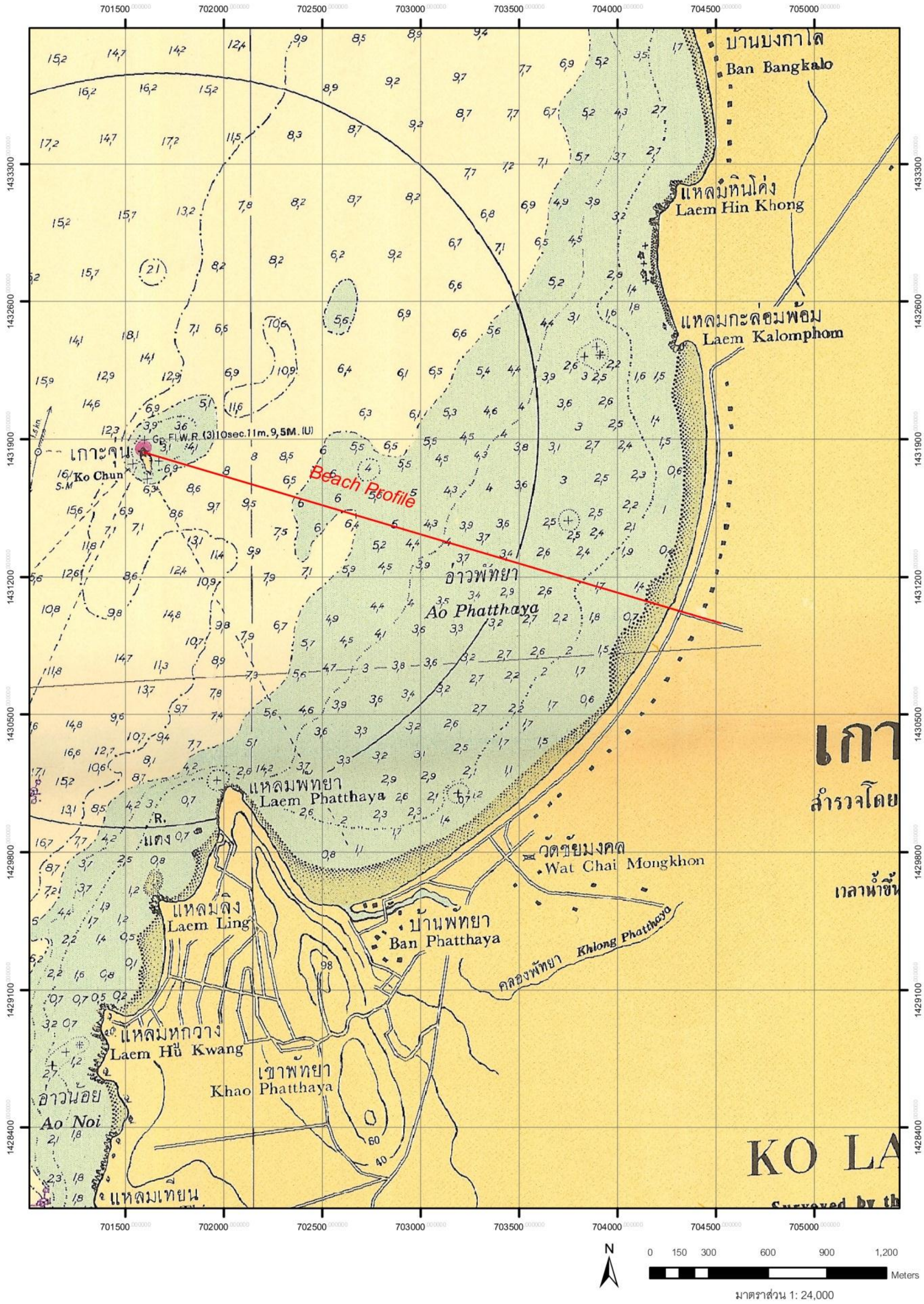

Figure 17 Bathymetry map for 1975 (data from Royal Thai Navy)

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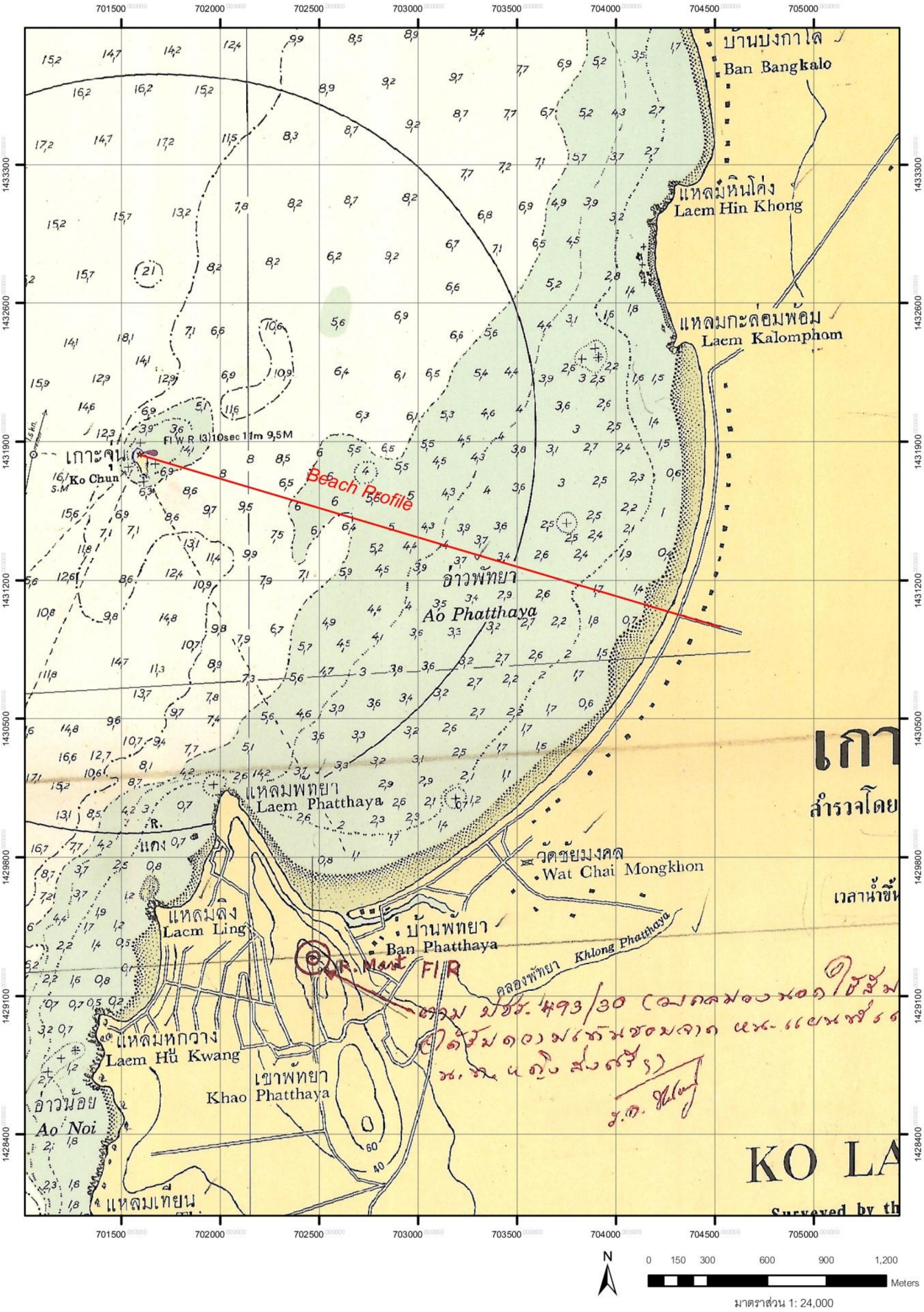

Figure 18 Bathymatry map for 1983 (data from Royal Thai Navy)

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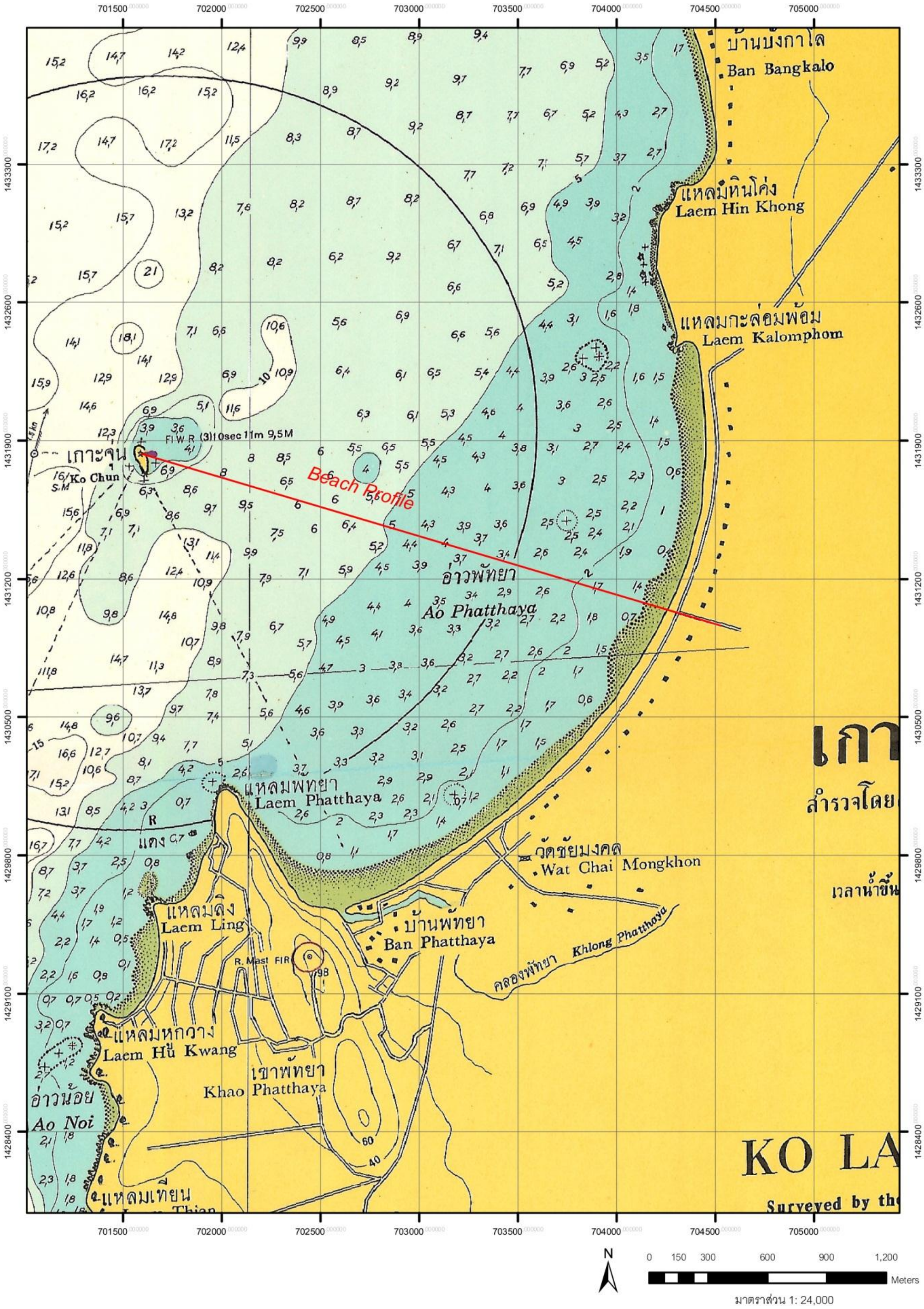

Figure 19 Bathymatry map for 1988 (data from Royal Thai Navy)

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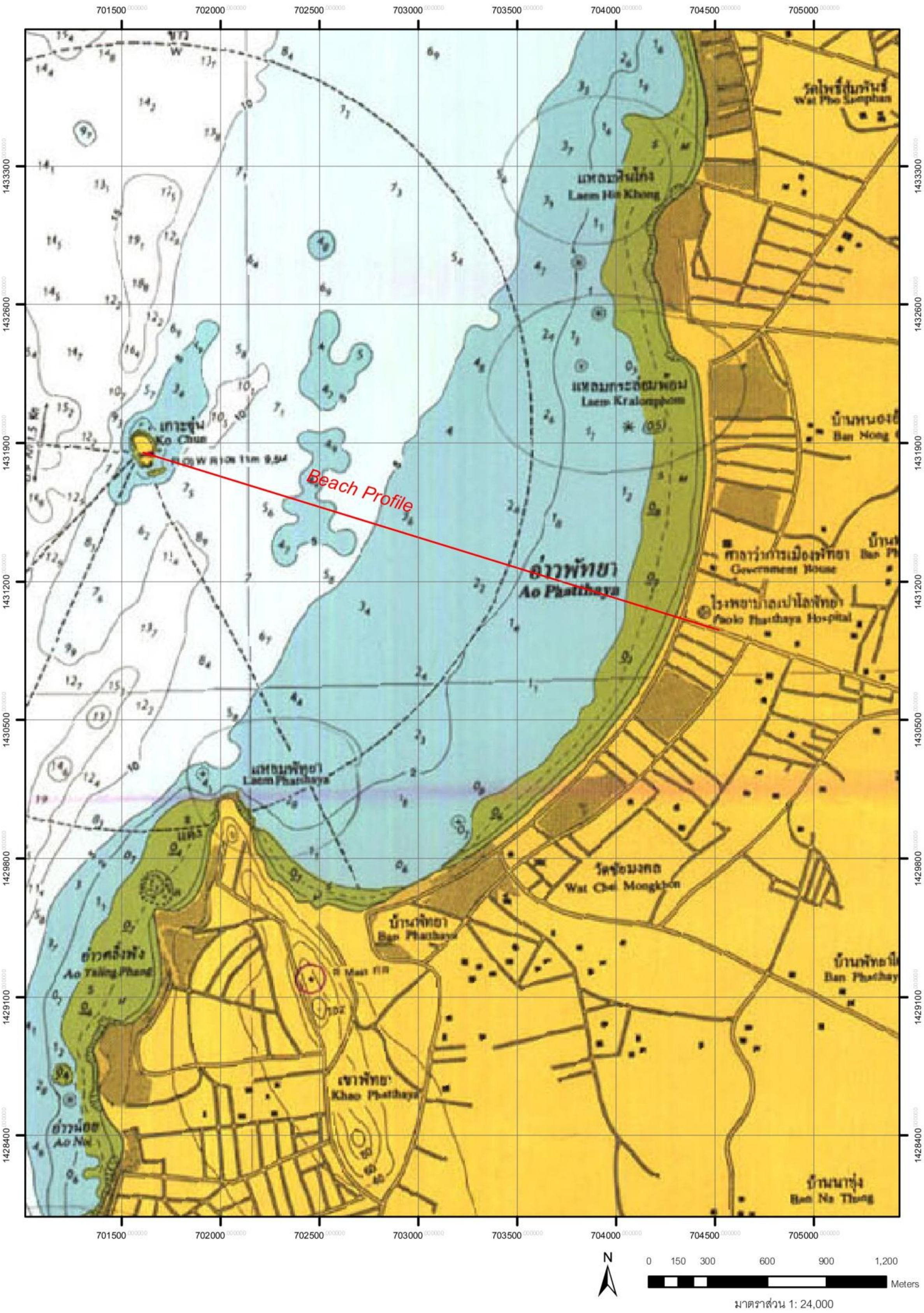

Figure 20 Bathymatry map for 1995 (data from Royal Thai Navy)

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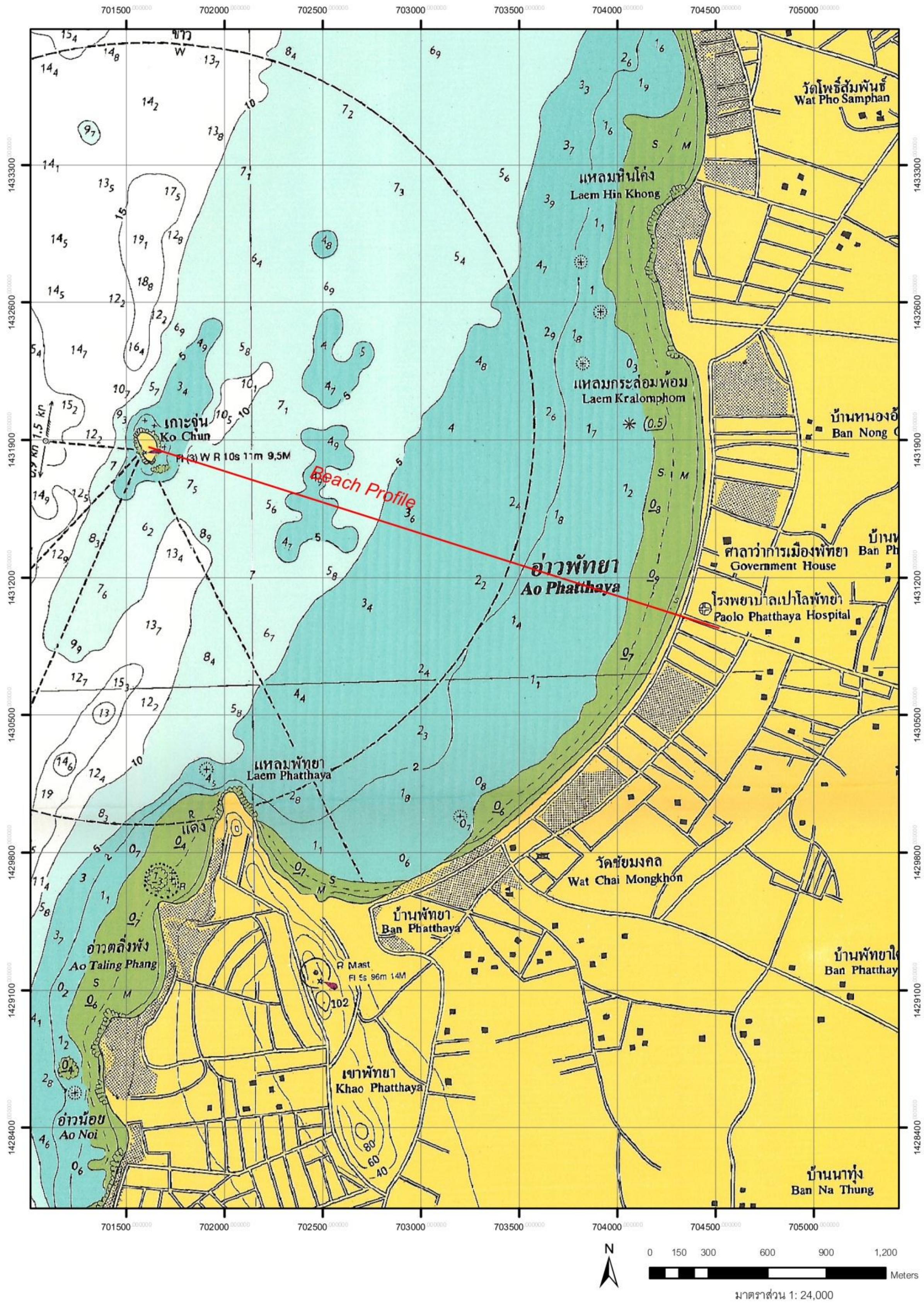


Figure 21 Bathymatry map for 2000 (data from Royal Thai Navy)

Figure 22 Bathymatry map for 2009 (data from Royal Thai Navy)

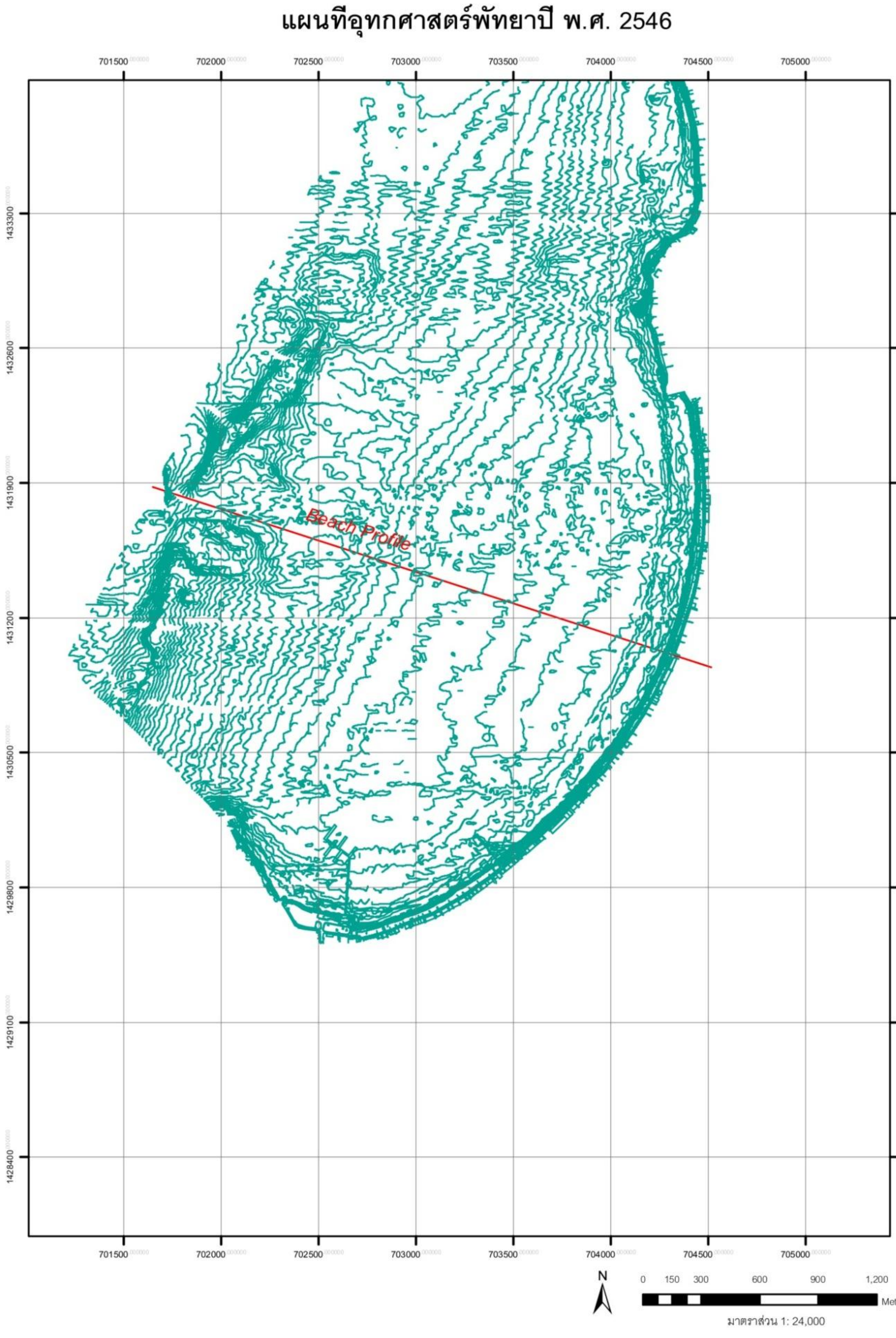


Figure 23 Digital bathymetry map for 2003 (data by Team Consulting Management Co. Ltd.)

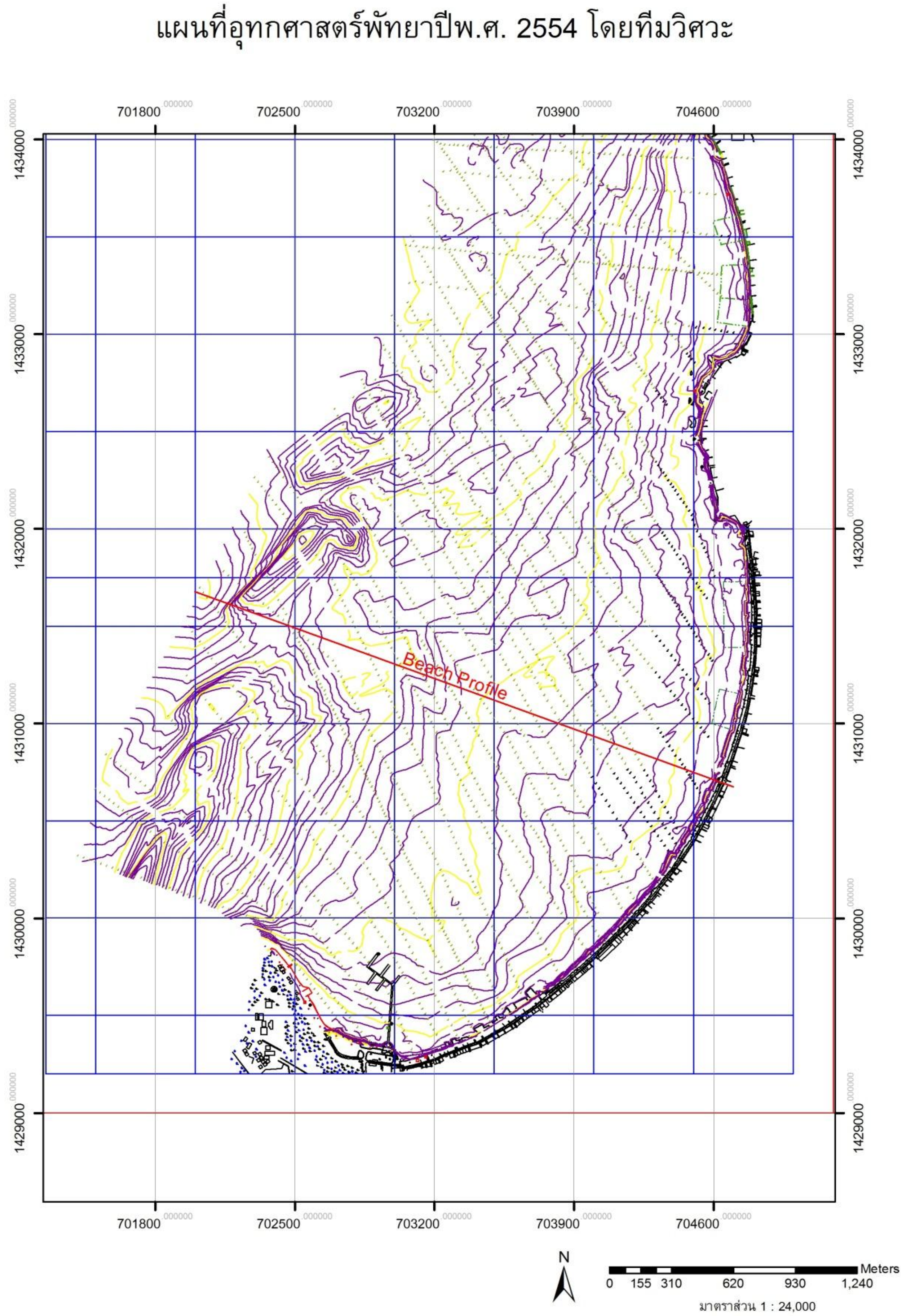


Figure 24 Digital bathymetry map for 2011 (data by Team Consulting Engineering and Management Co. Ltd.)

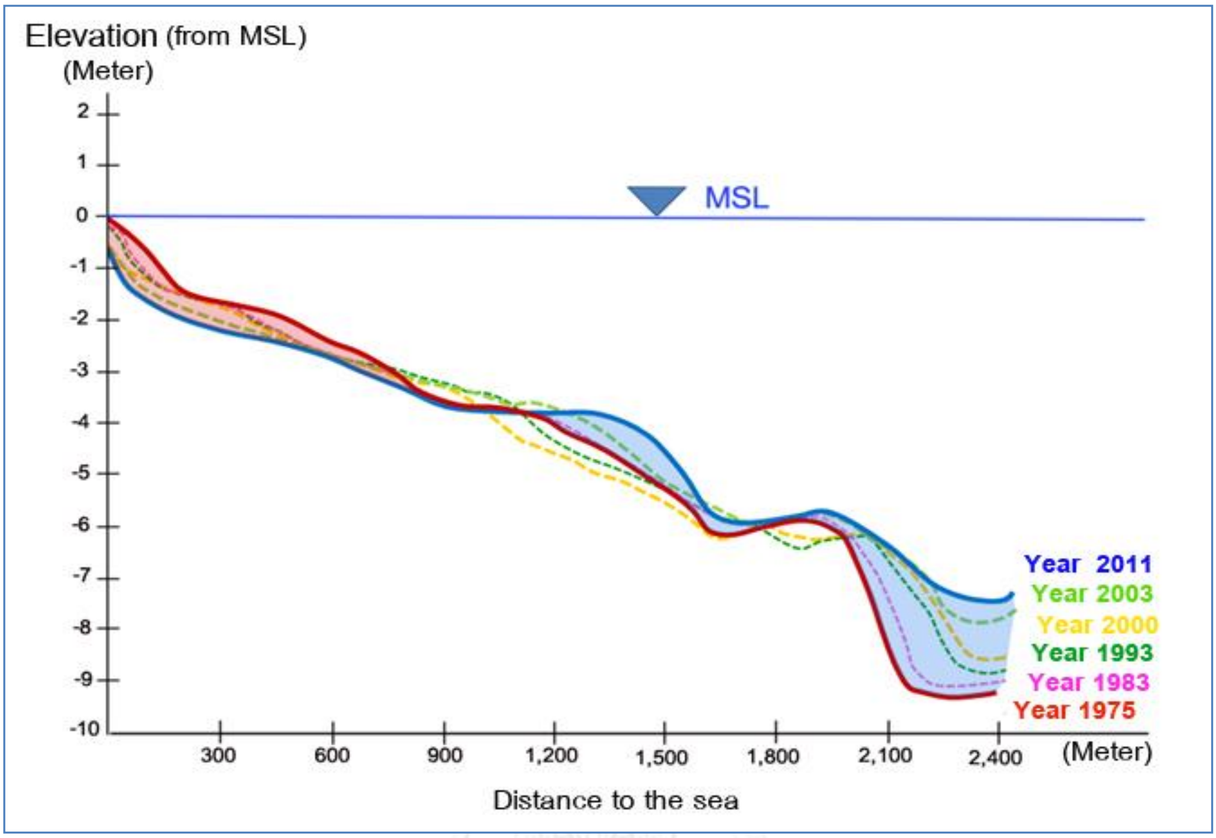


Figure 25 Beach profile of Pattaya Bay from central Pattaya to Koh Jun between 1975 and 2011, showing the eroded area (red color) and accumulated area (blue color). (Map scale: 1:24,000; vertical exaggeration = 240x).

3.4. Analysis of sediment layers from boreholes in Pattaya Bay

This section discusses the study of sediments collected in Pattaya Bay from exploratory drilling based on a survey of offshore sand sources in Pattaya Bay (ARRI, 2011)(9). Sediment samples were collected using a drilling survey system with counter flush reverse circulation using a Motorind Cathead lighter type machine (Figure 26).

Each core sample was sectioned into 50 cm long (depth) subsamples from the standard penetration test and the data was recorded in the field log. Each subsample was consequently evaluated for the sediment composition and from these records the distribution of the sediments at each borehole site was evaluated. The procedures are shown in Figures 27 to 35.

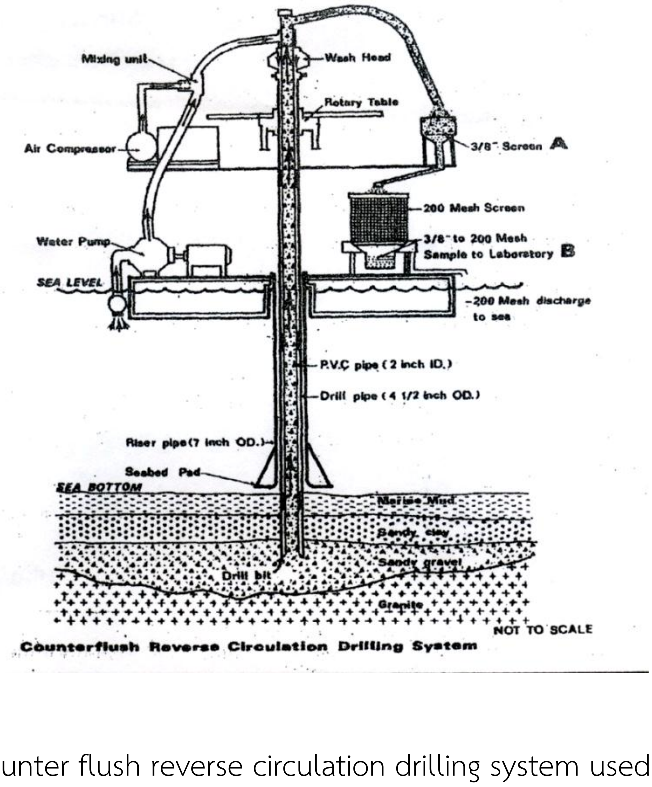


Figure 26 The counter flush reverse circulation drilling system used to obtain sediment layer samples.

Figure 27 Borehole sampling in Pattaya Bay

Figure 28 Counter flush reverse circulation.

Figure 29 Another borehole sampling in Pattaya Bay.

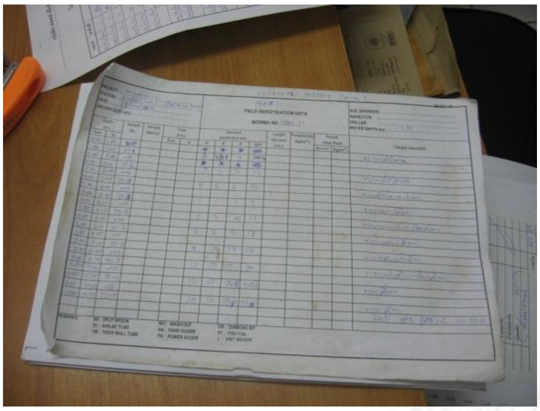


Figure 30 Recorded field data (Field log)

Figure 31 Sieve analysis of the sediment samples.

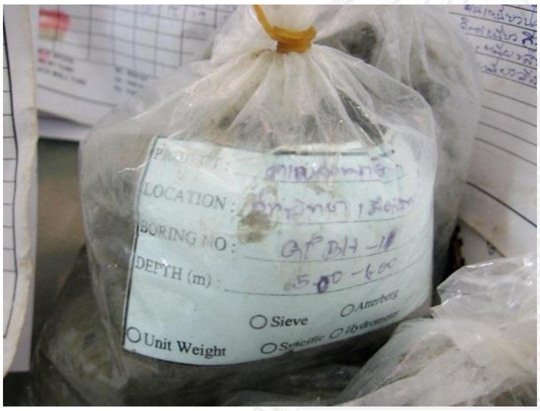


Figure 33 Sediment samples collected at every 50 cm depth

Figure 32 Drilling head of the lighter type (Motorind Cathead)

Figure 35 Offshore sandy mud in a deep layer of the borehole

Figure 34 Drying the samples in an oven

The borehole locations are shown in Figure 36. Boreholes 11 and 12 were drilled near the beach to use as an index, and so were not used to consider the offshore sand volume. Boreholes 2 and 5 were located in central Pattaya Bay and were short holes bounded by the bedrock underlying them. Boreholes 7 and 8 were in the offshore area of North Pattaya, in which the sand had accumulated throughout the depth, and BH-3, BH-6 and BH-10 were located in the offshore area of South Pattaya. Finally boreholes 1 and 4 were located in north Pattaya Bay inshore of BH-7 and BH-8, while BH-9 was located at central-south Pattaya Bay same as BH-3 and BH-6.

The sampled sediment was tested by sieve analysis, from which it was found that borehole numbers 2, 3, 5, 7, 8, 10, 11 and 12 had a large proportion of sand particles. Both BH-3 and BH-6 have sand in the deep layer, while BH-10 had gravel and sand particles accumulated throughout its depth. According to the results from the borehole data, the distribution of offshore sand particles in Pattaya Bay is consistent with the results of the Department of Mineral Resources in 2011, which reported sand dunes offshore of Pattaya Bay. This sand was Holocene sediment (see section 4.3). However, the test results showed that the distribution of sand particles in these boreholes had a proportion of clay mixed in every borehole. Therefore, these particles, which are black, are not suitable to be used as beach sand. Hence, this sand is of no use for the Project of Survey and Design Model Scheme Planning for Pattaya Beach Nourishment, Chonburi (2011), which advocated bringing offshore sand to build artificial beaches at Pattaya Bay.

3.4.1. Correlation profile of the borehole sediment data

From the analysis of the distribution of sand particles in each borehole, a cross-sectional image displaying sediments (correlation profile) in the Pattaya Bay was derived using the data from the boreholes in the following order: BH-11, BH-12, BH-3 and BH-5. The total length of the cross section is approximately 8 km from the beach to the offshore (Figure 36), and the derived correlation profile is shown in Figure 37.

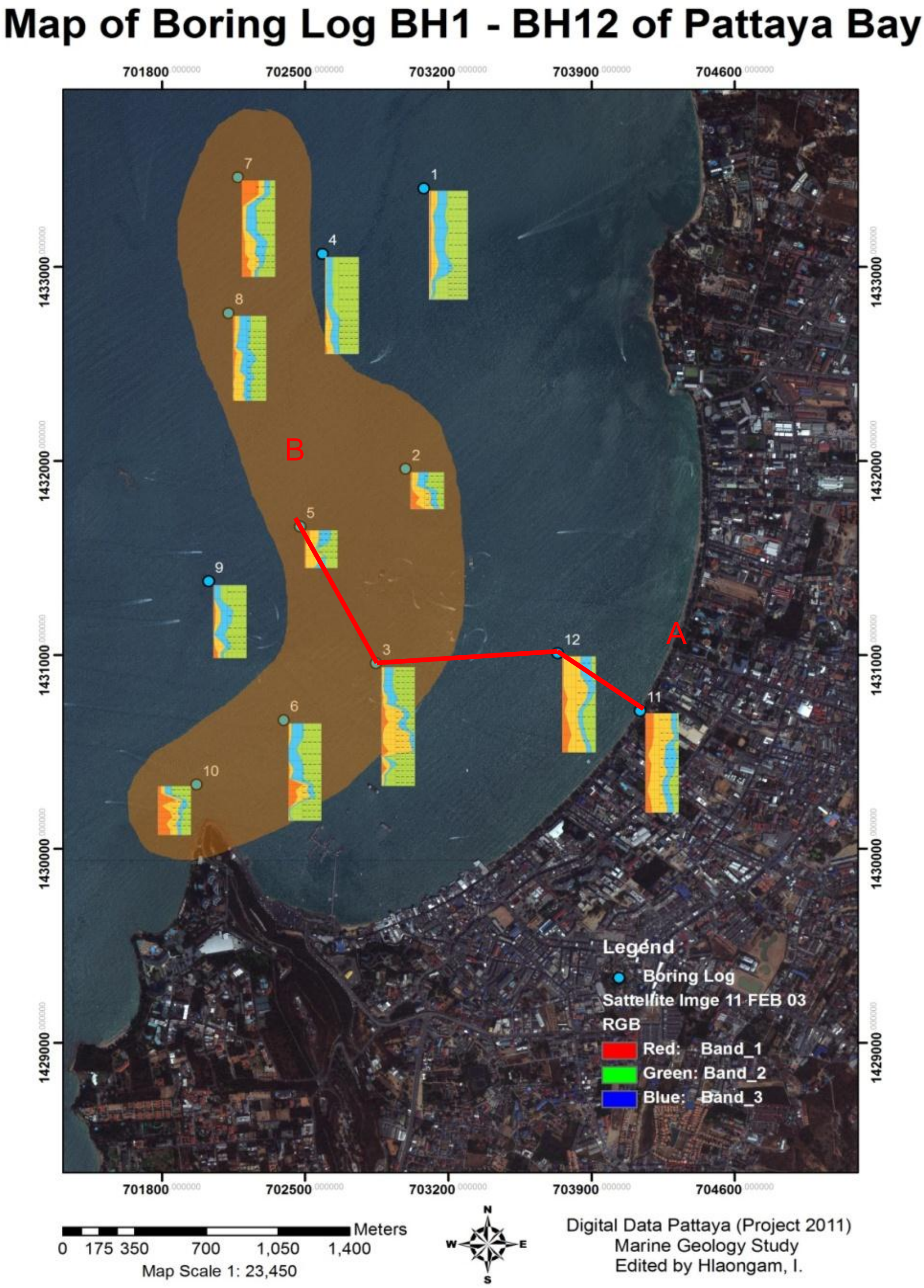


Figure 36 Map showing the location of boreholes (BH1 to BH12), the cross-section line, and offshore sand bar in deep layer of Pattaya Bay (orange area)

Comparing the correlation profile, which shows the relationship of sediments in Pattaya Bay (Figure 37), with the results of the particle size distribution at each depth, which show the relationship of the sediment layers in the coastal and offshore areas in Pattaya Bay, it can be seen that the sand in the offshore BH-3 and BH-5 are associated with sediments at the depth of 8-10 m below the seabed surface in BH-12 at the coast and at a depth of 7-10 m below the seabed surface in BH-5. The feature of the correlated sediment is silty sand (SM), clayey sand (SC) and poorly graded sand (SP) with a grey color (Table 6). Borehole 3 has an accumulation of SM, SC and SP at depths of 3-7 m depth below the seabed surface (the depth of the boreholes), and BH-5 has an accumulation of SM, SC and SP at depths of 0-3 m. The geological features of the sand layer by depth at BH-3 supports the coastal erosion of Pattaya Bay.

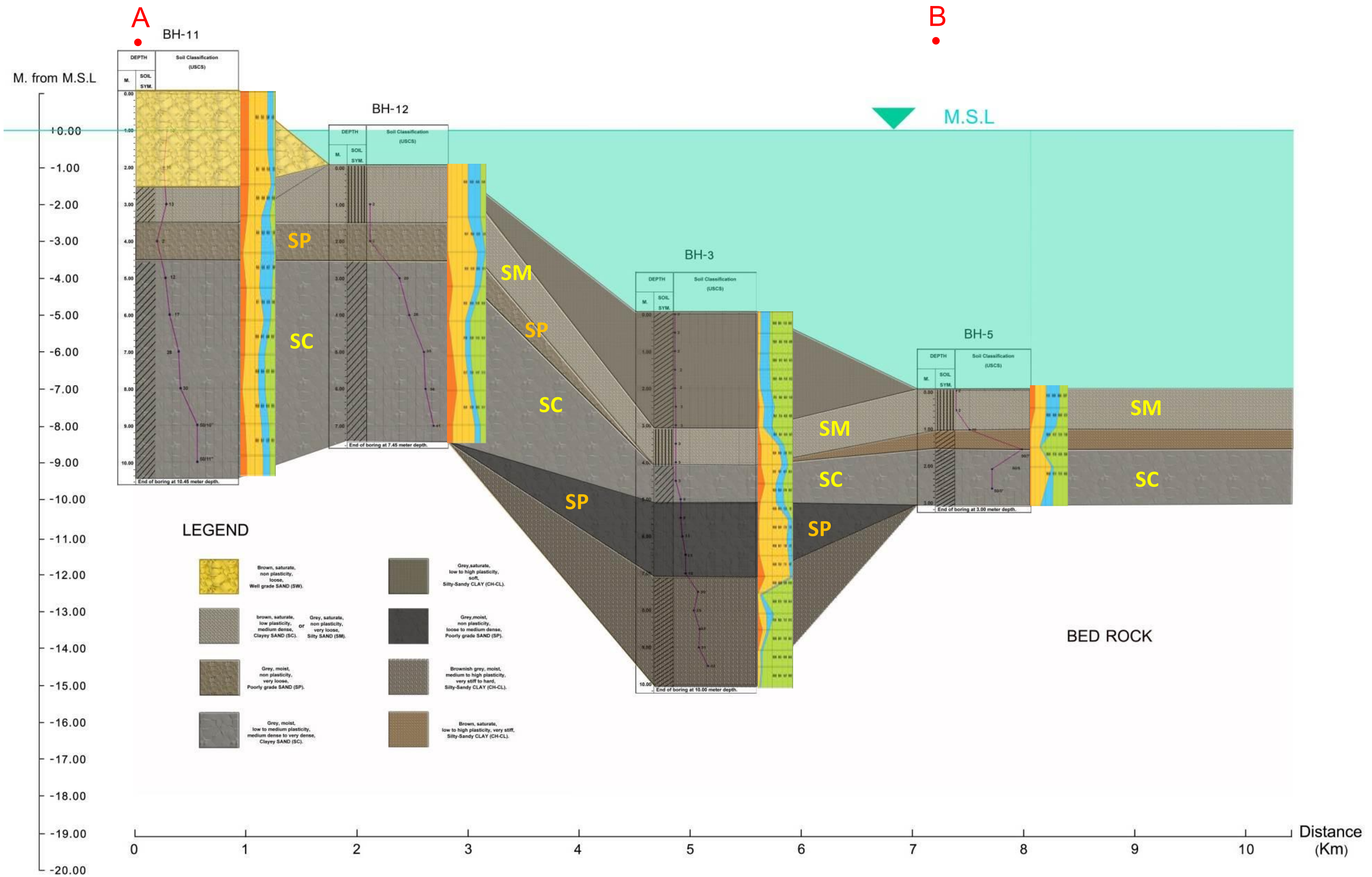
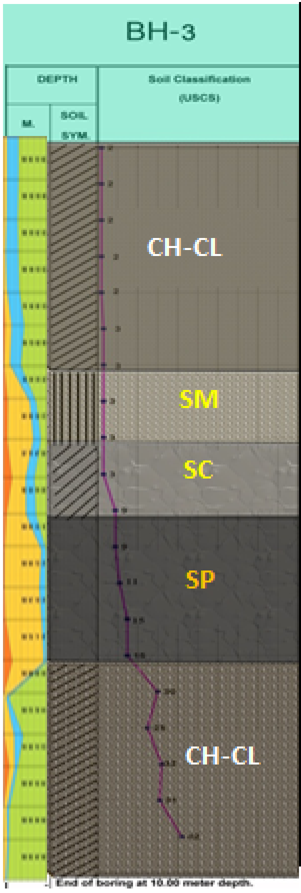


Figure 37 Sediment correlation profile of Pattaya Bay, derived from BH-11, BH-12, BH-3 and BH-5

Comparing the correlation profile, which shows the relationship of sediments in Pattaya Bay (Figure 37), with the results of the particle size distribution at each depth, which show the relationship of the sediment layers in the coastal and offshore areas in Pattaya Bay, it can be seen that the sand in the offshore BH-3 and BH-5 are associated with sediments at the depth of 8-10 m below the seabed surface in BH-12 at the coast and at a depth of 7-10 m below the seabed surface in BH-5. The feature of the correlated sediment is silty sand (SM), clayey sand (SC) and poorly graded sand (SP) with a grey color (Table 6). Borehole 3 has an accumulation of SM, SC and SP at depths of 3-7 m depth below the seabed surface (the depth of the boreholes), and BH-5 has an accumulation of SM, SC and SP at depths of 0-3 m. The geological features of the sand layer by depth at BH-3 supports the coastal erosion of Pattaya Bay.

Table 6 Geology of the Pattaya Bay by depth profile at BH-3.



Description
(0.00–3.00 m); Grey, saturate, low to high plasticity, soft, silty-sandy clay (CH-CL).
(3.00–4.00 m); Grey, saturate, no plasticity, very loose, silty sand (SM).
(4.00–5.00 m); Grey, moist, low plasticity, very loose, clayey sand (SC).
(5.00 – 7.00 m) ; Grey, moist, non plasticity, loose to medium dense, Poorly grade Sand (SP).
(7.00–10.00 m); Brownish-grey, moist, medium to high plasticity, very stiff to hard, silty-sandy clay (CH-CL).

3.5. Characteristics of the seasonal sediments of Pattaya Bay and their transportation by currents, monsoon and tides

3.5.1. General condition of sediments in Pattaya Bay

The hydro-oceanographic survey, obtained from ARRI (2011)(7), was derived from 34 samples of bottom sediments collected on 6th December, 2010 in Pattaya Bay and evaluated for the distribution of particles by sieve analysis and pipet test to reveal the general characteristics of the sediments. The results (Figure 38), as % (sediment weight / sample weight) composition, describe the overall distribution of the bottom sediments around Pattaya Bay in terms of the seabed depth bmsl (In figure 38, the five top right to bottom left diagonal rows of sampling points), as below:

Row 1 (points 1-6) is on the coast of Pattaya Beach and was comprised of more than 90% sand and gravel particles aggregated, except at point (south Pattaya), where more than 30% of silt particles and less than 2% of clay particles were present.

Row 2 (points 7-12) is offshore next to row 1 and had a very low proportion of gravel particles. Sand and silt particles were the major component of the bottom sediment. The proportions of silt particles increased from the North to the South. Clay particles were found at a small scale but with an increasing amount to the south of Pattaya Bay.

Row 3 (points 13-20) is next to row 2 and includes points 13 and 14 that were nearby to a rock cay at north Pattaya Bay, where there are strong waves and as a result the dominant particles were gravel. In addition, sand and especially silt particles were found at south Pattaya Bay at points 19 and 20. Clay particles were the least common component and were only found in the south of Pattaya Bay.

Row 4 (points 21-28) is next to row 3 and had various kinds of rocks, due to channel pattern and currents. At points 23-25 gravel and sand particles were found because they are located near Koh Jun, the rock cay in the bay that is the source of these two particles. Point 22 is near a whirlpool that can move compacted sediment to the offshore and so silt and clay particle components comprised about 40% of their sediment. At points 23-25 offshore gravel particles of Pattaya Bay were found, and at points 26-28 that were far away from the rock cay at north Pattaya Bay, the accumulation of silt particles was found to account for 40% of the sediment.

Row 5 (points 29-34) is next to row 4 but still had Koh Jun as the source of gravel and sand particles. At points 29-31 that were further away from the rock cay of north Pattaya Bay (about 2.5 km from the coast), silt particles were dominant. Point 33 was near the whirlpool and so had a higher level of silt particles in the composition.

Comparing the characteristics of the bottom sediments in Pattaya Bay, clay particles were found to be dominant in south Pattaya Bay, while in north Pattaya Bay the accumulation of gravel particles was dominant at offshore points 1, 12-15 and from Wong-amat Bay to south Pattaya Bay. This area is assumed to have strong waves that bring gravel particles to the offshore. Also, the morphological features at the seabed are important, where submarine channels control the accumulation of the bottom sediment.

In conclusion, in terms of the type of sediment around Pattaya Bay, sand and silt particles were the major components of the bottom sediments with small amounts of clay particles found in the offshore, especially in the south Pattaya Bay. Moreover, some gravel particles were scattered off the coast at the upper part of Pattaya Bay at Wong-amart Bay in the area of a rock cay and strong wave action. The finding of these gravel particles revealed that the wave energy is strong enough to carry the gravel particles to the offshore. The overall appearance of the bottom sediment of Pattaya Bay, in terms of the main components, is shown in Figure 39.

The interpretation of the bottom sediment composition is useful for evaluating the characteristics of the sediments in the bay, which can define the net trends of the coastal erosion phenomena. That is, it provides the overall appearance of the bottom sediment before the separate analysis of the seasonal movement of sediment type and quantity of the movement using a sediment catcher (sections 3.5.2 and 3.5.3, respectively).

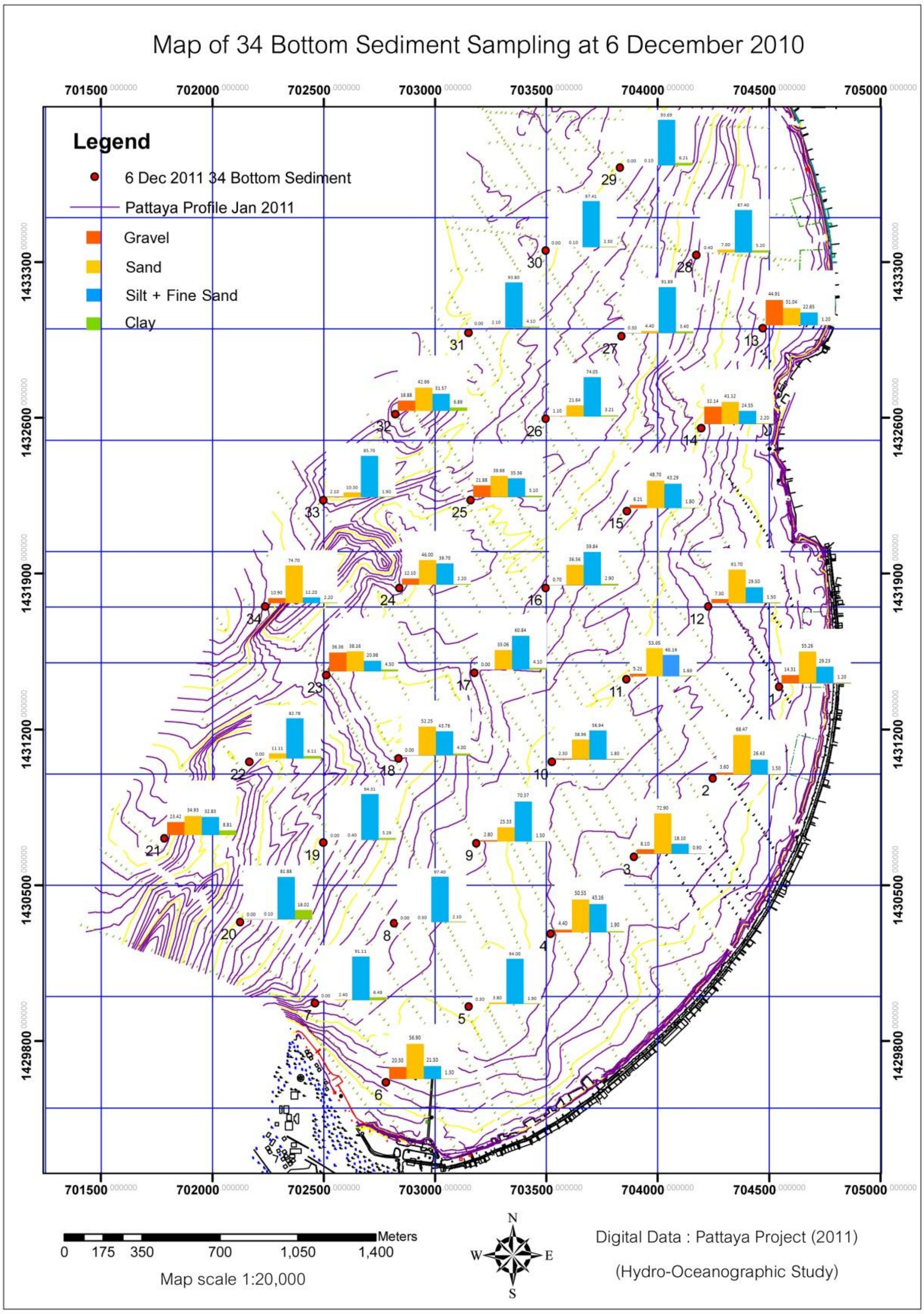


Figure 38 Map showing the distribution of the bottom sediment around Pattaya Bay (The proportion of sediment particles are divided into the four types of gravel, sand, silt + fine sand and clay)

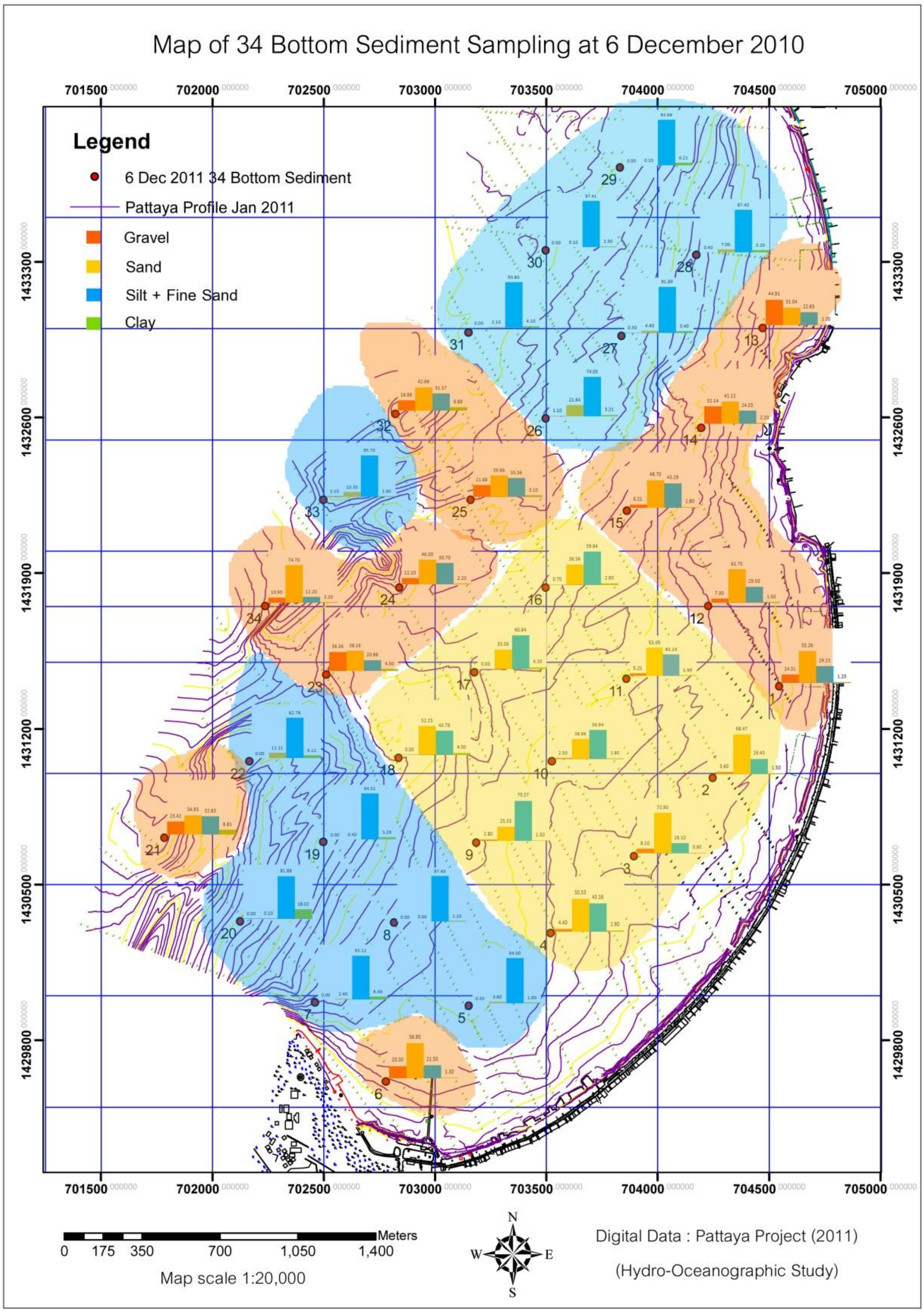


Figure 39 Overall appearance of the bottom sediment of Pattaya Bay, divided into the type of the main component.

3.5.2. Sediment movement along the coast by the currents

The quantity of sediment movement along the Pattaya Bay coast was evaluated using a sediment catcher (Figure 40) to determine the net sediment movement. The data was taken from the draft final report by ARRI (2011)(7), and was based upon data collected during 5-19 December 2010 (spring tide) and 4-11 February 2011 (neap tide). The amount of sediment that was trapped in each direction was analyzed and displayed on the map using the ArcGIS software.

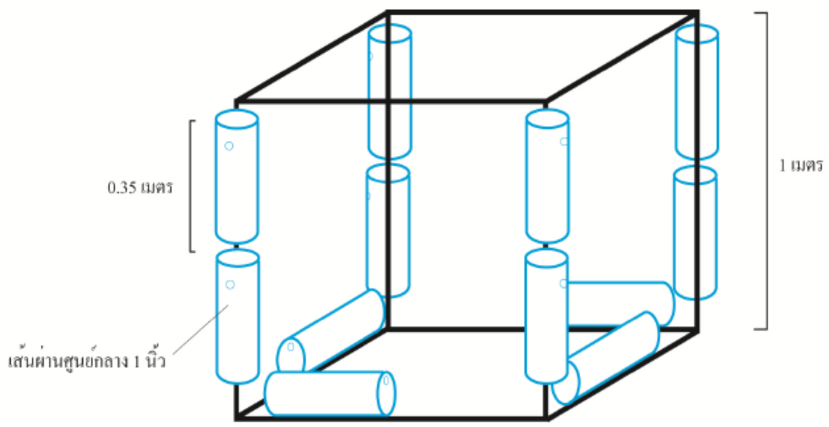


Figure 40 Schematic representation of a sediment catcher (ARRI, 2012 : Online)**(23)**

During the first field data collection on December 2010, seven of the 10 sediment catchers were lost during the operation and so only three collection points are available to display the sediment movement of Pattaya Bay. Two of them were in north Pattaya Bay and the other was in south Pattaya Bay (Figure 41; the number on the map shows the number of the sediment catcher). The first point only provided data from the suspended sediment receiver (cylindrical trap) because the cylindrical trap for the bottom sediment was lost (see Appendix C).

Comparing the upper and lower suspended sediment volume at points 1 and 2 in north Pattaya Bay, point 1 had a larger amount of sediment than at point 2 in all directions. Point 1 is nearer to the coast than point 2 and so it was inferred that the distance from the coast may have influenced the volume of transported sediment. With respect to the bottom sediment, points 2 and 7 showed the maximum volume of bottom sediment moved westwards to the offshore in both the north and south Pattaya Bay and the volume of trapped sediment in the cylindrical trap which turned to the east (E) was obviously higher than in the other directions.

The main cause for moving the suspended and bottom sediments towards the offshore direction is still unknown. The waves came from a northwards direction in the NW monsoon. Hence, the tide and current should be reconsidered to look for any local effect upon the movement of sediment in Pattaya Bay.

Briefly, the amount of suspended sediment and the movement direction vary with the terrain and the wind. As a result, the suspended sediment at point 7, which is near the community and buildings, was lower than those at points 1 and 2, but it had a maximum volume of bottom sediment. However, this is unusual for the bottom sediment movement and may reflect the action of the tide or other agents that cause the movement of bottom sediment direction to the offshore area in both the north and south area of Pattaya Bay during the spring tide period.

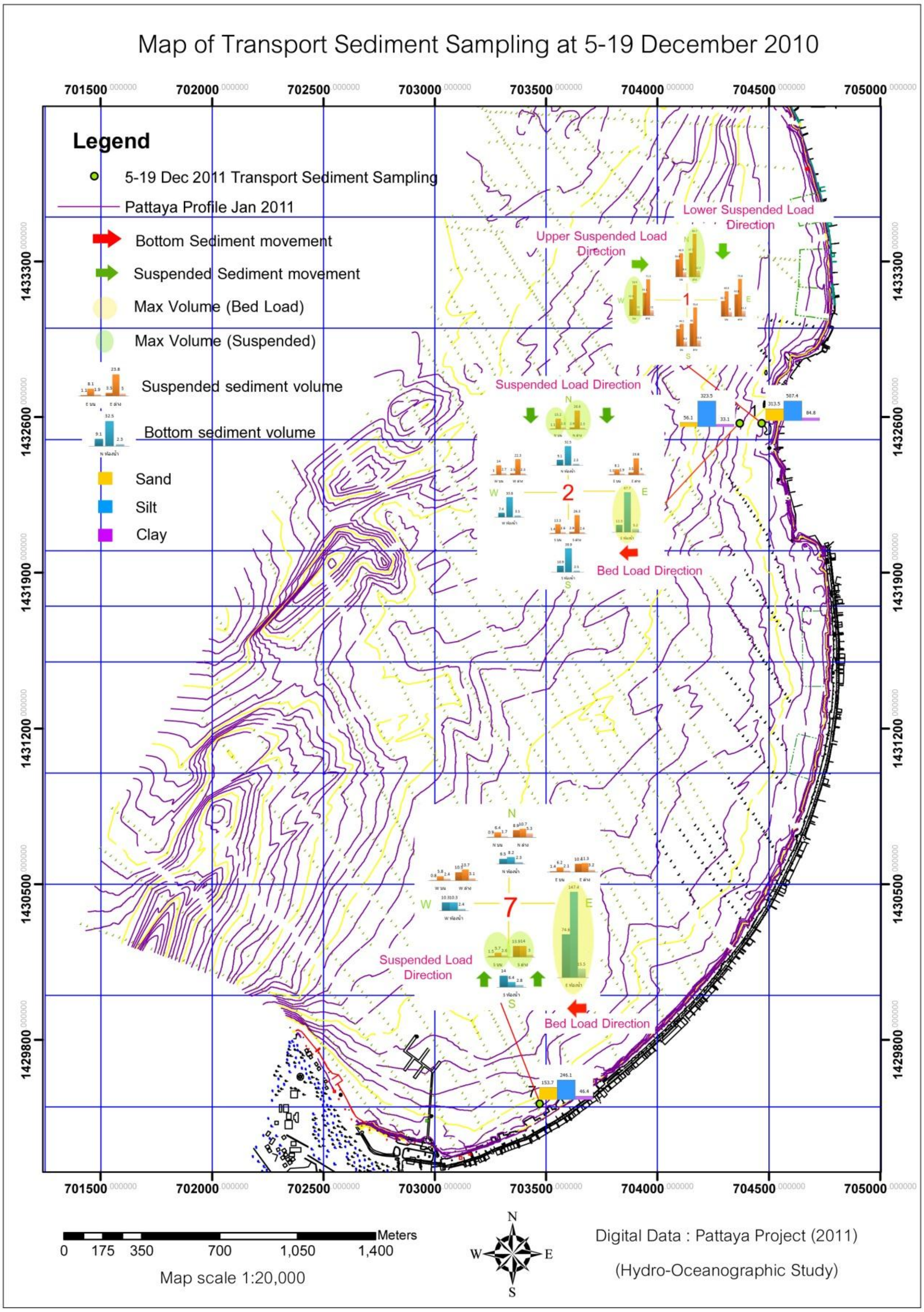


Figure 41 Map of sediment movement, obtained from the sediment catcher on 5-19 December 2010.

The data from the second field survey in February, which is in a neap tide and NE monsoon period, is shown in Figure 42. The wind from the NE monsoon was not severe and as a result the volume of trapped sediment dropped 50%. Note that the graphs in the map show the volume of suspended and bottom sediments in m^3 and a full fraction of 100, except for the points 8-10 which have a full fraction of 800, 500 and 500, respectively. It can be seen that point 8 had the maximum volume of bottom sediment movement in Pattaya Bay.

For points 1-3 at Wong-amart Bay, point 1 (nearest to the beach) had a larger volume of both suspended and bottom sediments than point 2, but point 3 had by far the highest volume of both suspended and bottom sediments, which reflects the turbulence off the coast and is likely to be the result of human activities, such as motorboats and Jet skis.

For points 4-6 in the north of Pattaya Bay, point 4 was dominated by clay particles. The suspended sediment movement was mostly to the west except for at point 6 and the lower suspended sediments at point 4. The direction of the bottom sediment movement in this area was northwards at every point. In addition, points 5 and 6 had a much higher proportion of sand and of larger particle sizes than at point 4, suggesting a higher wave power at points 5 and 6 than at point 4 (nearest the shore).

At point 7, which is near the walking street buildings at south Pattaya bay, there was a lower disturbance from human activities than at the other points. The upper suspended sediments moved to the south, and most of lower suspended sediments moved to the north, but the difference was not much. Also, the bottom sediments mostly moved to the north, the same as for the lower suspended sediments.

At points 8-10 near Bali Hai Cape (Pattaya Cape), the maximum volume of transported bottom sediment was found at point 8, which is nearest to the coast, and mostly moved southwards, while both the upper and lower suspended sediments moved to the west. At point 9, where the water depth increases, the suspended sediments moved with no clear direction. The upper suspended sediment mainly moved to the west, and the lower suspended sediment mainly moved to the north, and the bottom sediments mainly moved to the east (to the coast). At point 10, which had the greatest depth (8 m bmsl), both the upper and lower suspended sediments mainly moved to the west, while the bottom sediments mainly moved to the north and the east.

In summary, the analysis of sediment transport in Pattaya Bay using the sediment catcher data revealed that the amount and direction of the upper and lower suspended sediments varied with the direction of the waves and currents. Bottom sediments in the area of the upper north of Pattaya Bay (points 1-3) did not have a clear movement direction, but in north Pattaya Bay (points 4-6) the net bottom sediment movement was mainly northwards. In south Pattaya, point 7 had a lower sediment volume (which represent the movement of sediment) and the bottom sediment mainly moved northwards. Pattaya Cape (points 8-10) had the highest level of bottom sediment movement, which likely represented the high wave energy and turbulence of flow as a result of the NE monsoon winds that blow through Pattaya Cape at that time. Point 8 had the highest volume of bottom sediment movement and it moved southwards, while at points 9 and 10 the bottom sediment mainly moved to the west and northeast, respectively. The difference in the direction of bottom sediment movements at the south area of Pattaya Bay reflects the affect of the NE monsoon and the coastal morphology of Pattaya Cape.

The direction and volume of the suspended and bottom sediments suggested that waves and currents along Pattaya Bay cause the movement of the sediment in the bay. The opposite movement between the upper and lower suspended sediments was found at points 3, 6 and 7 and between the movement of the bottom sediment at points 8 and 10. In the neap tide period, the volume of transport sediment, which is the effect of the current on sediment movement along the beach, was lower compared to that in the spring tide period. Therefore, the supposed hypothesis that the monsoon wind caused sediment movement offshore during the spring tide period is discussed further in chapter 4.

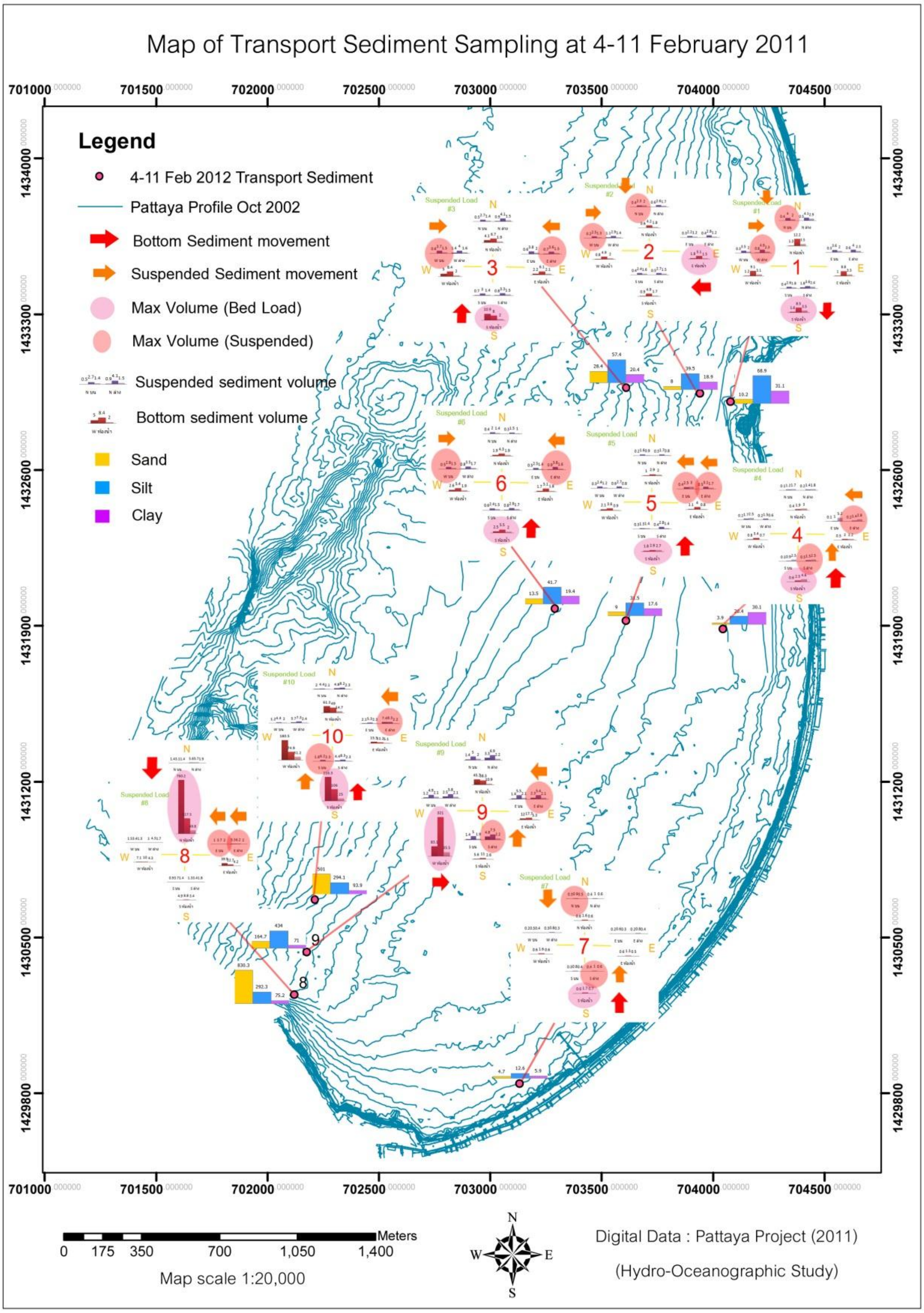


Figure 42 Map of sediment movement, obtained from the sediment catcher on 4-11 February 2011.

3.5.3. Sediment movement by the monsoon effect

Gathering the bottom sediment information in Pattaya Bay was performed twice. The first sampling period was performed in June 2011 in the SW monsoon period, whilst the second sampling was performed in January 2012 in the NE monsoon period (see Appendix B). The samples were taken at 0, 50, 100, 200 and 300 m from the beach, which is consistent with the behavior of tides (Department of Public Works and Town & Country Planning, 2003)(10). GPS was order to determine where to collect the samples in the sea. The distribution of sediments(24) found in the study, in terms of the type of component, are shown in Figures 43 and 44 for the first and second sampling period, respectively.

The distribution of bottom sediments at 0, 50, 100, 200 and 300 m from the beach in the SW monsoon (green bathymetric contour) and the NE monsoon (blue bathymetric contour) demonstrated different types of sediment movement. Gravel (orange graph) and sand (yellow graph) particles were predominant at the beach in the NE monsoon. In the SW monsoon period, with the wind direction from the south, there was movement of sand from the south to the north of Pattaya Bay, and clay particles (purple graph) were present in the main component of the moving sediment in the south of Pattaya Bay. However, these particles come from the sewers of the city. When the wind blows towards the coast, the clay particles were mixed with sand and moved into the bay area. This movement causes the sand in the area to have a darker color than that at the north Pattaya.

Likewise, for the sand samples collected during the NE monsoon period, the clay particles had been washed away from the original area in Figure 45a, and sand particles tended to move from the north down to the south of Pattaya Bay (Figure 45b). In the NE monsoon period the bottom sediments in both the north and the south of Pattaya Bay were found to move offshore in accord with the direction of the monsoon wind as discussed in section 3.5.2.

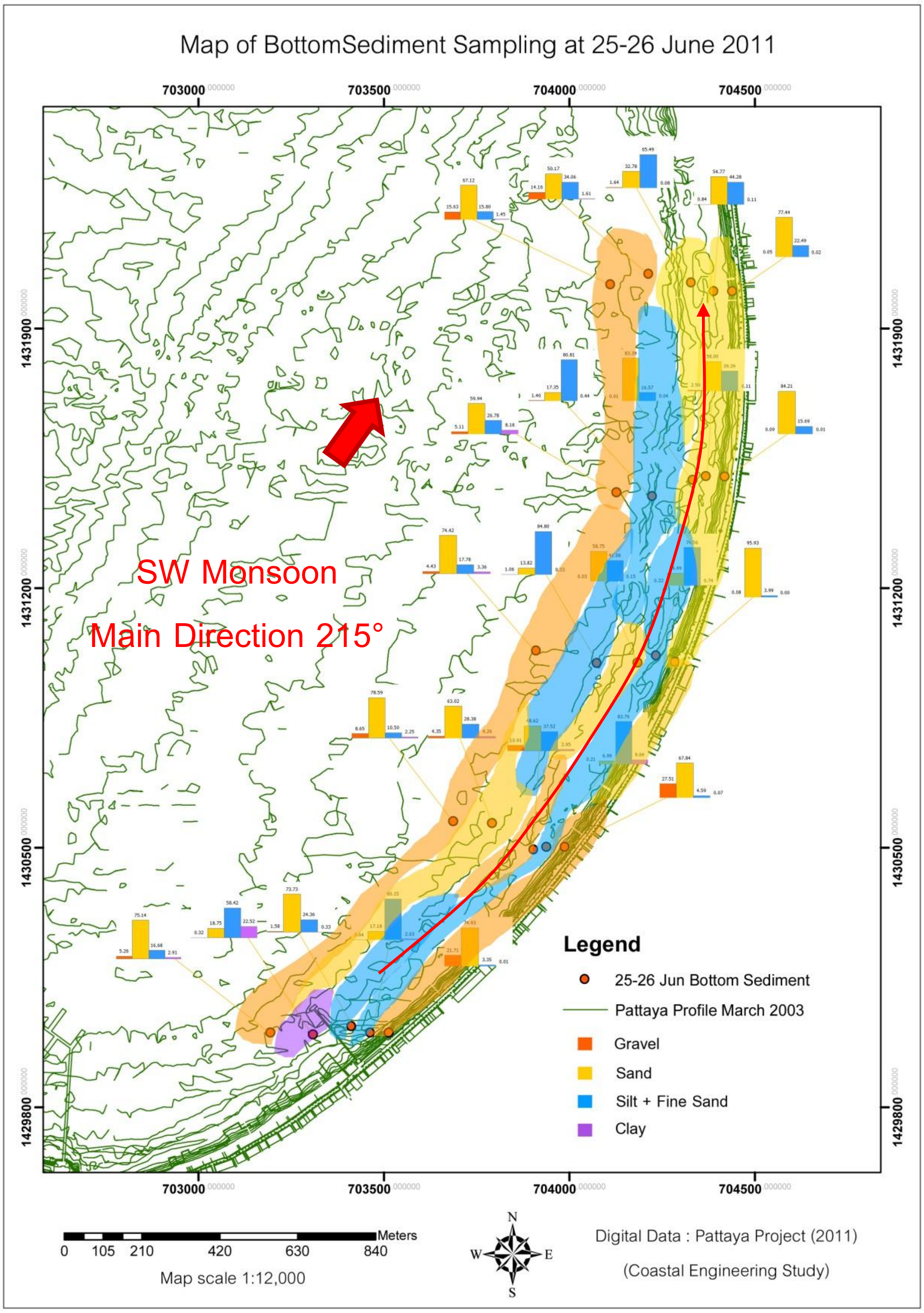


Figure 43 Distribution of sediment particles in the coastal area of Pattaya Bay in the SW monsoon season with the direction of sediment movement related to the monsoon wind direction.

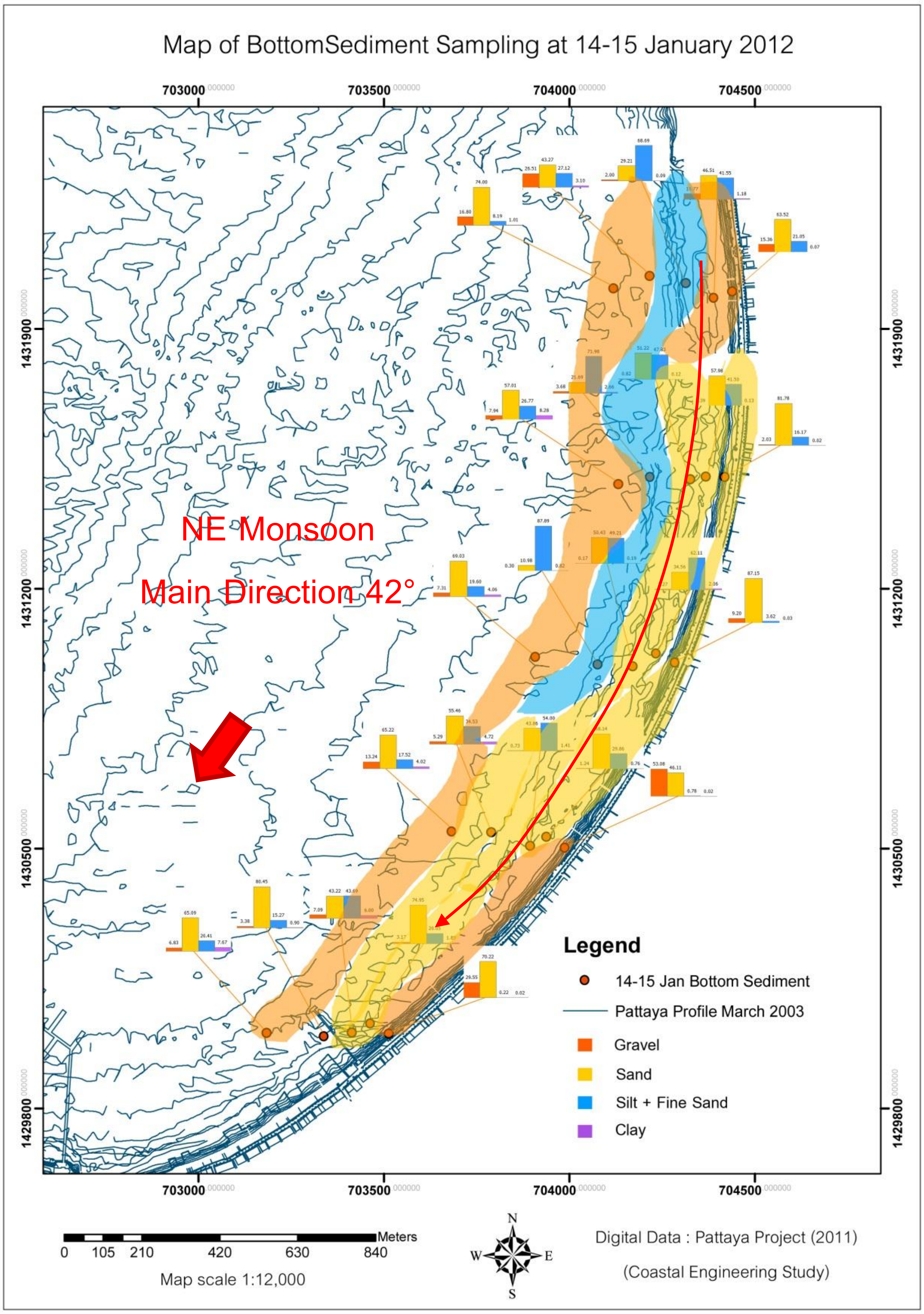


Figure 44 Distribution of sediment particles in the coastal area of Pattaya Bay in the NE monsoon season with the direction of sediment movement related to the monsoon wind direction.

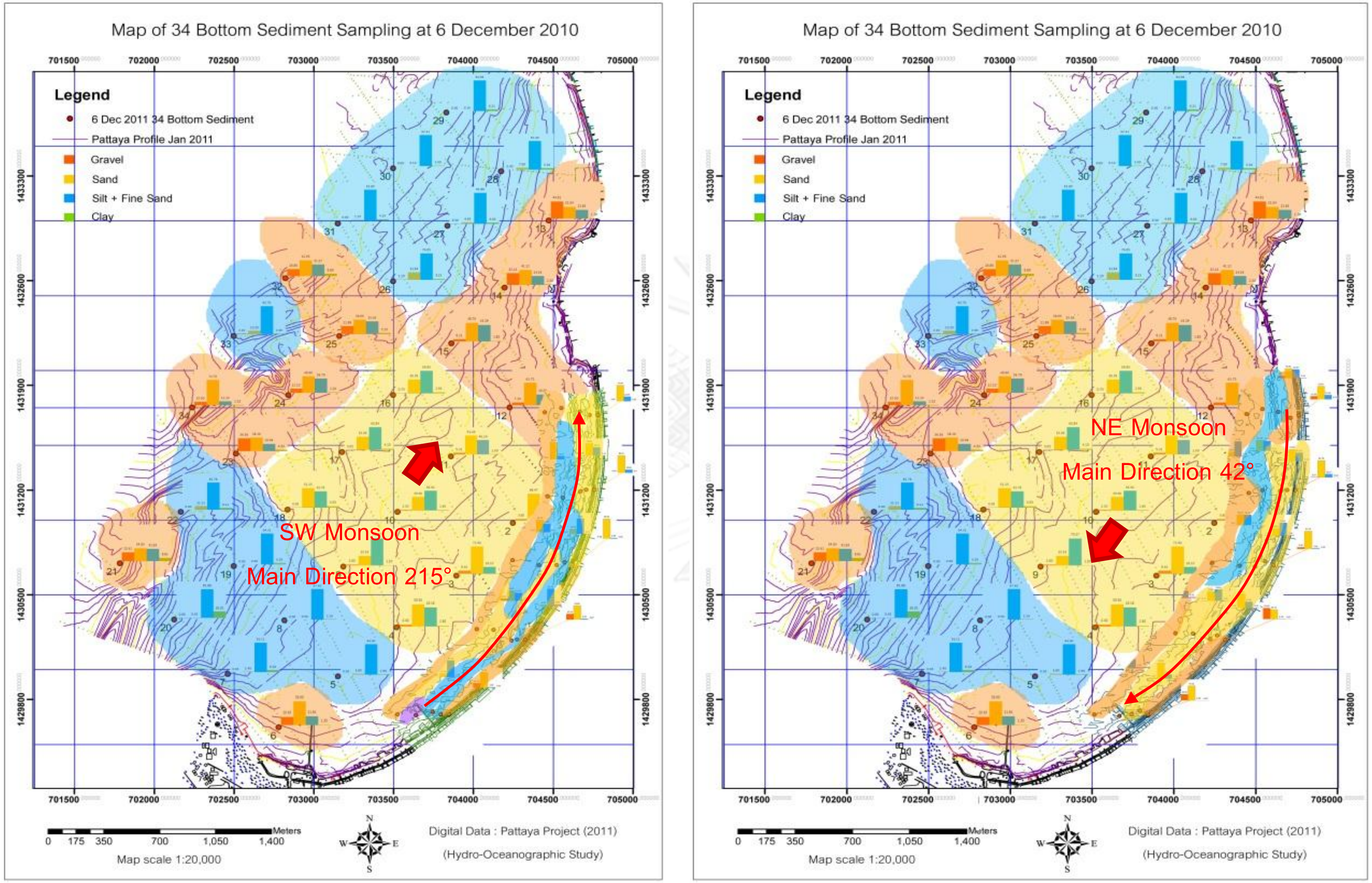


Figure 45a,b The bottom sediment feature of Pattaya Bay during the (A) SW monsoon and the (B) NE monsoon seasons

3.5.4. Sediment movement by the tide effect

Analysis of the tidal data taken from the measuring station at Ao Udom during the years 2010 and 2011 by the Marine Department, Thailand Transport Portal (25) revealed that the tidal pattern within Pattaya Bay was a semi-diurnal mixed tide (Figure 46).

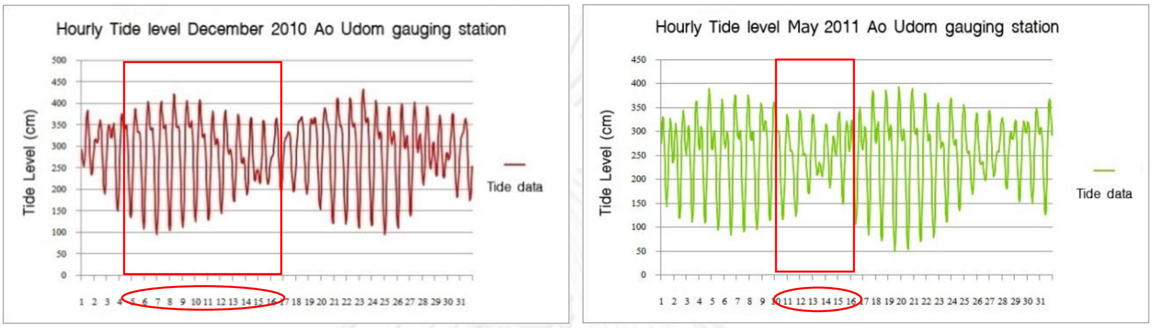


Figure 46 Hourly tidal data from the Ao Udom station in January 2010 and May 2011 (Red frame: spring tide and neap tide) (Marine Department, Thailand Transport Portal, 2011) (25)

The mixed tide at Pattaya Bay did not have an intense up-down flow compared to the single tides (diurnal tide) that can be found in some coastal areas in the Gulf of Thailand (Department of Marine and Coastal Resources, 2010)(26). When the tidal data was analyzed by a non-harmonics method it was found that the mean lower low water level (MLLW) and the mean higher high water level (MHHW) at Ao Udom, which was used to represent Pattaya Bay, was 1.07 and -1.33, respectively (ARRI, 2011)(7). When analyzed in conjunction with both the cross-section profiles of Pattaya Bay, selected from the coastal engineering profile (ARRI, 2011)(27), and the particle size distribution in the SW monsoon season, from this thesis, the effect of the tides in Pattaya Bay appeared to affected by the different beach slopes.

Pattaya Bay beach was divided into five segments (Profiles A–E), each of 500 m shore length, from profile A in the north of Pattaya Bay down to profile E in the south of Pattaya Bay (Figure 47). In relation to the nearby landmarks, profile A is located opposite the Pattaya soi 2 Rd., profile B, to the south of profile A, was located opposite the Toscana Trattoria & Pizzeria restaurant. Profile C is located opposite the Central Pattaya Rd., profile D opposite the Nautical Inn, Pattaya soi 11 Rd., and profile E opposite the Pattaya Walking Street’s gate.

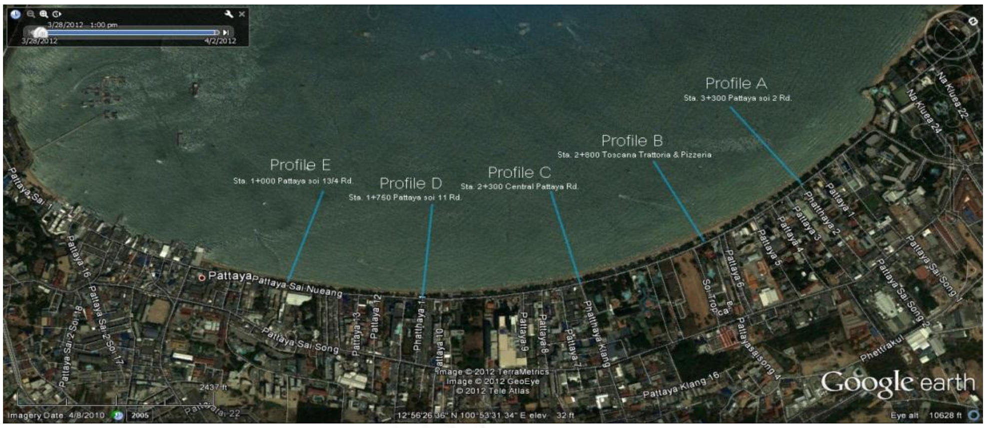


Figure 47 Coastal engineering profiles of Pattaya Bay (Profile lines A–E).

(1). Profile A: North Pattaya STA. 3+300 (Pattaya soi 2 rd.)

North Pattaya Profile A (Pattaya soi 2 Rd.)

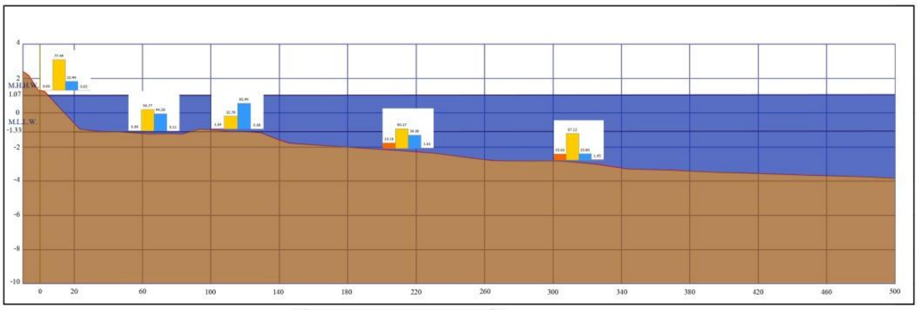


Figure 48 Profile A of Pattaya Bay at the mean higher high water level (MHHW).

North Pattaya Profile A (Pattaya soi 2 Rd.) low tide

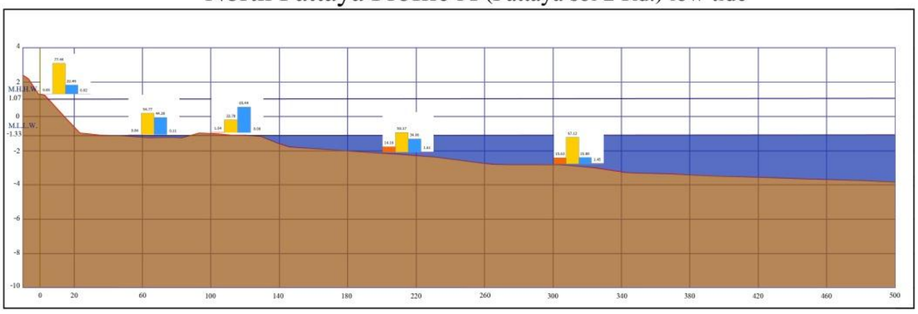


Figure 49 Profile A of Pattaya Bay at the mean lower low water level (MLLW).

Profile A is a cross-section of the north Pattaya Bay at Sta. 3+300. The histogram of the sediment types (% (particle weight/sample net weight of 500 grams) in composition), taken in the SW monsoon season from a distance of 0, 50,100, 200 and 300 m at the MHHW (+1.07 m) is shown in Figure 48 The highest water level reached the beach at 0 m, where it can affect Pattaya Bay directly.

In contrast, at the low tide level (MLLW at -1.33 m) the tide affected only three sample points all within 0–100 m from the beach (Figure 49). At a distance of 200–300 m from the shore, where gravel particles dominated the sediment composition, the low tide did not appear to have any affect on the sediment composition. Therefore, the sediment at this distance was not likely to have been pushed back to the shore by the tides. In addition, at ~90–130 m from the beach was a sand dune. This was a region of accumulated particles of fine sand, silt and clay that likely resulted from deposition of the removed beach sediments by coastal waves, tides and currents.

(2). Profile B: North Pattaya STA. 2+800 (In front of Toscana Trattoria & Pizzeria)

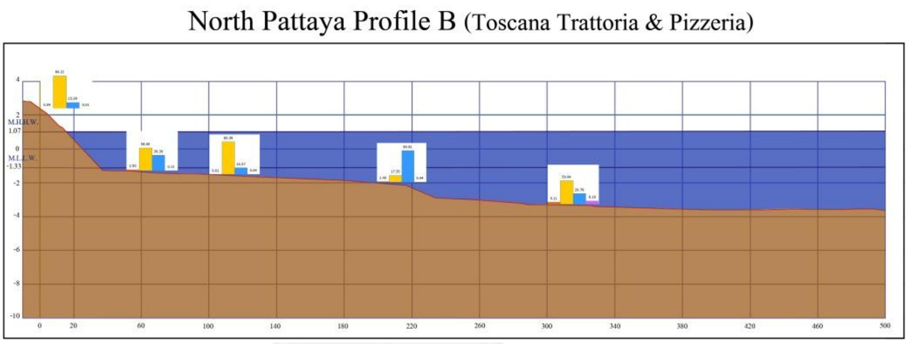


Figure 50 Profile B of Pattaya Bay at the mean higher high water level (MHHW).

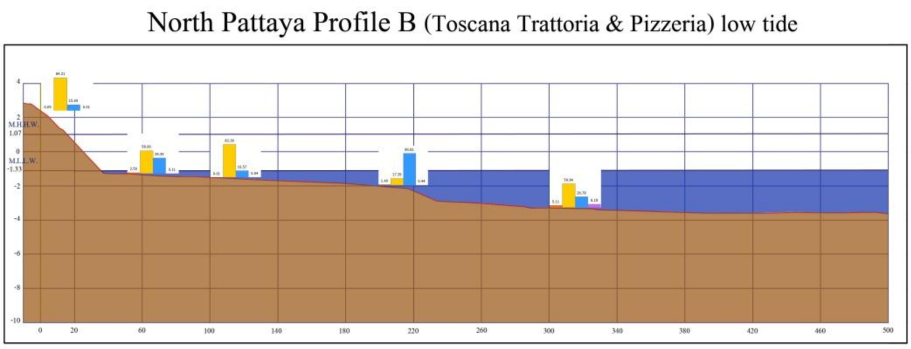


Figure 51 Profile B of Pattaya Bay at the mean lower low water level (MLLW).

For profile B (Figures 50 and 51), the beach had a different slope to that of the neighboring profile A, with no evidence of sand dunes out from the beach. There was no evidence of any change in the sediments at 100–200 m from the beach, where the bottom sediment at 100 m had an increased volume of sand and there was a larger amount of silt and fine sand particles at 200 m from the beach. In contrast to that found in profile A, there was no evidence of gravel particles at 200 m from the shore and so the wave energy in this area is likely to be different from that in profile A. With respect to the MLLW (Figure 51), the tides did not appear to affect the amount of sediment at 200–300 m from the beach as much as that in profile A.

(3). Profile C: Central Pattaya STA. 2+300 (Central Pattaya Rd.)

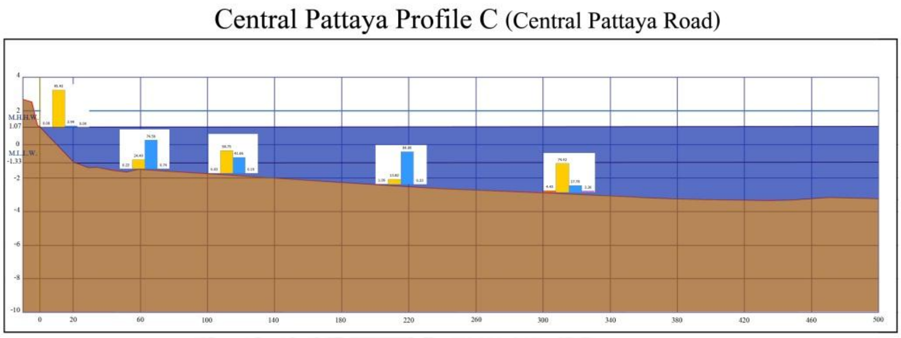


Figure 52 Profile C of Pattaya Bay at the mean higher high water level (MHHW).

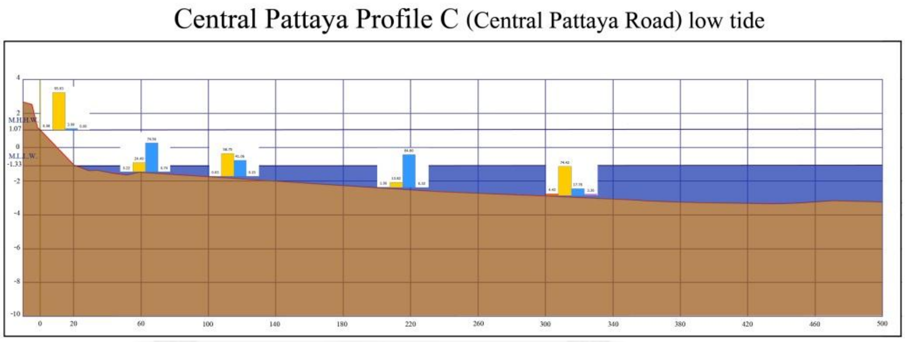


Figure 53 Profile C of Pattaya Bay at the mean lower low water level (MLLW).

For the cross-section profile of the Central Pattaya Bay (Profile C), the slope was greater than that in profiles A and B due to the large volume of silt and sand particles at a distance of 50 and 200 m from the beach. Evidence of scouring was also found at 20–30 m from the beach. The beach slope and the particle size distribution in this area showed a different influence of the waves and tide from the other profiles. For example, no significant gravel particles were found offshore in this profile. With respect to the MLLW (Figure 53), it was clear that there was no influence of the tides at 200–300 m from the beach.

(4). Profile D: South Pattaya STA.1+750 (Nautical Inn, Pattaya soi 11 Rd.)

South Pattaya Profile D (Nautical Inn, Pattaya soi 11)

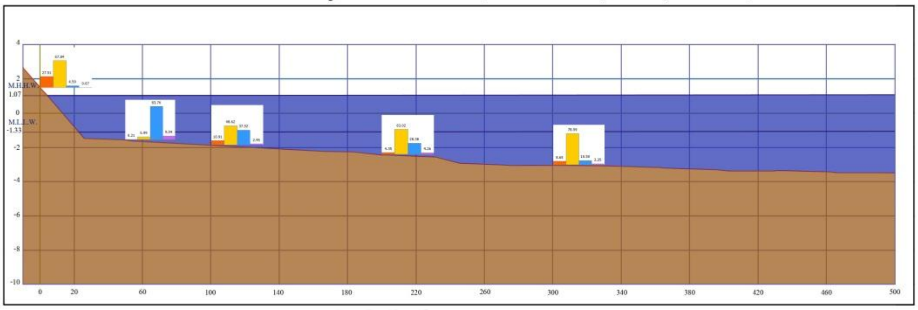


Figure 54 Profile D of Pattaya Bay at the mean higher high water level (MHHW).

South Pattaya Profile D (Nautical Inn, Pattaya soi 11) low tide

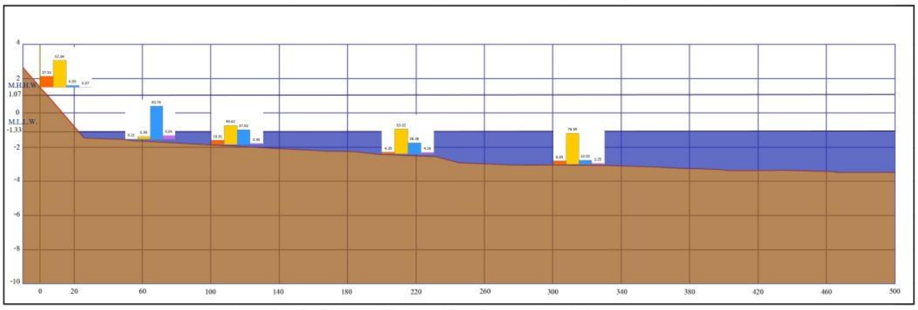


Figure 55 Profile D of Pattaya Bay at the mean lower low water level (MLLW).

From the cross-section of south Pattaya Bay (Profile D), the level of gravel particles at 0 m from the beach was much higher than in the other profiles, whilst the slope of the seafloor in the initial section was very steep decreased markedly from 20–25 m offshore. The slope then decreased further away from the shore line. The sediment at 100 m from the beach had gravel particles in its composition in contrast to the other profiles. When the MHHW sediment profile was compared to that of the MLLW (Figures 54 and 55) it was evident that at 100–300 m from the beach, the sediment was not influenced by the high or low tides.

(5). Profile E: South Pattaya STA.1+000 (Pattaya Walking Street's gate)

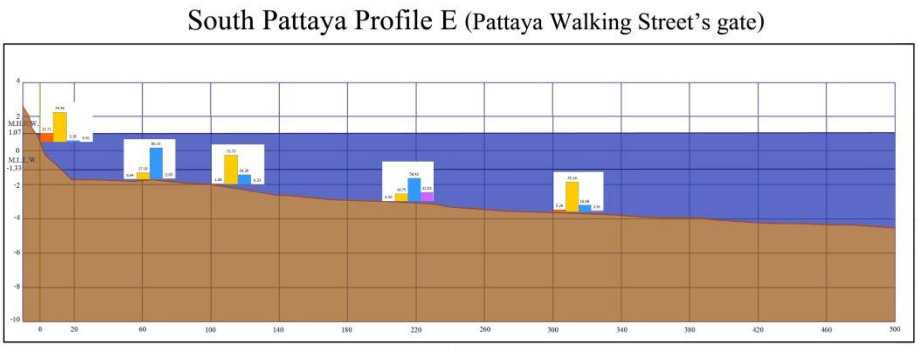


Figure 56 Profile E of Pattaya Bay at the mean higher high water level (MHHW).

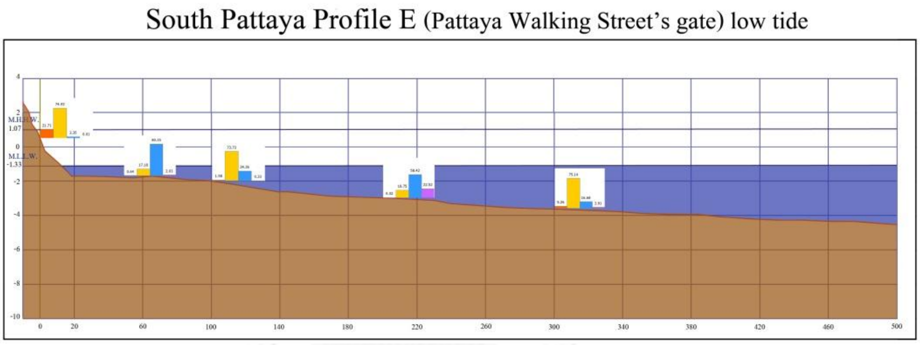


Figure 57 Profile E of Pattaya Bay at the mean lower low water level (MLLW).

The final profile, that of south Pattaya Bay in front of Soi 13/4 (Profile E) (Figures 56 and 57), revealed a very steep slope of the beach that then gradually decreased further offshore to a gentle slope by 20 m offshore. The particle size distribution was similar to that seen in profile D except that at 200 m from the beach clay particles were more dominant than in the other areas. This is because south Pattaya Bay is close to the city sewer. There was no evidence of any significant influence of the tides on the sediments at 100–300 m from the beach.

Moreover, the distribution of the sediment along the bay at 300 m from the beach had a similar feature in all five profiles. In summary, the lowest tide level caused no influence on the coastal sediments at 200–300 m from the beach, but tidal erosion caused changes in the sediment features within 100 m from the beach only. The hypothesis that sediment transportation to the offshore region is influenced by the currents, monsoon and tides is discussed further in chapter 4.

CHAPTER IV
DISCUSSION AND CONCLUSION

4.1. Discussion

Analysis of the cross section of Pattaya Bay derived from the bathymetry charts of the Royal Thai Navy, revealed that the offshore area of Pattaya Bay has accumulated sediment and so raised the sea bottom level up to 1 m. Considering the sediment correlation with that of boring log data, the deep layer of the offshore sediment of Pattaya Bay had a similar composition to the distribution of the sand particles at the beach. The marine geophysics study from DMR (2011)(8) revealed the presence of an offshore sand bar in the north Pattaya Bay. This sand bar accumulated in the Holocene period by the encroachment of the sea about 0.01 million years ago to the present. Sediment layers that were found offshore of Pattaya Bay were classified as Holocene or new age sediments. Thus, the seafloor elevation in Pattaya Bay is caused by deposition of sand that is eroded from the beach to offshore where it accumulates. The eroded sand can be found in the deep layers of sand offshore of Pattaya Bay mixed with mud particles.

Evaluation of the bottom sediment features in the two monsoon seasons using the data from sediment catchers revealed that the bottom sediment movement is related to the monsoon wind direction and currents with the accumulation of sand in south Pattaya Bay in the NE monsoon and the distribution of sand and silt in the SW monsoon. In addition, during the spring tide period there is far more (80%) sand transport than in the neap tide period. A higher level of bottom sediment along the shore was moved offshore during the NE monsoon in both the north and south areas of Pattaya Bay.

Meteorology data from the Pattaya meteorological station between 1981 and 2008 showed that the NE monsoon velocity has increased since 1991 and shifted to a northerly direction, while the SW monsoon has become stronger since 1997 and shifted direction to the south. Inspection of the alignment of Pattaya Bay with the effective wave power (ARRI, 2011)(7) revealed that the waves from the north in the NE monsoon had a higher effective wave power than the waves from the southwest to south in the SW monsoon, but the duration of the SW monsoon was longer than the NE monsoon. When the average power of the monsoon wind was stronger, the ability to transport sediment increased, and so the NE monsoon wind causes more coastal erosion than the SW monsoon. When considering the influence of the tide, tidal data from the Thailand Transport Portal at Ao Udom station during 2010-2011 revealed the tidal feature of Pattaya Bay to be a semidiurnal mixed tide(28).

The characteristics of this mixed tide is a less intense up - down flow compared to that of a single diurnal tide, which can be found in some coastal areas in the Gulf of Thailand (Department of Marine and Coastal Resources, 2010)(26). The non-harmonic analysis of the tidal data (ARRI, 2011)(7) revealed that the tidal data composition values MLLW and MHHW at Ao Udom station (used to represent Pattaya Bay) were 1.07 and -1.33, respectively. When analyzed with the cross section of Pattaya Bay by Coastal Engineering (ARRI, 2011)(7) and the sediment samples along the coast in the SW monsoon by the sediment catcher, it revealed that the movement of sediment along the coast of Pattaya Bay within 0-300 m by the tide was very low. The distribution of sediment along the bay at 300 m from the beach had similar features (See Appendix C) and the lowest tide level caused less influence on the coastal sediments at 200-300 m from the beach.

The current variations in the Pattaya Bay, at least in December 2010 (ARRI, 2011)(7), were largely caused by the direction and speed of the monsoon wind and tides. The current speed in the lower layer was slower than the current in the middle and upper layers of water due to the friction of the sea bottom. In addition, human activities, such as motorboats and ski jets, are also a variable that can change the direction of flow and suspended sediment concentration. The current flow was also controlled by the shape of Pattaya Bay and the net current movement within the upper Gulf of Thailand. The suspended sediment concentration near the sea bottom changed according to the strength of the waves. Therefore, the influence of waves and the strength of the tides cause the dispersion of sediment particles along the shore and increased the concentrations of suspended sediment in the measuring device (sediment catcher).

In summary, the current does not directly effect the changes in the sediment feature, but rather works with the tide and waves together to make the changes in the sediment characteristics around the coast of Pattaya Bay.

4.2. Conclusions and recommendations

The distribution of the sediment particles in Pattaya Bay result from the action of waves, tides and currents in the local area. Small-sized particles can be moved further by waves than large-sized particles, with clay particles being moved the furthest distance. However, the similar distribution of larger sediment particles, like gravel and sand, at offshore regions to the beach's distribution of sand revealed that the sand at the shore of Pattaya Bay had eroded to offshore in the past.

The movement of sand particles out of Pattaya Bay is enhance by the increased force of the wind and waves in Pattaya Bay in the two monsoon seasons, which have increased in intensity in recent years causing an increased erosion rate. In addition, the movement of sediments in Pattaya Bay in the spring tide period is some 50% greater than in the neap tide with the direction of movement being offshore in both the north and south of Pattaya Bay. However, this is especially the case at the south of Pattaya Bay, where there is the highest volume of transported sediment. From these results, it is possible that the eroded sediment had been transported offshore by the influence of the increased wave strength and tides compounded with currents.

Analysis of the bathymetry charts of Pattaya Bay from 1974 to 2011 revealed that the sea floor elevation offshore of Pattaya Bay had increased up to 1 m (depth bmsl decreased by up to 1m), which relates to the aerial photos of the area between 1952 and 2010 that showed the retreat of Pattaya beach. The average rate of erosion in the first period (1952-1974) was low but increased in the second period after 1996, which accords with the change in the land use around Pattaya Bay and the raising of beach structures. So, the decreased shoreline at Pattaya Bay has likely been influenced not only by the monsoon wind but also by local anthropogenic activities, such as urban-development and hard constructions along the beach that change the balance of energy in the bay. The average rate of erosion derived from the analysis using the ArcGIS program revealed that the average rate of erosion between 1952 and 1974 was -0.78 m/y and but was 2.3-fold higher at -1.8 m/y between 1996 and 2011. Predicting the beach area in the future, using the current maximum and minimum average erosion rates suggests that if there is no solution to reduce the rate of erosion then Pattaya Beach will be eradicated in the next five years.

Pattaya is a sensitive area to changes in the coastal land and near offshore use and has been developed for tourism activities, and especially beach-related tourism, for a long time. Accordingly, the transformation of the area affects a lot of the local people. The problem of coastal erosion should be considered for the impact to the community as the famous sights of the city. In addition, the data used in the analysis may overlap and there may be another important variable that has not yet been taken into account but will be required to determine the erosion of Pattaya Bay in each period with more accurate and clear data.

Understanding the process of change towards the coast is a complex process that consists of a variety of variables. Therefore, further studies are required to understand the various aspects of Pattaya Bay and remedy the incompleteness of the current datasets due to the limited amount of time.

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APPENDICES

Appendix A

Borehole Coordinates BH 1 – BH 12

BH	X	Y
1	703083	1433404
2	702994	1431958
3	702849	1430955
4	702587	1433066
5	702478	1431660
6	702399	1430662
7	702175	1433460
8	702129	1432761
9	702031	1431378
10	701971	1430330
11	704140	1430710
12	703737	1431007

Bottom Sediment sample coordinates on June 26, 2010

Sample	X	Y
PT1-1	704440	1432000
PT1-2	704390	1432000
PT1-3	704329	1432023
PT1-4	704214	1432047
PT1-5	704112	1432018
PT2-1	704420	1431500
PT2-2	704369	1431501
PT2-3	704333	1431491
PT2-4	704224	1431447
PT2-5	704128	1431457
PT3-1	704285	1431071
PT3-2	704235	1431017
PT3-3	704185	1430998
PT3-4	704075	1430997
PT3-5	703911	1431031
PT4-1	703989	1430501
PT4-2	703939	1430501
PT4-3	703904	1430494
PT4-4	703793	1430565
PT4-5	703688	1430570
PT5-1	703514	1430000
PT5-2	703464	1430000
PT5-3	703413	1430017
PT5-4	703310	1429995
PT5-5	703195	1430000

Bottom Sediment sample coordinates on 19 January, 2011

Sample	X	Y
PT1-1	704440	1432000
PT2-1	704420	1431500
PT3-1	704285	1431000
PT4-1	703989	1430501
PT5-1	703514	1430000
PT1-2	704390	1431983
PT2-2	704369	1431501
PT3-2	704235	1431024
PT4-2	703939	1430530
PT5-2	703464	1430027
PT1-3	704315	1432022
PT2-3	704327	1431494
PT3-3	704172	1430990
PT4-3	703915	1430506
PT5-3	703414	1430003
PT1-4	704217	1432042
PT2-4	704218	1431500
PT3-4	704077	1430995
PT4-4	703790	1430543
PT5-4	703339	1429993
PT1-5	704120	1432008
PT2-5	704133	1431481
PT3-5	703909	1431015
PT4-5	703684	1430545
PT5-5	703185	1430002

34 Bottom sediment samples coordinates of Pattaya Bay

point	N	E
1	1431390	704548
2	1430979	704250
3	1430625	703896
4	1430281	703521
5	1429954.17	703154.17
6	1429612.5	702781.25
7	1429968.75	702462.5
8	1430327.08	702818.75
9	1430687.5	703187.5
10	1431052.08	703527.08
11	1431422.92	703862.5
12	1431750	704229.17
13	1433000	704472.92
14	1432552.08	704197.92
15	1432179.17	703864.58
16	1431833.33	703500
17	1431452.08	703179.17
18	1431068.75	702839.58
19	1430689.58	702500
20	1430333.33	702127.08
21	1430708.33	701787.5
22	1431052.08	702168.75
23	1431441.67	702514.58
24	1431833.33	702841.67
25	1432229.17	703162.5
26	1432593.75	703500
27	1432964.58	703839.58
28	1433329.17	704175
29	1433722.92	703833.33
30	1433350	703500
31	1432981.25	703152.08
32	1432614.58	702822.92
33	1432229.17	702500
34	1431750	702239.58

Sediment Catcher Coordinates works on 5-19 December 2010

point	N	E
1	1432571	704470
2	1432571	704372
7	1429511	703474

Sediment Catcher Coordinates works on 4-11 February 2011

point	N	E
1	1432905	704080
2	1432942	704943
3	1432968	703613
4	1431884	704047
5	1431921	703611
6	1431975	703292
7	1429841	703133
8	1430241	702122
9	1430432	702178
10	1430668	702215

Appendix B

Sieve Analysis Result - Table #1 composition of sediment particle size.

1st Sieve analysis net weight* (SW Monsoon Samples)

No.	Name	Gravel(1)	VCS(2)	CS(3)	MS(4)	FS (5)	Silt (6)	Clay(7)	Total
1	PT1-1	0.2302	2.3794	299.89	84.9930	77.4182	35.0483	0.0996	500.06
2	PT2-1	0.4645	2.9692	273.53	145.155	68.7237	9.8273	0.0408	500.71
3	PT3-1	0.4069	4.5726	373.02	103.356	16.8277	3.1771	0.0101	501.37
4	PT4-1	137.679	99.7964	203.621	36.103	11.0947	11.8682	0.3313	500.49
5	PT5-1	108.445	117.691	125.33	131.358	14.2457	2.5146	0.0442	499.63
6	PT1-2	4.2056	3.4794	53.1355	216.569	194.415	26.4275	0.5472	498.78
7	PT2-2	12.4921	20.5645	138.701	130.044	149.672	46.8068	0.5474	498.83
8	PT3-2	1.0708	2.0081	24.7048	95.1769	299.16	72.0067	3.6745	497.80
9	PT4-2	1.0596	2.0799	11.0662	21.6036	160.262	255.95	44.9075	496.93
10	PT5-2	3.1964	4.319	19.3933	62.0757	320.55	79.6547	10.1563	499.35
11	PT1-3	8.2068	5.3804	13.3826	144.792	299.2	27.5144	0.4197	498.90
12	PT2-3	0.0278	1.2014	68.76	346.17	73.4717	9.1884	0.1804	499.00
13	PT3-3	0.1678	0.6967	21.3652	271.36	178.745	26.3325	0.7641	499.43
14	PT4-3	54.3324	63.5949	107.561	70.8873	46.2411	140.567	14.6746	497.86
15	PT5-3	7.9039	17.0397	141.767	208.959	84.292	37.2048	1.6614	498.83
16	PT1-4	70.5402	53.736	118.693	77.5088	124.739	44.9334	7.9967	498.15
17	PT2-4	6.9496	11.8152	28.8129	45.7741	336.19	66.2444	2.1868	497.97
18	PT3-4	5.2692	7.8203	23.9378	37.1398	377.8	45.0118	1.6438	498.62
19	PT4-4	21.639	48.0414	161.779	103.654	58.1687	82.9841	21.1688	497.44
20	PT5-4	1.2078	3.9185	36.7873	31.0478	37.216	186.383	86.2	382.76
21	PT1-5	77.8377	67.0192	170.593	96.6587	48.0545	30.6425	7.2388	498.04
22	PT2-5	25.4206	53.8937	163.284	81.2778	52.7236	80.5995	40.7115	497.91
23	PT3-5	21.6185	56.5627	223.651	82.9514	36.0599	50.7167	16.4128	487.97
24	PT4-5	43.0973	85.1937	224.842	81.3334	23.8218	28.4797	11.1976	497.97
25	PT5-5	26.1872	40.7012	162.017	171.137	36.8472	46.1521	14.4757	497.52

***** Sample net weight is 500 grams accept PT5-4 384.20 grams

Sieve Analysis result - Table #2 composition of sediment particle size.

2nd Sieve analysis net weight** (NE Monsoon Samples)

No.	Name	Gravel(1)	VCS(2)	CS(3)	MS(4)	FS (5)	Silt (6)	Clay(7)	Total
1	PT1-1	76.5622	56.0335	185.96	74.6195	82.4818	22.467	0.33	498.46
2	PT2-1	10.1206	23.5098	253.12	130.51	72.7159	7.8091	0.0868	497.87
3	PT3-1	45.8646	76.3471	283.65	74.3902	16.4432	1.618	0.1289	498.44
4	PT4-1	265.15	117.826	101.037	11.473	3.6234	0.2728	0.1088	499.49
5	PT5-1	147.645	252.12	91.5692	7.1727	0.9423	0.1391	0.0922	499.68
6	PT1-2	53.6601	20.6474	83.6359	127.41	128.983	78.0141	5.8584	498.21
7	PT2-2	1.967	3.9544	110.194	174.764	162.746	44.0456	0.658	498.33
8	PT3-2	6.3353	12.3711	75.8603	84.0789	188.631	120.993	10.2751	498.54
9	PT4-2	6.1676	10.4015	142.541	186.871	58.1247	90.7837	3.8067	498.70
10	PT5-2	15.7701	38.045	197.552	137.781	26.3663	73.4814	9.1398	498.11
11	PT1-3	9.9919	4.6042	24.4914	116.482	298.01	44.3346	0.4482	498.36
12	PT2-3	4.0941	4.2182	73.17	178.281	186.804	51.932	0.6153	499.11
13	PT3-3	0.8302	0.9748	34.9717	215.248	191.144	53.9577	0.9592	498.09
14	PT4-3	3.6321	5.9213	59.4824	153.016	79.6831	189.226	7.0165	497.98
15	PT5-3	35.3071	38.2106	100.69	76.3078	31.5629	185.945	29.8735	497.90
16	PT1-4	132.238	64.8586	101.545	49.4476	68.2409	67.0204	15.4626	498.81
17	PT2-4	18.2891	22.7822	51.6922	33.4543	158.98	199.22	13.2309	497.65
18	PT3-4	1.5209	2.9999	15.945	36.5089	310.65	129.607	4.1213	500.90
19	PT4-4	26.3778	54.5407	166.809	55.3669	31.5758	140.712	23.5569	498.94
20	PT5-4	16.9016	18.405	121.61	262.03	58.5073	17.795	4.4791	499.73
21	PT1-5	84.09	86.43	209.68	74.3758	28.8278	12.1777	5.0615	500.64
22	PT2-5	39.6727	61.9144	153.27	69.6195	54.7425	78.984	41.366	499.57
23	PT3-5	36.4858	52.3564	200.63	91.7994	47.9069	49.9761	20.2934	499.45
24	PT4-5	58.1437	31.9386	189.68	64.7807	32.7132	44.2194	17.643	439.12
25	PT5-5	34.0288	48.1994	154.78	121.425	40.6037	61.1087	38.2114	498.36

Appendix C

Suspended sediment and Bottom sediment by weight, Trapping of sediment on December 5, 2010 and recovered on 25 December, 2010 (ARRI, 2011).

Point	Cylindrical hole dir	Type of Sediment	Sand	Silt	Clay	Total
1	N	Upper Suspended	34.8	46.9	9.4	91.0
		Lower Suspended	47.4	84.7	12.3	144.4
	S	Upper Suspended	34.1	44.1	9.3	87.5
		Lower Suspended	45.0	76.6	11.6	133.2
	E	Upper Suspended	30.7	49.9	9.0	89.7
		Lower Suspended	43.8	73.8	11.2	128.7
	W	Upper Suspended	32.6	59.9	11.0	103.4
		Lower Suspended	45.1	71.5	11.0	127.6
2	N	Upper Suspended	1.1	15.2	2.8	19.1
		Lower Suspended	2.9	26.6	2.3	31.8
		Bottom	9.1	32.5	2.3	43.8
	S	Upper Suspended	1.4	13.3	2.6	17.3
		Lower Suspended	2.9	26.3	2.4	31.6
		Bottom	10.9	39.9	2.5	53.3
	E	Upper Suspended	1.1	8.1	1.9	11.1
		Lower Suspended	3.5	23.8	3.0	30.3
		Bottom	12.3	67.7	5.2	85.2
	W	Upper Suspended	1.0	14.0	2.7	17.7
		Lower Suspended	2.5	22.3	2.3	27.1
		Bottom	7.4	33.8	3.1	44.2
7	N	Upper Suspended	0.9	6.4	1.7	9.0
		Lower Suspended	8.9	10.7	5.3	25.0
		Bottom	6.5	8.2	2.3	17.0
	S	Upper Suspended	1.5	5.7	2.6	9.8
		Lower Suspended	13.9	14.0	3.0	30.9
		Bottom	14.0	6.4	2.8	23.3
	E	Upper Suspended	1.4	6.2	2.1	9.7
		Lower Suspended	10.4	11.3	3.2	24.9
		Bottom	74.6	147.4	15.5	237.5
	W	Upper Suspended	0.8	5.8	2.4	9.0
		Lower Suspended	10.5	13.7	3.1	27.2
		Bottom	10.3	10.3	2.4	23.0

Suspended sediment and Bottom sediment by weight, Trapping of sediment on 4-11 February, 2011 (ARRI, 2011).

Point	Cylindrical hole dir	Type of Sediment	Sand	Silt	Clay	Total
1	N	Upper Suspended	0.4	4.0	2.0	6.3
		Lower Suspended	0.5	4.1	2.9	7.5
		Bottom	1.3	12.2	3.5	17.1
	S	Upper Suspended	0.4	2.6	1.8	4.8
		Lower Suspended	1.8	3.6	2.4	7.8
		Bottom	1.6	8.5	3.5	13.7
	E	Upper Suspended	0.3	3.6	2.0	5.9
		Lower Suspended	0.6	4.0	2.3	6.9
		Bottom	1.0	8.8	3.3	13.1
	W	Upper Suspended	0.3	3.5	2.0	5.9
		Lower Suspended	0.8	4.9	2.3	8.0
		Bottom	1.2	9.1	3.1	13.3
2	N	Upper Suspended	0.4	2.3	2.0	4.7
		Lower Suspended	0.6	2.6	1.7	4.8
		Bottom	0.6	4.2	1.8	6.6
	S	Upper Suspended	0.4	2.4	1.6	4.4
		Lower Suspended	0.5	2.7	1.5	4.7
		Bottom	0.9	4.9	1.7	7.5
	E	Upper Suspended	0.3	2.2	1.2	3.7
		Lower Suspended	0.4	2.8	1.2	4.5
		Bottom	1.8	5.1	1.5	8.5
	W	Upper Suspended	0.2	2.5	1.3	4.0
		Lower Suspended	1.1	2.9	1.4	5.4
		Bottom	0.8	4.9	2.0	7.7
3	N	Upper Suspended	0.5	2.7	1.4	4.6
		Lower Suspended	0.9	4.1	1.5	6.5
		Bottom	4.1	6.7	1.9	12.7
	S	Upper Suspended	0.7	3.0	1.4	5.1
		Lower Suspended	0.8	3.3	1.5	5.6
		Bottom	10.9	8.0	2.0	20.9
	E	Upper Suspended	0.6	3.8	2.0	6.4
		Lower Suspended	0.7	3.6	1.5	5.9
		Bottom	2.2	6.1	2.1	10.4
	W	Upper Suspended	0.6	3.7	1.5	5.7
		Lower Suspended	1.4	4.0	1.6	7.0
		Bottom	5.0	8.4	2.0	15.4
4	N	Upper Suspended	0.1	1.2	1.7	3.0
		Lower Suspended	0.2	1.4	1.8	3.4
		Bottom	0.4	1.9	3.0	5.3
	S	Upper Suspended	0.1	0.9	2.5	3.5
		Lower Suspended	0.5	1.5	2.5	4.5
		Bottom	0.6	2.5	4.6	7.7
	E	Upper Suspended	0.1	1.0	5.2	6.4
		Lower Suspended	0.2	1.4	2.8	4.4
		Bottom	0.5	2.0	2.2	4.6

	W	Upper Suspended	0.2	1.7	2.5	4.3
		Lower Suspended	0.2	1.5	0.6	2.3
		Bottom	0.8	3.4	0.7	4.9
5	N	Upper Suspended	0.2	1.6	0.9	2.7
		Lower Suspended	0.3	1.7	0.8	2.8
		Bottom	1.0	2.9	2.0	5.8
	S	Upper Suspended	0.3	1.3	1.4	2.9
		Lower Suspended	0.4	2.8	1.4	4.7
		Bottom	1.8	2.9	2.7	7.4
	E	Upper Suspended	0.4	2.5	3.0	5.9
		Lower Suspended	0.5	3.1	1.7	5.3
		Bottom	1.1	4.0	0.8	6.0
	W	Upper Suspended	0.3	2.4	1.2	3.9
		Lower Suspended	0.6	2.7	0.8	4.1
		Bottom	2.1	3.6	0.9	6.5
6	N	Upper Suspended	0.4	2.0	1.4	3.8
		Lower Suspended	0.3	1.5	1.0	2.8
		Bottom	1.9	4.3	1.9	8.0
	S	Upper Suspended	0.6	2.4	1.5	4.5
		Lower Suspended	0.8	2.9	1.7	5.3
		Bottom	2.5	5.5	2.0	10.0
	E	Upper Suspended	0.5	2.5	1.4	4.4
		Lower Suspended	0.9	3.8	1.6	6.3
		Bottom	1.7	5.1	1.8	8.6
	W	Upper Suspended	0.5	2.8	1.5	4.9
		Lower Suspended	0.8	3.5	1.7	6.1
		Bottom	2.6	5.4	1.9	9.9
7	N	Upper Suspended	0.3	0.9	0.5	1.6
		Lower Suspended	0.4	1.0	0.6	1.9
		Bottom	0.6	1.6	0.6	2.8
	S	Upper Suspended	0.3	0.8	0.4	1.5
		Lower Suspended	0.4	1.0	0.6	2.0
		Bottom	0.6	1.7	0.7	3.0
	E	Upper Suspended	0.2	0.6	0.3	1.1
		Lower Suspended	0.2	0.8	0.4	1.4
		Bottom	0.6	1.3	0.5	2.4
	W	Upper Suspended	0.2	0.5	0.4	1.1
		Lower Suspended	0.3	0.8	0.3	1.4
		Bottom	0.6	1.6	0.6	2.8
8	N	Upper Suspended	1.4	3.1	1.4	5.8
		Lower Suspended	5.6	5.7	1.9	13.2
		Bottom	760.2	217.3	49.8	1027.3
	S	Upper Suspended	0.9	3.7	1.4	6.0
		Lower Suspended	1.3	3.4	1.8	6.5
		Bottom	4.9	8.8	3.4	17.1
	E	Upper Suspended	1.0	3.7	2.0	6.7
		Lower Suspended	5.5	6.2	2.0	13.7
		Bottom	39.9	22.7	4.2	66.8
	W	Upper Suspended	1.5	3.4	1.3	6.2

		Lower Suspended	1.0	4.3	1.7	6.9
		Bottom	7.1	10.0	4.3	21.3
9	N	Upper Suspended	1.4	5.0	2.0	8.4
		Lower Suspended	3.3	6.9	2.2	12.4
		Bottom	45.7	38.3	10.9	94.9
	S	Upper Suspended	1.4	5.0	1.9	8.4
		Lower Suspended	4.8	7.5	2.2	14.4
		Bottom	5.6	11.0	2.6	19.1
	E	Upper Suspended	1.4	5.5	2.1	9.0
		Lower Suspended	2.3	5.4	2.1	9.8
		Bottom	12.0	17.7	5.3	34.9
	W	Upper Suspended	1.2	4.9	2.1	8.2
		Lower Suspended	2.5	5.8	2.1	10.4
		Bottom	83.1	321.0	35.5	439.6
10	N	Upper Suspended	2.0	4.4	2.1	8.6
		Lower Suspended	4.8	8.2	2.3	15.4
		Bottom	61.3	49.0	14.7	125.0
	S	Upper Suspended	1.8	6.2	2.3	10.3
		Lower Suspended	4.4	8.3	2.3	15.0
		Bottom	216.3	106.0	25.0	347.4
	E	Upper Suspended	2.1	5.3	2.3	9.7
		Lower Suspended	7.4	8.9	2.2	18.6
		Bottom	15.5	11.2	5.1	31.8
	W	Upper Suspended	1.2	4.4	2.0	7.7
		Lower Suspended	3.7	7.3	2.4	13.4
		Bottom	180.5	74.9	31.2	286.6

VITA

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